VOLUME ESTIMATION AND PHYSICO-CHEMICAL AND BIOLOGICAL CHARACTERIZATION OF WATER TREATMENT PLANT SLUDGE: A CASE STUDY OF BAREKESE AND SUNYANI WATERWORKS

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Abstract

Conventional water treatment process in most parts of the world, Ghana inclusive, remains an integral component of water purification. The use of large volumes of coagulant, particularly alum and polyelectrolyte, as part of the process is therefore inevitable. Previous studies found significant volumes of water treatment plant sludge (WTPS) produced as a by-product with varied physiochemical constituents. However, continuous monitoring of WTPS volume generated and varying physicochemical and biological attributes remains sparsely executed globally particularly in Africa. It was within this context that the study sought to determine the volume of the WTPS generated to develop a model to project the WTPS produced at any water treatment plant. The physicochemical and biological characteristics of the sampled WTPS were also examined. To achieve these objectives, the study explored knowledge from already published literature and online data. Series of laboratory testing and analysis were undertaken to characterize the WTPS samples. The data set collated was then analyzed using statistical charts and the developed model for WTPS volume estimation. The study found that Ghana Water Company Limited's (GWCL) treatment plants procured large volume of coagulant and generated about 4.29 million m^3 *of WTPS annually. The developed model for WTPS generation was expressed as* $(V_{wsg})=(V_{rw}+V_c) - (V_{bw}-V_{tw}-V_f-V_{elo})$*: It was also evident from the laboratory analysis that the concentration of hazardous elements in the samples occurred at levels consistent with Ghana Standard Authority's (GSA) guidelines. However, there were traces of E. coli in Sunyani WTPS. Based on this study's findings, it is recommended that WTPS be dewatered and treated to reduce sludge volume and remove harmful chemical element in them prior to disposal into the environment. To significantly contribute to WTPS reduction and environmental safety, it is recommended that GWCL in partnership with government provides research funding support for further studies into the Donnan Dialysis technique of coagulant recovery and its economic applicability across the water industry.*

Keywords: *Water Treatment, Donnan Dialysis, Coagulant Recovery, Water Treatment Plant Sludge.*

1.0 INTRODUCTION

It is inevitable that water and wastewater are effectively treated (Anastosios and Nikos, 2008). The demand and consumption of freshwater resources are steadily increasing due to the high rate of population growth, the enlargement of industries and the springing up of new ones. The consumptive use of water in Ghana in 2020 was estimated at five (5) billion m^3 representing about 13% of the total surface water resources (MSWR, 2024), which makes water treatment at a lower cost relevant today. Water treatment involves the removal of biological, chemical, or physical substances that are potentially harmful for humans (Pakharuddin et al., 2021).

Conventional water treatment processes of widespread application in the water industry consist of a combination of physical, chemical, and biological processes and operations including coagulation, flocculation and sedimentation, filtration, and disinfection (Pakharuddin et al., 2021). However, the non-conventional water treatment process which involves the use of more advanced equipment and technology such as membrane and oxidation processes, activated carbon adsorption, ozonation, oxidation become inevitable under extreme water contamination and high turbidity. Within the framework of this study, conventional water treatment processes, as practiced in most water treatment plants in Ghana, remains the core research focus with emphasis on the volume and physiochemical properties of the WTPS generated.

Despite the numerous literature available on water resources and wastewater treatment, limited works exist regarding detailed investigation on the volume and physio-chemical characterization of waterworks sludge generated in Ghana. This knowledge gap presented an opportunity to undertake this research to at least provide real time data on the volume of WTPS generated and a detailed physio-chemical and biological analysis thereof.

2.0 MATERIALS AND METHODS

2.1 Case Study Area Profile

The study domain of this research featured both the Barekese and Sunyani Water Treatment Plants (WTP) located within the Ashanti and the Bono regions of Ghana respectively. The Barekese WTP is one of the largest plants in the region and situated approximately 26 km North of Kumasi, the regional capital. One key attribute of the plant is that it has an impounded Dam located on the Offin River with an estimated volume of 27.4 mm^3. Over the years, the plant has gone through phases of expansion to the current capacity of 136,000 m^3 with a designed yield of 220,000m^3/day.

Sunyani water works, on the other hand, is the main and largest treatment plant within Bono region and located at the outskirts of Abesim, a suburb in the Sunyani municipality. The plant draws its raw water from the Tano River, situated 3.5 kilometers North-East of Tanoso. The daily production from the plant stands at 1.5 million gallons of water as against an actual daily demand of 6 million gallons, the reason for Ghana Water Company Limited's (GWCL) expansion works to improve water supply to the municipality. The expansion project is designed with the capacity to produce 12.1 million gallons of water per day. This plant was also selected as part of the case study due to its proximity to the various mining communities within the enclave.

2.2 Determination of Volume of WTPS Generated at Barekese Water Treatment Plant

Lack of accurate data in most countries on the water treatment plant sludge (WTPS) generation to inform interventions has been a global challenge (Zhao et al., 2021). Besides, available data revealed that the WTPS generation in China was the highest globally at 2.3 million tonnes per annum, whereas Denmark generates the least WTPS at 10,000 tons per annum (Zhao et al., 2021). It has also been estimated that WTPS production constitutes about 1% – 3% of the total volume of raw water used during the purification process (Zhao et al., 2021). Limited work has also been done on the subject in Ghana and there is no historical data on the total WTPS generation nationwide. Most part of the world including Africa faces similar challenges.

