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ORIGINAL ARTICLE

Development and performance evaluation of low-cost wastewater treatment plant

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Abstract

A pilot-scale wastewater treatment plant was developed for the purpose of treating wastewaters in south-western Nigeria. The plant, mounted on a roller frame was divided into three sections, viz. wastewater holder, purification chamber and treated water collector. The purification chamber contained three sets of strainers with locally sourced materials which include *Azolla pinnata* fern, fine sand, chlorine pellets, alum cubes and palm kernel shell charcoal (PKSC). The performance of the treatment plant was evaluated using four different wastewater (WW) sources which were industrial (IW), municipal (MW), domestic (DW) and aquaculture (AW) wastewaters. Sixteen physicochemical parameters and ten metals were monitored in the four WW samples which included temperature, turbidity, electrical conductivity (EC), pH, total suspended solids (TSS), total dissolved solids (TDS), total solid (TS), acidity as $CaCO_3$, total hardness, total phosphorus (TP), total nitrogen (TN), ammoniacal nitrogen, dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), fecal coliform, *Escherichia coli* and total coliform count. The metals were Na, K, Ca, Mg, Zn, Fe, Pb, Cu, Cd, and Mn. Water quality analysis was done using standard laboratory procedures and results obtained were subjected to statistical analysis. From the results, 100% removal efficiencies were obtained in some heavy metals such as cadmium (Cd) and manganese (Mn) and in parameters such as turbidity, TP, and TN after passing through the treatment plant. The presence of pathogens and microorganisms that were also reduced does not in any way affect its use for agricultural purposes. All other parameters reduced appreciably with results which were statistically significant at $P < 0.05$. This indicated the high efficiency of the treatment plant in the removal of the water pollutant and heavy metals from the four WW sources considered.

Keywords Wastewaters · Treatment plant · Low cost · Metals · Pollutants

Introduction

In many arid and semi-arid regions of the world, water has become a limiting factor, particularly for agricultural and industrial developments. Continuous research on water management and planning are on the increase looking for additional sources of water to supplement the limited resources available (FAO 2007). Agricultural use of water resources is of great importance due to the high volumes that are necessary while irrigated agriculture has been a dominant user of water due to its role in the sustainability of crop production for food security in the face of burgeoning global population. Studies has shown that between 2009 and 2050, the world population will increase by 2.3 billion, from 6.8 to 9.1 billion (UNDESA 2009). Similarly, urban populations will increase by 2.9 billion, from 3.4 billion in 2009 to 6.3 billion in 2050 meaning increased pressure on water supplies, pollution and waste generation (UN-Habitat 2006). Water pollution by effluent has become a question of considerable public and scientific concerns in the light of evidence of their extreme toxicity to human health and to biological ecosystems (Katsuro et al. 2004). The occurrence of heavy metals in industrial and municipal sewage effluents constitutes a major source of the heavy metals entering aquatic media. Hence, periodic assessment of these sewage effluents to ensure that adequate measures are taken to reduce pollution level to the minimum is suggested (Katsuro et al. 2004).

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On a world-wide basis, wastewater is the most widely used low-quality water, particularly for agriculture and aquaculture (Corcoran et al. 2010). The disadvantages of urban non-potable reuse are usually related to the high costs involved in the construction of dual water-distribution networks, operational difficulties and the potential risk of cross-connection. Potable urban reuse can be performed directly or indirectly. Indirect potable reuse involves allowing the reclaimed water (or in many instances, raw wastewater) to be retained and diluted in surface or groundwater before it is collected and treated for human consumption. In many developing countries unplanned, indirect potable reuse is performed on a large scale, when cities are supplied from sources receiving substantial volumes of wastewater. Often, only conventional treatment (coagulation–flocculation, clarification, filtration and disinfection) is provided and, therefore, significant long-term health effects may be expected from organic and inorganic trace contaminants which remain in the water supplied (Akinbile and Omoniyi 2018).

