Septage Purification and Nutrient Uptake Potential of Water Hyacinth (*Eichhornia crassipes*) in a Batch System

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Abstract— **Septage arising from septic tanks in urban areas represents complex water-carrying waste of high-strength which needs to be safely disposed. Inappropriate handling of septage due to poor construction of septic tanks and processes of evacuation of its content into waterways leads to environmental pollution and associated health problems in developing countries such as Nigeria. Several emergent aquatic plants such as water hyacinth, water lettuce etc. had been utilized to handle wastewater of varying degree and strength. This study evaluated the nutrient uptake potentials of water hyacinth in septage purification processes and the effect on plant's behaviour. Septage evacuated from septic tanks by mechanical evacuators from six Districts within Abuja were collected. The septage samples were diluted 0, 25, 50 and 75% with water and used in 50L capacity containers. The samples were planted with water hyacinth and tested daily for ammonia, phosphate, BOD5, TSS and DO for 2 weeks. The efficiency of Water hyacinth for ammonia, phosphate, BOD5 and TSS removal were found to be 100%, 92%, 97%, and 99% in the 75%, 75%, 50%, and 75% diluted septage, respectively. Water hyacinth thrived in septage with low organic loading of 75% water and 25% septage. Water hyacinth is not suitable for raw septage treatment as the plants did not survive in the undiluted septage and did not recover even after 14 days.**

Index Terms— **Septage, aquatic plant, water hyacinth, nutrient removal, treatment**

I. INTRODUCTION

Septage is high-strength, wastewater requiring adequate treatment before discharge into the environment. It contains pollutants such as oxygen-depleting substances, suspended solids, nutrients, toxic chemicals and pathogens (Mihelcic and Zimmerman, 2010). Generally, contaminants in wastewaters like septage, can be classified as organic, inorganic, pathogenic and non-pathogenic microorganisms, solids, gases, and toxins among others (Adeniran, et al., 2012). According to Jiménez and Beltrán (2002), the potential hazards caused by pathogens are from direct or indirect consumption of water contaminated from wastewater effluents. Reports also showed pathogens affecting humans and animals arising from slaughtered animals in abattoir wastewater (Coker, et al., 2001).

Diseases caused by bacteria, viruses and protozoa are the most common health hazards associated with untreated wastewater. These health hazards may also be chronic in nature and with long-term effects such as degenerative heart disease and stomach ulcer (Paillard, et al., 2005; Kris, 2007). Viruses are generally more resistant in wastewater treatment, most infectious, more difficult to detect and require smaller doses to cause infections (Toze, 1997; Okoh, et al 2007). Wastewater treatment is necessary for protection of public health and the environment.

Over the years, several wastewater treatment technologies have been designed and operated to handle varying types of wastewater. These technologies are classified as physical, aquatic, or terrestrial systems and they have been operated on full, pilot and laboratory scales. Studies have confirmed that aquatic weeds are low-cost powerful bio-agents which purify wastewater lying under them by physical, chemical and biological actions (Abbasi and Abbasi, 2010). Many cities in developing countries lack appropriate wastewater treatment facilities while available ones are not fully operational. Satellite towns of Abuja in the Federal Capital Territory (FCT) of Nigeria lack these facilities, hence they construct soak-away and septic tanks for their wastewater management even though this is not what is provided for in the Abuja Master Plan. This system of wastewater management has led to the generation of high volume of septage and sludge in the septic tanks which are evacuated when the septic tanks are filled and indiscriminately discharged into the environment. Hence, there is need to evolve a functional, cost effective, acceptable and environmentally friendly wastewater treatment system that can be easily constructed, operated and maintained. This paper describes the use of Water hyacinth for purification of septage and also evaluate its nutrient uptake potential in relation to plants growth in a batch system.

A.Septage Purification Potential of Water Hyacinth

As far back as the 19^{th} century, amidst several emergent aquatic plants termed weed with potentials for wastewater treatment, water hyacinth (*Eichhornia crassipes*) has received great attention because of its obstinacy and high reproductive capacity especially when grown in domestic sewage lagoons (McDonald and Wolverton, 1980). Water hyacinth is also known to have a promising potential for the removal of toxic heavy metals and other pollutants from aquatic environments (Mahamadi and Nharingo, 2010), though the potential of Water hyacinth to purify wastewater has not been fully exploited in some parts of the world (Alade and Ojoawo, 2009). Meanwhile, in other parts mostly developed countries, water hyacinth has been used to remove nutrients or pollutants from wastewaters (Boyd, 1970; Scarbrook and Davies, 1971; Wolverton and McDonald, 1978; Rai et al., 1994; Yedla et al., 2002; Xia, 2008; Abbasi and Abbasi, 2010). Once in wastewater, water hyacinth proliferates rapidly gaining up to 0.38 shoot/day in 28 days (Kutty et al., 2009).