This study therefore attempted to establish the WTPS production per annum using Barekese and Sunyani Water Treatment Plants as a case. Consequently, relevant stakeholders' information on the volume of WTPS generated per annum and the measuring technique deployed. It was discovered that the Barekese waterworks, in recent past, had an installed volumetric device and the recorded daily average volume was 442.5 m^3. However, based on in-depth understanding of the treatment process and water usage at these facilities, a logical model relating to certain key parameters was developed for the estimation of the daily volume of WTPS generated at the treatment facility. The model expressed the average daily volume of WTPS generated as: WTPS Generated $(V_{wsg}) = (V_{rw} + V_c) - (V_{bw} - V_{tw} - V_f - V_{elo})$ ....Eq. (1)

where V_{wsg} – the estimated volume of waterworks sludge generated daily;

V_{rw} – the average inlet volume of raw water; V_{bw} – volume used backwashing of clog filters; V_{tw} = the volume of treated water (daily water supply); V_c – Volume of coagulant;

V_f - the volume used for internal purposes at the facility; V_{wsg} – the volume of WTS generated; and V_{elo} – the volume of water lost through evaporation, leakages, among others.

2.3 Sampling Technique

Considering the research focus and its nature, only two (2) major treatment plants within the study's geographical area were selected – Barekese and Sunyani Water Treatment Plants. The similarity in water treatment processes across most existing treatment facilities means that it is unlikely to record significant variations in sludge characteristics that could influence the experimental results. The sludge sample volume collected at respective treatment facilities for testing aligned with the laboratory technicians' recommendation of 1.5L per sample size. Prior to the collection of the sample at Barekese WTP, one of the clarifiers was stopped for about 30 minutes and then the sludge valve was opened and the sample collected in a clean transparent plastic bottle. However, at the Sunyani WTP, the sample was taken from a pool of sludge already discharged into the sludge chamber. These sampling activities were done in the month of June, 2024. It is important to also add that, only relevant stakeholders knowledgeable in the subject matter were contacted and interviewed using the purposive sampling technique.

2.4 Physico-chemical Characterization of Waterworks Sludge

Waterworks sludge possesses varied physico-chemical properties depending on the quality of the source water, the nature of the coagulant used, and the treatment technology deployed. Generally, waterworks sludge may contain traces of organic matter, aluminum (Al) or iron (Fe) salts, and other heavy metals. To establish the biological and physico-chemical characteristics of the Water Treatment Sludge generated at Barekese and Sunyani waterworks, samples of the sludge were collected from the respective locations and tested at the Kwame Nkrumah University of Science and Technology (KNUST) Civil Engineering Laboratory Facility located within the Regional Water and Environmental Sanitation Centre Kumasi (RWESCK) building. However, due to the facility's lack of capacity to detect certain heavy metals such as mercury, lead, zinc, aluminum and cyanide, some samples were sent to the Soil Research Institute Laboratory at Kwadaso in Kumasi to determine the concentration of these elements. The number of parameters examined was based on state-of-the-art apparatus available at the time.

2.5 Laboratory Testing Procedures or Protocols

The Ghana Standards Authority (GSA) guidelines or manual for testing water quality parameters guided the conduct of the laboratory analysis. This methodological reference manual is quite voluminous, and so the study captured the test procedures for a limited number of parameters. It is worth noting that the testing protocols, apparatus and sample condition were similar for some chemical elements. Table 1 summarizes the list of parameters measured and the respective analytical reference methods as per the GSA manual. The laboratory procedures used for some of the physical and chemical constituents of the sampled WTPS were as follow:

2.5.1 pH Determination

This was done in accordance with GSA guidelines specifically reference method number 'SM 4500-H' by using a multiparameter pH meter which also uses a multiparameter probe. The meter has a pH probe with a bulb and electrode as the sensitive part of the probe. The pH electrode was immersed into the sample, the bulb and the electrode then detected the pH of the sample by displaying it on the meter. Prior to the pH determination of the samples, the probe was calibrated with a buffer solution which has a known pH of 4, 7 and 10 to determine its accuracy. The following step by step procedures were applied to measure the pH value of the samples. The beaker was washed very well with distilled water and filled halfway with the sample. The pH meter was then put on while rinsing the pH probe and the sample was stirred with the stirring rod. After that, the pH probe was put in until the sample covers the bulb of the pH probe. The pH meter reads till the final value is displayed on the device interface representing the pH of the sample.

2.5.2 Electrical conductivity

Conductivity is measured to know the ability of a sample to carry or conduct electric current. It is determined by the presence of ions in the samples using a multi-parameter pH meter which reads the conductivity when the probe is connected. The protocols applied here conformed to the GSA guidelines, particularly reference code 'SM 2510-B' in Table 1 and included the following steps. Just as in the case of pH determination, the beaker was washed very well with distilled water and filled halfway with the sample. The pH meter was then put on while rinsing the electrical conductivity (EC) probe and the sample was stirred with the stirring rod. After that, the pH probe was dipped into the sample until its bulb was covered. The EC button on the pH meter was then activated and the measured value was displayed on the device interface as the EC of the sample.