The continuous discharge of wastewater with little or no treatment into natural water bodies can make them become highly polluted (Qadir et al. 2010). A huge amount of urban sewage is discharged into lakes, rivers and oceans each year and over two million tons of human waste is disposed of in water every day (Ogedengbe and Akinbile 2004). These discharges into water bodies constitute a growing problem especially to the aquatic community and have gained increased political awareness in recent years. The volume of liquid wastes generated globally has increased steadily and every world government are focusing on methods to approach the challenges posed by the waste management (Schwarz-Herion 2004). Domestic wastewater, industrial sewage and municipal wastewaters are continuously added to water bodies thereby affecting the physiochemical quality of such water bodies making them unfit for use for agricultural and non-agricultural purposes (Nyenje et al. 2010). Uncontrolled domestic wastewater discharged into pond has resulted in eutrophication of ponds as evidenced by substantial algal bloom and dissolved oxygen depletion in the subsurface water leading to disruptions of the aquatic ecosystems (Akinbile et al. 2012a). In many countries, water available for agriculture is already limited and is set to worsen with agricultural withdrawal accounting for over 44% of total water withdrawals in Organization of Economic Cooperation and Development (OECD) countries (FAO 2007) which implied that considerable quantities of usable and useful waters are wasted due to mismanagement. Only 20% of the world's wastewater discharged is currently being treated, indicating that the other 80% is discharged into water bodies without treatment and were injurious for freshwater animals and humans alike (UNEP 2015). Wastewater treatment systems were developed in response to the adverse conditions caused by the discharge of raw effluents to water bodies and the treatment is aimed at removing biodegradable organic compounds, suspended and floatable material, nutrients and pathogens. However, the design criteria for the intended usage of the wastewater (e.g. irrigation, domestic, discharge into waterbodies) differ considerably from one another (WHO 2010). Similarly, the components to be used for purification be it biological or chemical or combination of both is also a function of the intended purpose of reuse. The need to design and develop low-cost technologies for wastewater treatment for reuse became highly imperative. Therefore, the objective of this study is to design, develop and conduct evaluation performance of a simple but inexpensive water treatment plant using locally available and easily affordable materials. The intention is to treat polluted wastewater for recycling and reuse purposes especially for agricultural and non-agricultural to reduce the pressure on freshwater demand which is declining rapidly due to burgeoning global population with African continent as the worst hit.

Materials and methods

The study area and WW types

The study was carried out at the Federal University of Technology, Akure (FUTA) community and its environs all within Akure metropolis which is the capital of Ondo state in Nigeria. Located between latitude 9°17′N and longitude 5°18′E, the population has been increasing with time and is known to have a tropical humid climate with two seasons, a dry season from November to March and a rainy season from April to October. Climate change has brought about some variations in the season periods which have been reported that the average annual rainfall ranged between 1405 and 2400 mm of which the rainy season accounts for 90% while the month of April usually marks the beginning of rainfall (Akinbile et al. 2016). Four different types of wastewaters which were industrial (IW), municipal (MW), domestic (DW) and aquaculture (AW) waters were used in carrying out performance evaluation of the water treatment plant. The WWs were passed through the plant thrice per wastewater sample while some low-cost materials used in the treatment plant included, *Azolla pinnata* fern, palm kernel shell charcoal (PKSC), sand and chlorine tablets. IW was sampled from the wastewaters from a personal care industry with a major production factory in the town with products such as bathing soaps and home care products such as washing materials. MW was obtained from a local abattoir serving considerable portion of the populace, DW was sampled from a local restaurant near the southern gate of the federal University (FUTA) while AW was obtained from the wastewaters from one of the fish ponds from the department of Fisheries and Aquaculture Technology (FAT), FUTA. All the wastewaters were sourced from within Akure metropolis since the focus was water sources from Akure but with capacity to scale it up to cover other major cities in the province and the nation at large.

Materials for the treatment plant

Materials used in the construction of the low-cost wastewater treatment plant included aluminum (Al^{2+}) sheets of 4 mm thickness and dimensions 5 m^2 which was used for the construction of treatment plant at the Agricultural and Environmental Engineering workshop (FUTA). Others were fine sand for filtration, palm kernel shell charcoal (PKSC) burnt to produce activated carbon using acid activation method (Arami-Niya et al. 2010; Hasfalina et al. 2015), alum ($Al^2SO_4{}^{2-}$) to promote coagulation, chlorine tablets for disinfection and *Azolla pinnata* fern used as hyperaccumulators (Sachdeva and Sharma 2012; Akinbile et al. 2016) which were incorporated into the plant as purification materials.

Design considerations for treatment components

Frame rigidity was designed to avoid structural failure while considering maximum weight of untreated wastewater (UWW) in the collecting chamber. The frame was made from L-section Al of 6 mm thickness and 1.5 m high. Formed into box shape and braced at the top and bottom to ensure rigidity and stability. It was mounted on four rollers of about 25 kg axial loading capacity to rollers for ease of movement from one location to the other. Also, weights of trays in the purification chamber, the loading system (distribution) and reactions of forces at the joints were also designed for. Resolution method was applied in solving the forces in pin-jointed frames based on the conditions of static equilibrium which is as shown in Fig. 1.

Design calculations

Resolution method was applied in solving the forces in pin-jointed frames based on the conditions of static equilibrium. The force in any member was resolved into vertical component F_y and horizontal component F_x:

$$F_y = F \sin\theta , \tag{1}$$

$$F_x = F \cos\theta . \tag{2}$$

And to achieve equilibrium in the static structure, the following conditions were satisfied:

