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RESEARCH PAPER

AN EVALUATION OF GROUNDWATER POTENTIAL FOR SUSTAINABLE WATER SUPPLY ON KNUST CAMPUS, GHANA

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ABSTRACT

Many boreholes have been drilled on KNUST campus to aid meet water supply demands due to the rising population and inadequate water supply from Ghana Water Company Limited (GWCL). Unfortunately, these boreholes are managed individually by units without any institutional scheme leading to water shortages at some units whilst other boreholes are underutilized. Therefore, this study seeks to assess the groundwater potential from the boreholes against the water demands on campus towards a sustainable efficient water supply. The methodology employed involved mapping of all the campus boreholes, acquisition of available data on the boreholes, carrying out pumping tests on selected boreholes to validate their yields and water quality suitability for drinking, and administering questionnaires for water demand estimation. The study results indicate that there are 112 functional boreholes on campus; these boreholes generally have suitable drinking water quality except in few areas where the levels of colour, turbidity, pH, iron, and total coliform are outside the recommended WHO guideline values. The estimated groundwater volume that can be abstracted from the boreholes is 8.04 million l/day when pumped for 16 hours a day. This is far higher than the current estimated water demand of 4.60 million l/day and the projected future water demand of 7.95 million l/day for 2029. Thus, the existing boreholes on campus can be relied on solely for sustainable water supply for the next ten years if managed together as a system.

Keywords: Groundwater potential, potential yield, groundwater quality, water demand, water supply

INTRODUCTION

Water is the elixir of life, without which there would be no life on earth. Our everyday lives depend on the availability of clean water and safe ways to dispose of it after use. Globally, groundwater is the second most abundant and available freshwater resource in many countries of the world (Subramanya, 2008). Worldwide, more than 2 billion people depend on groundwater for their daily supply (Kemper, 2004). It constitutes about 97 % of all freshwater found on the earth, excluding frozen water in glaciers (MacDonald *et al*., 2005). It is an important source of freshwater for domestic water supply, agriculture and industry use in many regions of the world (Murthy, 2000), and it is increasingly becoming the most dependable source of water for inhabitants of both rural and urban areas in developing countries. This is as a result of its several essential advantages, including good natural quality, resistance to seasonal and perennial fluctuations, widespread and continuous availability, and less vulnerability to contamination (Todd and Mays, 2005) when compared with surface water. In Ghana, most communities have embraced groundwater resources as an important source of water supply due to their economically viable nature (Gyau-Boakye, 1999; Nsiah *et al.,* 2018). Thus, about 70 % of the Ghanaian population in most communities depend on groundwater for domestic water supplies (Tay and Kortatsi, 2008; Anim-Gyampo e*t al*., 2012).

The availability and occurrence of groundwater in every geological formation depends primarily on the geology, presence and nature of pores, and the volume and intensity of rainfall. These aforementioned factors give rise to complex hydrogeological environments with countless variations in the quantity, quality, ease of access and renewability of groundwater resources. In Ghana, the occurrence of groundwater is associated with three (3) main geological formations; these are the basement complex, the consolidated sedimentary formations (Voltaian formations) and the mesozoic and cenozoic sedimentary rocks (Dapaah-Siakwan and Gyau-Boakye, 2000). The basement complex, Voltaian formation and the mesozoic and Cenozoic sediments cover 54 %, 45 % and 1 % of the country respectively. Groundwater occurrence in the basement complex is associated with the development of secondary porosity as a result of jointing, shearing, fracturing and weathering; thus, the aquifer formation types mainly found in the basement complex are weathered-zone and fractured-zone aquifers (Kortatsi, 1994). However, three aquifer formation types are found in the mesozoic and cenozoic formations, and they are unconfined aquifers with varying depth between 2 m and 4 m, semi-confined aquifers with varying depth from 6 m to 120 m and limestone aquifers varying between 120 m and 300 m deep (Kortatsi, 1994). In the consolidated Voltaian sedimentary formations, groundwater occurs within the pore spaces and/or fractures of sandstones and weathered zones within limestone whereas in the Mesozoic and Cenozoic, groundwater is found within sands and gravels.

Generally, evaluation of groundwater potential in most communities has become necessary due to the increasing demand for sustainable water. As a result, a number of techniques have been employed by several researchers in evaluating the groundwater potential of an area; these methods include geological, geophysical, hydrogeological and geospatial techniques. Anornu *et al.* (2009) and Kumar *et al.* (2016) employed hydrogeological method in evaluating the groundwater potential of an area by estimating the yield of the borehole from pumping test results.