2.5.3 Determination of Total Dissolved Solids (TDS)

Determination of TDS was done by using pH Palin-test meter which has two probes. The probe with an electrode is used for pH while the other probe is for electrical conductivity and TDS. It is a convenient and efficient method for the determination of the concentration of TDS in the water quality analysis. Before using the Palin-test meter, it was first calibrated to ensure it works correctly. The TDS probe was inserted into the sample (raw and treated) carefully to avoid any air bubble and then the TDS button on the meter was pressed for it to read. It was then allowed to read to a stable figure and that figure was recorded as TDS in ppm for the sample. This procedure was in line with the GSA guidelines with reference code 'SM 2540-D' as shown in Table 1.

2.5.4 Determination of Turbidity

Turbidity is done to determine the cloudiness or haziness of a sample caused by large numbers of individual particles that are generally invisible to the naked eye. This was determined by using the Hach turbidity meter. The instrument emits light and measures the number of scattered particles in the sample. As indicated for other test procedures, the accuracy of the meter is determined by calibrating the meter with solutions which have a known turbidity of 10, 20, 80 and 100. The following step by step procedures as per GSA guidelines were executed to determine the turbidity of the samples. First, a sample of water was poured into the sample cell of the turbidimeter to the 10ml mark and all excess water present on the cell was cleaned to avoid interferences. After that, the sample cell was covered firmly and inserted into the turbidimeter. Finally, the 'NORMAL' button on the turbidimeter followed by the 'READ' button were pressed to display the results.

2.5.5 Hardness (Calcium Carbonate) ($CaCO_3$) Determination

This was done by the titrimetric method where the sample was titrated against edta to determine the concentration of the ions in the water sample. The edta and its sodium salts form a chelated soluble complex when added to a solution that has a certain metal cation such as calcium and magnesium in it. If a small amount of dye (Eriochrome black t) is added to an aqueous solution at a pH of 10 and titrated against the edta, there is always a colour change from wine to blue which indicates that the edta has reacted with the calcium and magnesium ion in the solution. The test procedures followed through aligned with the GSA guidelines with reference code SM 3500-C. In line with this, 50 ml of mineral water was pipetted into a conical flask and 1ml of NH_4 buffer solution added to give a pH of ten (10). Next, the Eriochrome indicator was added and titrated with 0.01M edta until it changes from wine to blue. The titration was repeated to obtain two concordant results. After these experimental steps, the total hardness $\left(\frac{mgCaCO}{L}\right) = (V \times M \times 100) \times \frac{1000}{ml}$ of the samples was computed using the equation: , where V and M are the volume and the molarity of EDTA (0.01) respectively.

2.5.6 Determination of Calcium (Ca) Hardness

Calcium ion or hardness was also determined by using the same titrimetric method to determine the concentration of the ion with NaOH as the buffer to increase the pH of the solution to ten (10) and helps the edta to react with calcium concentration in the sample. It also has murexide as its indicator with a colour change from pink to violet. It is important to state that the test procedures applied here also aligned with GSA guidelines 'SM 3500 Ca D' and were as follows. A 50 ml of mineral water was pipetted into a conical flask and 2ml of NaOH buffer solution added to give a pH of ten (10). Also, a murexide indicator was added and titrated with 0.01 M EDTA until it changes from wine to blue. The titration was repeated to obtain two concordant results. At the end of this, the calcium hardness measurement was then calculated using the equation: $\text{Calcium Hardness } (\text{Ca}^{2+}\text{ ion}) = \left[V \times M(edta) \times M(Ca^{2+}) \times \frac{1000}{ml} of sample\right]$, and where V and M represent the volume and molarity of EDTA (0.01) respectively and $M(Ca^{2+}) = 40$. After deriving the calcium hardness, it became easy to compute the magnesium (Mg) hardness from the equation: *Magnesium Hardness=Total Hardness-Calcium Hardness*.

2.5.7 Determination of Chloride (Cl-) (SM 4500 Cl)

This was determined by argentometric titration. Potassium chromate was used as the indicator which helps to indicate the endpoint of $AgNO_3$ titration of Cl^-. AgCl was then formed as precipitate before red $AgCrO_4$ was formed. The procedures for chloride determination at the laboratory were as follows. 50ml of the sample was measured using a measuring cylinder into the conical flask while 0.5ml of potassium chromate (K_2CO_3) was added as an indicator. The resulting mixture was then titrated against 0.0141N ($AgNO_3$). The colour change indicating the endpoint was from yellow to brick red precipitate. Since the determination was done by titration method, it became necessary to compute the chloride concentration using the expression: $\frac{[V \times N(0.0141) \times 35.45 \times 1000]}{volume} of\ sample$, where V is the volume of acid (50ml), N denotes the normality of the acid used and the 35.45 in the expression also represents the molar mass of the chloride ions.

2.5.8 Determination of Manganese (Mn)

The following procedures as per the GSA guidelines 'SM 3500-B' guided the detection of manganese concentration in the samples. The spectrophotometer was put on and the stored program was activated. The test option labelled 'Manganese LR PAN' was selected and the sample cell filled with 10ml deionized water as blank to zero. A second sample cell was also filled with 10ml of the sample and the contents of one Ascorbic Acid powder pillow was added to each cell.