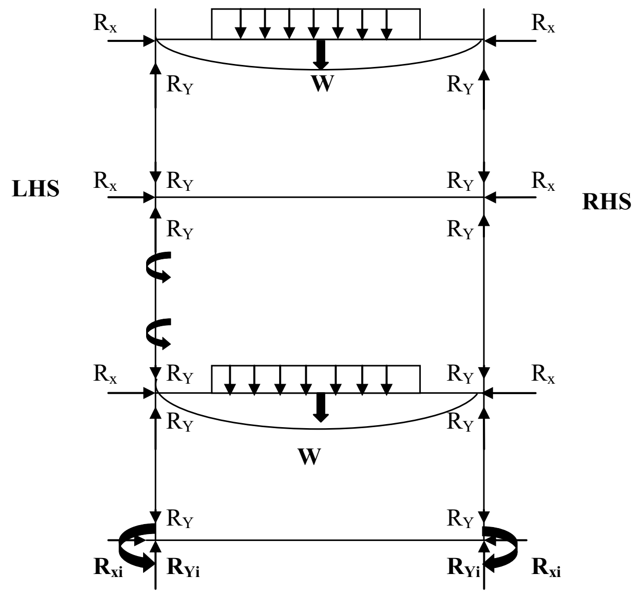
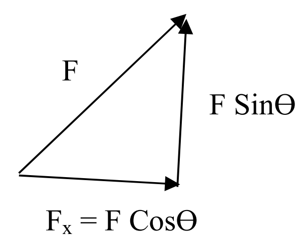


Fig. 1 A free body and bending moment diagram for force resolution and balancing



To achieve equilibrium in any static structure, the following conditions were satisfied:

$$\sum F_y = 0, \tag{3}$$

$$\sum F_x = 0, \tag{4}$$

$$\sum M_o = 0. \tag{5}$$

For horizontal balancing of forces $\Sigma R_x = 0$, i.e. the summation of forces on the right hand side (RHS) was equal to that on the left hand side (LHS). For vertical stability, the equivalent of $\Sigma R_y = 0$ that means that the computation of forces in the upward direction must be equal to that in the downward direction and for moment stability, $EM_o = 0$, but in a rigid structure moment is absent.

Assumptions made in the plant construction

The assumptions made in the conception include the following:

1. The plant was made of aluminum (Al) material so that a near zero reaction between wastewater and the material is permitted not to further contaminate the wastewater.
2. The plant was made in a circular shape to prevent pockets for sludge hiding.
3. The base was made of conical shape to allow treated wastewater to be fully drained from the container.
4. The small cylinder was designed to trap gas from the anaerobic digestion that takes place within the storage tank of the wastewater. This process requires detention time and so it becomes useful during batch operation.
5. A door was installed on the purification chamber to allow ease of access to any of the three trays in case of replacement, adjustment or cleaning.
6. A flow meter was installed to measure the flow rate of wastewater into the purification chamber.
7. All the components were mounted together on a frame with rollers for ease of movement from one location to the other.

Description of the wastewater treatment plant

The treatment plant was partitioned into three parts, namely the UWW holder, the purification chamber and the TWW holder. They were all fixed on a solid frame which was mounted on rollers.

The UWW holder is cylindrical in shape, about 2.5 m in height and 0.8 m in diameter. It has three openings with which one facilitates the loading process, the other creates an outlet for the trapped gas within the digester if there is a buildup of gas and the last opening located at the base allows the onward movement of the wastewater into the purification chamber. It is fitted with a faucet to ensure airtightness of the digester.

The purification chamber is also cylindrical in shape produced from the Al^{2+} material of 5 mm thickness, 3 m high and also 0.8 m wide. A semi-circular door was mounted on it which facilitates access to the inner chamber. Three sets of trays were arranged inside, each having a diameter of 0.7 m allowing for clearance fit in the chamber and about 0.01 m deep. Its bases were made from wire gauze of 0.4 mm thickness and 0.2-mm opening. The first screen holds a finer sieve with 0.1-mm-diameter aperture, alum cubes and activated carbon made from PSKC; all these facilitate trappings of suspended solids, allow for coagulation of finer particles and the removal of oil particles (if present). The second screen housed sand and *Azolla pinnata* fern; the sand would allow for slow sand filtration while *Azolla pinnata* would perform the process of phytoremediation, i.e. the removal of heavy metals through the use of biological means called hyperaccumulators (Akinbile et al. 2012b). The third screen holds a sieve with an aperture of smaller diameter and chlorine cubes, for the last stage of filtration and disinfection, and it also traps any particle still left in the water. From this point, the clean water moves onward into the collection chamber. The movement action is controlled through the use of the faucet fitted to the base of the purification chamber. The TWW holder simply collects the treated wastewater for storage and sampling. The assembly view of the water treatment plant and orthographic projections and the exploded view are as shown in Figs. 2 and 3, respectively.

