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Phytoremediation Efficiencies of Water Hyacinth in Removing Heavy Metals in Domestic Sewage (A Case Study of University of Ilorin, Nigeria)

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ABSTRACT

Sewage treatment is posing serious techno-economic problems in cities, particularly in underdeveloped countries. A new technology, sewage purification by water hyacinth (Eichhornia crassipes), is a feasible solution. This paper studied the suitability and efficacy of water hyacinth in domestic sewage treatment. The study was carried out in the Department of Agricultural and Biosystems Engineering. Three treatments of water hyacinth replicated two times were used in the study. These treatments include no water hyacinth (control), 1kg and 2kg water hyacinth plant density cultures. The system was designed based on Completely Randomized Design (CRD). Sewage samples were collected during the growth of water hyacinth. Purification of water hyacinth on sewage was rapid during the first three weeks in the sewage cultured with water hyacinth (especially 2kg water hyacinth plant density) and there was low absorption in nutrients in the last two weeks when attaining maturity. Parameters such as Cl^-, Fe, Cu, Mn, Pb, K, F^-, Nitrate and Sulphate were drastically reduced from 9mg/l to 3.33 mg/l, 1.25 mg/l to 0.36 mg/l, 0.3mg/l to 0 mg/l, 0.5mg/l to 0.08mg/l, 0.2mg/l to 0.01 mg/l, 1.7 mg/l to 0.17mg/l, 0.7 mg/l to 0.08mg/l, 8.6mg/l to 0.03mg/l, 17.5mg/l to 6.20 mg/l respectively throughout the course of the study. Also, the 2kg water hyacinth plant density cultured in the sewage purifies more compared to the 1kg water hyacinth plant density which is moderate and minimal in the control.

KEYWORDS: *Heavy Metals, Phytoremediation, Sewage, Water Hyacinth (Eichhornia crassipes)*

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I. INTRODUCTION

Water hyacinth (Eichhornia crassipes) is a noxious weed that has attracted worldwide attention due to its fast spread and congested growth, which lead to serious problems in navigation, irrigation, and power generation. On the other hand, when looked from a resource angle, it appears to be a valuable resource with several unique properties. As a result, research activity concerning utilization (especially wastewater treatment or phytoremediation) of water hyacinth has boomed up in the last few decades. Wastes resulting from water treatment operations (sludge) are usually discharged into surface waters. This method of disposal often causes the build-up of a sludge deposits in streams. The effects of sludge effluent has a characteristics such as dissolved oxygen (DO), nitrates and suspended solids on the environment have been established for sewage plant effluents. However, little work has been done on determining the levels of these parameters in water treatment plant effluents [1]. The use of aquaculture as a means of treating wastewater involves both natural and artificial wetlands and the production of algae and higher plants (submersed and emersed), invertebrates and fish to remove contaminants such as manganese, chromium, copper, Zinc and Lead from the water. The water hyacinth (Eichhornia crassipes) appears to be one of the most promising aquatic plants for the treatment of wastewater and has received the most attention in this regard. The remarkable ability of aquatic plants, particularly the water hyacinth to extract compounds and elements from water efficiently has become well recognized.

Phytoremediation is one of the biological wastewater treatment methods [2], and is the concept of using plants-based systems and microbiological processes to eliminate contaminants in nature. It is defined as the engineered use of green plants (including aquatic microbes, grasses, forbs, and woody species) to remove, contain, or render harmless such environmental contaminants as heavy metals, trace elements, organic compounds, and radioactive compounds in soil or water Phytoremediation is a promising cleanup technology for contaminated soils, groundwater, and wastewater that is both low-tech and low-cost. The remediation techniques utilize specific planting arrangements, constructed wetlands (CW), floating-plant systems and numerous other configurations [3]. Besides water quality improvement and energy savings, CWs have other environmental protection features such as promoting biodiversity, providing habitat for wetland organisms and wildlife (e.g. birds and reptiles in large systems), serving climatic (e.g. less CO_2 production [4]; hydrological functions and biomethylation [5]. These systems are generally cost effective, simple, environmentally non-disruptive [2, 6] ecologically sound [7] with low maintenance cost [8] and low land requirements [9]. Studies conducted by some researchers show that water hyacinth has the huge potential for removal of the vast range of pollutants from wastewater [10, 11)] and has the ability to grow in severe polluted waters [12]. It is also used to improve the quality of water by reducing the levels of organic, inorganic nutrients [13] and heavy metals [14, 15, 16, 17, 18]. Presence of its fibrous root system and broad leaves help them to absorb higher concentrations of heavy metals [19]. It readily reduces the level of heavy metals in acid mine drainage water [20] and silver from industrial wastewater in short time [21]. This capability makes them a potential biological alternative to secondary and tertiary treatment for wastewater [22, 23, 24, 25].Although several studies have documented that hyacinths are good metal-accumulating plants none of these studies have documented the ability of this plant cultured under different density conditions to remove heavy metals from wastewaters. This paper, therefore, elucidates the phytoremediation potential of water hyacinth**,** for removal of nutrients (heavy metals) from domestic sewage.