Groundwater quality generally varies spatially due to influence of geology and anthropogenic activities (Subramani *et al*., 2005; Babiker *et al*., 2007; Ganyaglo *et al*., 2011; Ramesh and Elango, 2012). In Ghana, the quality of groundwater is relatively good for domestic, agricultural and industrial use except in certain localities where there are high concentrations of iron and manganese, high levels of TDS around the coastal areas and the presence of low pH (3.5-6.0). Low pH waters are mostly found in the forest zones of southern Ghana (Kortatsi, 1994; Owusu *et al*., 2014). These aforementioned researchers further opined that the most serious direct health problems related to drinking water are considered to be from iodine deficiency and high concentrations of fluoride, which have been noted in the northern parts of Ghana. The key factor controlling the quality of groundwater in most of the hydrogeological terrains in Ghana is the weathering of silicate minerals and cation exchange activity (Yidana, 2010). Globally, several researchers (Kumar *et al*., 2007; Aghazadeh and Mogaddam, 2010; Nagarajan *et al*., 2010; Balakrishnan *et al*., 2011; Annapoorna and Janardhana, 2015; Madhav *et al*., 2018) have employed conventional graphical methods, various indexes, GIS and remote sensing in hydrogeological studies to assess groundwater suitability for drinking and irrigation.

This study, therefore, seeks to assess the potential of the available boreholes on KNUST campus to, sustainably, meet the current and future water supply demands of the populace. The campus is within the Kumasi metropolis and faces a huge water supply challenge due to irregular water supply from Ghana Water Company Limited (GWCL) to meet the demands of the increasing population and changing consumption patterns. As a result, many boreholes have been drilled, which are being managed individually by various units on campus leading to underutilization of some boreholes and water shortages in other units. Thus, the study envisages to provide information to aid in effective and collective management of the drilled boreholes on campus to ensure all units are sustainably provided with water.

MATERIALS AND METHODS

Study area description

The study area is Kwame Nkrumah University of Science and Technology, located within the Oforikrom Municipal Assembly. It is about 13 km to the east of Kumasi central business area and between latitudes 6° 39'30'' and 6° 42'0'' N and longitudes 1° 32'0'' and 1° 35'30''W (Fig. 1). The KNUST campus covers an area of about 18 km^2 of undulating land with River Wewe and Bibini traversing through the campus. The Bibini River is a tributary of Wewe River. It is bounded to the East by Ayeduase and Kotei, and on the south by Ahensa and Atonsu. KNUST campus has student and staff populations of 44,122 and 3,652 respectively (KNUST, 2018).

The main sources of water on campus are piped water supplied by GWCL and groundwater accessed via boreholes. The distributed piped water from GWCL at Suame flows by gravity to the university hospital, other parts of campus and the Booster Station at the KNUST Primary School. An underground storage reservoir of 4,500 m^3 capacity stores the water received from Suame at the campus booster station. The stored water is then pumped into two (2) elevated tanks each with a capacity of 2,250 m^3, which then flows by gravity to the university community. Thus, the combined gravity and pumping system distribution scheme is used to supply water to the university community. On campus, some units including KNUST basic school and the staff housing unit solely depend on GWCL for their water supply and the distribution to these units is by gravity flow from the booster station. However, some units including GUSSS hostels solely depend on boreholes for their water supply and their distribution is by gravity flow to the buildings from the water pumped into the elevated tanks at specified locations while other units including residential halls, other hostels on campus, university facilities, health centres, and restaurant and guesthouses depend on a combination of boreholes and GWCL for their water supply.

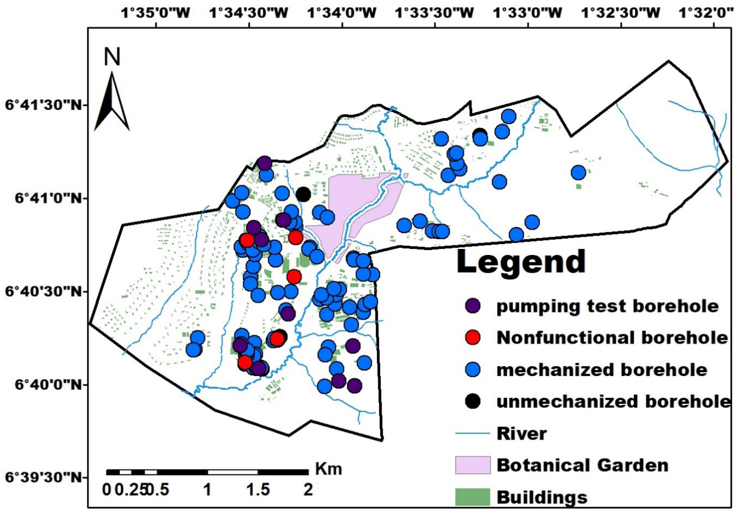

Fig. 1. KNUST campus with study borehole locations

According to the Ghana Meteorological Agency office in Kumasi, the climate of the study area is wet sub-equatorial type with two rainfall seasons. May to June and September to October accounts for the major and minor rainfall seasons, respectively. The mean monthly rainfall ranges from 15 mm in January to 214 mm in June. The average minimum temperature is about 21.5 ^{o}C and the maximum average temperature is about 30.7 ^{o}C. The evapotranspiration is between 86 mm in October and 157 mm in January while the mean annual evapotranspiration is 1412 mm. The average humidity is approximately 84.16 % and 60 % respectively at sunrise and sunset (Ghana Statistical Service, 2014).