Water hyacinth is a yellow-spotted with sky-blue flowers perennial, tropical aquatic plant. The flower has a six-parted calyx, a six-lobed corolla, three stamen, and a lone pistil. It

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has a many-seeded fruit with swollen leafstalks containing air which contributes to it buoyancy and aids floating on water (Obasa, 2010; Truijen and van der Heijen 2013). The plant spreads laterally covering water surfaces while increasing vertically in growth. Hyacinth is very productive photosynthetic plant, having extensive root system capable of rapid growth (Figure 1). This attribute serves as an advantage when used in wastewater treatment system. Naturally, their roots absorb pollutants (organic, inorganic and metals) of various concentrations including carcinogenic compounds. It can be distinguished from other aquatic plants by its highly glossy leaves (Maine, 2006; Skinner, 2007).

Water hyacinth has demonstrated its capacity as an excellent pollutant removal from wastewaters as reported in several researches (Schneider, et al., 1995; Al Rhamali, et al., 2005; Elangovan, et al., 2008 and Hassan, et al., 2010; Shah and Hashmi 2012 and Sridhar et al., 2014; Achi et al, 2014). Water hyacinth reproduces primarily by vegetative propagation. It develops a large canopy, which often provides a good thriving and surviving edge over other floating aquatic plants growing in the same system. Its growth rate as an aquatic macrophyte is rated among the world's ten weeds. Growth of water hyacinth is influenced by effective usage of solar energy by the plant, wastewater nutrient composition, cultural methods and Environmental factors (Reddy and Sutton, 1984; Truijen and van der Heijen, 2013).

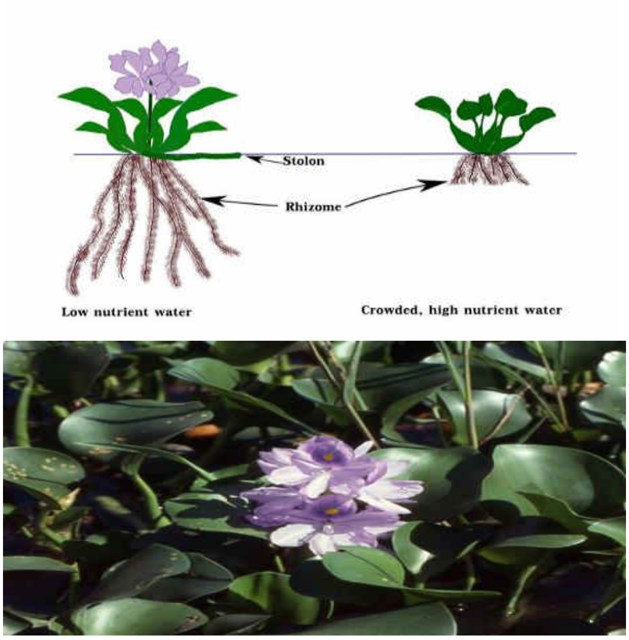

Figure 1: Extensive root system of water hyacinth and its glossy leaves
(Source: Sim, 2003; Truijen and van der Heijen, 2013).

II. METHODOLOGY

A. Study Area

This study was carried out in Abuja, the Federal Capital City of Nigeria. The city has 8000 Kilometer square area centrally located and easily accessible by all the states of the Federal Republic of Nigeria. Abuja was a City created for political reasons. Its status was clearly defined by the 1976 by Federal Capital Territory (FCT) Federal Government Decree. Consequently, a Master Plan was developed to define the general structure along with the most needed infrastructure including buildings, roads, water and sewage system (International Planning Associates, IPA, 1979). The FCT is divided into six Area Councils namely Kuje, Gwagwalada, Abaji, Bwari, Kwali and Abuja Municipal Area Council (AMAC) as shown in Figure 2. Also, the Area councils consist of Satellite Towns most of them are currently not being developed as per the Abuja Master Plan.