II. METHODOLOGY

Experimental Site Location

The location for this experiment was at department of Agricultural and Biosystems Engineering's experimental centre. The experiment was done under a naturally controlled environment where some parameters/effect that may interrupt the result of the experiment was avoided such as the effect of rainfall, sun intensity, rodents and pest on the hyacinth plant and human activities, other external effects was put into consideration when taking the experiment sample.

Experimental Design

The experiment was based on completely randomized design replicated twice as shown in Figure 1.

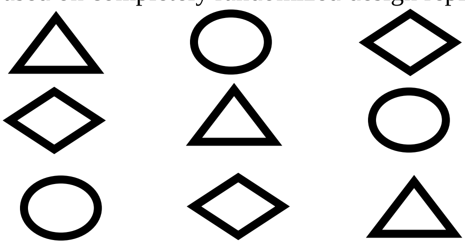

Figure 1: Experimental Design

Note that: Triangle represents the control experiment without the water hyacinth
Oval shape represents the plastic drum with 1kg water hyacinth plant density culture
Diamond shape represents the plastic drum with 2kg water hyacinth plant density culture

The Laboratory Test Parameters

The laboratory test parameters areTotal Hardness (Calcium and Magnesium), Calcium (Total), Magnesium (Total), Carbon(iv)oxide (CO_2), Chloride (Cl^-), Total Iron (Fe^{2+}), Copper (Cu^{2+}), Manganese (Mn^{2+}), Lead (Pb^{2+}), Fluoride (F^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^-), Phosphate (PO_4), Sodium (Na^+), Potassium (K^+), Ammonia (NH_3), Biochemical Oxygen Demand (BOD), Oxygen Consumed (COD), Total Solids (Suspended solid and Dissolved solids), Dissolved Oxygen

SEWAGE SAMPLING METHOD

The following are the procedures of collecting the sample of sewage for the various laboratory tests.

[1] The samples of sewage are collected out.
[2] The sampling bottles are of 50cl capacity.
[3] The bottles are properly cleaned before taking the sample.
[4] The bottles are tightly closed by stopper as soon as they are filled up.
[5] The bottles were kept in a cool dry place.
[6] The samples were collected from all the experiment and replicate.
[7] The sewage analysis started with an hour from the point of collection.
[8] The date and place of collection of the sample were noted on each bottle. [26]

Materials Used

Water hyacinth (Eichhornia crassipes) collected from Asa Dam River in Ilorin, Kwara State. The sewage was gotten from the septic tank in Agricultural Engineering Department premises. Other materials include three 80 litres plastic drums each for the weight of 1kg water hyacinth plant density culture, 2kg of water hyacinth plant density culture and control experiment (zero kilogram), nine sampling bottles, glove for protection when taking samples and overall coat.

Experimental Methods

The sewage was fetched and batched into the nine 80 litres plastic drums from the septic tank for three experiments. Water hyacinth plants of 1kg and 2kg was weighed and planted in three of the 80 litres plastic drum each with equal volume of sewage (70 litres). A similar control experiment was set-up simultaneously without water hyacinth in a three 80 litres plastic drums. The initial sewage characteristics were analyzed before planting the hyacinth plant. The samples were taken to the laboratory and wrapped with black cellophane bags to prevent further contaminations. Also, the sewage with 1kg, 2kg plant density of hyacinth and without hyacinth was taken at one week interval for measured analysis in the laboratory. The whole experiment lasted for 6 weeks and was regularly harvested during the course of the study. The samples for these tests were collected initially from septic tank and later from each experimental design and replicate.

III. RESULTS AND DISCUSSION

The results of the chemical analyses performed on the sewage samples collected from all the experimental set up for the 6 weeks treatment is as shown in Figures 2 to 24. The followings are the observation on the chemical characteristics of sewage during the experiment. The measured value of the pH in the raw sewage was 7.3 for all treatments. There was a reduction in the pH values of treatment processes after the 6 weeks treatment period, showing all treatments tend toward being acidic. However, pH values observed within the last 1 week in the 1kg and 2kg water hyacinth plant density cultures were very close in comparison with that of the control. The raw sewage was alkaline in nature but tends towards acidic in water hyacinth culture after 2 weeks of treatment and was as a result of consumption of impurities while in the control there was slight decrease due to environmental factors such as sunlight, this can be seen in Figure 2.