The Kumasi metropolis is predominantly underlained by the middle Precambrian rocks, comprising the Lower Birimian (metasediments) and the Upper Birimian (metavolcanics). These Birimian rocks were formed during the eburnean orogeny between 2.25-2.02 Ga (Kesse, 1985). According to Dapaah-Siakwan and Gyau-Boakye (2000), borehole drilling success rates in the Lower and Upper Birimian systems are around 75 % and 76.5 % with average yields of 12.7 m^3/h and 7.4 m^3/h respectively. KNUST campus and its environs are predominantly underlained by the Lower Birimian rocks intruded by the basin type granitoids. The basin type granitoids found on KNUST campus are mostly rich in muscovite and biotite, and distinctly foliated. The texture and composition of these basin type granitoids range from typical granites to granitic gneisses due to the variation in the intensity of metamorphism.

Data and preliminary analyses

Secondary data on 60 campus boreholes were obtained from the Geological Engineering Department and the Groundwater Division of GWCL at Adum, Kumasi. Information obtained from the secondary data were borehole yields, static water levels (SWL) and borehole depths. A field reconnaissance survey was carried out to locate all the available boreholes on campus, which were 120 in all with 112 in use and the remaining non-functional. The exact locations of the various boreholes were mapped using the Garmin GPSmap 60CSx at an accuracy of 4 m or better.

A pumping test was carried out on ten (10) selected boreholes to validate and check the accuracy of the secondary data obtained on the borehole yields. These ten (10) boreholes were selected based on the demand priority, spatial location, accessibility and/or availability of the borehole, and for the purposes of water quality information on campus. The pumping test included a step drawdown, constant rate and recovery tests. The static water level, depth, and pump setting of each borehole was first recorded on the field prior to starting the pumping test. The step drawdown test was performed for at least four hours with equal time duration of one hour for each step. That is, a minimum of four steps were carried out at each borehole with equal time intervals for each step. A low discharge rate was used for the first step depending on the depth and water column of the borehole and was progressively increased evenly after each step. A minimum of an hour recovery was performed after every last step of the step drawdown test to have an idea of the recovery rate of the borehole, except in cases where 95 % recovery were attained before an hour. The dynamic water levels (DWL) and the recovery water levels (RWL) were respectively recorded against time during the pumping and recovery phases. Constant rate tests were carried out the next day after the step drawdown test to aid determine the optimum yield from the step drawdown test analysis. The boreholes were pumped at a constant rate for a minimum of six (6) hours until either steady state or minimal drawdown value differences were obtained. The optimal pumping rate used for each constant test was monitored every hour by checking the time it takes to fill the known volume of the bucket. The dynamic and recovery water levels were monitored and recorded against their respective times during the tests.

Also, secondary water quality data on ten (10) boreholes were obtained from Geological Engineering Department and GWCL. The validity of the water quality data were checked by calculating the Charge Balance Error (CBE) for each of the water samples using equation 1.

$$\textit{CBE (\%)} = \frac{([C]-[A])}{([C]+[A])} \times 100 \qquad (1)$$

Out of the ten, only two of the samples had their charge balance error within the acceptable limit of less than 5%. As a result, water samples were collected from the ten (10) boreholes selected for pumping tests for water quality analysis and evaluation. The water samples were collected using 1.5 litres plastic bottles after the borehole had been purged enough by pumping for a minimum of six (6) hours during the constant rate tests. The sample bottles were rinsed at least three times with the water to be sampled prior to filling the bottle to the brim. They were sealed to prevent air from entering and were labelled accordingly. The samples were then taken to the laboratory for the determination of their microbiological and physicochemical constituents. In all, water quality information from twelve (12) boreholes were used to assess the quality of groundwater on campus.

