Performance Evaluation of a Water Hyacinth Based Institutional Wastewater Treatment Plant to Mitigate Aquatic Macrophyte Growths at Ibadan, Nigeria

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Abstract

Phytoremediation technology is an age-long concept, which utilizes aquatic or terrestrial macrophytes in the treatment of wastewaters. This study assessed the performance of a water hyacinth based wastewater treatment plant at University of Ibadan, Nigeria. This treatment plant was built with a view of treating institutional wastewater which was otherwise polluting the Awba lake, a source of drinking water on the campus. Wastewater samples were collected at the influent point (IP) and effluent point (EP) of the treatment plant. The samples were analyzed for physicochemical parameters, viz. Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). Standard methods specified by the American Public Health Association (APHA) were followed. The results showed a reduction of 51.9% in COD, 43.3% in BOD, and 85.95% TSS and they did not meet the required effluent standards. Other parameters (pH, temperature and odour) were, however within the permissible limits set by National Environmental Standards and Regulations Enforcement Agency (NESREA). Factors that contributed to the poor effluent quality were found to be as a result of poor maintenance, inadequate training, poor funding and poor attitude of the plant operators. Based on these findings certain remedial measures were suggested to save the Awba lake from eutrophication.

Keywords: Phytoremediation, Water hyacinth, Aquatic macrophytes, Municipal wastewater, BOD, Effluent

1.0 Introduction

In many developing countries impounded water bodies are grossly polluted by surface runoffs and untreated wastewater. Some of these water sources are used for domestic water needs and they pose public health problems if care is not taken for the effluent quality. On the campus of University of Ibadan, south west Nigeria, a major water body is Awba lake. This natural lake has been in existence since the establishment of the University in 1948. The lake is a source of potable water and also a variety of fish are caught for food needs. This lake receives two seasonal streams / tributaries which flow through the city and picks pollutants from markets, residential areas and small and medium scale process industries before entering the lake. At one time the pollution load was so high, it became eutrophic with aquatic weed cover. Up to 1984, the predominant weed cover has been water lettuce (*Pistia stratiotes*) (Sharma and Sridhar, 1981). In 1984, water hyacinth entered Nigerian waters and established in all the surface water bodies. Awba lake is not left out. Since the University population increased rapidly, potable water supply diminished. To augment water needs, wastewater recycling was adopted in which the treated effluent is discharged into the lake directly.

The older trickling filters and packaged aerobic treatment plants were replaced by a low cost biological treatment using aquatic macrophyte, water hyacinth (*Eichhornia crassipes*) (Sridhar, 1988; Coker et al, 2009).

Aerobic biological treatment plants are quite expensive to construct, and needs some level of skills to operate and maintain. They also leave carbon footprints behind as a result of the use of heavy equipment demanding energy for operation. As a result of this, untreated wastewater enters into soil and water thus causing environmental degradation. They also pollute the ground waters. They are therefore a concern to public health. The major problem encountered in several parts of the country is the degradation of aquatic ecosystems by profuse growth of water hyacinth. This aquatic weed is alien to Nigeria until 1984 as it entered accidentally from the neighbouring countries through coastal waterways.

Natural ecosystems have been successfully harnessed to treat wastewater and remediate polluted soils and waters (Belmont et al, 2004; Erakhrumen, 2007; Coker et al, 2009). Bioremediation is the use of microorganisms to remove pollutants from soil or water bodies. But phytoremediation utilizes aquatic macrophytes to restore balance in the environment through the extraction and elimination of contaminants. Phytoremediation can reduce treatment cost, restore habitat and clean up contamination on site rather than transporting the problem to another site (Zynda, 1994).