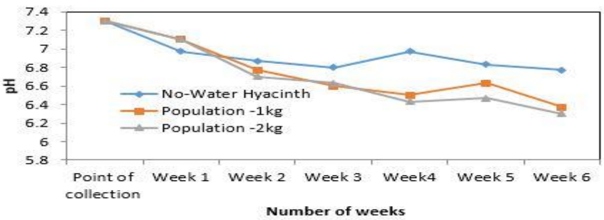

Fig 2: Effect of Water Hyacinth Treatment on pH

From the experiment, it can be seen that the value of the calcium hardness was unchanged for the first two weeks for the control experiment, 1kg and 2kg water hyacinth plant density cultures. A slight change was noticed in the third week, the calcium hardness varied downward on water hyacinth plant density culture of both 1kg and 2kg from 28mg/l to 26mg/l and 28mg/l to 25mg/l respectively while 28mg/l to 25.7mg/l for the control experiment without water hyacinth plant shown in Figure 3.

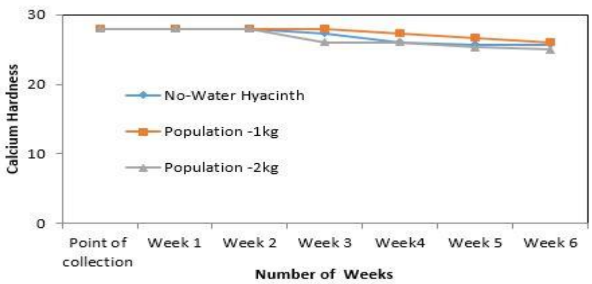

Fig 3: Effect of Water Hyacinth Treatment on Calcium Hardness Removal

The value measured for magnesium hardness in the raw sewage was 24mg/l. For both no-water hyacinth culture (control) and the 2kg-water hyacinth plant density culture, there was a decrease to 20mg/l in the first week and remain constant till the third week excepting the water hyacinth plant density culture of 1kg that slightly reduced by 0.7mg/l. also, there was little decrease in the measured value of the magnesium hardness for the three treatments showing that the effect of water hyacinth is not so significant as can be seen in Figure 4.

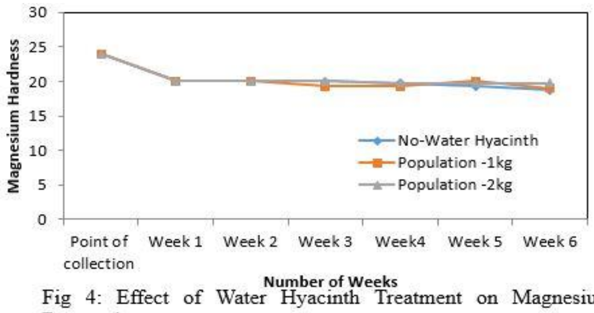

Fig 4: Effect of Water Hyacinth Treatment on Magnesium hardness Removal

As it was observed in the magnesium hardness, the magnesium total was also infinitesimally reduced from 8.6mg/l to 7.5mg/l, 8.6mg/l to 7.53 and 8.6mg/l to 7.4mg/l for the control, water hyacinth plant density culture of 1kg and 2kg respectively showing that the water hyacinth's feeding rate has little or no effect on the magnesium total as it can be seen in the control experiment. This can be seen in the Figure 5.

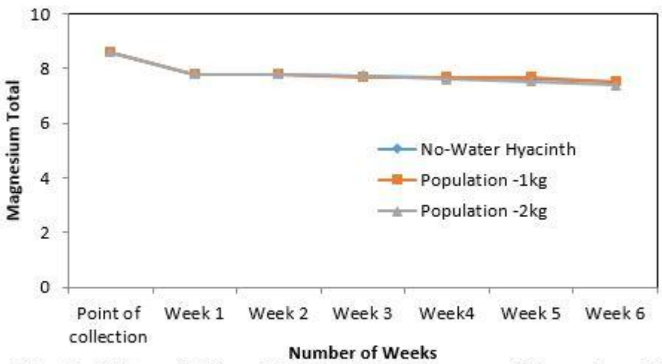

Fig 5: Effect of Water Hyacinth Treatment on Magnesium Total Removal

Right from the point of collection, it can be noticed that the value of calcium total remains constant for the first two weeks for the three experiments as can be seen in Figure 6. Very minute decrease was observed in the remaining 21 days of the period of study revealing that the effect of the metabolic activities of water hyacinth did not consume calcium ion present in the sewage.