Borehole yield estimation

The available borehole yield data were plotted on the campus map in an ArcGIS environment. These included the estimated yield from the ten (10) boreholes selected for the pumping test in this study. The potential yield of each of the selected boreholes were computed using a modified Van Tonder (2000) relation, given in Equation (2), which estimates the sustainable yield of a borehole taking into consideration the boundary information, drawdown derivatives and uncertainty propagation. This relation was selected for the potential yield estimation of the boreholes as it is reliable for analyzing steady-state data. Thus, all efforts were put in place to ensure the attainment of steady-state or minimal drawdown value differences in the constant rate tests.

$$\text{Potential yield} = \text{Specific capacity} * \text{Available drawdown} \\ = \frac{Q}{S_{max}} * [(\text{Pump setting} - \text{static water level}) * 70\ \%] \quad (2)$$

In the estimation of the potential yield, 70 % of the available drawdown was factored in the computation to ensure that the pump does not get burnt and also to cater for the changes in the discharge rate measurement that normally occurs during the constant rate test as the water level declines.

The volume of water that could be abstracted from the available campus boreholes were estimated by multiplying the total potential yield, which was obtained by summing together all the yields from the 112 functional boreholes, by an acceptable pumping duration of 16 hours from the Small Town Sector Guidelines (CWSA, 2010). In summing together all the yields from the 112 functional boreholes, the known yields of each of the 60 boreholes were used whereas a minimum pumping rate of 10 l/min was assumed for the remaining 52 boreholes with unknown yields since that is the minimum rate for a successful borehole per the CWSA (2010) guidelines.

Groundwater quality analysis

Water quality tests were carried out on the groundwater samples collected from the ten (10) selected boreholes in the study area. At the laboratory, microbiological analysis was carried out first before the physicochemical analysis to prevent contamination of the sample. During the microbiological analysis, appropriate steps were taken to disinfect the mouth of the sample bottles, medium bottles, and the analysis table among others with 70 % alcohol prior to measuring the microbiological parameters. The microbiological parameters analyzed were total coliform and faecal coliform. The physicochemical parameters analysed were pH, colour, temperature, turbidity, electrical conductivity (EC), Total Dissolved Solids (TDS), total hardness, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), iron (Fe^{2+}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}), fluoride (F^{-}), sulphate (SO_4^{2-}), and nitrate (NO_3^{-}). The concentration of HCO_3^{-}, Cl^{-}, F^{-}, SO_4^{2-}, NO_3^{-}, Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, Fe^{2+} and TDS were all measured in mg/l whereas total coliform and faecal coliform were measured in cfu/ml. However, parameters including colour, turbidity, EC, temperature were measured in Hazen units, Nephelometric Turbidity unit (NTU), Microsiemens per centimeter (µS/cm), and Degree Celsius (°C) respectively.

The water quality parameters were analyzed in the laboratory in accordance with the methods given in the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF 2017) as presented in Table 1. Also, the measured physicochemical and microbiological parameters were compared to the World Health Organization (WHO, 2011) guideline values for drinking water.

Table 1: Methods used to measure the samples

Parameter	Method
Total Coliform	Plate Count Method
Faecal Coliform	Plate Count Method
pH	Ion Selective Electrode
Electrical Conductivity	Ion Selective Electrode
Total Dissolved Solids	Ion Selective Electrode
Turbidity	Colorimetric
Temperature	Ion Selective Electrode
Ca and Mg	EDTA Titration
Na, K and Fe	Spectrophotometric
Cl^- and HCO_3^-	Titrimetric
F^-, SO_4^{2-}, NO_3^-	Spectrophotometric

Estimation of water demands

In water demand estimations, it is important to know the details of actual water use and consumption patterns such as drinking, bathing, washing of clothes, cars and utensils, urine and toilet flushing, and other uses. As a result, a primary survey was conducted to obtain information on the water consumption pattern at the various units on campus using a semi-structured questionnaire. The questionnaires included questions on the populations of students, teaching and non-teaching staffs, daily water use patterns, main source(s) of water supply, and consistency of water supply at various units. The questionnaire was administered via face-to-face interviews with various respondents to reduce inaccuracies of inconclusive responses and difficulties. Some units were visited twice in order to overcome intrinsic biases that emerge from single observations and a single data collection method. Information on the population of students and staff as well as university facilities were obtained from the management of residential halls, hostels and various units on campus, and crosschecked with records at the University Registry. Also, data on the volume of water supplied by the municipal water system to KNUST campus daily was obtained from GWCL.

The water demands at the various units were estimated by multiplying the population data of students and staffs by the per capita water consumption. From the questionnaire responses, most students bath twice a day at the residential halls and hostels. Also, water use for toilet and urine flushing was assessed by measuring the flush tank capacity used at various units on campus; this ranged from 6 to 9 litres. The quantity of water used for bathing by students were ascertained by measuring the volume of buckets used by students when there was no flow from the tap as a measurement of running water from the tap was a challenging task. However, the quantities of water used for washing of clothes, cleaning, cooking, and other uses by individuals on campus were difficult to measure; hence, they were estimated using standard quantities that have been established as guidelines and through direct observation (WHO, 2003).