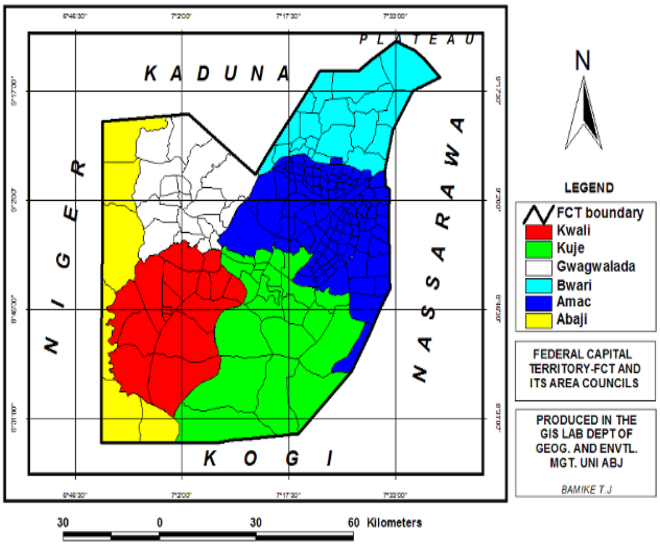

Figure 2: Map of the FCT showing the Six Area Councils
(Source: Aondoakaa, 2012)

B. Materials and Experimental Setup

This study utilized an experimental approach to investigate the nutrient removal potential and behavioural pattern of Water hyacinth in septage. Changes in the septage strength and effect of its dilution with water on the growth of Water hyacinth and its nutrient removal were investigated. The experimental design involved the selection of a suitable site for the experiment. Wupa Basin Sewage Treatment Plant location was identified and used as the experimental site. Six evacuated septage samples were collected from different Districts within Abuja.

The materials used for this study were: Water hyacinth plants, five (5) numbers of 50 L calibrated plastic containers, laboratory apparatus and equipment for Physicochemical and biological analysis of wastewater. Accordingly, the materials were collected as follows: Water Hyacinth was collected from Jabi Dam Lake in Abuja where they had been identified as growing naturally. This aquatic plant was temporarily planted in a prepared pre-nursery bed for 3-days and then each of the plants were washed, weighed and prepared for culturing. Ten (10) healthy off-shoots of Water hyacinth with an average weight of 85.43g was transferred into each of the experimental containers of varied septage dilution concentrations prepared and labeled as follows and the set up shown in Figure 3.

Sample A_{WH}: This represents a highly concentrated septage devoid of dilution as maybe obtained during the dry season.

Sample B_{WH}: This represents 75% septage sample and 25% tap water. This depicts the early months of raining season or the August break with low wastewater dilution.

Sample C_{WH}: This scenario represents 50% septage concentration and 50% tap water depicting high dilution during raining season or otherwise.

Sample D_{WH}: This scenario represents septage of 25% concentration with dilution of 75% depicting a highly diluted wastewater as obtains during rainy reason.

Sample E_C: About 30 L grab sample of undiluted septage was collected into a 50 L container without introducing aquatic plant. This served as the control sample.

Standard analytical procedures for wastewater analysis were adopted in the experiments. The Physicochemical characteristics of the wastewater were measured daily for 2 weeks to ascertain the levels of nutrient removal. Specifically, NH_4^+-N, PO_4^{2-}, BOD_5, DO, TN, TP and TSS were measured and compared with the permissible limits of effluents as given by World Health Organization (WHO) and Nigerian Federal Environmental Protection Agency (FEPA) transformed to National Environmental Standards and Regulations Enforcement Agency (NESREA) for effluent discharge and usage (WHO, 1989 and FEPA, 1991). Standard laboratory and wastewater analysis were carried out according to American Public Health Association (APHA) and American Water works Association (AWA) standard. The retention time to achieve acceptable effluent quality was noted from the analytical results.

Figure 3: Experimental setup of Different Septage Dilutions and Control

III. RESULTS AND DISCUSSION

A. Composition of septage

The general characteristics composition of six septage samples directly evacuated from septic tanks within the Abuja Metropolis is as presented in Table 1. The samples minimum, maximum, average and standard deviation of the measured parameters were also presented. Also, variation in concentration of measured parameters from the initial to the 7th and 14th day experimental period is shown in Table 2.

