

Received:
25 March 2018
Revised:
30 May 2018
Accepted:
9 July 2018

Cite as: Samuel Kofi Tulashie,
Francis Kotoka,
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Woananu,
Gifty Rhodalyn Tetteh.
Assessment and remediation
of pollutants in Ghana's Kete-
Krachi District Hospital
effluents using granular and
smooth activated carbon.
Heliyon 4 (2018) e00692.
doi: [10.1016/j.heliyon.2018.e00692](https://doi.org/10.1016/j.heliyon.2018.e00692)



Assessment and remediation of pollutants in Ghana's Kete-Krachi District Hospital effluents using granular and smooth activated carbon

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Abstract

The need for simple, cheaper and high performance hospital effluent treatment system in Kete-Krachi District which is adjacent to the Lake Volta has necessitated this study. This study focuses on assessing, and treating Kete-Krachi District Hospital effluent using packed granular (GAC) and smooth activated carbon (SAC). The use of activated carbon is due to its less expensive method of operation, the ease to prepare from local raw materials, high availability, and effectiveness for treating hospital effluent. The dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), nutrient compounds (P-PO₄, N-NO₃), turbidity, pH, conductivity and total coliform parameters were investigated and later treated with the activated carbon. The average conductivity and P-PO₄ removals were <50%. The average BOD₅, COD, coliform, N-NO₃, and turbidity

removals for all the SAC treatments were 58.36%, 62.26%, 84.39%, 83.86%, and 50.74%, respectively. The DO also improved 3.8 times on the average. The pH of the raw and treated samples was within the limit 6.5–9. The results of this study suggest that the SAC is predominantly effective for reducing the pollutants concentrations of the hospital effluent which can result in oxygen depletion, eutrophication, algal bloom and ecosystem disturbance in the Lake Volta. It will also decrease the susceptibility of the Kete-Krachi residents to waterborne diseases as the effluents seep into the Lake.

Keywords: Environmental science, Engineering

1. Introduction

Hospital effluent is described as the wastewater from hospitals or health care centers, which is discarded and not intended for further use [1]. It may contain both organic and inorganic substances, including pathogenic microorganisms and heavy metals. In high concentrations, the effluents may be dangerous to the health of residents when disposed off into nearby water bodies or the atmosphere without pretreatment [2]. Thus, the effluent may contain pathogens, human tissues and fluids, pharmaceuticals, genotoxic substances, chemical substances, heavy metals, and radio-active wastes, which may pose threat to public health and welfare [3, 4]. Some heavy metals pollutants such as gadolinium, copper, platinum, and iron have been found in concentrations reaching $\leq 300 \mu\text{g/L}$, 2.84 mg/L, $\leq 300 \mu\text{g/L}$ and 3.38 mg/L respectively [5, 6]. Pharmaceuticals residues such as analgesics, anti-bacterials, anti-infectives, cytostatics and contrast media (>40%) as well as anti-epileptics, anti-inflammatories, psychoanaesthetics, and β -blockers ($\leq 20\%$) have also been found in hospital effluent [6].

According to Halling-Sorensen et al. (1998), the presence of some hospital effluents in the environment poses serious environmental health implications as a result of their toxicity, genotoxicity, and carcinogenic effects [7]. For instance, it has been reported that about 10%, 15%, 15–35%, and 20% of hospital wastes in the USA, most developed countries, India and Pakistan, may be capable of causing harm respectively [2, 8, 9]. The knowledge on the toxic effects of these pollutants on other species is still scarce. However, laboratory studies have reported that fluoxetine, roxithromycin, propranolol, formaldehyde, and mixture of other pharmaceutical compounds in the effluent could lead to increased perturbations and acute toxicity to aquatic species such as *Carassius auratus*, and *Clarias gariepinus* (African Catfish) [10, 11, 12].

In addition to the health threat hospital effluents may induce to the public, their nutrient concentrations may also contribute to eutrophication when allowed to freely enter water bodies [3]. They may also be accumulated in the food chain and can defect the natural environment biological balance and species receiving it [2, 13].

The potential health implications of hospital effluents to the public and the environments have been a major concern in some countries. In view of this, a number of hospitals in some countries such as Greece, Denmark, and India have established systems for managing and treating hospital effluent [14, 15, 16]. Also, several studies have been conducted on the characterization and treatment of hospital effluents so as to massively reduce the associated risks. Some of the treatment methods, techniques, technologies, and materials employed were reverse osmosis (RO), nanofiltration (NF), ozonation, ultraviolet (UV), ion exchange, activated carbon, and coagulation-flocculation and flotation [17, 18, 19, 20]. However, most of these treatment methods are expensive and difficult to operate, especially, by small communities as well as rurally established and less endowed hospitals in developing countries that want to treat their hospital effluents prior to discharge.