According to CWSA (2010) small towns sector guideline, the general design period for a water supply project in small towns shall be ten (10) years with individual components of the system having design periods of fifteen (15) years. In the future, water use and consumption patterns at the various units may be the same. Factors that may cause changes in the estimated future water demand assessment are mostly dependent on student and staff population growths on campus. Hence, the growth rate of students and staff members over the past five (5) years was computed to help in determining the estimated future water demand. The population growth rate was estimated as:

$$GR = \frac{\left(\frac{C_p - P_p}{P_p} * 100\right)}{n} \quad (3)$$

where GR is growth rate, is current population, is past population, and n is the number of years used.

In the past five (5) years, the population growth rate for the entire student populace and staff members have been 6.4 % and 1.12 % respectively whereas the population growth rate at the KNUST basic school was 0.8 %. For the future water demand estimation, the geometric increase method was used to forecast the population for the next fifteen (15) years within five (5) years intervals at the various units on campus. Due to the fast-growing nature of KNUST, a period of five (5) years was used to reflect the actual population growth rate on campus though this method usually depends on n^{th} decade. Thus, the population at the end of "n" years was estimated as:

$$P_n = Po\,(1 + r)^n \quad (4)$$

where P_n = population after n years, Po = current population, and r = population growth rate.

RESULTS AND DISCUSSION

Available groundwater on campus

In all, one hundred and twenty boreholes (120) were mapped on campus, out of which eight (8) boreholes are non-functional with the remaining 112 in use. Out of the eight (8) non-functional boreholes, four (4) were abandoned because they were dry after drilling, three (3) had faulty pumps, and the remaining one (1) borehole had problems with water quality. Figure 2 shows the variation of borehole yields within the study area.

The potential yield of the 60 boreholes with known yields ranged from 16.10 l/min to 926.17 l/min with an average of 131 l/min whereas those of the 10 boreholes selected for pumping test ranged from 25.95 l/min to 492.10 l/min with an average of 128.39 l/min. The total estimated potential yield on campus from all the 112 functional boreholes is estimated to be 8,379.7 l/min. Hence, the total available groundwater estimated from the 112 functional boreholes on campus is approximately 8.04 million l/day when pumped for 16 hours a day.

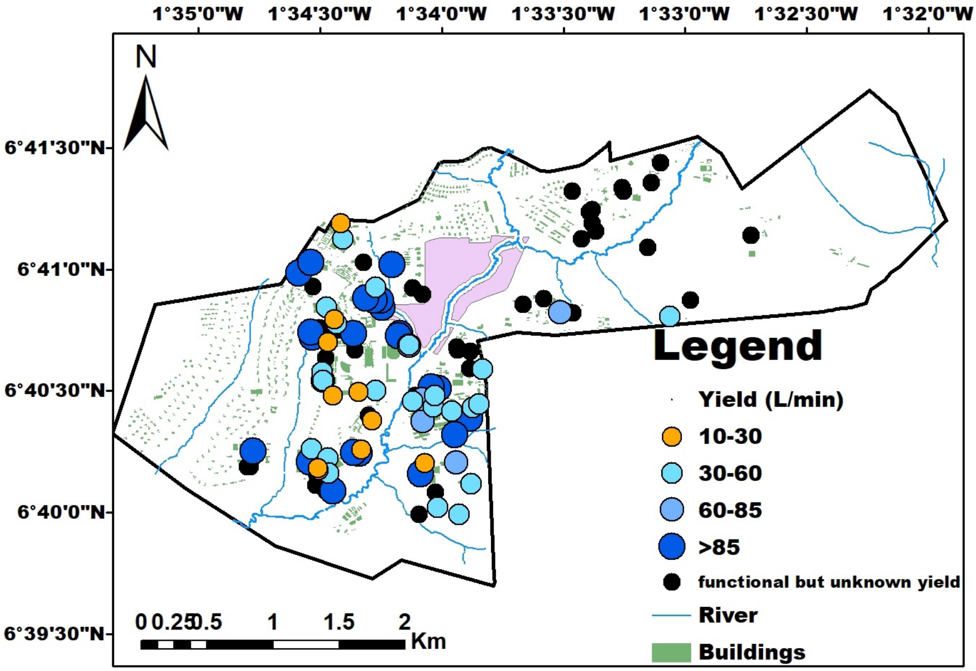

Fig. 2: Variation of borehole yields within the study area.

Groundwater quality on campus

In all, water quality information from twelve (12) boreholes were used to assess the quality of groundwater on campus. The CBE of the various samples computed ranged from 0.44 to 3.98 %, showing that the laboratory results can be used for the analysis since they fall below the desirable limit of ±5 %. The descriptive statistics of the measured water quality parameters are presented in Table 2.