Water quality monitoring and analysis

Wastewater samples were collected from different sources and analyzed in the laboratory. Twenty-six parameters comprising of 13 physicochemical, 3 bacteriological and 10 metal constituents in all the sampled wastewaters were analyzed in the study. These include: temperature, turbidity, electrical conductivity (EC), pH, total suspended solid (TSS), total dissolved solids (TDS), total solid (TS), acidity as $CaCO_3$, total hardness, total phosphorus (TP), total nitrogen (TN), ammoniacal nitrogen, dissolved oxygen (DO) chemical oxygen demand (COD), and biochemical oxygen demand (BOD_5). As for the bacteriological assay, the following were analyzed: fecal coliform, *E. coli* and total coliform count while these were the metals investigated in the samples: Na, K, Ca, Mg, Zn, Fe, Pb, Cu, Cd and Mn. All analyses were carried out according to the Standard Methods for the Examination of Water and Wastewater (APHA 2005). The wastewaters were analyzed before and after introducing them into the developed wastewater treatment plant. The wastewater was allowed to remain within the developed wastewater treatment plant for 7 days of hydraulic retention time (HRT) after which the treated water samples were collected and analyzed in the laboratory for the same sets of parameters earlier tested for. The equipment was thoroughly cleaned before the introduction of batches of wastewater samples to prevent pollutant accumulation which can influence inflow and outflow water concentrations.

Pollutant removal efficiency calculations

The pollutant removal efficiency of the developed wastewater treatment plant on the basis of the concentration of the parameters monitored before and after treatment was calculated as follows (Abdelhakeem et al. 2016):

$$\text{Removal efficiency (\%)} = \left(\left(C_{\text{in}} - C_{\text{out}}\right)\right)/C_{\text{in}} \times 100, \quad (6)$$

where C_{in} and C_{out} are the inflow concentration and outflow concentration, respectively (mg/L).