There are many types of phytoremediation techniques, generally referred to as constructed wetlands, aquatic systems, reedbed technology, etc. The principal mechanism is to use different kinds of plants, aquatic or terrestrial. This technology is characterized by the symbiotic relationship between the plant and its rhizobial populations (Peterson and Teal, 1996; Perkins and Hunter, 2000). Water hyacinth (*Eichhornia crassipes*), is one of the most widely used aquatic plants successfully applied globally for wastewater treatment over the last five decades. The weed is capable of removing ammonia, phosphorus and nitrate from the wastewater effluents. Use of water hyacinth can help reduce eutrophication in receiving streams through this ability to removing nutrients (Reddy and Sutton, 1984; Reddy and DeBusk, 1985; DeBusk et al, 1989; Reddy and D'Angelo, 1990). This macrophyte is also classified as one of the most dangerous and most invasive aquatic weeds in the world (USEPA, 1988; Kusemiju, 1988; Aoi and Hayashi, 1996; Maine et al, 1999; Wilson et al, 2005). Abundant literature is available on its nuisance value and beneficial uses, particularly its use in wastewater treatment (de Casabianca and Laugier, 1995; Chua, 1998; Maine et al, 2001; Sim, 2003; Mangabeira et al, 2004). But the information on the peculiar problems encountered during the wastewater treatment are scanty. This study reports some of the problems encountered over the years of operation of this wastewater treatment that led to weed coverage of the Awba lake which is being used as a drinking water source. . In view of the importance and sensitivity of maintaining a healthy environment for students and averting the eutrophication of a water resource, this udy was conducted in order to evaluate the performance of the wastewater treatment plant.

2.0 Materials and Methods

2.1 Study Location

The study area was the University of Ibadan, Nigeria which lies between latitude 3°53'E and 7°26'N and at altitude of 185m above sea level (Akin-Oriola, 2003). The mean daily air temperature is 24.6°C. Rainy season occurs between April and October while the dry season is between November and March. The University is estimated to have a land area of 670.896 Hectares, out of which 5.96% (39.943 Ha) is for the faculties and 10.51% (70.539Ha) is for students housing (Coker et al, 2009).

The Awba lake has a surface area of 6 Ha. The Reservoir is 8.3m high, 110m long with a crest of 12.2m high. It has a maximum depth of 5.5m and a maximum length of 700m. It can hold about 230 million litres of water (Sharma and Sridhar, 1981; Omotosho, 1981). Sharma and Sridhar (1981) made extensive studies on the Awba lake and showed that Pistia was the dominant macrophyte which was later replaced by water hyacinth in 1984. This lake receives water from two streams (Shango stream from the west and Awba stream from the east) flowing through the city of Ibadan where municipal wastes, surface runoff and solid waste leachates enter their course thus causing pollution. In addition, municipal effluents from partially treated wastewater and septic tank from University of Ibadan campus enter, stay in the lake and undergo decomposition and other changes. This lake is covered by a variety of aquatic macrophytes (Water hyacinth, Water lettuce, Nymphaea and others) due to eutrophication. During the year 2013 the University has embarked on dredging the lake and to remove the vegetation cover to restore the lake. The tropical climate favours the growth of water hyacinth.

Having realized the water hyacinth infestation, its nuisance value, a strategy was adopted to utilize the weed for wastewater treatment and also to convert the harvested weed to make compost and produce biogas.

2.2 The Water Hyacinth Based Wastewater Treatment Plant

Three Halls of Residence for students with a total population of 3,644 generate the wastewater being treated at the water hyacinth wastewater treatment facility. These are: Obafemi Awolowo Hall (1700 students), Queen Idia Hall (1244 students) and Abdulsalami Abubakar Hall (700 students). The estimated volume of wastewater flow is 255,080 litres/per day, which enters the treatment plant by gravity flow. The wastewater flows through underground drainage pipes and travels about 100m to 200m before discharging into the treatment plant. Figures 1 shows the Awba lake and the nearby wastewater treatment plant (about 500m away) using the waterhyacinth plants. Figure 2 shows the plan view of the treatment plant with various chambers and the flow direction. The combined flow from the three Halls enters into a Grit chamber where debris and other solid materials are removed. From this unit, the wastewater flows into the main plant. The plant consists of two sets of tanks in series (4 compartments each), one on the right and the other on the left. There are two separate control valves, which direct the flow of wastewater to either of the series. All the tank units have dimensions 9m x 9m x 1.2m deep. In each unit, water hyacinth was planted evenly to aid in treatment. A depth of 1.2m is just sufficient to allow maximizing root growth and the absorption of nutrients and heavy metals. The design also favours closer contact of the roots with the wastewater flow.

Detention time is very important for better contact between the plant and the wastewater. While 5 days detention time is recommended by Reed et al (1981), the present design has a detention time of 7 days (Ojoawo, 2002). Wastewater flows into the first unit, then progressively flows into the second unit, then the third and fourth units, until it is finally discharged and flows into Awba lake. Outlets to each of the tanks are alternated to favour settlement of sludge. Periodical sludge removal is practiced. In the design of the plant, the site characteristics were considered with the following features: elevation, topography, geology, surrounding land use, wind direction, odour and air quality at and near the site, existing collection system and receiving water proximity and other environmental considerations. The plant is hydraulically suitable for gravity flow which can avoid pumping costs. The study design is experimental.