The samples cells were inverted gently to mix, and twelve drops of Alkaline-Cyanide Reagent solution was added to each cell and swirled gently to mix. Again, twelve drops of PAN indicator solution 0.1%, was added to each sample and swirled gently to mix. An orange colour developed which affirmed the presence of manganese. A two (2) minutes reaction time was then allowed after which the blank was wiped and inserted into the cell holder with the fill line facing right and the 'zero button' on the device was activated. Finally, the second cell was wiped and inserted into the cell holder. The 'read button' was then pressed and the reading recorded.

2.5.9 Determination of Iron (Fe)

As per the GSA guidelines reference code 'SM 3500-Fe D', the following procedures were deployed to determine whether there were iron molecules in the sample and the level of concentration present. The spectrophotometer was put on and the stored program activated. The test option labelled 'iron ferrover' was selected and the sample cell filled with 10ml of the sample as blank to zero. A second sample cell was also filled with 10ml of the sample and iron powder pillow added. A three (3) minutes reaction period was allowed and a pink colour developed which confirmed the presence of iron. After the time elapsed, the blank was wiped and inserted into the cell holder with the fill line facing right and then the 'zero button' was activated. Lastly, the second cell was wiped and inserted into the cell holder and then 'the read button' was pressed.

Table 1: List of the Parameters Tested and Corresponding Analytical Reference Methods

PARAMETERS	GSA GUIDELINES	REFERENCE METHOD
pH	6.5 – 8.5	SM 4500-H
Electrical Conductivity	1500	SM 2510-B
TDS (ppm)	1000	SM 2540-D
True Colour (TCU)	0 – 15	SM 2540-D
Suspended solid (mg/l)	0	SM 2540-D

Fluoride (mg/l)	1.51	SM 4500-F- D
Ammonia (mg/l)	0-2	SM 4500-BC
Iron (mg/l)	0 - 0.3	SM 3500-Fe D
Manganese (mg/l)	0 - 0.4	SM 3500-B
Hardness (mg/l)	500	SM 3500-C
Ca Hardness(mg/l)	250	SM 3500-Ca D
Mg Hardness(mg/l)	250	SM 3500-Mg E
Calcium (mg/l)	200	SM 3500 Ca D
Magnesium (mg/l)	100	SM 3500-Mg E
Sodium (mg/l)	200	SM 3500-Na B
Potassium (mg/l)	100	SM 3500-K B
Total Alkalinity (mg/l)	250	SM 2320-B
Bicarbonate (mg/l)	-	SM 2320 -B
Chloride (mg/l)	250	SM 3500 Cl - B
Nitrate (mg/l)	10	SM 4500-NO^{-}_{3} E
Nitrite (mg/l)	0.10	SM 4500 NO^{-}_{2} E
Phosphate (mg/l)	1.00	SM 4500 P E
Total Phosphorus (mg/l)	0.1	SM 365.1- P
Sulphate (mg/l)	250	SM 4500 $SO_4)^{2-}$ E
Silica SiO_2	-	SM 4500 D
Cyanide (mg/l)	0.07	HACH-8027-CN-
Arsenic (mg/l)	0.01	HACH 8049-AsO_4^{3-}
Mercury(mg/l)	0.01	SM 3500-Hg B
Lead(mg/l)	0.01	SM 3500-Pb C
Zinc(mg/L)	0.20	SM 3500-Zn F
Cadmium (mg/l)	0.003	HACH-8146-Cd^{2+}
Aluminum (mg/l)	0.20	SM 3500-Al D
Chromium (mg/l)	0.05	SM 3500-Cr D
E. coli (cfu/100ml)	0	SM 9222-D
Coliform (cfu/100ml)	0	SM 9222-B
Salmonella (cfu/100ml)	0	SM 9260-D

2.6 Fourier Transform Infrared Spectroscopy (FTIR) Analysis of the Samples

To determine the functional groups or organic compounds present in the samples, analysis was done at the KNUST Central Laboratory using the PERKIN-ELMER UATR-FTIR TWO Instrument model which uses the ATR (Attenuated Total Reflectance) with a diamond crystal. Protocols applied in the FTIR analysis included – the diamond crystal was cleaned with isopropanol and a background scan done, the sample was then placed directly on the crystal and the pressure gauge was applied to ensure maximum contact, and finally a scan of the sample was then taken and the spectrum graph was generated to show the functional groups.

3.0 RESULTS AND DISCUSSIONS

3.1 Quantification of Water Treatment Sludge Generated Annually

Given the dearth of reliable data on the volume of waterworks sludge produced at various treatment plants operated by Ghana Water Company (GWC), it was imperative to conduct a thorough analysis of the Barekese Water Treatment System to ascertain the approximate value of volume of sludge produced annually. From the field survey, the following key parameters as illustrated in Table 2 were made available to aid the waterworks sludge volume estimation analysis.