In spite of the high manufacturing and operational costs of most of these treatment methods, the use of activated carbon has been mentioned to be a less expensive method since the activated carbon can easily be prepared from low cost raw materials such as saw dust, rose seed, cornel seed, bamboo, calabash, and coconut shell even when prepared commercially [21, 22, 23]. Moreover, according to Makeswari and Santhi (2013), activated carbon is equally effective for treating hospital effluent [22]. Other study also reported that activated carbon was effective for eliminating groups of micropollutants such as iodinated X-ray contrast media (61% elimination), pharmaceuticals (86% elimination), and industrial chemicals (96% elimination) in hospital effluent [20]. These imply that activated carbon can be employed to treat hospital effluents, especially, in less endowed hospitals in many developing countries such as Ghana that may be unable to afford the other treatment methods, though the effluent poses threat to the residents. A typical example is the Kete-Krachi District Hospital in Ghana.

Kete-Krachi is a small community in Ghana that lives adjacent to the Lake Volta which serves as aquatic habitat and a source of drinking water [24]. Though it is a small community, its hospital serves an average of 100,000–200,000 people [25]. However, their hospital effluent is left untreated and does not join any sewage system. This means that the Lake Volta which serves as aquatic habitat, the main source of drinking water and fishing is prone to heavy contamination of the effluent, thereby, making it unsafe for residents and other organisms. Hence, it is necessary to treat the effluent before discharge to reduce its potential pollution to the Lake and the environment.

This present study, therefore, focused on assessing the effluent of Kete-Krachi District Hospital effluent and treating it with activated carbon so as to reduce its potential contamination on the Lake Volta and the environs. The effluent was first characterized, and later treated with the granulated and powdered activated carbon. The physico-chemical and biological parameters were determined before and after

treatment which will be presented and discussed. The effects induced by the granular, and the smooth activated carbon treatments will also be considered.

2. Materials and methods

2.1. Study area

Kete-Krachi is the capital town of the Krachi West District of the Volta Region of Ghana. It is located adjacent to the Lake Volta, with a population of over 12,000 people and in the GPs coordinate $7^{\circ} 48' 5.2020''$ N and $0^{\circ} 3' 4.7700''$ W [24, 26]. The hospital is a government primary hospital that provides general services. It provides a 24 hr activity. Being a district hospital in Ghana, it serves an average population of 100,000–200,000 people. In addition, it provides curative care, preventive care, treatment techniques such as surgeries, laboratory and diagnostic techniques. Currently, it has a refurbished maternity block, a 50 bed capacity childrens' ward, skills acquisition laboratory and basic medicine production plant almost completed [25, 27, 28].

2.2. Sampling

The sample was collected from a point where all the effluents from the various departments in the Kete-Krachi District Hospital met. Composite sampling method was employed during the study. The sampling was conducted for three weeks at one week interval. In each week, samples were taken on Mondays and Fridays, thus, 6:00 and 18:00 GMT in each day. Samples were collected by immersing a 1 L polyethene bottle into the bulk flowing hospital effluent to avoid trapping of air. All samples which were not analyzed in situ were stored at 4°C and $\text{pH} \leq 2$.

2.3. pH, turbidity, and conductivity measurement

Immediately after sampling, the pH was measured using a portable pH meter (Suntex Model SP 701 Combination electrode type No. PHM-110-010Y, USA). The turbidity, and conductivity were also measured using turbidity meter (Partech Model-DRT 100B, Britain), and a field conductivity meter (Orion model 120, conductivity cell probe type PCM/141, Cell constant = 0.9, USA), respectively. The pH measurement was conducted according to standard method employed by Popa et al. (2012) [29] whereas the turbidity analysis was conducted using nephelometric method employed by USEPA [30].

2.4. Determination of dissolved oxygen (DO) and biochemical oxygen demand (BOD)

The iodometric (Winkler) method was applied in the analysis of the dissolved oxygen, and biochemical oxygen demand as modified in PN-EN 25813:1997 [31].

Using 250–300 ml DO vials, 300 ml of the sample volume was used for each DO, and BOD analysis. The BOD result was expressed in BOD₅.

2.5. Determination of chemical oxygen demand (COD)

As described by ASTM (1995), the close reflux colorimetric method was adopted for measuring the COD values of the samples [32]. 15–25 ml culture tubes were used for the COD. 5 ml of the samples was digested at 150 °C for 2 h in an oven (fisher scientific model 738f, 30–250 °C). The COD values were determined by titration.