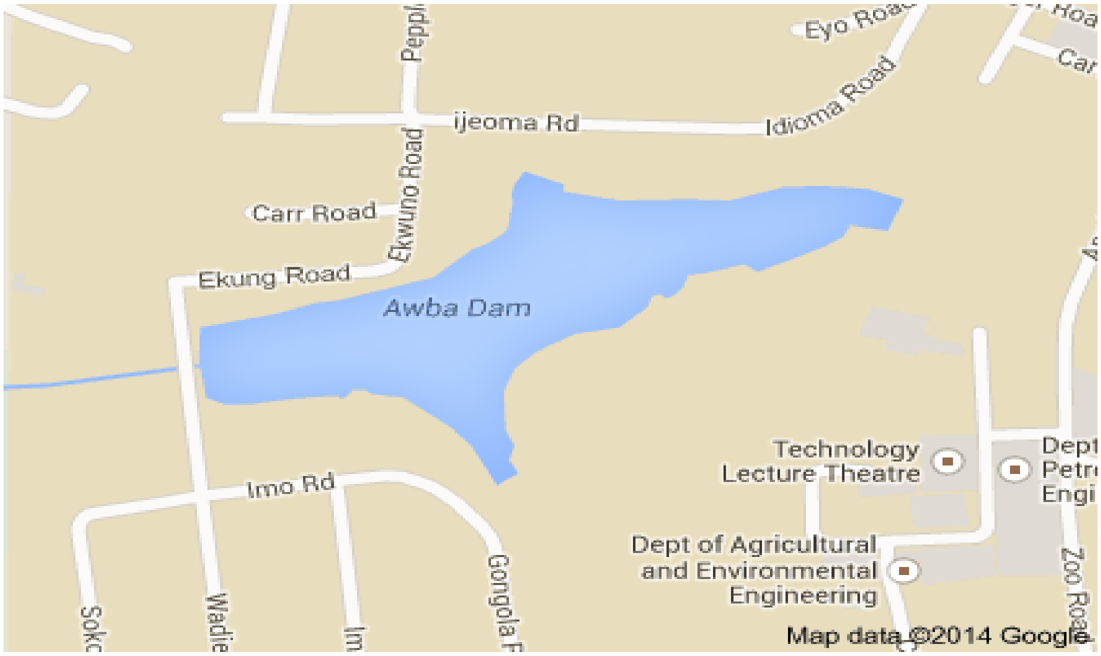

Figure 1 A: The Awba Lake (Above) and the Nearby Water Hyacinth Based Wastewater Treatment Plant

Figure 1 B: Plan View of the Water Hyacinth Based Wastewater Treatment Plant

2.3 Collection of Wastewater Samples

Grab samples of the wastewater were collected at the point of entry into the treatment plant. The samples were collected at about 9:30AM in the morning when the wastewater flow is expected to be at its peak. Two respective samples were collected: 'Influent' at the point of entry into the first unit of the tank just after the grit chamber and 'Effluent' from the fourth unit (last chamber) in the series at the point of exit into the receiving water body, the Awba lake. At the time of collection of the samples, the Influent was yellowish brown and effluent was colourless.

All bottles and glassware were pre-washed thoroughly in distilled water, soaked with 0.1N HCl, and then washed again with distilled water. Glass bottles were used for dissolved oxygen (DO) and Biochemical Oxygen Demand (BOD) determination, while acid pre-washed polyethylene bottles were used for other physical and chemical parameters. Samples for DO were immediately fixed on the field with manganous sulphate and well stoppered and labeled.

2.4 Methods

The temperature of the samples was determined using a calibrated the thermometer and it was recorded as 24^0C. Examination of the influent and effluent samples was carried out as prescribed by the (Americal Public Health Association, APHA (1998) to ascertain the levels of the physicochemical parameters and to evaluate the purification efficiency of the treatment plant. The parameters determined include pH, which was determined using a pH meter (Model Metrohm Herisau E520), amounts of total phosphate, ammonia and nitrate were determined using the auto-analyzer. BOD and DO were determined using the iodometric (azide modification) method. The total dissolved solids was determined using a portable TDS meter, while the total suspended solids were obtained in the laboratory using gravimetric method after filtration through a standard filter paper and drying.