Table 1: Septage characteristics composition and permissible discharge limits into waterways

Samples	Location	Septage Parameters (mg/L)				
		TSS	**NH_4^+- N**	**PO_4^{2-}**	**BOD_5**	**DO**
1	Berger Yard, Wuse	745.00	28.00	19.15	330.00	2.82
2	Gwarinpa I	1190.00	28.00	17.35	170.00	1.85
3	Berger Yard, Idu	2500.00	25.65	21.50	450.00	1.50
4	Garki II	3000.00	30.05	26.90	750.00	0.80
5	Wuye District	3000.00	28.05	30.00	700.00	0.80
6	Dantata Yard, Garki II	2970.00	29.00	32.50	500.00	1.00
	Minimum	745.00	25.65	17.35	170.00	0.80
	Maximum	3000.00	30.05	32.50	750.00	1.85
	Average	2234.17	28.13	24.57	483.33	1.19
	Standard Deviation	1009.26	1.46	6.14	219.61	0.47
WHO	**Permissible Limit (mg/L)**	**30.00**	**10.00**	**5.00**	**30.00**	**NS**
FEPA		**25.00**	**1.00**	**5.00**	**50.00**	**>2.00**

NS: Not Specified

Table 2: Summary of Variation in Septage characteristic concentrations in days

S/N	Septage Parameters (mg/L)	Day(s)	Percentage Water to Septage Dilution				Undiluted Control Sample
			0%	**25%**	**50%**	**75%**	
1	**TSS**	0	745.00	560.00	375.00	290.00	746.00
		7	77.00	10.50	17.60	53.20	136.00
		14	18.60	26.00	28.90	4.10	40.00
2	**BOD_5**	0	330.00	247.00	170.00	84.00	330.00
		7	112.00	70.00	30.00	14.30	135.00
		14	80.00	10.00	5.00	5.00	121.00
3	**DO**	0	2.82	1.90	2.96	4.09	2.82
		7	4.74	4.23	4.60	6.10	2.60
		14	4.71	5.60	5.50	6.15	4.00

4	**$NH4^{+}$-N**	0	28.00	21.09	14.50	7.15	28.00
		7	16.00	15.20	8.00	2.30	19.00
		14	10.00	13.15	3.15	0.00	14.70
5	**PO_4^{2-}**	0	19.15	14.96	10.50	4.97	19.15
		7	11.70	9.10	4.50	2.50	13.00
		14	10.00	7.00	1.88	0.40	11.00

B. Growth of Water Hyacinth in Septage Samples

The findings from the four samples planted with Water Hyacinth with respect to the plant's growth pattern and subsequent nutrient removal are discussed below with physical changes in growth of plant shown in Figure 4 (a-d).

Sample A_{WH}: The undiluted septage sample was found to be unsuitable for water hyacinth growth. More than 70% of the introduced water hyacinth died within the 7days of the experiment as shown in Figure 4a. Significant reduction in the septage characteristics was observed before and after the death of the plants. This finding was supported by the report of USEPA (1998) which stated that heavy organic loading results in death of the Water hyacinth aquatic plant.

Sample B_{WH}: In this sample, the plants were also not thriving well. There was neither increase in shoot or stallion but death of 50% of the plant within the first 7 days of the experiment as shown in Figure 4b. This result is also in accordance with USEPA (1998) in which aquatic plants die off due to heavy organic loading.

Sample C_{WH}: Water hyacinth was observed to thrive well with evidences of increase in the height of the inoculated plants as shown in Figure 4c and supported by the research conducted by Shahabaldin, et al., (2013).

Sample D_{WH}: similar to sample C_{WH}, water hyacinth was observed to thrive very well with evidence of increase in the height of inoculated plants as shown in Figure 4d. This finding is also in consonance with result of the study by Shahabaldin, et al., (2013).

Figure 4a: Sample A_{WH} after 7 days

Figure 4b: Sample B_{WH} within 7 days

Figure 4c: Sample C_{WH} within 7 days

Figure 4d: Sample D_{WH} within 7 days

C. Nutrient Removal in varied Septage Dilutions

Removal of particulate matter: The undiluted septage, 25%, 50% and 75% dilutions samples attained the acceptable limit in 9, 5, 5 and 9 days with an efficiency of 97%, 97%, 95 and 88% respectively. On the contrary, the unplanted septage control sample did not attained the discharge limit within the 14 days experimental period. The percentage TSS removal within the 14 days experimental period as shown in Table 3 and Figure 5 for 0%, 25%, 50%, 75% dilutions and the unplanted septage control sample were 98%, 95%, 92%, 99%, and 95% respectively. This result is in consonance with 86% reduction in TSS recorded by Achi, et al (2014) in performance evaluation of a water hyacinth based Institutional wastewater treatment plant.

