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Full Length Research Paper

Evaluation of groundwater resources potential in the Ejisu-Juaben district of Ghana

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The increasing stress on freshwater resources due to ever-rising demands and profligate uses as well as growing population of Ejisu-Juaben District is an issue of great concern. The purpose of this study is to make a quantitative estimate of the available groundwater resources in the Ejisu-Juaben district for efficient utilization and management of groundwater resources. The methodology involved the collection and analysis of existing well data and chloride mass balance. The results indicate that the aquifers are composite and composed of weathered regolith of low permeability and high storage and overlying fissured bedrock of high permeability and low storage. Semi unconfined aquifers prevail in major portions, which constitute the principal source of groundwater. The depths of boreholes in the District range from 17 - 75 m with an average of 51 m. Generally Ejisu-Juaben district has low groundwater potential with mean yield, transmissivity and specific yield values of 2.8 m^3/h, 12.5 m^2/d and 0.95 m^3/h/m respectively. Recharge in the district is estimated as 7 - 9% of the average annual rainfall of 1874 mm. The permanent water reserve of 326,064,375 m^3 and recoverable water reserve of 130,425,750 m^3 for the aquifer of the basement complex aquifer were estimated from the records of 97 boreholes.

Key words: Groundwater assessment, water quality, recharge, water management, water resources.

INTRODUCTION

Modern developments and population growth have increased demands for water resources globally. Thus the welfare of every society is tied to the sustainable exploitation of water resources (Bear, 2000). Groundwater continues to serve as a reliable source of water supply to most rural communities in Ghana. Although groundwater is a renewable resource, its availability and use are influenced by many factors such as the lithology of the area, climatic patterns and water quality. Due to these climatic changes, computations based on historical data are sometimes erroneous, therefore, the margin of variation should be factored in and abstraction should be less than recharge by this estimated margin.

The largely unseen nature of groundwater has resulted in development initiatives which are unaware of the hydrodynamic limits of the resource and unable to regulate the resulting patterns of abstraction. There is the need for efficient management and utilization of groundwater resources on a sustainable basis to meet the future challenges. As with other renewable resources, demand can exceed supply and therefore some form of control or management of the resource should be in place, to ensure long term access by users. Management does not imply that users are guaranteed to have access to unlimited quantities of the resources at all times, but rather that under normal circumstance, users will be assured of a specified minimum quantity at all times. The Ejisu-Juaben district located in a region of varied rainfall conditions and periods of extreme climatic conditions do occur; and there may be times when even these minimum standards of supply cannot be met. Due to these climatic changes, computations based on historical data are sometimes erroneous, therefore, the margin of variation should be factored in and abstraction should be less than recharge by this estimated margin.

For the past 20years, Ejisu-Juaben district has been without pipe borne water supply. Until 1984, Ghana Water

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Company limited (GWCL) was supplying water to some selected areas of the district with water from its head works at Barikese a suburb of Kumasi. Currently, the district relies mainly on groundwater for its water supply needs. Therefore the proper management of this resource is a matter of great concern and the most effective and economic means to sustain water supply in the district is through the protection and sustainable management of water resources in the district.

There are a number of governmental departments and non-governmental organizations (NGOs) engaged in the exploitation of groundwater and the supply of potable drinking water for the rural communities in Ghana. During the last 17 years, a large number of boreholes and hand dug wells have been constructed in the rural communities across the country. Available records show that about 130 boreholes and 300 hand dug wells exist in the Ejisu-Juaben District. Unfortunately, all the borehole and well construction projects were implemented without due attention to the source and amount of replenishment of groundwater in the aquifers being tapped and this has resulted in reduction in yield culminating in long queues and water quality deterioration (Acheampong and Hesse, 2000). The population of the district is rapidly increasing and it is expected that, new industries will be established as a result of the proposed inland port project at Boankra in the Ejisu-Juaben District, will lead to further population growth. This development will certainly increase stress on groundwater due to the increase in water demand for various purposes like domestic, industrial and agricultural. There is the tendency of over-exploitation of groundwater resources in the near future, which may have serious repercussions on the environment. This therefore calls for the assessment of water resource for planning and optimal utilization. The main objective of this paper is to provide information on the potential of groundwater resources and perspective planning necessary for a rational use of the resource in the district.