Table 2: Statistical summary of the measured water quality parameters

Parameter	Min	Max	Mean	STDEV	WHO GV	% outside WHO GV
Colour	*0*	*80*	*12.67*	*27.21*	*15*	*16.67*
Turbidity	*0.01*	*77.9*	*14.33*	*27.13*	*5*	*25*
EC	36	515	103.92	131.36	1000	-
Temperature	25	28.9	25.34	1.12	-	-
TDS	18	257.5	51.96	65.68	1000	-
pH	*6.12*	*7.26*	*6.82*	*0.36*	*6.5-8.5*	*16.67*
Total hardness	7.98	169.9	58.77	50.31	500	-
Ca^{2+}	2.4	64	17.17	18.42	-	-
Mg^{2+}	0.19	7.78	3.77	2.39	-	-
Na^{+}	3.12	10.92	6.28	2.42	200	-
K^{+}	2.6	21	6.03	4.94	30	
Fe (Total)	*0*	*7.4*	*0.74*	*2.10*	*0.3*	*25*
Cl^{-}	8	28	16.08	6.29	250	-
HCO_3^{-}	8.54	131.76	53.38	45.55	-	-
NO_3^{-}	0.340	4.9	1.27	1.27	50	-
SO_4^{2-}	0	96	11.33	26.98	250	-
F^{-}	0.01	1.45	0.46	0.45	1.5	-
Faecal Coliform	0	0	0	0	0	-
Total Coliform	*0*	*66*	*5.5*	*19.05*	*0*	*8.33*

The colour of groundwater ranged from 0 to 80 TCU with an average of 12.67 TCU. Colour levels above 15 TCU are frequently unacceptable to consumers as most individuals can easily discover colour beyond 15 TCU in a glass of water (WHO, 2011). About 17 % of the samples had their colour above the permissible limit of 15 TCU; this could be attributed to the high iron concentrations in those boreholes. Turbidity values ranged from 0.01 to 77.9 NTU with an average of 14.33 NTU. About 25 % of the samples had turbidity values outside the WHO permissible limit of 5 NTU, which could be attributed to the precipitation of non-soluble reduced iron in those boreholes. The minimum, average and maximum pH values recorded on campus were 6.12, 6.82 and 7.26, respectively. About 17 % of the water samples recorded pH values outside the WHO guideline value; thus, recorded low pH, which is slightly acidic. Though a low pH value has no health implications, it gives a sour taste to water and is more likely to be corrosive. Hence, these low pH values recorded at those areas can be conditioned with lime to increase the pH of the water. The minimum and maximum iron concentrations recorded were 0 mg/l and 7.4 mg/l, respectively with a mean of 0.74 mg/l. Although there is no harmful effect on individuals consuming waters with significant amounts of iron, levels above 3 mg/l stains laundry and plumbing fixtures. About 25 %

of the samples recorded Fe concentrations outside the WHO guideline value, which can affect the taste of the water when consumed by individuals. Total coliform tests give an indication of the general level of microbiological contamination of the water. Hence, about 92 % of the water tested for total coliform is safe for human consumption with 8 % exceeding the WHO health-based guideline value, thereby posing a health threat to the consumers.

Water demand estimation

There are six (6) traditional halls of residence on KNUST campus with a total student populace of 7,735. The water use and consumption patterns at these halls included drinking, bathing, cooking, washing of clothes, brushing, urine and toilet flushing, washing of utensils, and room cleaning. An average toilet and urine use were about 2 to 3 times per day and bathing was about 1 to 2 times per day. Hence, an average of 50 *l*, 25 *l*, 20 *l*, 10 *l*, and 5 *l*/C/day water consumption was estimated for bathing, urine, and toilet flushing, washing of clothes, brushing, utensil washing and room cleaning, and drinking and cooking respectively at these halls as bathing consumed the highest amount of water used, followed by urine and toilet flushing, washing of clothes, brushing, utensil washing and room cleaning and, cooking and drinking. Therefore, a total average estimate of 110 *l*/C/day water consumption was used; hence a demand of 850,850 l/day is required. There are 247 workers managing and/or working at these halls of residence whose water use includes drinking, waste disposal, cleaning of floors and washrooms. With an average estimate of 20 *l*/C/day of water consumption allocated for these workers, the water demand amounts to 4,940 l/day. Hence, the total estimated water demand for the six halls of residence was 855,790 l/day.