Removal of BOD_5 and Oxygenation: Septage dilutions of 25%, 50% and 75% attained acceptable discharge limit in 13, 4 and 1 day(s) with an efficiency of 84%, 71% and 42% respectively. On the contrary, undiluted septage and the unplanted septage control sample did not attained the discharge limit within the 14 days experimental period. Nutrient removal rate was very significant within the first 3 days. The percentage removal of BOD_5 within the 14 days experimental period for 0%, 25%, 50%, 75% dilutions and the unplanted septage control sample were 76%, 96%, 97%, 94%, and 63% respectively as shown in Table 3 and Figure 6. On the other hand, the oxygenation potential of water hyacinth also varied with dilutions of septage. Plotted chart of undiluted septage depict a typical highly polluted river DO curve as shown in Figure 8. The undiluted septage sample and the 25% dilution attained acceptable DO limits within 3 and 1 day(s) at 4% and 38% efficiency respectively. The 50% and 75% septage dilutions samples upon dilution attained the acceptable limit while the unplanted control septage sample attained the permissible limit in 5 days at 29% efficiency which may be due to atmospheric oxygen. The percentage DO ingestion by the plants within the 14 days experimental period is shown in Table 3 and Figure 7 for 0%, 25%, 50%, 75% dilutions and the unplanted control septage sample which are 67%, 195%, 86%, 50%, and 30% respectively. Similarly, about 100% increase in DO was reported by Achi, et al (2014) in a water hyacinth-based Institutional wastewater treatment plant in Ibadan, Nigeria.

Removal of Nitrogen and Phosphorus: The efficiency of water hyacinth for ammonia removal varied with percentage dilution of the septage as shown in Table 3 and Figure 8. In the undiluted septage, acceptable discharge limit was attained in 11 days with removal efficiency of 64%. In 50% dilution, it attained the discharge limit within 6 days with 34% efficiency while dilution of 75% reduced the septage concentration for mmonia to acceptable discharge limit. On the contrary, 25% septage dilution and the unplanted septage control did not attain the discharge limit within the 14 days experimental period. The percentage removal of ammonia within the 14 days experimental period for 0%, 25%, 50%, 75% dilutions and the unplanted septage control sample were 64%, 38%, 78%, 100% and 48% respectively.

Also, phosphorus in the form of phosphate in 50% septage dilution attained the acceptable phosphate discharge limit in 7 days with 64% while 75% dilution already reduced the concentration of phosphate to acceptable discharge limit. On the contrary, 0% and 25% septage dilution and the unplanted septage control sample did not attain the discharge limit within the 14 days experimental period. The percentage removal of phosphate within the 14 days experimental period is shown in Table 3 and Figure 9 for 0%, 25%, 50%, 75% dilutions and the unplanted septage control sample were 47%, 53%, 82%, 92% and 43% respectively.

Table 3: Percentage Efficiency of Water Hyacinth in varied Dilution for 2 weeks

S/N	Septage Parameters	Day(s)	Percentage Water to Septage Dilution				Undiluted Control Sample
			0%	25%	50%	75%	
1	**TSS**	0	0.00	0.00	0.00	0.00	0.00
		7	89.66	98.13	95.31	81.66	81.77
		14	97.50	95.36	92.29	98.59	94.64
2	**BOD_5**	0	0.00	0.00	0.00	0.00	0.00
		7	66.06	71.66	82.35	82.98	59.09
		14	75.76	95.95	97.06	94.05	63.33
3	**DO**	0	0.00	0.00	0.00	0.00	0.00
		7	40.51	55.08	35.65	32.95	7.80
		14	40.13	66.07	46.18	33.50	29.50
4	**$NH4^+$-N**	0	0.00	0.00	0.00	0.00	0.00
		7	42.86	27.93	44.83	67.83	32.14
		14	64.29	66.81	87.03	94.41	60.71
5	**PO_4^{2-}**	0	0.00	0.00	0.00	0.00	0.00
		7	38.90	39.17	57.14	49.70	32.11
		14	47.78	53.21	82.10	91.95	42.56