3.0 Results

3.1 Effluent Quality

The results of the influent and effluent quality showed that the treatment plant is working but the, efficiency is not satisfactory (Table 1).

Table 1: Characteristics of the Influent and Effluent from Water Hyacinth Based Treatment Plant

Parameters	Influent	Effluent	% Change	National Guidelines FEPA (2009)
Temperature, ^{0}C	24	24	-	<40
pH	8.80	7.80	-11.4	6.0-9.0
Turbidity, FTU	29.00	8.00	-72.4	-
Conductivity, μs/cm	249	200	-19.7	-
Total Suspended Solids, mg/l	463.00	65.03l	-85.95	30
Total Dissolved Solids, mg/l	955.50	266.50	-72.1	2000
Total Solids, mg/l	1418.50	331.53	-76.63	
Dissolved Oxygen, mg/l	0.00	2.03	Increased	-
COD, mg/l	2160.00	1040.00	-51,85	-
BOD, mg/l	686.10	388.60	-43.36	50.0
Alkalinity, mg/l	0.00	150.00	Increased	-
Total Hardness, mg/l	330.00	270.00	-18.18	-
Ammonia, $NH_{3,\ mg/l}$	168.00	98.00	-41.67	-
Nitrate, mg/l	7.80	4.80	-38.46	20
Phosphate, mg/l	0.33	0.04	21.21	5
Total Chloride, mg/l	280.00	120.00	57.14	600

From the above results, total solids, suspended solids, and dissolved solids, were 1418.58mg/l, 463.00mg/l and 955.50mg/l respectively for the influent. These values reduced in the effluent to 331.53mg/l, 65.03mg/l and 266.50mg/l, respectively. This shows a significant reduction. The percentage reductions of total solids and suspended solids after passing through the water hyacinth treatment were 76.6% and 85.95%, respectively. But still the reduction did not meet the national guidelines. The pH and the turbidity values of the influent reduced reasonably though they have no significant effect on the overall performance of the treatment plant.

The ammonia, phosphate and nitrate contents were 168.00mg/l, 0.33mg/l and 7.80mg/l respectively in the influent, which were reduced by 41.67%, 38.36% and 21.21%, respectively which are well within the guideline limits. This further confirms that phytoremediation method is good in the removal of the minerals which are effectively removed by the water hyacinth during its growth.

There was also a 51.9% reduction in COD and 43.3% reduction in BOD after passing through the treatment plant. But still the national guidelines demand a BOD level not more than 50mg/l. As one would expect, the dissolved oxygen level increased marginally as the BOD was still high in the effluent. The overall conclusion is that the treatment plant has not been working effectively.

3.2 Identified Defects of the Treatment Plant

The following defects were observed for the inadequate performance of the plant.

A) **Design faults**

The design was faulty as it was not designed according to the hydraulic and organic loading. There was no balancing tank before letting into the treatment units. This treatment plant was an adhoc arrangement to overcome the problem of raw wastewater entering into the Awba lake. In addition, the student population increased after the plant has been commissioned and there was no provision made for the population fluctuations. Silting was high and it settles in the tanks with no provision for silt removal.

B) **Desludging of the tanks**

Most of the ponds were heavily silted, which had caused a reduction in the overall depth of the treatment tanks and consequently reduced the retention time of the wastewater. Ever since the plant started operating, there was no plan for desludging schedules. Also there was no harvesting of the overgrown water hyacinth. As a result, the older plants die, decompose and add to the organic matter in the effluent.

C) Evacuation of manholes, drains and grit chambers

It was observed that the volume of wastewater flowing from the Halls of residence was not commensurate with the volume of wastewater influent on the treatment plant. There were several leakages from the broken drains and manholes, and also obstructions in the form of silt and debris present inside the drains and the flow line causing clogging.

D) Replacement of Sluice Valves

There are 7 sluice valves at the treatment plant (Three, 203 mm and four, 152.4mm). Sluice valves are used to control the flow of wastewater from one tank to another and also for final discharge. Due to lack of timely maintenance, 5 out of the7 valves stopped working. They were never greased during the operation over the years.