The study area

Ejisu-Juaben District lies within longitude 6.42 to 6.83°N and latitude 1.58 to 1.25°W covering an area of about 637.4 km^2. The annual rainfall ranges between 1092 and 2344 mm with a mean annual value of about 1874 mm. The mean maximum monthly temperature of about 32°C occurs in February/March and the mean minimum monthly temperature of about 20°C in December/January (Dickson and Benneh, 1988). The average monthly temperature in the district is approximately 26°C. The relative humidity averages at 85% during the rainy season and 65% during the dry season. The economy of the district is predominantly agrarian in nature like in most rural communities in Ghana. According to the District's Five-Year Development Plan (2000 - 2005), agriculture constitutes 58.55% of the districts Gross Domestic Product (GDP). The main food crops grown are plantain, cassava, maize and cocoyam. One of the major cash crops grown include cocoa, is the driving force of the economy. Oil palm is also another cash crop that is widely grown in the district. The industrial sector is characterized by wood processing and small-scale agro processing industries and accounts for 17.58% of the labour force.

Geology

The Project area is predominantly underlain by crystalline rocks. These rocks belong to the Birimian, Granites formation (Kesse, 1985). Figure 1 shows the geological map of the project area.

The Birimian formation

The Birimian formation commonly occurs in the north-western corner of the region and a smaller portion in the south. It has two main divisions, the lower and upper Birimian series, with the lower Birimian series dominating. The lower Birimian is mainly of politic origin. It consists of great thicknesses of intercalation of shales, phyllites, greywacke and argillaceous beds with some tuffs and lavas. Slates and phyllites have been commonly altered to quartz-biotite schist close to granite intrusion. They are usually highly folded and fractured with subparallel intrusions of quartz veins in the rocks. Their water yielding potential is high due to the intense fracturing and quartz veins imposing secondary permeability to the rocks.

The upper Birimian overlies the lower Birimian conformably and is volcanic in origin. The series consist of great thicknesses of basaltic andesitic lavas, beds of agglomerate, tuff and tuffaceous sediments. The basic volcanics and pyroclastics have been altered largely to chloritised and epidotised rocks that are loosely grouped together as greenstones. Where the greenstones have been subjected to dynamothermal metamorphism, they have converted to hornblende schists and amphibolites. The upper Birimian rocks are usually fractured and sheared presenting mylonitic textures in places. Due to the intrusive relationship with granitoids, they are usually strewn with quartz veins. The water-bearing and yielding capacity is high due to the faults, fractures and quartz veins.

Granites and basic intrusive

The Birimian formation is greatly intruded by large masses of granites and basic intrusive of uncertain age but probably of post-Birimian and Pre-Tarkwaian age. They are two types, Cape Coast and Winneba granites and Dixcove granites.

The Cape Coast and Winneba types are often well foliated, as well as magmatic and are potassium-rich, which come in the form of muscovite-biotite granite and