Table 2: Key Parameters Leading to the Final Waterworks Sludge Volume Estimation

#	Parameters	Daily Volume (m^3/day)	Monthly Volume (m^3/ month)	Annual Volume (m^3/ annum)
1	Average inlet Volume of raw water (V_{rw})	110,644.00	3,319,320.00	39,831,840.00
2	Average Volume of treated water (daily water supply) (V_{tw})	104,649.00	3,139,470.00	37,673,640.00
3	Volume used of Backwashing of clog filters (257.5m^3 per 18 minutes per day) (V_{bw})	4,635.00	139,050.00	1,668,600.00
4	Volume used by the Facility for various uses (V_f)	5.00	150.00	1,800.00
5	Volume of Coagulant (Polyelectrolyte) 5591.82kg (V_c)	5.59	167.70	2,012.40
6	Volume of Sludge discharge or dislodge daily (442.5m^3 per 5 clarifiers for 3 shifts) (V_{wsg})	442.50	13,275.00	159,300.00
7	Volume lost through evaporation, leakages and others (0.01% of average volume of raw water) (V_{elo})	11.06	331.93	3,983.18
Estimated Volume of Sludge Generated		**1,349.53**	**40,485.77**	**485,829.22**

Source: Field Survey (2024)

The various parameters illustrated in Table 2 were assigned specific abbreviations to form an equation linking them as follows:

The Average inlet volume of raw water = V_{rw}

Volume used backwashing of clog filters = V_{bw}

Volume of treated water (daily water supply) = V_{tw}

Volume used for internal purposes at the facility = V_f

Volume of coagulant = V_c

Volume of waterworks sludge generated = V_{wsg}

Volume lost through evaporation, leakages and others = V_{elo}

The relationship between these parameters can therefore be expressed as:

$$(V_{wsg}) = (V_{rw} + V_c) - (V_{bw} - V_{tw} - V_f - V_{elo}) \quad \text{.................Eq. (2)}$$

It is evident from Table 2 and equation (2) that the estimated daily sludge volume generated at Barekese water treatment plant was approximately 1,350 m^3. Therefore, for everyone (1) cubic meter of raw water treated, the volume of sludge generated was estimated at 0.0122 cubic meter, which constituted 1.22%. However, the field survey found that the volume of sludge generated and discharged daily to a nearby sludge disposal site was 442.5 m^3 and represented 32.78% of the total sludge volume generated daily. On the annual equivalent of these daily generations, it was projected that close to 485,829.22m^3 of waterworks sludge was generated at Barekese Water Treatment Plant annually. Based on this finding, the annual estimated sludge generation by Ghana Water Company Limited (GWCL) nationwide, given an average daily production of 950,995 m^3 was approximately $([((950995))/((1-0.0122))]\times0.0122\times365) = 4,287,083.15\ m^3$. This significant volume of sludge generated and released into the environment without prior treatment has adverse health implications given the hazardous elements present. To achieve a significant reduction in the volume of sludge discharged into the environment and minimize its associated health risk, was to enable a large-scale coagulant recovery using the DD technology as emphasized in Section one (1) of this study.

3.2 Physico-chemical and Biological Characterization of the WTPS Samples

Modern chemistry and the state-of-the-art laboratories available across Ghana mean that numerous chemicals in water can be detected very fast, even at extremely low concentrations. Understanding the physical, chemical, and biological characteristics of water treatment plant sludge (WTPS) samples collected was a key objective of the study. To achieve this, the samples were taken to the Department of Civil Engineering, environmental quality laboratory located within the RWESCK building at the Kwame Nkrumah University of Science and Technology (KNUST) for testing. The facility supported the testing of as many chemical elements as possible except for a few heavy metals which were tested at the Soil Research Institute Laboratory at Kwadaso in Kumasi. The laboratory analysis deployed diverse apparatus, technology, and standard methodology to test specific chemical elements and biological constituents of the samples. The preceding sub-headings details the physicochemical and biological constituents of the tested samples and their respective concentration levels.

3.2.1 Physical Characteristics of the Samples

Samples' physical characteristics of measured included pH, electrical conductivity, colour, total dissolved solids (TDS) and suspended solid (SS) (Table 3). The odour of both samples was non-offensive and the electrical conductivity of the Barekese WTPS was low compared to the Sunyani WTPS. The colour of both samples was indicative of the level of turbidity of each sample. By extension, the higher the colour, the lower the turbidity of the sample and vice versa. Hence, the Sunyani WTPS has a high turbidity as compared to the Barekese WTPS. Moreso, the total dissolved and the suspended solid contents of the Sunyani WTPS appeared extremely higher than that of the Barekese WTPS, validating the high turbidity shown. Column 3 of Table 3 profiled the Ghana Standard Authority (GSA) guidelines for portable water and it was intended to give an indication of how low or high the values were. Overall, the physical attributes of the samples were consistent with GSA guidelines except for the colour and SS values recorded for the Sunyani WTPS. With reference to available literature on WTPS characterization, the pH and the total dissolved solids were the main parameters analyzed (Zhao et al., 2020 and Ahmad et al., 2016). The pH and the total dissolved solid measurement of these publications vary slightly and greatly from the study's experimental result respectively. This affirms the fact that different WTPS samples exhibits varied physico-chemical and biological characteristics due to factors such as; source water quality, coagulant type used, treatment method adopted etc. (Zhao et al., 2020).