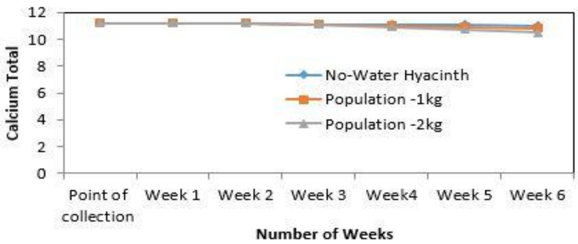

Fig 6: Effect of Water Hyacinth Treatment on Calcium Total Removal

The CO_2 for all the plastic drums initially was 6.5mg/l. A decrease was noticed in the first week for all the treatments while a sudden increase was observed in the second week as a result of gain in the carbon dioxide in the environment and got reduced drastically in the remaining weeks in both 1kg and 2kg water hyacinth plant density culture because of the depletion of the available carbon dioxide caused by the water hyacinth plant since there was no fresh supply of sewage, it eventually leads to wilting of the water hyacinth plant (Figure 7).

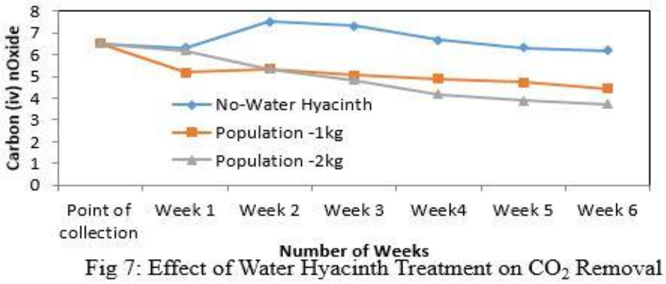

Fig 7: Effect of Water Hyacinth Treatment on CO_2 Removal

The chloride content was initially 9mg/l for all plastic drums. Figure 8 indicates that there was a drop in chloride content to 8.33mg/l for the first week for the three treatments. During the period of study, the chloride content was consumed to 3.67mg/l for the 1kg water hyacinth culture and 3.33mg/l for 2kg water hyacinth plant density culture while the control records 4.67mg/l at the end of the whole experiment showing that the more the density of the plant, the more chloride ion consumed.

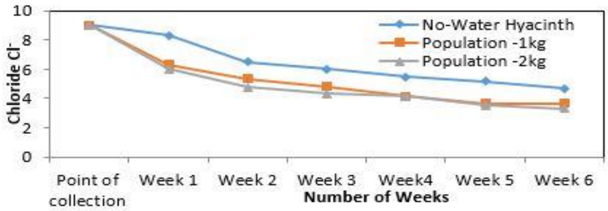

Fig 8: Effect of Water Hyacinth Treatment on Chloride Removal

The iron content was initially 1.25mg/l from the point of collection for all the plastic drums. Figure 9 shows that the iron content dropped to 0.98mg/l for first week and to 0.52mg/l for the last week for the control treatment (without water hyacinth plant). The fall was to 0.8mg/l in the first week and 0.4mg/l in the last week for the 1kg water hyacinth plant density. The fall was to 0.65mg/l for the first week and 0.36mg/l for the last week for the 2kg water hyacinth plant density culture. The Figure 9 shows the rapid absorption of iron due to the metabolic activities of the plant which was rapid in the first three weeks and low during maturity in the last three weeks.

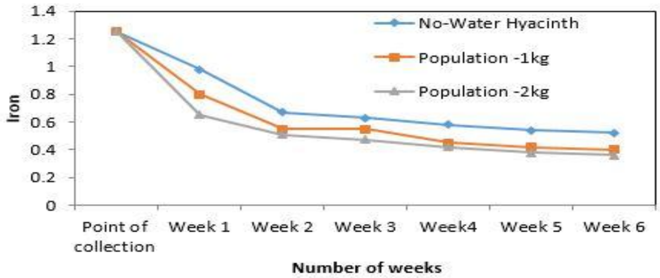

Fig 9: Effect of Water Hyacinth Treatment on Iron Removal

The copper was initially measured to be 0.3mg/l for the three treatments from the point of collection showing a very low concentration. In the subsequent weeks, the copper concentrated was consumed to zero as it can be seen in Figure 10.