2.6. Determination of phosphate (P-PO₄), and nitrate (N-NO₃)

The phosphate, and nitrate concentrations of the samples were determined by adopting the US standard methods [33]. The method for determining the phosphate concentration actually involved the formation of orange-yellow molybdo-vanado phosphoric acid complex from orthophosphate-sulphuric acid-ammonium vanadate-ammonium heptamolybdate solution. The absorbance values of phosphate in the samples were measured using the spectrophotometer (ULTROSPEC model II, Biochrom, UK) at a wavelength of 410 nm.

Also, the nitrate concentration of the samples was determined based on the formation of red-violet indophenol dyes from nitrate-resorcinol-chloride complex. The absorbance values of nitrate in the samples were measured using the spectrophotometer (ULTROSPEC model II, Biochrom, UK) at a wavelength of 500 nm.

2.7. Measurement of total coliform (TC)

The coliform (*Escherichia coli*) count was measured using standard methods [34]. The samples were diluted into well labeled sterilized containers in the ratios 1:10, 1:100 and 1:1000. The sample incubation was done at 37 °C for 24 h.

2.8. Determination of lead (Pb) content

The sample preparation, wet digestion system (HNO₃-H₂SO₄ mixture) and analysis were conducted based on ASTM Standards (D1971-11), and Hoenig and Kersabiec (1996) [35, 36]. The lead content of the samples was measured by Flame Atomic Absorption Spectrometry (FAAS) using air-acetylene flame and Unicam 969 AAS (Thermo Elemental UK).

2.9. Sample treatment with activated carbon

The weekly collected samples were separately treated with packed granular, and smooth activated carbon (Brita activated carbon, Brita GH, Germany). Fig. 1(a) and (b) are the respective models of the sample treatments with the granular, and