The other hostels on campus include GUSSS (Chancellor's Hall, Nana Afia Kobi Serwaa Ampem II Hall, Otumfuo Opoku Ware II Hall, Otumfuo Osei Agyemang Prempeh II Hall), Tek Credit, GRASAG, Spring, RTEP, Steven Paris, Shaba, SRC, Wilkado, Crystal Rose, Georgia, KNUST Ghana Hostels Limited (Gaza and Suncity), Banivillas, Anglican, and Catholic. Their water use and consumption patterns from the questionnaire responses were similar to that of the halls of residence; hence an average estimate of 110 *l* and 20 *l*/C/day water consumption was used, respectively, for students and workers in these hostels. The total population of students and workers in these hostels were 7,658 and 274, respectively; thus, the total estimated water demand for these hostels was 847,860 l/day.

There are six (6) colleges on KNUST campus with a total student, teaching and non-teaching staff population of 44122, 976 and 981, respectively. The water use and consumption patterns by students and teaching staff from the questionnaire responses were solely for urine and toilet flushing whereas that of the non-teaching staff included cleaning of lavatories, cleaning of various classrooms, offices, libraries and laboratories, drinking, sanitation and waste disposal, toilet and urine flushing. The average toilet and urine use by students and teaching staff was about 1 to 2 times a day. Hence, with an average of 15 *l* and 30 *l*/C/day water consumption estimated for students and teaching staffs, and non-teaching staffs respectively, the water demand for the six (6) colleges was 705,900 l/day. However, with respect to the laboratories in some of the colleges, 25 % of the water demand at the colleges (176,475 l/day) was estimated as the water demand for the laboratories. Hence, the total estimated water demand for the six (6) colleges was 882,375 l/day.

The estimated water demand at the university facilities was 182,161 l/day with its breakdown presented in Table 3. The water use from the questionnaire responses included cleaning of lavatories, urine and toilet flushing, watering of grasses, cleaning of office floors, drinking, washing of vehicles, swimming, and animal feeding and cleaning. The average toilet and urine use by staff at these units were about 1 to 2 times per day. At Paa Joe sports complex, daily water demand equals 41,346 l/day as the water used for watering Paa Joe, the full-size pitch (Maa Joe) and the Hockey field was factored.

Table 3: Estimated water demand at the various university facilities

Various Units	Staffs	Cleaners	Staff Daily Consumption (l/C/day)	Cleaner Daily Consumption (l/C/day)	Total (l/day)	
Units at Commercial Area	631	40	15	20	10,265	
Units on main campus	358	39	15	20	6,150	
Other administrative units	100	20	15	20	1,900	
Sub-total I	*1,089*	*99*			*18,315*	
	Total Capacity	Daily average number of cars washed	Daily average no of animals fed	Daily average no of individuals accessing the unit	Consumption (l/C/day)	Total (l/day)
Great hall	2,000			500	10	5,000
Paa Joe				300	10	41,346*
Library				1,200	10	12,000
Transport		50			120	6,000
Jubilee mall				500	10	5,000
Commercial area offices				300	10	3,000
Religious Centres						1,000
Animal farm						50,000
Swimming pool						40,000
KNUST Museum				50	10	500
					Sub-total II	*163,846*
					Overall Total	**182,161**

The estimated water demand at the residential units was 325,200 l/day with its details shown in Table 4. The water use from the questionnaire responses included drinking, bathing, cooking, washing of clothes, brushing, urine and toilet flushing, washing of utensils, room cleaning, watering gardens and growing food, and washing of vehicles. As a result, an average of 90 *l*/C/day water consumption was estimated for junior staff members, and 120 *l*/C/day water consumption for both senior staff and senior members.

Table 4: Estimated water demand at staff residential units

Housing unit	Total number	Average No of Occupants	Daily Consumption (*l*/C/day)	Total (l/day)
Junior staff	212	5	90	95,400
Senior staff	108	5	120	64,800
Senior members	275	5	120	165,000
Total	**595**			**325,200**

The estimated water demand at the health facilities was 39,020 l/day. The water use by hospital staff members included drinking, laundry services, cleaning of lavatories, wards, offices and floors, watering of lawns, urine and toilet flushing, sanitation and waste disposal, and emergency cases. Out-patients use water for washing of hands, and urine and toilet flushing while water usage by in-patients included bathing, washing of clothes, hand washing, and toilet and urine flushing. As a result, an average of 60 *l*, 10 *l* and 100 *l*/C/day water consumption was estimated for staff members, out-patients and in-patients respectively. Responses from the questionnaires indicated that the average number of staffs on duty in a day were 562 with 400 out-patients and 13 in-patients accessing the unit in a day.