E) Perforated metal pipes leading to corrosion

The perforated pipes help in conveying wastewater to outer drains. There are 4 perforated pipes at the treatment plant (2 at the inlet end and 2 at the outlet end). The 2 at the inlet end will also serve as outlet conduit for the wastewater during storm overflow. Whereas the other two at the outlet section conduct treated wastewater to the outlet drains. It was observed that the perforated metal pipes were rusted and partly broken due to prolonged exposure to the various chemical reactions in the wastewater as they are always immersed.

4.0 Discussion

Surface water bodies in Nigeria are grossly polluted. The pollution has resulted in aquatic macrophte growths which in turn affect the dissolved oxygen levels and the aquatic life. The pollution may be point source or non-point diffused sources. Awba lake in general receives the non-point sources of pollution but due to its strategic location on the University campus added a peculiar problem in that the partially treated wastewater also enters the lake in large quantities. The University assumed that the wastewater that enters the lake is adequately treated. This conviction is based on practices elsewhere and not evidence based. The pollution of the lake is not new. But the intensity is different at different periods. In the early 1980s, when water lettuce was predominant, Biomass of the Pistia plant varied: 23,677Kg/Ha at the area where the Awba stream entered the lake. Here the size of the weed was much larger and the number of plants (plant density) per m^2 ranged between 36 to 50 (mean 50.8). Here the lake water showeda BOD of 16.3mg/l. As the lake water is flowing, at the downstream end the biomass was 23,833Kg/Ha. Though biomass remained the same, the size of the plants was smaller and the plant density varied between 100 to 251 per m^2 (mean 149). At that time the wastewater treatment on University campus was reasonably efficient (Sridhar and Sharma, 1980).

Conventional wastewater treatment plants have been found to fail in the developing countries (Adeniran, 2011). Nigeria, in the past built some wastewater treatment plants mostly the aerobic type (trickling filters, aerated lagoons, activated sludge and waste stabilization ponds) to manage medium wastewater flows emanating from institutions and industries.

Some of these plants were package treatment plants imported from other countries which were phased out due to troubleshooting after a brief period of operation and non-availability of spare parts . There are 26 wastewater treatment plants recorded as of today in several cities such as Lagos, Abuja, Warri, Port Harcourt and Ibadan. Of these, only five or six are working satisfactorily as of today. The rest of them were non-functional or abandoned.

Under the backdrop of this history, the current water hyacinth based wastewater treatment plant is of interest. No doubt, this treatment plant is a low cost type. It is also well known that aquatic macrophytes remove nutrients from waters efficiently. These can occur only when the operation and maintenance are sound. Since 1980s (about 8,865 students and 1,500 staff) and now, the University population has increased more than fivefold. At the same time water demand and wastewater outflow has increased proportionally. However, the infrastructure has not grown at the same pace. The existing treatment plants were operated anyhow with no design capacities. This is reflected in the effluent quality described in this paper. Added to this problem, expenditure on maintenance was driven by need and emergency. Some of the hardware from the treatment plant described were never repaired or replaced. As a result by 1990s, the Awba lake has reached a stage of peak pollution, water hyacinth cover, silting and practically there was no record of how much water is available for drinking water needs. Thus the current administration has embarked on dredging of the lake. However, the waste water treatment and the flow of effluents are not adequately addressed. This paper highlights the need for addressing the wastewater treatment particularly the design, flow rates, population using the facility and preventive maintenance put in place. The Institutional wastewater has a definite impact on the pollution and eutrophication of the Awba lake which is being developed currently as a tourist centre for the University. A plan is developed to repair the defects and train the operators on proper maintenance of the system.

5.0 Conclusions

The technology of using water hyacinth for the treatment of institutional wastewater is an alternative method to the conventional methods available. It is more cost effective. Through the use of water hyacinth, considerable amount of BOD in the wastewater is biodegraded and mineral constituents are removed However, the overall performance did not meet the required effluent standards laid down by the national regulatory body, National Environmental Safety and Regulations Enforcement Agency (NESREA). This was traced to lack of adequate maintenance, breakdown of the hardware, negligence by the operators and lack of proper maintenance procedures for dislodging and harvesting of the plant biomass. In order to make the wastewater suitable for disposal into receiving water body, the system needs to be upgraded and proper maintenance culture should be ensured with adequate supervision of the Operation & Maintenance activities on site. These actions may help in saving the Awba lake from eutrophication and further degradation.

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