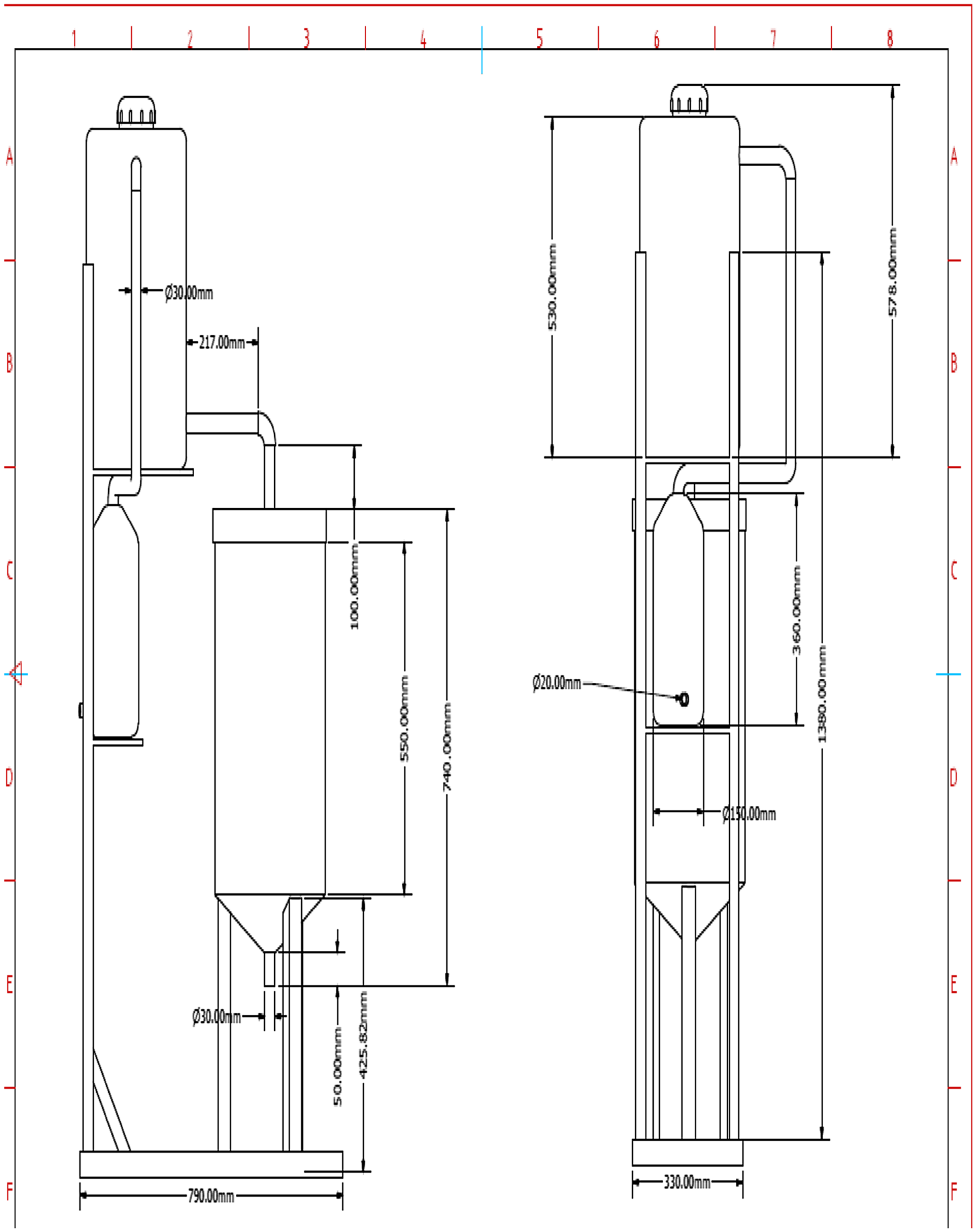


Fig. 2 Assembly view of the water treatment plant

Data analysis

Microsoft Excel was used for all statistical analyses. The effluent characteristics and the removal efficiencies of the constituents were analyzed using ANOVA: single-factor analysis ($\alpha = 0.05$). The null hypothesis (Ho: $\mu_{\text{before}} = \mu_{\text{after}}$) and alternate hypothesis (Ha: $\mu_{\text{before}} \neq \mu_{\text{after}}$) at $\alpha = 0.05$ were also tested. Pollutant removal efficiencies of the system were also checked for different pollutants.