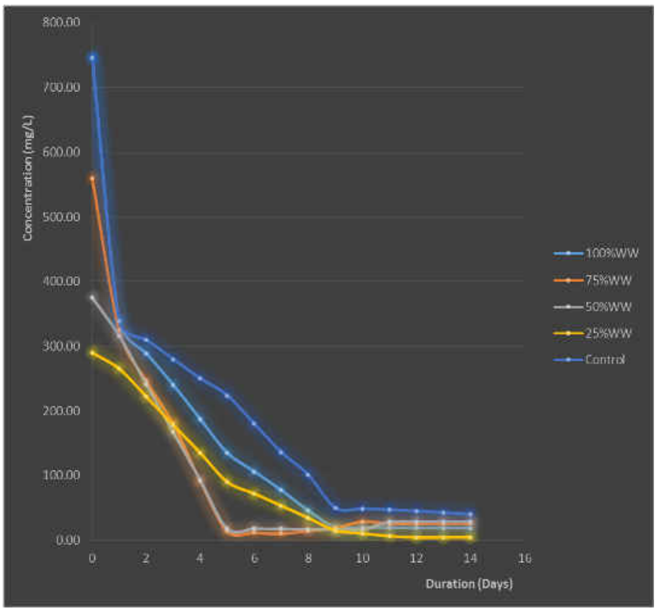

Figure 5: Rate of Total Suspended Solids (TSS) removal

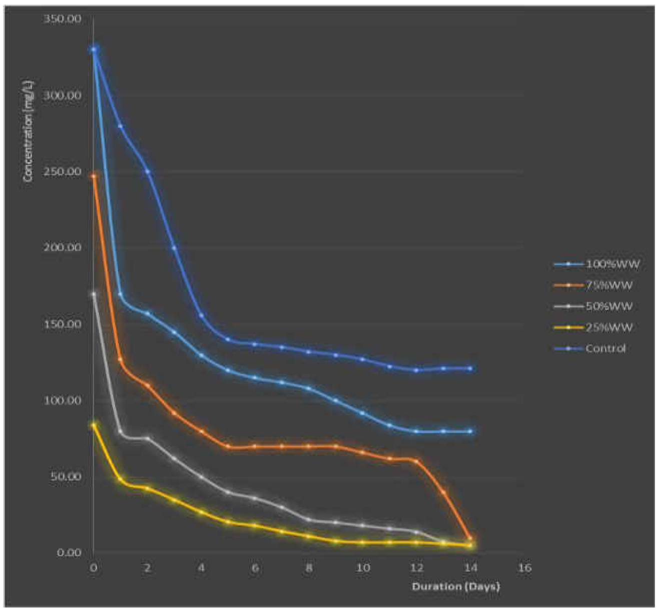

Figure 6: Rate of BOD_5 removal

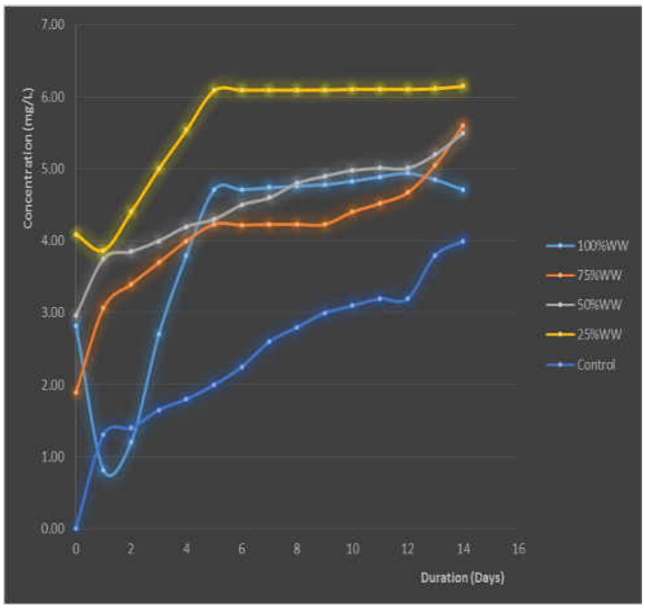

Figure 7: Rate of Oxygenation (DO)