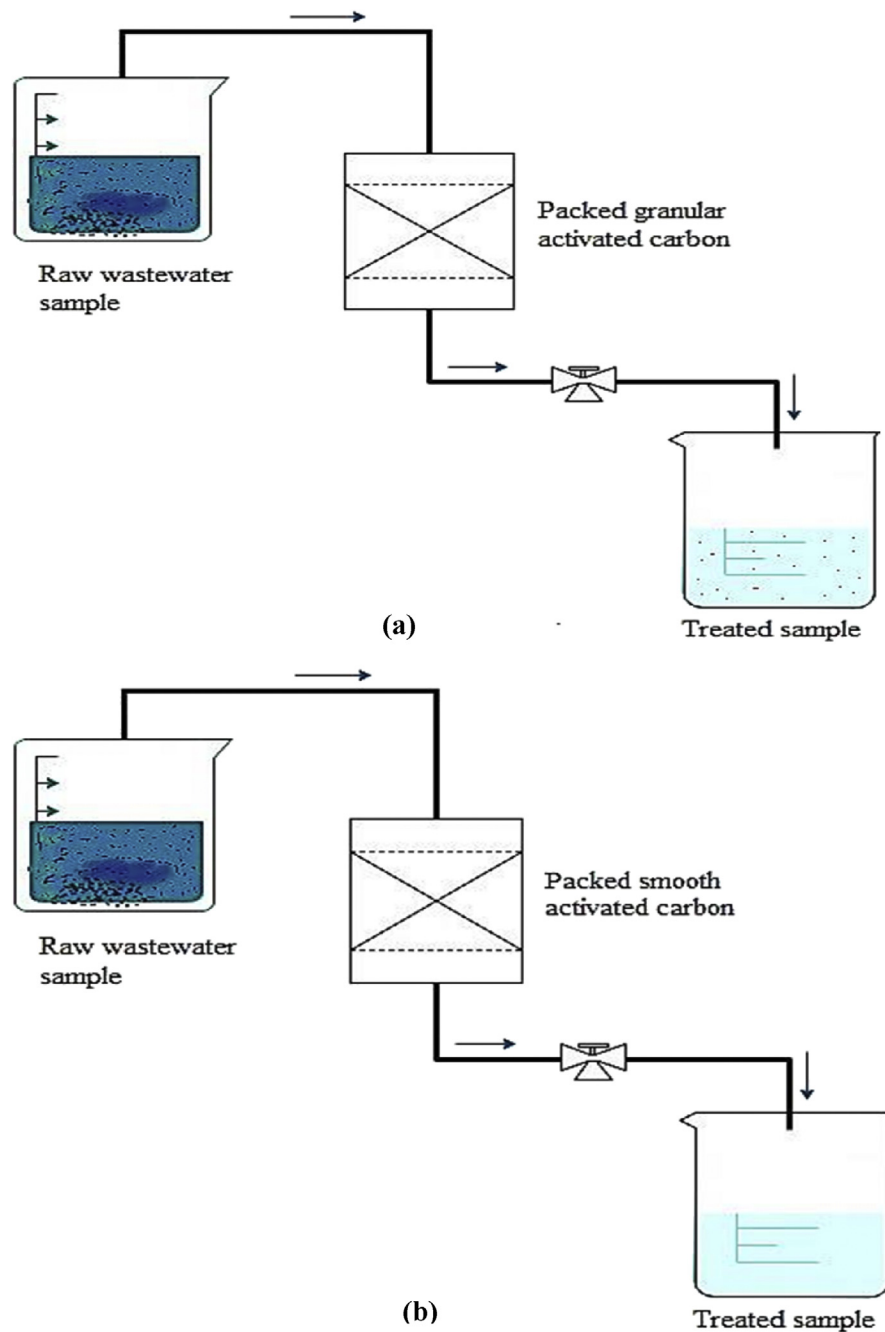


Fig. 1. (a) Sketch of the sample treatment with granular activated carbon; (b) Sketch of the sample treatment with smooth activated carbon.

smooth activated carbon in the laboratory. The GAC and SAC were packed separately into two single columns. The height (h), diameter (D) and volume of the activated carbon beds were 0.5 m, 0.05 m and $9.82 \times 10^{-4} \text{ m}^3$, respectively. Also, the residence time of the GAC and SAC treatment samples were 3 mins and 5 mins respectively. The volumetric flowrates of the GAC and SAC treatment samples

were calculated using Eq. (2). The first, second and third week samples treated with GAC were labeled as, GACW1, GACW2, and GACW3 while that of the SAC were labeled as, SACW1, SACW2, and SACW3, respectively.

The height of carbon bed followed the relation [37]

$$\frac{h}{D} = 10 \quad (1)$$

$$F = \frac{V_c \times 60(\text{min/hr})}{C_t} \quad (2)$$

Where F = volumetric flowrate (m³/hr);

V_c = Volume of activated carbon bed (m³);

C_t = Residence time (min)

Reproducibility measurements of this study were repeated twice under the same conditions and the average reported. All graphs and statistical calculations were conducted using Microsoft excel 2010.

3. Results and discussion

3.1. Characteristics of hospital wastewater effluent before and after treatment with granular activated carbon

The significance of this study is to help reduce the pollutants concentration in Kete-Krachi District Hospital effluent before it is discharged, so as to reduce its pollution on the Lake Volta and the environs. This will help reduce the disturbance on aquatic life and protect residents who use the Lake Volta as a source of drinking water, from associated waterborne diseases.

Table 1 shows the results of the physiochemical and biological characteristic of the hospital effluent from the Kete-Krachi District Hospital of Ghana collected in the first, second and third week (RSW1, RSW2, and RSW3 respectively). The samples were treated with granular activated carbon and their physico-chemical properties investigated.

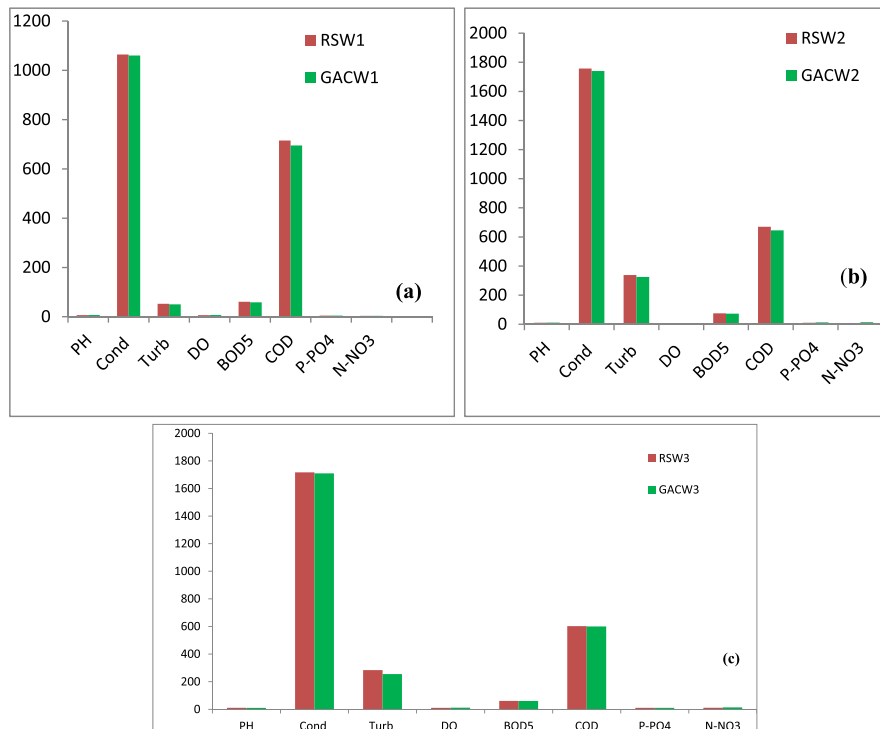
The lead content was appreciably low (<0.005 mg/L) before and after treatment. The pH of all the samples was within the standard permissible limit 6.5–9 [38]. However, it was observed that the physico-chemical and biological characteristics of the studied hospital effluent generally had very little improvement in all the treatment weeks. Thus, from Table 1, the TC only improved at range of 6.8–14.3%. Also, in Fig. 2(a), the highest performance of the GAC with respect to the BOD₅, COD, P-PO₄, N-NO₃, turbidity, and conductivity was 15.25%. Similarly, in Fig. 2(b)