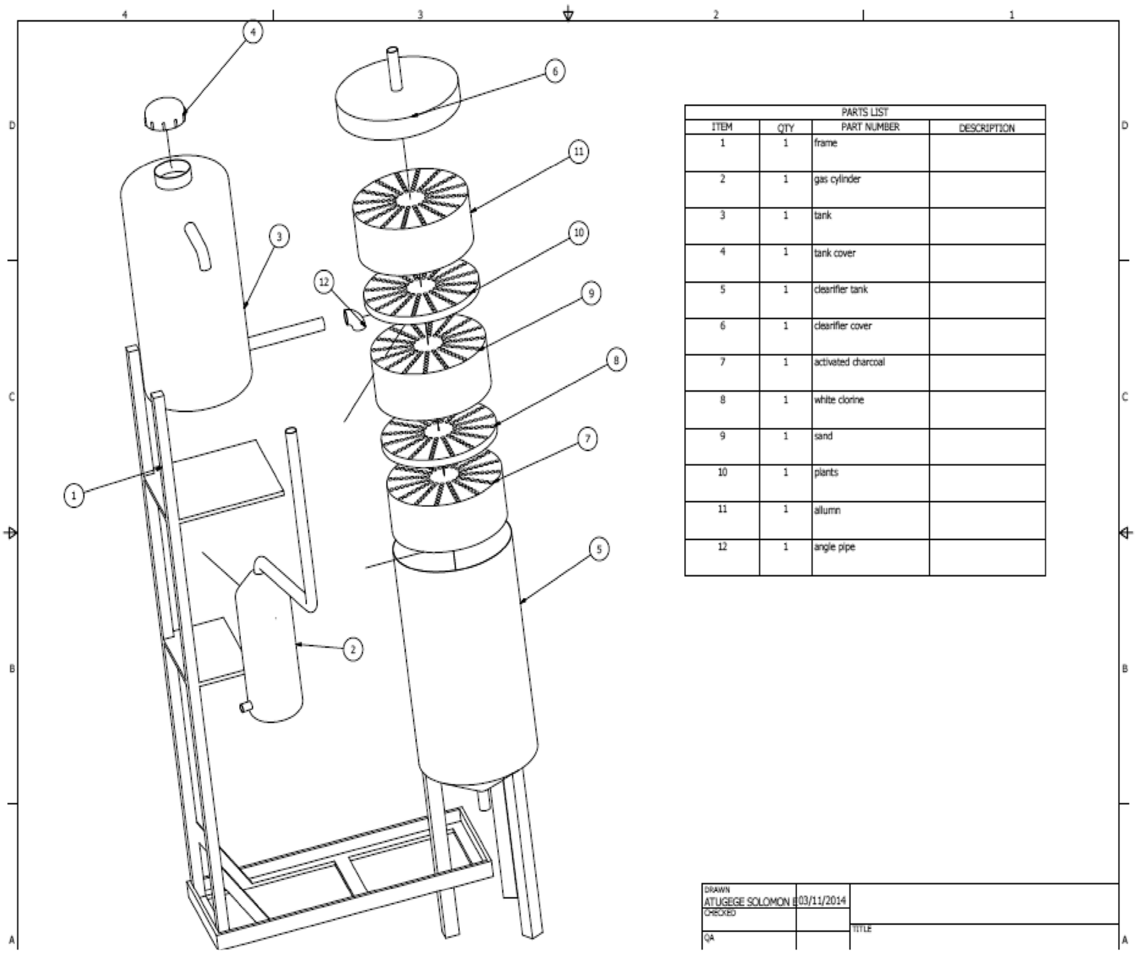


Fig. 3 Exploded view of the water treatment plant

Results and discussion

The results of the performance of the developed wastewater treatment plant before and after the treatment as well as the removal efficiency (RE) in all the four wastewaters are as shown in Table 1. The TN experienced 100% removal in all the four wastewaters (WWs) treated while turbidity and TP removal efficiency rate were 100% in all but for the IW. The turbidity of 70% was recorded for IW while TP had RE of 75.7% in MW. Other parameters recorded considerable reduction in their concentration values after undergoing treatment using the treatment plant which ranged from 91.55% for TS (AW) to 95.36% for TDS (DW). The considerable reduction of turbidity (100%), TS (91.55%), and TDS (95.21%) in all the AW samples analyzed and underscored the natural reductive ability in the *Azolla pinnata* fern, not only as hyperaccumulator to metals but also the coagulative tendency to trap particles. This observation was supported by Aziz et al. (2018) in their studies. There was a slight reduction in temperature with very low values, 2.04% (AW), 1.01% (DW), 0.99% (MW) and 8.84% (IW). The reduction observed in all the parameters in the four WWs underscored the efficacy of the system. In other words, the performance of the locally-developed treatment plant and the components used in the procedure, such as PKSC, *Azolla* fern, fine sand and chlorine pellets, agreed with the findings of Akinbile et al. (2016) but a sharp contrast with the findings of Ayodele and Percy (2011) on TDS for DW who opined that a better removal efficiency value can be obtained with longer detention time in the purification chamber. However, Hasfalina et al. (2015), Akinbile and Yusoff (2012) supported the findings of this study since the process was designed for a continuous system. The position of Ayodele and Percy (2011) supports a batch system where longer detention time becomes a factor in removal efficiency. The importance of *Azolla pinnata* fern in removing harmful pollutants in the four WWs considered was established which corroborates the findings of Akinbile et al. (2016) in their studies. Results of the bacteriological assay are as presented in Table 1 and considerably high values of total coliform, fecal coliform, and *E. coli* were recorded which gave credence to the fact that the samples from AW, IW and MW were severely

Table 1 Removal efficiencies of parameters from the four wastewaters

Parameters	AW			DW			MW			IW		
	a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
Physical												
Temperature (°C)	24.50	25.00	2.04	24.75	25.00	1.01	25.25	25.50	0.99	28.74	26.21	8.84
Turbidity (NTU)	3.87	0.00	100.00	3.86	0.00	100.0	0.05	0.00	100.0	29.90	8.95	70.07
Conductivity (μΩ/cm)	545.00	141.25	67.11	547.50	141.25	67.56	552.50	145	67.44	904.00	273.86	57.08
Chemical												
pH (dimensionless)	7.20	5.28	27.08	7.48	5.28	26.56	7.55	5.75	23.23	7.66	6.21	24.95
Total suspended solid	12.29	10.5	12.53	12.33	10.5	14.26	14.13	9.09	35.67	15.03	11.0	54.95
Total dissolved solid	263.55	12.13	95.21	263.80	12.38	95.36	100.86	13.59	86.53	556.35	108.57	85.36
Total solid	276.48	23.43	91.55	276.22	23.43	91.53	114.95	22.87	80.10	115.68	22.90	80.21
Acidity as $CaCO_3$	76.75	45.00	47.05	82	45.00	45.00	4.27	2.55	51.09	5.56	4.19	31.0
Total hardness	1.18	0.49	58.90	1.21	0.49	59.50	171.70	176.68	2.90	182.76	0.93	99.49
Total phosphorus	0.09	0.00	100.0	0.09	0.00	100.0	2.14	0.52	75.70	0.49	0.00	100.0
Total nitrogen	5.05	0.00	100.0	3.56	0.00	100.0	2.03	0.00	100.0	1.35	0.00	100.0
Ammoniacal nitrogen	5.80	8.53	47.30	5.82	8.53	48.2	0.07	0.05	28.57	2.47	5.56	108.0
Dissolved oxygen	4.60	3.55	78.0	4.62	3.55	22.03	6.61	8.36	26.5	10.68	4.50	66.88
Bacteriological												
Fecal Coliform	2.09	1.00	52.15	0.00	0.00	0.00	1.65	1.10	55.0	0.02	0.01	50.0
Escherichia coli	2.54	1.00	60.63	ND	ND	ND	2.01	1.05	96.0	0.01	0.00	100
Total coliform	1.65	1.00	39.39	ND	ND	ND	2.78	1.11	60.07	0.01	0.01	0.00

Each value represents a mean of the triplicate values obtained

All units in mg/L except where otherwise stated

Nil zero removal efficiency, *a* before treatment, *b* after treatment, *c* removal efficiency

Table 2 Removal efficiencies of elements from the four wastewaters

Elements	AW			DW			MW			IW		
	a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
Na	37.61	24.00	36.20	99.12	56.56	42.94	103.25	61.50	40.44	120.56	39.18	67.50
K	31.59	10.71	66.10	48.12	56.87	18.17	50.13	57.75	15.2	68.43	33.99	50.34
Ca	51.25	22.19	48.80	42.56	11.88	72.03	42.56	11.88	72.09	54.56	64.38	34.00
Mg	11.97	8.44	24.55	11.23	7.72	31.31	11.23	7.72	31.29	22.46	11.53	48.69
Zn	7.10	1.29	81.80	3.39	2.56	23.12	3.33	2.56	24.71	5.81	7.14	22.9
Fe	1.29	0.13	89.90	0.16	0.00	100.00	0.17	0.00	100.00	0.63	1.65	16.2
Pb	0.003	0.00	100.00	0.00	0.00	Nil	0.00	0.00	Nil	3.94	0.04	98.98
Cu	0.52	0.00	100.00	0.00	0.00	Nil	0.00	0.00	Nil	2.60	0.73	72.03
Cd	0.00	0.00	Nil	0.02	0.00	100.00	0.02	0.00	100.00	0.03	0.00	100.00
Mn	0.00	0.00	Nil	0.02	0.00	100.00	0.02	0.00	100.00	0.04	0.00	100.00