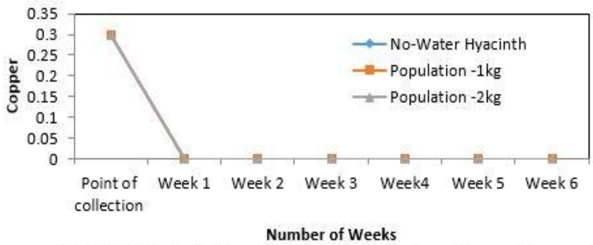

Fig 10: Effect of Water Hyacinth Treatment on Copper Removal

The manganese content measured 0.5mg/l initially for the three treatments as can be seen in Figure 11. It can be observed that there was no change in the consumption of manganese in the control treatment while there was a drop in the 1kg and 2kg water hyacinth plant density culture in the first week. In the subsequent weeks, the manganese dropped to 0.18 mg/l, 0.15mg/l and 0.08mg/l for the control, 1kg and 2kg water hyacinth plant density culture respectively at the end of the week showing that the consumptive rate of the water hyacinth culture depend on the density.

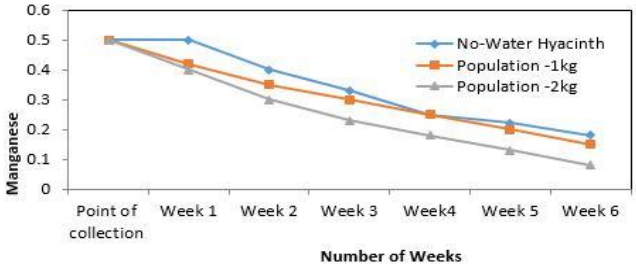

Fig 11: Effect of Water Hyacinth Treatment on Manganese Removal

From the value gotten initially for the lead content which is 1.2mg/l revealing that there is little concentration of lead in the raw sewage as shown in Figure 12. The values remain constant in the control and 1kg water hyacinth plant density in the first three weeks except for the 2kg water hyacinth plant density culture that was consistent in the consumptive rate throughout the course of the study.

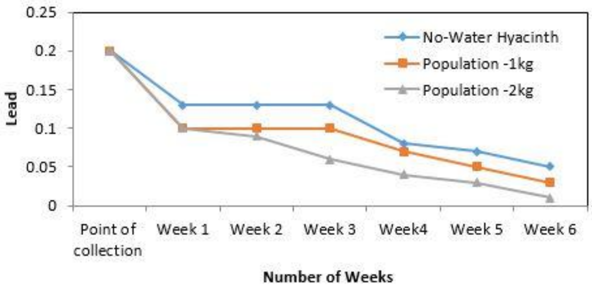

Fig 12: Effect of Water Hyacinth Treatment on Lead Removal

The fluoride content for all the samples was initially 0.7 mg/l. Figure 13 show that the fluoride content fall to 0.68mg/l in the first week and 0.43mg/l for the last week for the control treatment. The fall was to 0.62mg/l in the first week and 0.38mg/l for the last week for the 1kg water hyacinth plant density culture. The fall was to 0.58mg/l in the first week and 0.08mg/l in the last week for the 2kg water hyacinth. The fall was rapid in the 2kg water hyacinth plant density culture compared to the 1kg water hyacinth plant density culture and control as a result of its high plant density which accelerate the consumption of nutrients.

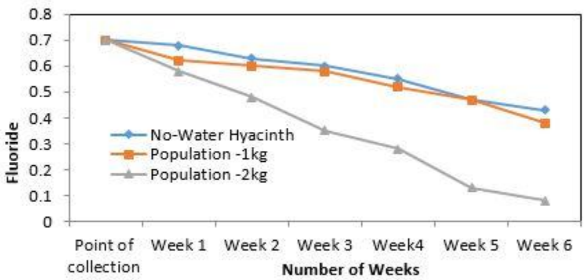

Fig 13: Effect of Water Hyacinth Treatment on Fluoride Removal

The initial sulphate content was 17.5mg/l was decreased to 16.7mg/l between one week in the control experiment while it was decreased to 0.15mg/l and 12.8mg/l in the 1kg and 2kg water hyacinth plant density culture respectively. Subsequently, decrement finally placed the sulphate level at 11.3mg/l, 9.0mg/l and 6.2mg/l for the control experiment, 1kg and 2kg water hyacinth plant density culture respectively (Figure 14). It is noted that the water hyacinth plant density culture (1kg and 2kg) consumes more as a result of its vigorous growth and metabolic activities on the sewage while there was a gradual decrement in the control experiment.