Table 1. Physico-chemical and biological characteristics of the sample before and after treatment with GAC.

	pH	Cond ($\mu\text{S/cm}$)	Turb (NTU)	DO (mg/L)	BOD ₅ (mg/L)	COD (mg/L)	P-PO ₄ (mg/L)	N-NO ₃ (mg/L)	Pb (mg/L)	TC (Cfu/100 ml)
Raw hospital effluent										
RSW1	6.70	1064	52.6	3.20	60.6	715	1.77	0.082	<0.005	42×10^6
RSW2	8.09	1757	338	1.40	75.0	670	2.19	0.353	<0.005	230×10^6
RSW3	8.17	1717	284	2.20	61.0	602	2.76	0.005	<0.005	138×10^6
Hospital effluent treated with granular activated carbon										
GACW1	7.15	1060	50.5	4.0	58.5	695	1.50	0.080	<0.005	36×10^6
GACW2	8.50	1740	325	3.5	73.0	645	2.15	0.345	<0.005	215×10^6
GACW3	7.90	1710	255	4.0	60.5	600	2.65	0.010	<0.005	127×10^6

and (c), they were 3.85% and 10.21% respectively. Moreover, for all the GAC treatment weeks, the DO value improved only about 1.9 times. Essentially, the lower DO values (<3 g/L) in the RSW2 and RSW3 reflect the hypoxic activities which adversely affect aquatic lives and the environment [39].

This means that the hypoxic nature of the effluent can contaminate the lake with heavy bacterial, viral and organic pollutant loads which could adversely disturb

**Fig. 2.** The effects of granular activated carbon on the first week sample (a), second week sample (b), and third week sample (c).

aquatic organisms such as fishes, crustaceans and mollusks. The trend in the characteristics of the hospital effluent agrees with Ekhaise and Omavwaya (2008) who reported high values of COD, CT and others in a University hospital effluent [40].

The poor performance of the GAC may be due to poor sorption capacity, smaller surface area (lumpiness), and larger space between adjacent granules which might have impeded the sorption of the pollutants from the wastewater. This implies that granular activated carbon alone may not be effective and efficient for treating hospital effluents.

3.2. Characteristics of hospital effluent before and after treatment with smooth activated carbon

The characteristics of the wastewater were also measured after treatment with the SAC. Unlike the GAC, SAC had better performance during the treatments. As depicted in Table 2, the total coliform removal in the first (SACW1), second (SACW2) and third week (SACW3) treatments were 71.43%, 92.61% and 89.13% respectively. These resulted in 84.39% average coliform removal. The high count coliform load in the effluent reflects the extent of pollution, especially, faecal contamination [41]. Hence, the appreciable reductions in the coliform count imply that the SAC was very effective and efficient for the coliform removal. In effect, the SAC can predominantly help reduce the risks of faecal and non-faecal contaminations to the Lake Volta during the effluent seepage. If the community and residents drink from the Lake, it can also save them from water related diseases such as typhoid fever, cholera, dysentery and gastroenteritis, which according to WHO, kill millions of people yearly [42, 43]. Therefore, the SAC can be employed to significantly remove pathogenic microorganisms from the effluent.