Table 3: Physical Characteristics of Barekese and Sunyani Water Treatment Sludge (WTPS)

#	PARAMETERS	GSA GUIDELINES	Barekese WTPS	Sunyani WTPS
1	Ph	6.5 – 8.5	6.74	6.03
2	Electrical Conductivity	1500	125.6	478
3	Total Dissolved Solid (ppm)	1000	55.3	211
4	True Colour (TCU)	0-15	5	35
5	Suspended Solid (mg/l)	0	0	1870

3.2.2 Chemical Characteristics of the Samples

The study considered several chemical elements present in the samples, particularly heavy metals and other hazardous substances. With the state-of-the-art technology, the study tested 17 major chemical elements including heavy metals such as mercury (Hg), lead (pb), Arsenic (As), aluminium (Al) and Zinc (Zn) (Table 4). The total hardness and alkalinity of each sample were included into the chemical analysis. Furthermore, the inbuilt functionalities of the equipment supported the testing of ammonia compound (NH_3) and five (5) radicals specifically, phosphate (PO_4), sulphate (SO_4), nitrate (NO_3), bicarbonate (HCO_3) and Nitrite (NO_2). The arrangement of the elements in table 4 was based on their increasing atomic number as per the periodic table. A careful study of the chemical concentration of each of the elements found in the samples indicated that these concentration levels were within the recommended GSA guidelines for portable water. Although the chemical constituents of both samples were within allowable limits, the Sunyani WTPS had higher concentration of the chemical parameters measured as compared to the Barekese WTPS. Despite the low concentration levels recorded per the GSA guidelines, it is important to note that continuous disposal of these waterworks' sludge into the environment without prior treatment or heavy metals recovery could threaten the ecosystem as these chemicals' elements accumulate in significant quantities with the passage of time. Figures 1 and 2 show the major chemical composition of the Barekese and Sunyani WTPS samples, respectively. It is important to emphasize that most of the chemical elements presented in this paper were also analyzed in previous studies for other types of WTPS. However, the concentration levels of these chemical elements particularly heavy metals reported in available literature were extremely high in most cases compared to this report (Zhao et al., 2020; Ahmad et al., 2016; Suman et al., 2018; Gopalakrishnan and Velkennedy, 2016). Again, the experimental results were slightly lower than values reported by Ashong et al. (2024) on Post Treatment Sludge at Barekese Treatment Plant.

Table 4: Chemical Characteristics of the Samples

#	PARAMETERS	GSA GUIDELINES	Barekese WTPS	Sunyani WTPS
1	Fluoride (F-), mg/l	0.15	0.09	0.015
2	Sodium (Na), mg/l	200	19.911	146.406
3	Magnesium (Mg), mg/l	100	12	11
4	Aluminium (Al), mg/l	0.20	0.15	0.10

5	Phosphorous (P), mg/l	0.10	0.018	0.021
6	Chloride (Cl-), mg/l	250	17	125
8	Potassium (K), mg/l	100	1.44	6.86
9	Calcium (Ca), mg/l	200	10	64
10	Chromium (Cr), mg/l	0.05	0.001	0.011
11	Cadmium (Cd), mg/l	0.003	0.001	0.001
12	Manganese (Mn), mg/l	0 - 0.4	0.001	0.102
13	Iron (Fe), mg/l	0 - 0.3	0.07	0.10
14	Zinc (Zn), mg/l	0.2	0.004	0.015
15	Arsenic (As), mg/l	0.01	<0.001	0.0013
16	Mercury (Hg), mg/l	0.01	<0.001	<0.001
17	Lead (Pb), mg/l	0.01	0.001	0.0011
18	Cyanide (CN), mg/l	0.07	0.001	0.001
19	Sulphate (SO_4), mg/l	250	0	1
20	Phosphate (PO_4), mg/l	1.00	0.22	0.25
21	Bicarbonate ($2CO_3$), mg/l	-	46.36	48.80
22	Nitrate (NO_3), mg/l	10	0.05	0.35
23	Nitrite (NO_2), mg/l	0.10	0.001	0.017
24	Silica (SiO_2), mg/l	-	2.948	3.852
25	Ammonia (NH_3), mg/l	0 – 2	0.05	0.35
26	Hardness, mg/l	500	60	204
27	Ca Hardness, mg/l	250	24	159
28	Mg Hardness, mg/l	250	36	45
29	Total Alkalinity, mg/l	250	76	80