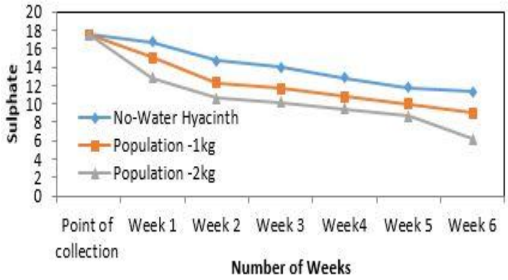

Fig 14: Effect of Water Hyacinth Treatment on Sulphate Removal

The nitrogen content measured as nitrate in all the treatment processes were observed to be 8.6mg/l in the raw sewage. From Figure 15, the nitrogen content was on the decrease throughout the treatment period due to the serious feeding of the water hyacinth showing that the more the density of water hyacinth culture, the more the consumption rate of Nitrate as can be seen in the case of sulphate.

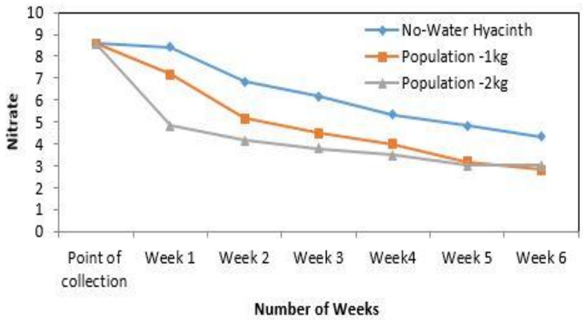

Fig 15: Effect of Water Hyacinth Treatment on Nitrate Removal

The phosphorus content measured as phosphate in the treatment processes observed in 7.5mg/l from the point of collection. Figure 16 shows that the phosphorus content fall to 6.73mg/l in the first week and 4.33mg/l in the last week for the control experiment. The fall was to 5.67mg/l in the first week and 2.67mg/l in the last week for the 1kg water hyacinth and the fall was to 5.17mg/l in the first week and 2.5mg/l in the last week for the 2kg water hyacinth plant density culture. There was rapid absorption of phosphate due to metabolic activities of plant as they are growing in the first three weeks and low absorption in the last week during maturity.

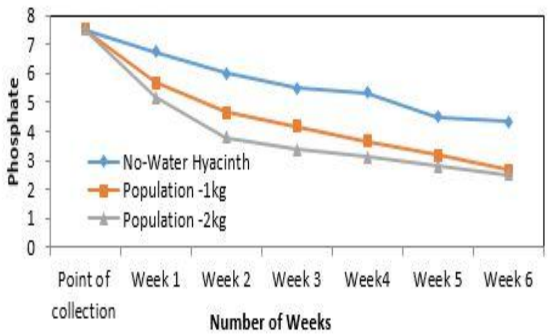

Fig 16: Effect of Water Hyacinth Treatment on Phosphate Removal

From the point of collection, the sodium content was measured to 2.3 mg/l. Figure 17 reveals that there was a diminution to 2.2 mg/l in the first week and 1.8 mg/l in the last week for the control experiment (no water hyacinth plant). The diminution was to 2.07 mg/l in the first week and 1.13 mg/l in the last week for the population of 1kg water hyacinth plant density culture and the diminution was to 1.67 mg/l in the first week and 0.7 mg/l in the last week for the 2 kg water hyacinth plant density culture. There was a great decline of sodium as a result of rapid growth (as it grows new root hairs) of water hyacinth plant in the first three weeks and low absorption in the last three weeks during the maturity.

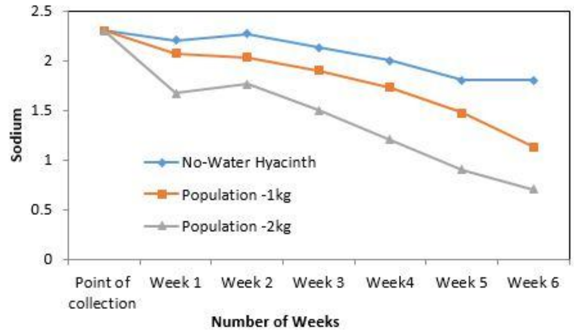

Fig 17: Effect of Water Hyacinth Treatment on Sodium Removal

The potassium content was initially measured to be 1.7mg/l showing that there is low concentration of potassium in the raw sewage. Figure 18 shows the reduction in the concentration of potassium and this is more obvious in both the 1kg and 2kg water hyacinth plant density culture as a result of their metabolic activities compared to the control experiment which is affected by the environmental factors such as sunlight.