Furthermore, the N-NO₃ removal was 98.78%, 72.80%, and 81.00% during the first, second, and third week treatments, having 84.19% average removal. Increasing the

Table 2. Physico-chemical and Biological characteristics of the sample before and after treatment with SAC.

	pH	Cond ($\mu\text{S/cm}$)	Turb (NTU)	DO (mg/L)	BOD ₅ (mg/L)	COD (mg/L)	P-PO ₄ (mg/L)	N-NO ₃ (mg/L)	Pb (mg/L)	TC (Cfu/100 ml)
Raw hospital effluent										
RSW1	6.70	1064	256	3.20	60.6	715	1.77	0.082	<0.005	42×10^6
RSW2	8.09	1757	338	1.40	75.0	670	2.19	0.353	<0.005	230×10^6
RSW3	8.17	1717	284	2.20	61.0	602	2.76	0.005	<0.005	138×10^6
Hospital effluent treated with smooth activated carbon										
SACW1	6.90	597	130	9.5	27.2	275	1.55	<0.001	<0.005	12×10^6
SACW2	7.18	1040	185	8.5	25.6	245	2.06	0.096	<0.005	17×10^6
SACW3	7.42	1442	120	5.5	28.0	230	2.16	<0.001	<0.005	15×10^6

nitrogen concentration in the presence of other nutrients in wastewater can induce eutrophication [3]. Therefore, the enormous removal of the N-NO₃ indicates that treating the hospital effluent will drastically reduce N-NO₃ triggered eutrophication processes which result in algal bloom. This will help maintain the ecological balance as aquatic organisms such as fishes, crustaceans, and mollusks in the Lake will not be deprived of oxygen.

In the first week treatment, as shown in Fig. 3(a) and (b), the BOD₅, COD, conductivity, and turbidity characteristics removals were 55.12%, 61.54%, 43.89%, and 49.22% respectively. The DO improved significantly from 3.20-9.50 mg/L, about 3 times better.

Conversely, the parameters were improved in the second and the third week treatments. The results of the second week treatments are depicted in Fig. 4(a) and (b). In this case, the BOD₅, conductivity, turbidity, and COD were reduced by 65.87%, 40.81%, 45.27%, and 63.43% respectively. The BOD₅ is one of the most vital parameters of wastewater. It measures the amount of dissolved oxygen required by the natural aerobic biological systems to break down the effluent under defined conditions [44]. Hence, the 65.87% removal in the BOD₅ indicates that the waste decomposition which depends on the BOD can effectively be stabilized to about 66% using the SAC. This indicates that the organic pollutant loadings in the effluent have been reduced appreciably. Consequently, this will tend to significantly reduce waterborne diseases in the Kete-Krachi community. It will also retard the potential of microbial growth, oxygen depletion and ecological disturbance in surrounding river bodies [45, 46] such as the Lake Volta.

COD is also a very important property of wastewater, hence, reducing it by 63.43% means that the SAC can help reduce the oxidative potential of the organic and inorganic compounds in the wastewater [47] to about 63%. This will tend to effectively

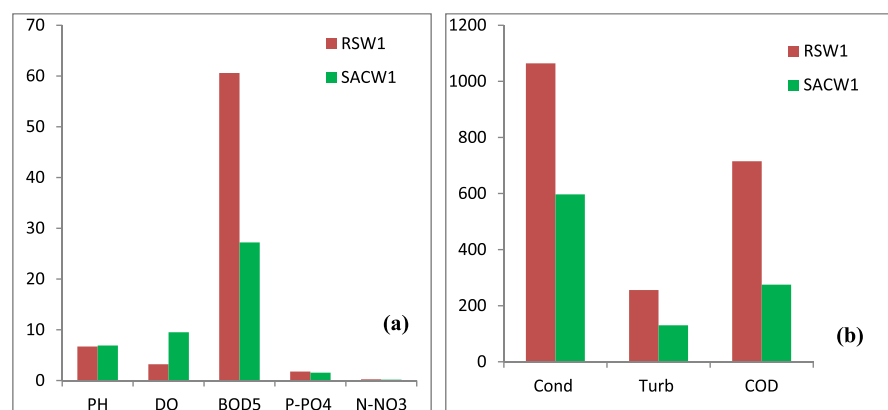


Fig. 3. (a) Comparison of the physico-chemical and biological characteristics of RSW1 and SACW1; (b) Comparison of the conductivity, turbidity and chemical oxygen demand of the RSW1 and SACW1.