Each value represents a mean of the triplicate values obtained

All units in mg/L except where otherwise stated

Nil zero removal efficiency, *a* before treatment, *b* after treatment, *c* removal efficiency

polluted with bacteria from the human and animal wastes discharged into the samples considered. Although, high reduction was also recorded in their reduction but does not take away the fact that the presence of pathogens and microorganisms was heavy in the samples and the presence of chlorine pellets was definitely responsible for the reduction observed which brought the values to an approximate 1/100 MPN approved by the WHO and FAO guidelines for safe discharge into the water bodies (FAO 2007; WHO 2010). The reduced levels of total coliform, fecal coliform, and *E. coli* does not portend any danger to plants' development and growth since the treated wastewater is essentially meant for irrigation purposes.

Considerable reductions were also observed for the elements and metals from the four different WWs passed through the treatment plant as shown in Table 2. RE of

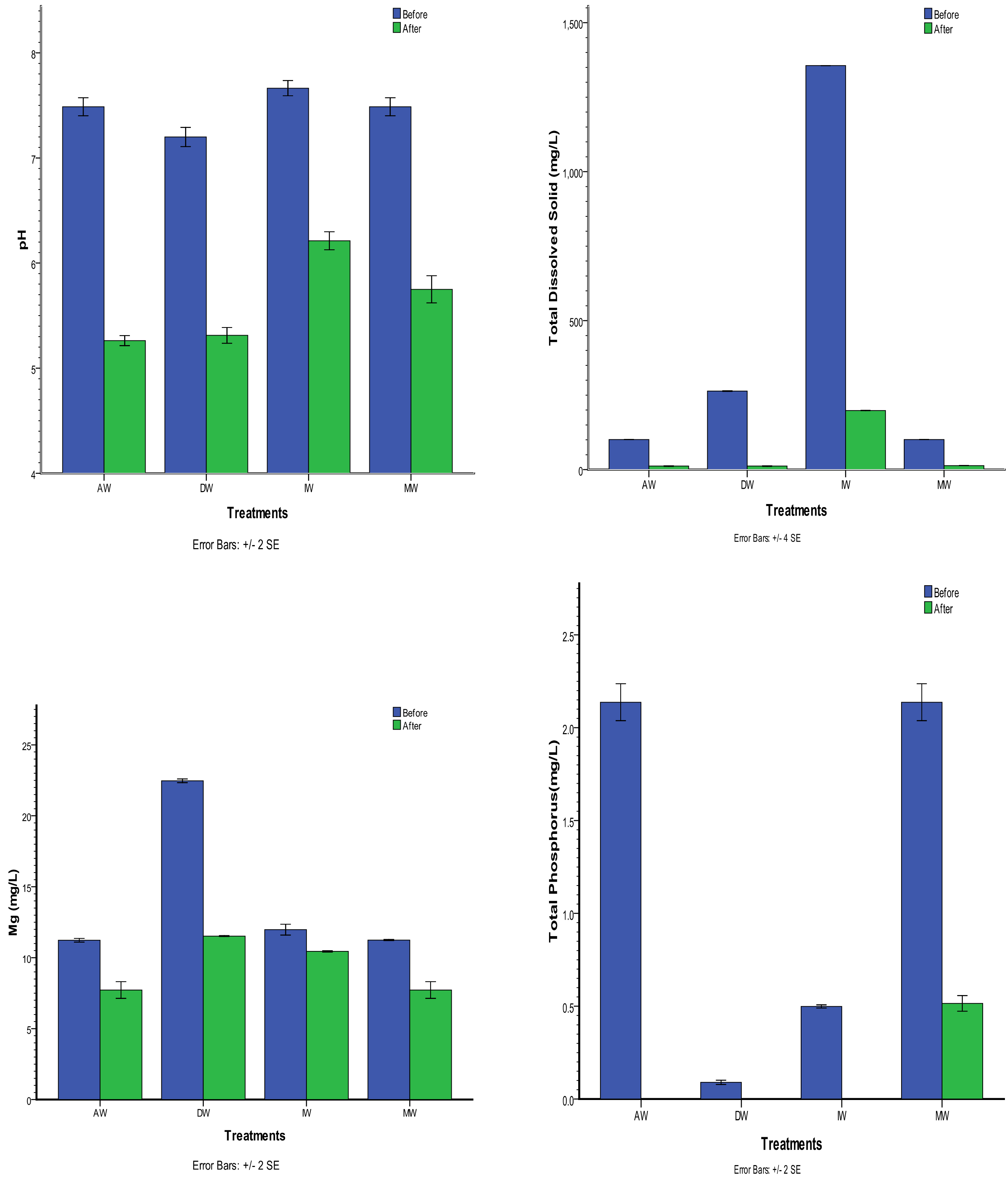


Fig. 4 comparison between initial and final values of **a** Mg, **b** pH, **c** TDS and **d** TP