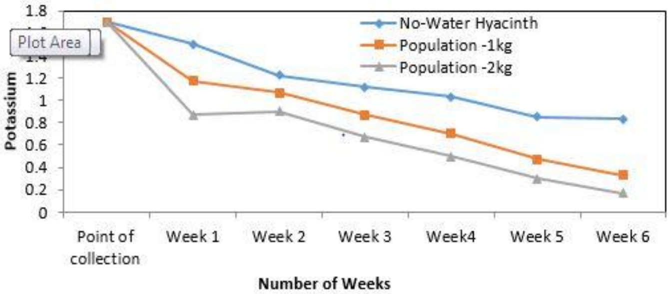

Fig 18: Effect of Water Hyacinth Treatment on Potassium Removal

The initial concentration of the dissolved solids was 444mg/l in the raw sewage. Figure 19 shows that the concentration subsides to 416mg/l at the end of the last week for the control experiment while the 1kg and 2kg water hyacinth plant density culture subside to 392mg/l and 389mg/l respectively. The presence of the water hyacinth through the development of new roots in the sewage hastens the reduction of the concentration of dissolved solids compared to the control experiment.

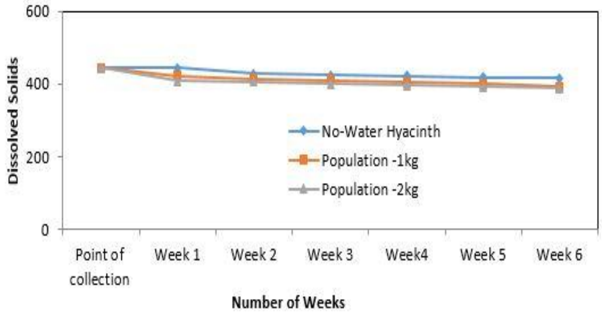

Fig 19: Effect of Water Hyacinth Treatment on Dissolved Solid Removal

The initial concentration of the suspended solids in the raw sewage was measured to be 92 mg/l. Figure 20 show that the concentration lessens 82.7mg/l in the first week and 66.3mg/l in the last week for the control while it lessens from 78mg/l to 62mg/l and 71.3mg/l to 54mg/l for the 1kg and 2kg water hyacinth plant density culture respectively and this also reveals that the action of the water hyacinth on sewage speed up the consumption in nutrients (pollutants).

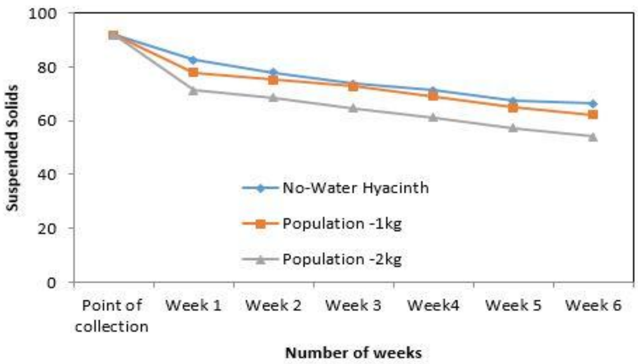

Fig 20: Efect of Water Hyacinth Treatment on Suspended solids Removal

The COD content in the raw sewage was measured to be 5.8mg/l and a sudden rise was observed in the content in the second week of the experiment for all the three treatments and a fall was observed right from the third week to the end of the experimental analysis as shown in Figure 21. This is as a result in the depletion in the leaves of the water hyacinth plant.

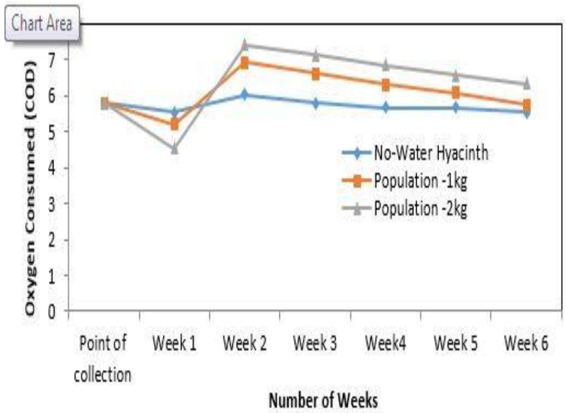

Fig 21: Effect of Water Hyacinth Treatment on COD removal

The concentration of the dissolved oxygen right from the point of collection was measured to be 5.6 mg/l. Figure 22 shows the gradual drop in the concentration of the dissolved oxygen in the control treatment from 4.87mg/l in the first week and 4.06mg/l in the last week of the experiment. There was a little decrease in the dissolved oxygen in the second week of the experiment for both 1kg and 2kg water hyacinth plant density culture showing their vibrant growth that leads to the release of oxygen and a gradual decrease right from the third week to the last week due to the depletion of the water hyacinth leaves when attaining maturity.