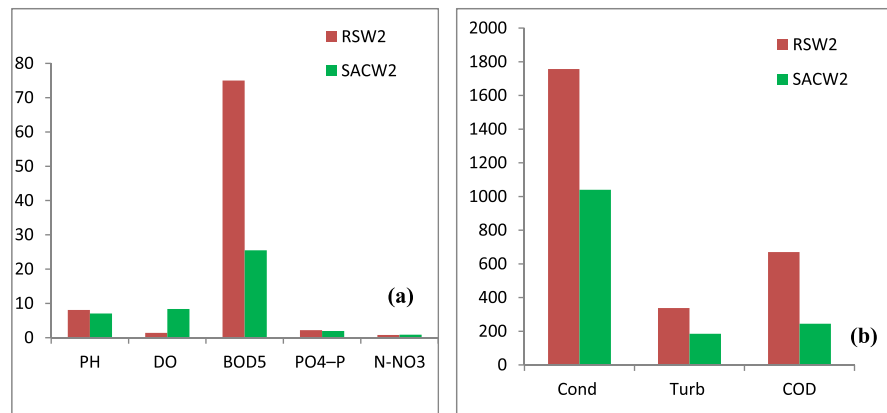


Fig. 4. (a) Comparison of the physico-chemical and biological characteristics of RSW2 and SACW2; (b) Comparison of the conductivity, turbidity and chemical oxygen demand of the RSW2 and SACW2.

reduce the chemical oxidative degradation of the effluent, thereby, reducing disturbance of the ecosystem in the Lake Volta and the associated risk posed to public health. Again, the DO was massively improved from 1.4 to 8.5 mg/L (about 6 times better). The DO values > 4 mg/L indicate that the anaerobic activities in the effluent caused by anaerobic organisms such as bacteria were enormously reduced after treatment since sufficient oxygen decreases anaerobic decomposition of the organic matter [33]. Therefore, the treated effluent has enough oxygen capacity to absorb and digest the organic waste it receives [39].

However, the SAC was not effective for P-PO₄ removal, since only 5.93% was removed from the effluent. This may be due to a lower affinity of the SAC for the P-PO₄. Our future studies will consider investigating how to effectively reduce the P-PO₄ from the waste.

In the third week treatment, as shown in Fig. 5(a) and (b), the BOD₅, COD, P-PO₄, and turbidity were also reduced by 54.10%, 61.79%, 21.74%, and 57.75% respectively. The DO also improved from 2.2 to 5.5 mg/L (about 2.5 times better).

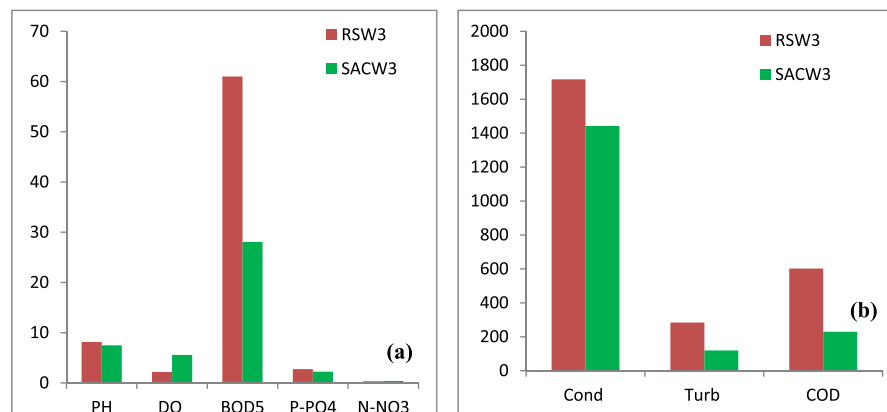


Fig. 5. (a) Comparison of the physico-chemical and biological characteristics of RSW3 and SACW3; (b) Comparison of the conductivity, turbidity and chemical oxygen demand of the RSW3 and SACW3.

Comparatively, the SAC entirely had better performance than the GAC in treatment weeks. This may be due to the higher surface area of the SAC than the GAC. The results of the study of the SAC treatments were consistent with another study on hospital waste which reported 61%, 86%, and 91% eliminations of pollutants using packed activated carbon alone (average of 62% in all eliminations) [20].

3.3. Proposal of a treatment model using locally available materials

Based on the observations and the results of this study, a new treatment model (Fig. 6) is being established to treat the Kete-Krachi District Hospital. This model is a prototype of Fig. 1(a) and (b) which includes various combinations of the locally available materials such as adjustable wooden board, palm nut fibre, and a holding tank. Thus, because the community does not have the means to afford most of the international standard materials such as pumps, valves, holding tank, and packed beds, the model includes locally made materials and it will be operated based on