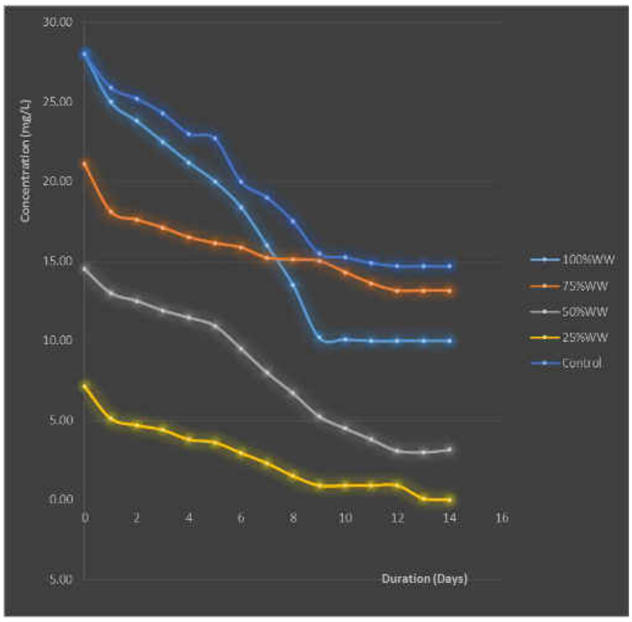

Figure 8: Rate of Ammonia removal

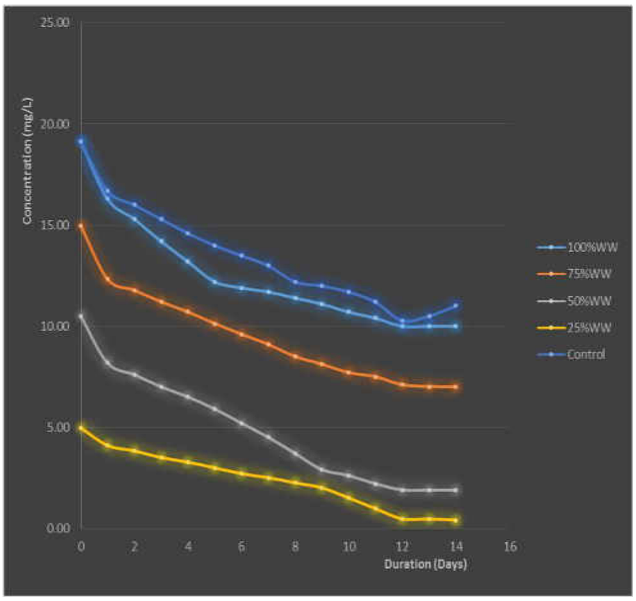

Figure 9: Rate of Phosphate removal

CONCLUSIONS AND RECOMMENDATIONS

The use of water hyacinth for septage treatment is comparatively low in cost and easy to set up. Irrespective of the degree of pollution, water hyacinth oxygenates wastewater at a high rate, however, the redox potential of the medium decreases immediately after their introduction. The removal efficiency of contaminants like TSS, Phosphate, BOD_5, etc. varies for different aquatic plants. Water hyacinth exhibited a high Ammonia, Phosphate, BOD_5 and TSS removal efficiency of 100%, 92%, 97%, and 99% in water to septage dilution of 75%, 75%, 50%, and 75% respectively.

In conclusion, the efficiency of water hyacinth for nutrient removal can be maximized in an average-strength wastewater. The plant flourishes and removes pollutants in the septage labeled sample with lower concentration. Water hyacinth is better utilized at the latter part of a wastewater treatment train for further nutrient removal and subsequent polishing. It is therefore a suitable plant for secondary treatment.