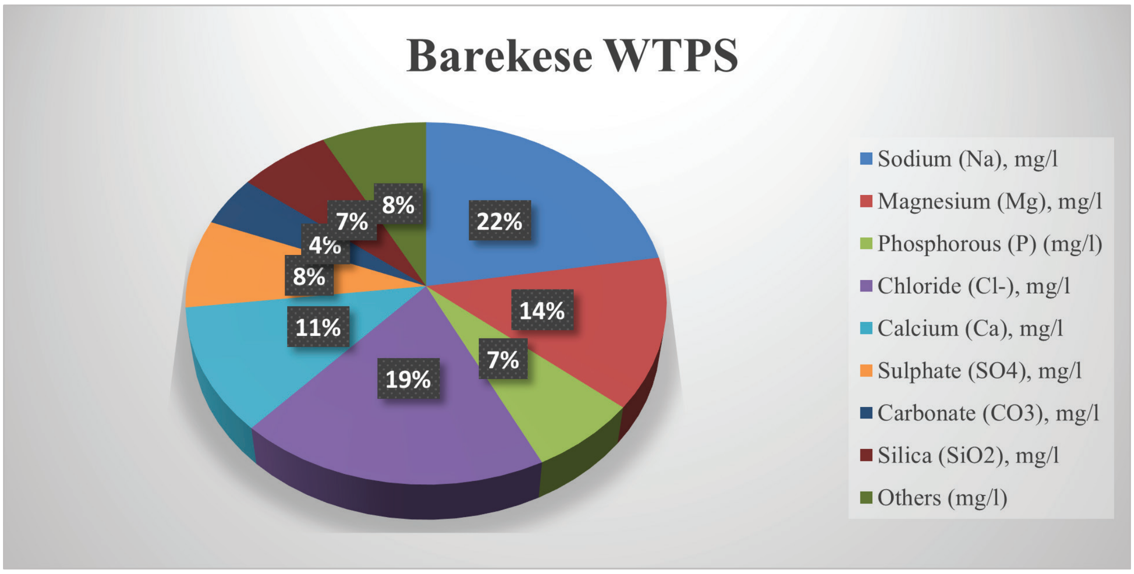

Figure 1: Major Chemical Constituents of Barekese WTPS

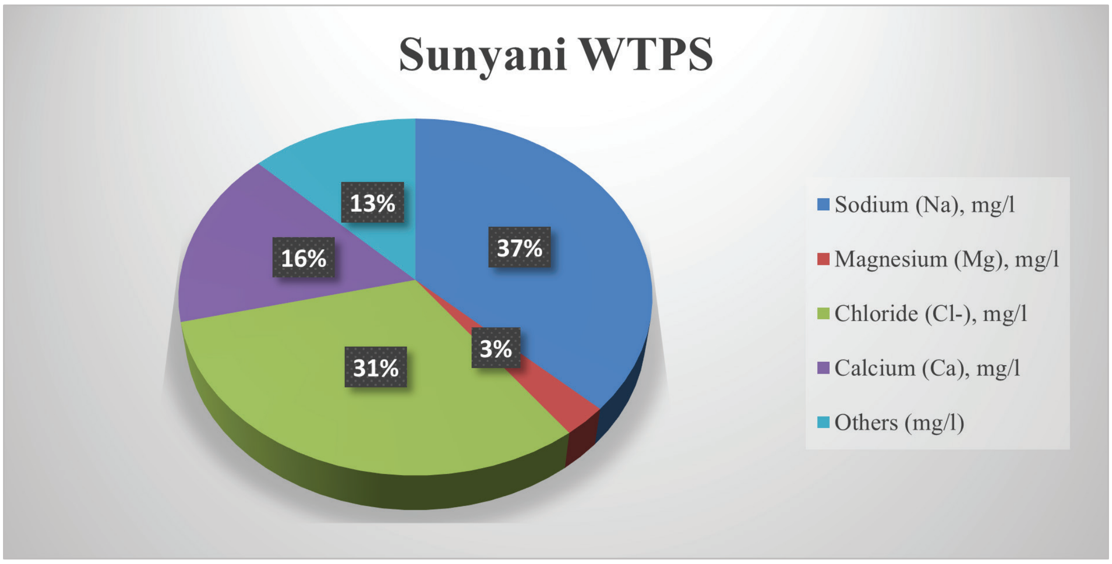

Figure 2: Major Chemical Constituents of Sunyani WTPS

*3.2.3 Biological Characteristics of the Samples

There were three (3) commonly known microbiological components tested in the samples at the laboratory namely, Escherichia coli (E. coli), coliform and salmonella. The testing of these microorganisms in water and wastewater is a reasonable indication of fecal pollution and the possible presence of pathogens (disease causing organisms). It is evident from Table 5 that the Barekese sample had no traces of these bacteria unlike the Sunyani WTPS which shows the presence of the E. coli bacteria. By implication, the Sunyani WTPS test results are indicative of the fact that the source water is polluted with fecal remains and contains pathogens. Thus, the disposal of such WTPS into the environment without prior treatment could be risky to public health. The absence of these microbiological contents in the Barekese WTPS does not suggest that samples of WTPS from other treatment plants will exhibit similar properties. Even the coagulant type applied could influence the microbiological composition of WTPS (Pei et al., 2017). Moreso, available research on WTPS characterization revealed that different kinds of microorganisms including proteobacteria, firmicutes, cyanobacteria could be found in WTPS (Messa et al., 2025).

Table 5: Biological Characteristics of the Samples

#	PARAMETERS	GSA GUIDELINES	Barekese WTPS	Sunyani WTPS
1	E. coli (cfu/100ml)	0	0	1
2	Coliform (cfu/100ml)	0	0	0
3	Salmonella (cfu/100ml)	0	0	0