100% removal was recorded in AW for Pb and Cu, same values (100%) were also recorded in DW for Fe, Cd, and Mn while the same results were obtained Fe, Cd and Mn in MW and Cd, and Mn in IW, respectively, (Table 2). All the values were obtained within permissible levels of FAO and NDWQS. There were other significantly high removal efficiencies such as 98.98% in Pb for IW, 89.90% in Fe for AW and 81.80% in Zn for AW. Other efficiencies were within 12.9% for Mg and 67.50% for Na; low removal was perhaps due the fact that most of the purification materials used was disinfectants and coagulants which may not be able to precipitate out the metals. This agrees with the report of Yeh et al. (2009) in which concentrations of metals were higher in the vegetated sediments than in the non-vegetated sediments. The sequential extraction results of sediments indicated that most retained metals were in less mobile fractions. This also agreed with the findings of some reports (Kamal et al. 2004; Choo et al. 2006; Lesage et al. 2007). Low removal of Mg in all the WWs was an indication of the limited potency of *Azolla pinnata* fern and PKSC in effectively dealing with the metal in a closed chamber which is a sharp contrast to the findings of Akinbile and Yusoff (2012) when a free water surface (FWS) constructed wetland was used. This was supported by Perbangkhem and Polprasert (2010) in their studies. Efficient removal of Pb, Cd, Cu, and Mn were desirable as their absence would make the TWW useful for reuse, especially for irrigation purposes while the trace quantities of Zn present in DW, MW and IW portend great danger for its reusability purposes. The presence of Zn in water is unfriendly to crop growth and such trace metals could be hyper-accumulated in crops thereby causing serious damage to the internal organs of the consumer of such crops/plants. This view is supported by the findings of Akinbile and Yusoff (2012) when a Zn-laden water was used in the growth of water lettuce in their studies.

The comparative analysis of some of the parameters carried before and after passing the WWs through the treatment plant is as presented in Fig. 4. Considerable reductions were observed in the pH, TDS, Mg and TP. These underscored the effect of *Azolla pinnata* and other purification materials on the removal of TDS which agreed with the findings of Axtell et al. (2003); however, Patil et al. (2012) opined that TDS level can be reduced by the use of simple biological or physical purification methods as in a stilling tank. Similar observations could be given to the removal efficiencies obtained in Mg and TP which could largely be traced to the effectiveness of *Azolla pinnata* as hyperaccumulator in this study thereby confirming the findings of Akinbile et al. (2016) in another research where the *Azolla pinnata* fern was extensively used for phytoremediation studies. This efficacy of this fern and other components has been widely reported and published; hence, the focus of this research is to assess the workability of the developed low-cost water treatment plant for ease of replication and adaptation in various communities where fresh water supplies are an extremely scarce resource. This is with a view of treated wastewater reuse especially for food production and reduction in incidences of illnesses and diseases caused by lack of access to potable water for domestic purposes. The ANOVA analysis shows that the null hypothesis is rejected in that the means of RE before and after treatment are equal (Ho: $\mu_{\text{before}} = \mu_{\text{after}}$) should be rejected and alternate hypothesis is accepted (Ha: $\mu_{\text{before}} \neq \mu_{\text{after}}$) at $\alpha = 0.05$. That is to say that all mean values were significantly different.

Conclusions

A wastewater treatment plant was developed for the purpose of treating wastewater for recycling and reuse. The efficacy of the locally sourced materials such as *Azolla pinnata* and PKSC used for the purification were also ascertained. Considerable reduction in concentration values of the parameters tested for including heavy metals was established from the study. 100% removal efficiencies were obtained for some heavy metals such as cadmium (Cd) and manganese (Mn), and in parameters such as turbidity, TP and TN after passing through the treatment plant. All other parameters reduced appreciably with results which were statistically significant at $P < 0.05$. Also, from the overall performance of the wastewater treatment plant, it was established that this method was efficient in removing a high amount of pollutants from the wastewater samples which confirmed its effectiveness in water purification and treatment although higher efficiencies could be achieved if the system is operated on a batch basis as this design is for continuous loading, since higher HRT will be achieved during batch operations. Further statistical analyses also show significant differences between the initial and the final values obtained after passing through the treatment plant. The treatment plant can be useful in other parts of the country and beyond to ascertain its efficiency. Further performance evaluation on the efficacy of the treatment plant can be carried out by subjecting it to wastewaters from other sources apart from the four used in this study. Scaling-up and compartmentalizing of the constructed wastewater treatment plant to handle larger volumes of wastewaters and from different sources simultaneously from this prototype is hereby suggested.

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