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Emmanuel Abiodun Oluwadamisi was born on 23rd December, 1964 at Erin-Ile Kwara State, Nigeria. He holds a Master of Philosophy from University of Ibadan in 2013 and currently a PhD researcher at the same Institution. He also graduated with PGD (M.Eng) in Sanitary Engineering from International Institute of Hydraulic & Environmental Engineering, Delft Netherlands in 1996; MSc in Construction Management from University of Jos, Nigeria in 1995; and a Bachelor of Engineering (Civil & Water Resources) from University of Maiduguri, Nigeria in 1989. He worked on Wastewater Treatment Plants and Sewerage Network in Abuja for over 20 years during which he travelled on study tour to several water treatment, sewage treatment plants and solid waste management facilities in Germany, France, Switzerland, Netherlands, Italy, Kenya, Mozambique, China, Malaysia, and Japan amongst others. He had served as consultant in several water resources and environmental engineering projects some of which includes Technical Audit of Little Osse/Egbe Ekiti Water Treatment works in Nigeria, Irrigation channelization works at Peremabiri, Nigeria and Fadama II Agricultural projects amongst others. He is a registered Civil Engineer with Council for Regulation of Engineering in Nigeria (COREN-R8339), Fellow of the Nigerian Society of Engineers (FNSE-9637) and a past Chairman of the Nigerian Society of Engineers, Abuja Branch with over five hundred engineers as members. His current research in phytoremediation involves the use of Water hyacinth, Typha and Phragmites for low cost treatment of generated municipal wastewater in Abuja, Nigeria for which a pilot scheme has been constructed.

Professor Mynepalli K. C. SRIDHAR

Professor Mynepalli Sridhar was born on 8th December 1942 in Vellatur, Andhra Pradesh, in India. He obtained BSc in chemical and biological Sciences and went for MSc (Biochemistry with Fermentation chemistry specialty) at MS University, Baroda, India. He obtained PhD from Indian Institute of Science, Bangalore, India, worked on wastewater treatment for 13 years years before moving to University of Ibadan, Ibadan in 1977. His research projects ranged from water resources, eutrophication and pollution control, water treatment, low cost wastewater treatment, Phytotechnologies, waste management, environmental toxicology, and community mobilization. Developed waste to wealth projects since 1980s particularly compost and organo-mineral fertilizers, biogas for communities using stakeholder approach. He established several pilot scale or demonstration projects on waste to wealth which include organic fertilizer, plastics recycling, biogas, smokeless charcoal/biochar and several other innovative processes in communities. He was a consultant to UNDP, UNICEF, World Bank, several NGOs and Government bodies and agencies. Traveled extensively and visited several waste management facilities in India, Switzerland, Sweden, Finland, Denmark, and USA. Trained various categories in environmental field and published over 400 scientific papers in books, journals and Technical Report. He was awarded 'Outstanding Researcher Award 2016' by the College of Medicine, University of Ibadan.

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Akinwale Oladotun COKER holds a doctorate degree in Environmental Engineering of Nigeria's premier university, the University of Ibadan, which he obtained in 2002. He researched on Engineering Applications in the Management of Health Care Wastes from General and Specialist Hospitals in Ibadan, Nigeria. He had earlier in 1991, graduated with a Master of Science degree in Water and Waste Water Engineering from Obafemi Awolowo University, Ile-Ife, Nigeria. He had his first degree in Civil Engineering in 1987 at the University of Ibadan. Akinwale joined the same Department in 1991 as a Lecturer II and rose to become a Professor in 2010. His research works in over two decades at Ibadan have focused on Water Resources and Environmental Health Engineering. He has travelled far and wide to present conference and workshop papers in America, Europe, Asia and numerous nations in Africa. In addition, he has extensive consultancy experience in water resources and environmental health engineering. Alongside being a teacher and researcher at the University of Ibadan, he is currently the Director and Chief Executive of Nigerian Network for Awareness and Action for Environmental Health (NINAAFEH), a Non-Governmental, Organisation devoted to environmental sustainability. He is also the current Head of the Department of Civil Engineering, University of Ibadan. He has about sixty scientific publications and two patents to his credit.

Samuel O. JACOB
Samuel Oluwatosin Jacob was born in August 1986 and a Bachelor and Masters' Degree holder in Civil Engineering from University of Ilorin. He is a Registered Civil Engineer with the Council for the Regulation of Engineering in Nigeria (COREN) and has carried out several research projects in Water Resources and Environmental Engineering. His research interests are in the areas of Water and Wastewater Treatment; Urban Solid Waste Management; Climate Change Impacts on Water Resources & Adaptation Strategies; and Water Sanitation & Hygiene (WASH). He is a graduate research student at the Department of Civil Engineering, University of Ilorin, Nigeria. Also, he has worked as a research assistant on several PhD projects in the area of Urban Water supply; Public Health; Water and Environmental Engineering. He has two pair review publications in Nigerian National journals and one in an International journal. He is currently working with an International Non-Governmental Organization as a Public Health Engineering Officer.