The estimated water demand for restaurants, guesthouses and other eating centres on campus was 154,719 l/day. From the questionnaire responses, the water use by staff included drinking, cooking, washing of utensils, sanitation and waste disposal, cleaning, watering of lawns, urine and toilet flushing, and laundry services. Also, the patrons used water for bathing, urine and toilet flushing and food consumption at the guesthouses and restaurants. Hence, an average of 75 *l*, 65 *l* and 10 *l*/C/day water consumption was estimated for staff members, individuals that patronize guesthouses daily and the average number of people that patronize food daily at the restaurants. However, there are other eating centres on campus that use water for washing of utensils, cooking, drinking, and food waste disposal. These eating and/or drinking centres are mostly found at the halls and hostels of residence, the various six (6) colleges, and KNUST Basic School. Hence, an assumed 5 % of the daily water demand at these aforementioned units were estimated to account for the daily water demand at these other eating centres.

The estimated water demand at the KNUST basic school was 45,360 l/day. From the questionnaire responses, the entire student, teaching-staff and non-teaching staff was 2727, 189 and 54 respectively. The water use by both students and teachers included hand washing and toilet/urine flushing whereas that of the non-teaching staffs included drinking, sanitation and waste disposal, watering of lawns, urine and toilet flushing, and cleaning of lavatories and various offices. As a result, an average of 15 *l* and 30 *l*/C/day water consumption was estimated for both students and teachers, and non-teaching staffs respectively.

Physical losses are bound to occur during distribution as some of the pipes get burst and, also, due to the old nature of the distribution pipes. In addition, water wastages at various units are bound to occur as some students and individuals may leave tap and/or showers running for hours. According to CWSA small towns sector guideline, physical losses accounts for 10-15 % of the sub-total water demand (CWSA, 2010). Using 15 % for physical losses, the total water wastages and leakages was 499,873 l/day.

Thus, the total average daily demand equals the sub-total demand and physical losses which amounted to 3,832,358 l/day. However, for the purposes of sustainable water supply, daily variations are bound to happen as people will use more water during certain hours of the days. Hence, to cater for the daily variations, the average daily demand on campus was multiplied by a daily peak factor of 1.2 from the Small Town Sector Guidelines (CWSA, 2010) to get the maximum (peak) daily demand on campus. Therefore, the maximum daily demand of water on KNUST campus was estimated to be 4,598,830 l/day (4,598.83 m^3/day). Applying a population growth rate of 6.4 % for the entire student populace, 1.12 % for staff members on campus and 0.8 % growth rate at the KNUST Basic school, the projected maximum daily water demand on KNUST campus for the next five (5), ten (10) and fifteen (15) years were 6.03 million l/day, 7.95 million l/day and 10.53 million l/day respectively. The summary of the estimated current and future water demand projections are presented in Table 5.

Table 5: Estimated water demand across KNUST campus

Various Units	Current water demand (l/day)	Future water demand (l/day)		
	Academic years			
	2018/2019	**2023/2024**	**2028/2029**	**2033/2034**
Student residential halls	855,790	1,165,500	1,587,760	2,163,490
Residential hostels on campus	847,860	1,154,519	1,572,604	2,142,630
Colleges	882,375	1,186,386	1,599,990	2,162,985
University Facilities	182,161	228,624	272,263	321,105
Staff Housing Unit	325,200	343,823	363,514	384,332
Health facility	39,020	42,890	47,520	53,280
Restaurant and Guesthouses, and other eating centres	154,719	201,495	265,038	351,336
KNUST Basic School	45,360	47,205	49,110	51,120
Sub-total	3,332,485	4,370,442	5,757,799	7,630,278
Physical losses	499,873	655,566	863,670	1,144,542
Average daily demand	3,832,358	5,026,008	6,621,469	8,774,820
Maximum Daily Demand	**4,598,830**	**6,031,210**	**7,945,763**	**10,529,784**

CONCLUSIONS

This study has estimated the available groundwater on campus from the potential yield of the 112 functional boreholes and its potential to meet current and future water demands. The suitability of groundwater for drinking has also been assessed by comparing the measured physicochemical and microbiological parameters of the groundwater samples with the World Health Organization (WHO) guideline values for drinking water.

The study results show that the 112 functional boreholes have a total potential yield of 8,379.7 l/min and produce a total estimated volume of 8.04 million l/day when pumped for 16 hours in a day. Also, the quality of groundwater from the boreholes is good for drinking except in some isolated cases where boreholes had quality issues with respect to colour, turbidity, pH, iron, and total coliform. The current estimated maximum water demand on campus is 4.60 million l/day and the projected maximum water demand for the next ten (10) years is 7.95 million l/day.

Therefore, the study has demonstrated that the estimated available groundwater from the campus boreholes generally has the potential to sustainably meet the water demands of the students and staffs currently, and at least, up to the next ten (10) years. Hence, the campus boreholes can be solely relied on to supply water sustainably to the various units for the next ten years when utilized as a system.

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