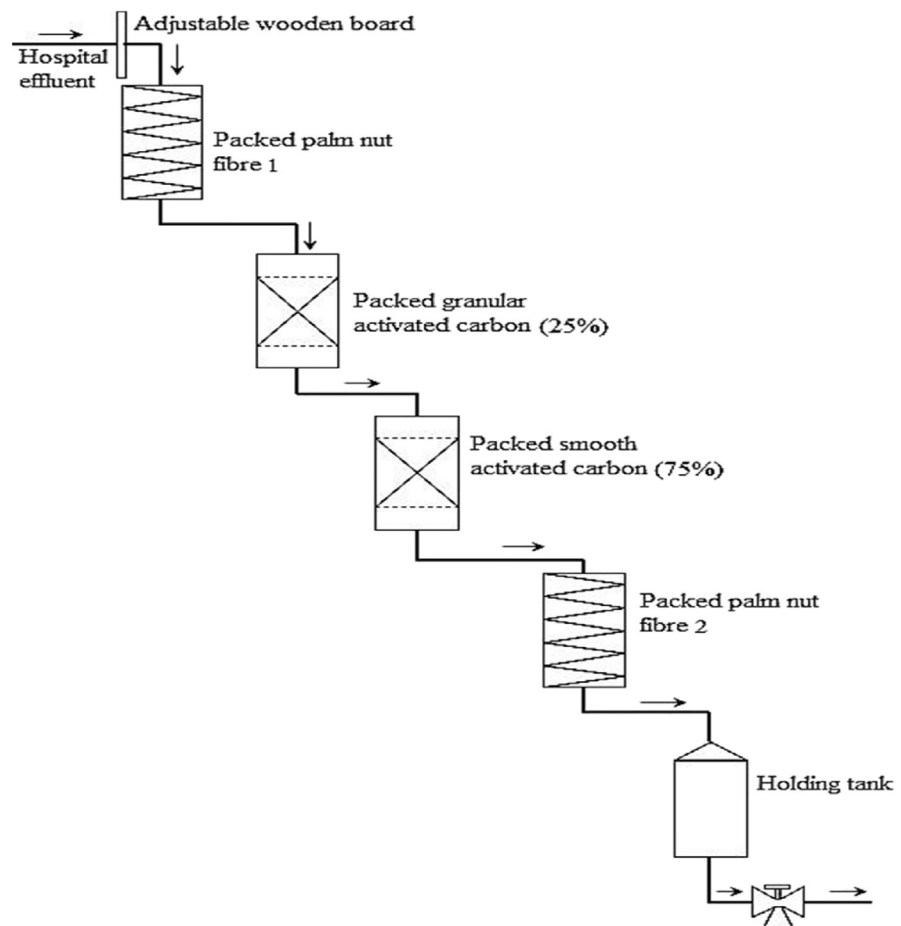


Fig. 6. Sketch of the treatment model using locally available materials.

differences in elevation so as to reduce the dominant usage of pumps. The adjustable wooden board will act as a manual gate valve to control the flow of the hospital effluent before it enters the packed palm nut fibre 1.

The packed palm nut fibre 1 will be acting as a filter which will separate granular particles of the effluent by size exclusion. It will also serve as an adsorbent. The granular activated carbon will be packed 25% to initially enhance fast flow of the effluent after leaving the packed palm nut fibre 1. This is also based on the results that the granular activated carbon did not perform well in this study compared with the smooth activated carbon. The smooth activated carbon will be packed 75% to enhance sufficient contact time with the effluent. The packed palm nut fibre 2 will also act as a filter to trap any of the smooth activated carbon particles which may be found in the entrainment. The holding tank will temporarily hold the treated sample to allow further analysis before the sample is released.

Our future study will consider employing other characterized activated carbon locally prepared from coconut shell, bamboo, and calabash.

4. Conclusions

This study presented the assessment and remediation of Ghana Kete-Krachi District Hospital effluent via packed activated carbon. The results of the study showed that the smooth activated carbon was predominantly effective for reducing the BOD₅, COD, coliform, N-NO₃, and turbidity by 58.36%, 62.26%, 84.39%, 83.86%, and 50.74% respectively. Also, the DO improved about 3.8 times on the average.

The results of this study, therefore, suggest that the smooth activated carbon in combination with the granular activated carbon is significantly effective for improving the turbidity and DO, and reducing the BOD₅, COD, coliform, N-NO₃ of Kete-Krachi District Hospital effluent. This will help reduce the contaminations which can result in oxygen depletion, eutrophication, algal bloom and ecosystem disturbance in the Lake Volta and the environs. It will also decrease the susceptibility of the Kete-Krachi residents to waterborne diseases as the effluents seep into the Lake.

Declarations

Author contribution statement

Samuel Tulashie, Francis Kotoka: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Foster Kwame Kholi, Gifty Rhodalyn Tetteh: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Samira Esinam Elsie Aggor-Woananu: Performed the experiments; Analyzed and interpreted the data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

We are grateful to the University of Cape Coast-Ghana and the Council for Scientific and Industrial Research (CSIR), Ghana for the availability of their laboratories.

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