3.2.4 Fourier Transform Infrared Spectroscopy (FTIR) Analysis of the Samples

A FTIR test was performed on both samples at the KNUST Central Laboratory to determine the presence of various functional groups and chemical bonds. The FTIR technique was used to obtain infrared spectrum based on the transmittance of the infrared radiation (IR) in a sample. The IR spectrum was broadly divided into two (2) wavenumber regions: the analytical region above 1500 and the fingerprint region which is below 1500 . However, for the purposes of this study, the spectrum interpretation was confined to the analytical region. The underlying principle here is that the wavenumber of each peak within the analytical region corresponds to a particular function group or organic compound on the FTIR database or reference table of possible functional groups and their quantified frequencies. A careful observation of the spectra as illustrated in Figure 3 and Figure 4 shows that both samples have identical functional groups given the similarity in the spectra curves. With reference to both figures, there are two peaks with different wavenumbers shown in the analytical regions. The first peak occurred at a wavenumber of approximately 3339cm^{-1} with a medium transmittance strength of 50% and this indicates the presence of N-H functional group (NH_2 - amines) in the samples. The second peak, on the other hand, also occurred a frequency of approximately 1634cm-1 with a slightly low transmittance strength of 70% and this gave a strong indication of the presence of alkenyl (C=C) in the samples. These results are quite different from reported findings on other WTPS samples reaffirming the assertion that different WTPS possess varied chemical characteristics (Suman et al., 2018; Lebogang et al., 2023).

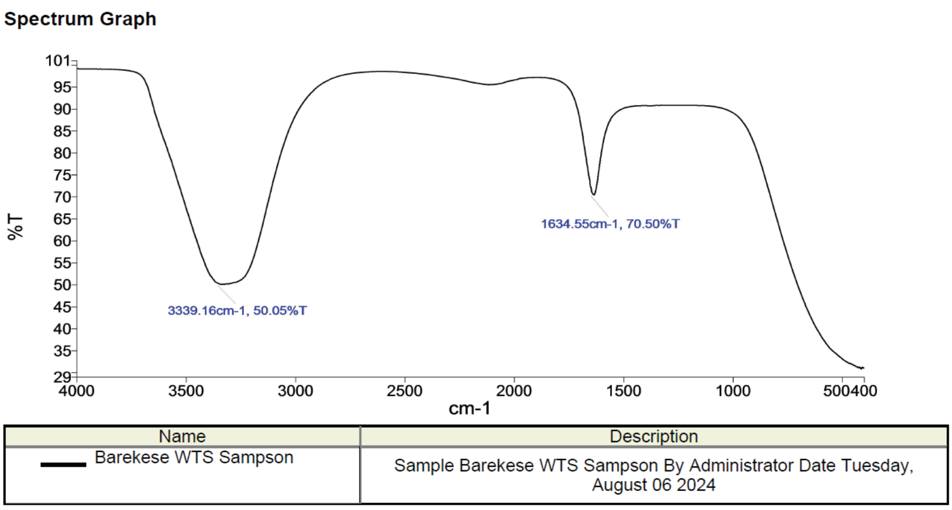

Figure 3: FTIR Spectrum graph for the Barekese WTS Sample (Source: KNUST Central Lab.)

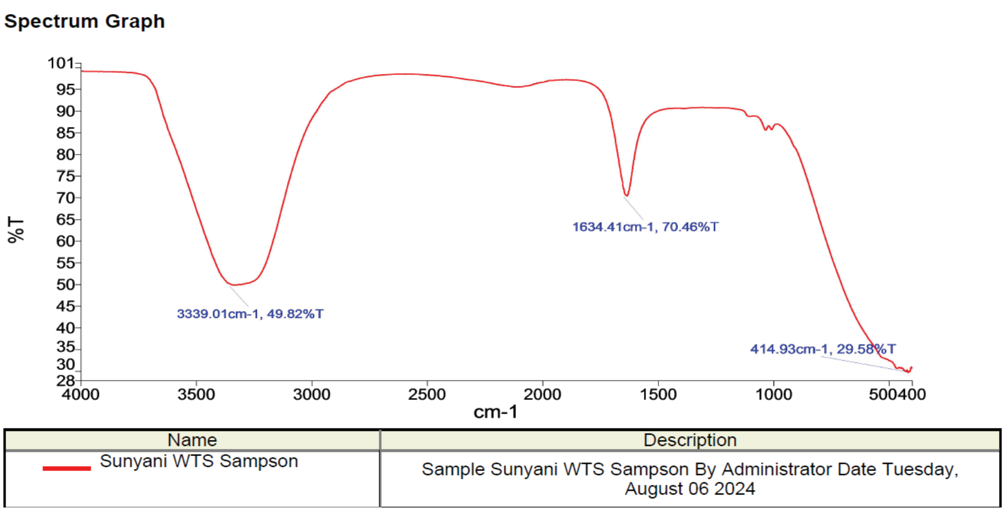

Figure 4: Spectrum Graph for the Sunyani WTS Sample (Source: KNUST Central Lab.)

4.0 CONCLUSION

Based on the findings presented above, it can be concluded a significant volume of water treatment plant sludge (WTPS) is generated across the country annually and GWCL should build dewatering systems at its respective facilities. Again, due to the large volume of coagulant usage in water purification, it is further recommended that the water industry, investors, entrepreneurs, researchers, and state institutions in charge of the environment explored advanced coagulant recovery technology such as the Donnan Dialysis process not only to reduce the WTPS volume discharged into the environment but also to make great economic gains in the process. Finally, the laboratory analysis of WTPS samples collected from the study area indicated the presence of heavy metals and other hazardous chemical elements that could lead to adverse environmental impacts if discharged indiscriminately into the surroundings without prior treatment.

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Conflicts of Interest: "The authors declare no conflict of interest."

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