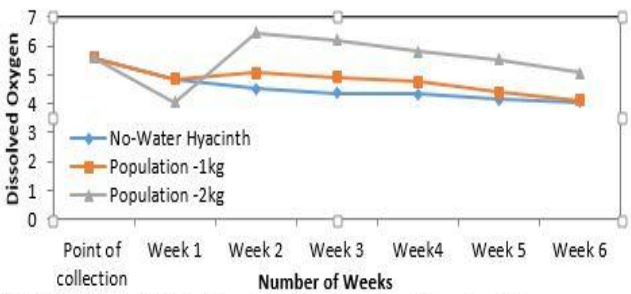

Fig 22: Effect of Water Hyacinth Treatment on Dissolved Oxygen

The measured value of the BOD in the raw sewage was 5.0 mg/l. Figure 23 shows the gradual reduction in the BOD content for all the treatments. In the control treatment, BOD content records a value that is a little bit higher compared to the 2kg water hyacinth plant density culture that has the least value showing the metabolic activities of the plant on the sewage leading to the better reduction.

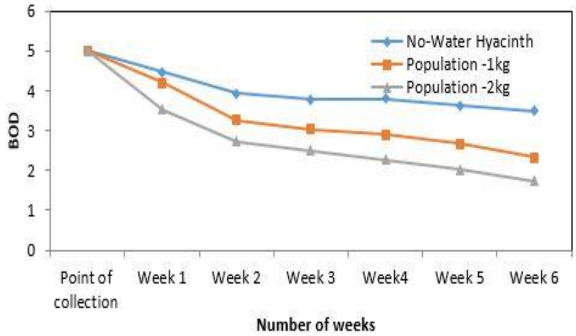

Fig 23: Effect of Water Hyacinth Treatment on BOD Removal

The initial concentration of the ammonia in the raw sewage was diminutive and measured to be 0.062mg/l. As it was observed in the BOD content in Figure 24, there was also a continuing reduction in the ammonia content for all the treatments during the course of the experimental analysis but better in the 1kg and 2kg water hyacinth plant density culture and this is as a result of buoyant growth of water hyacinth on the sewage.

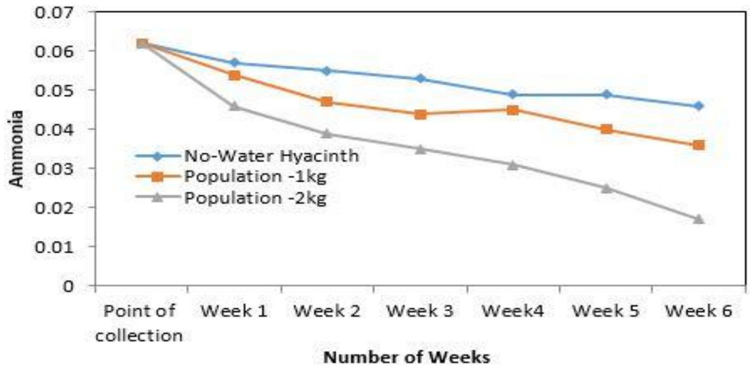

Fig 24: Effect of Water Hyacinth Treatment on Ammonia Removal

IV. CONCLUSION

From the experimental analysis, it can be observed that the variation pattern of most sewage characteristics measured in the water hyacinth plant density culture (1kg and 2kg) depicted by the rate of nutrient absorption when compared with the control treatment (no water hyacinth) could be best described as impulsive in the first three weeks in the water hyacinth culture while it is gradual throughout the experiment in the control experiment with the exception of calcium hardness, COD and Dissolved Oxygen. There were drastic reduction in concentration of Chloride, Iron, Copper, Manganese, Lead, Fluoride, Sulphate, Nitrate, Phosphorus and Potassium. It is concluded that *Eichhornia crassipes* (water hyacinth) can be usefully employed to extract nutrients from sewage. It is also proved useful in treating effluents polluted with toxic heavy metals. The study reveals the potential and effectiveness of aquatic plant especially water hyacinth in the removal of nutrients on sewage. It can also be concluded that the higher the density of the plant (water hyacinth) on sewage, the more the absorption of nutrients (pollutants) that is, the best of purification will be obtained.

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