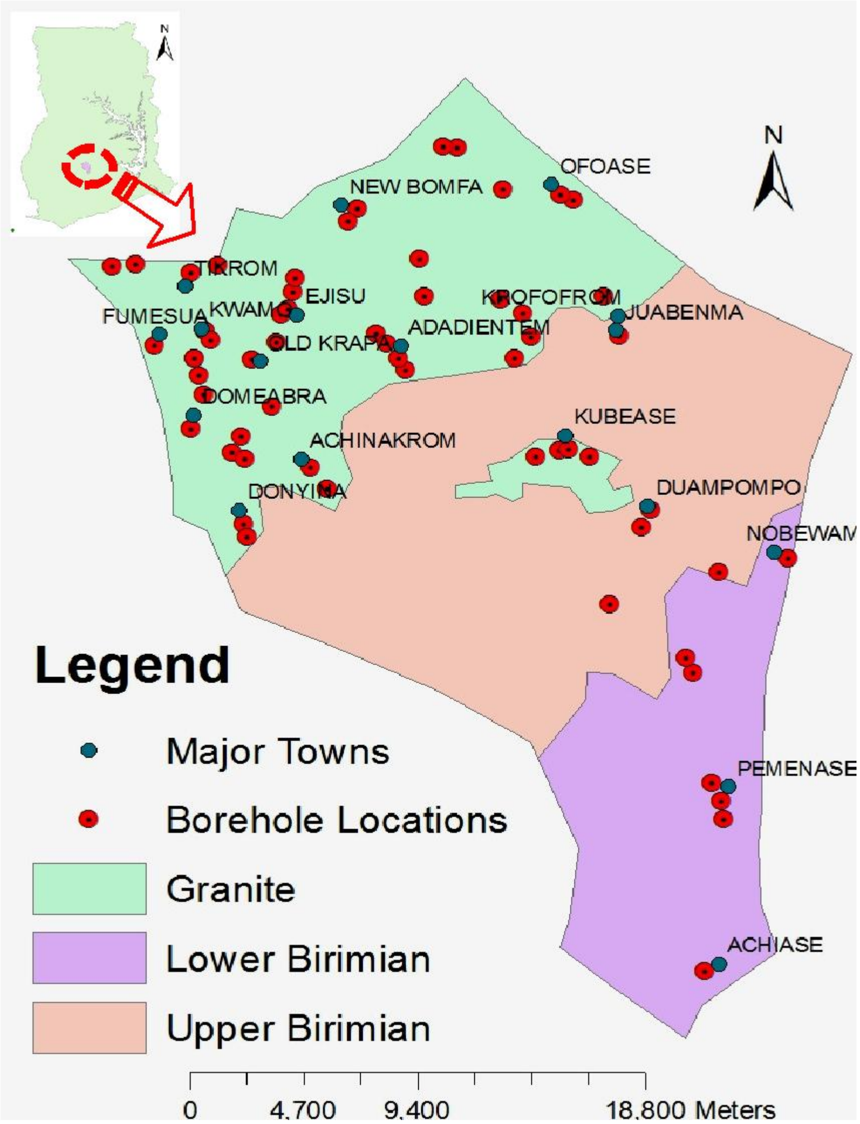

Figure 1. Geological map of the study area showing borehole locations.

granodiorites, porphyroclastic biotite gneiss, aplites and pegmatites. The Dixcove type consists of hornblende granites, granites and granodiorites grading locally into quartz-diorites and hornblende-diorite. The Dixcove granite complex is intruded along deep-seated faults in three distinct phases which follow one another from basic to acid gabbro-diorite-granites.

MATERIALS AND METHODOLOGY

The methodology includes collection and analysis of existing borehole data, total chloride data (chloride in precipitation and dry fall out) collection, analysis and determination of chloride concentration from the saturated zone (groundwater). Thirty rainwater samples were collected from 5 rain gauges and 200 groundwater samples collected from boreholes between 2003 and 2005. Additionally, ten 0.3 m based, 0.1 deep plastic containers were placed on selected roof tops for dry fallout collection. All the samples were taken to the laboratory for Cl^- determination using standard methods (APHA, 1998).

Recharge estimation

Estimating the rate of aquifer replenishment is probably the most difficult of all measures in the evaluation of groundwater resources. Hence two methods of estimation (the chloride balance and the water balance equations) were used.

Chloride balance equation

The measured Cl^- concentration from rainwater, dry fall out and groundwater in addition to the median values of 36 years rainfall data for the area obtained from the Ghana Meteorological Agency were used in chloride mass balance method (Equation 1) for the estimation of recharge.

$$GWR = \frac{PT_P + D}{T_R} \quad 1$$

Where; GWR = recharge (mm); P = precipitation (mm); T_R = groundwater tracer concentration (mg/1); T_P = precipitation tracer concentration (mg/1); D = dry fall out.

This method however is based on the following assumptions:

a) That there is a steady input of the tracer at the surface.
b) That the water and tracer are transported at the same rate.
c) That there is no input of the tracer from rook minerals or anthropogenic sources.
d) Since the study area is remote from the sea and covered with thick vegetation, dry fallout is very significant compared with the precipitation flux and thus cannot be neglected.

Water balance equation

Assuming the surface water divide coincides with the groundwater divide in the watershed and there is no external inflow or outflow of groundwater, then the water balance equation would be given by the expression in equation 2 (Freeze and Cherry, 1979).

$$P=R+E+D+ \ S_S + \ S_G \quad 2$$

Where; P = Precipitation; R = Runoff; E = Evapotranspiration; D = Annual average recharge/ discharge; ΔSs = Change in surface water storage; ΔS_G = Change in groundwater storage (both saturated and unsaturated).

Averaging over several years, $S_S \approx \ S_G \approx 0$. Equation (2) then becomes:

$$P=R+E+D \quad 3$$

Making D the subject of the formula, equation (3) becomes

$$D=P-R-E \quad 4$$

Hydrometeorological data analysis

Hydrometeorological data, such as rainfall, temperature and evapotranspiration between 1968 and 2003, for the study area were used in the analysis.

Total and recoverable groundwater storage

The total groundwater storage in an area can be determined using Equation 5 (Schoeller, 1967).

$$Q_T = \alpha\theta HA \quad 5$$

The recoverable or usable storage capacity is the amount of groundwater that can be economically withdrawn from a basin as a source of long term annual supply. It was typically computed using Equation 6.

$$Q_R = \alpha\gamma HA \quad 6$$

Where; Q_t = total groundwater storage, m^3; Q_r = recoverable groundwater storage; α = percentage of study area underlain by groundwater zone; γ = specific yield; θ = porosity, H = mean thickness of the saturated zone, m; A = hydrogeological basin extent of the study area, m^2

RESULTS AND DISCUSSIONS

Hydrogeological parameters

The distribution of the boreholes in these formations is shown in the Figure 1. Available records show that about 130 boreholes exist in the study area. Out of these, 55% were drilled in the granites, 34% in the Lower Birimian and 11% in the Upper Birimian. The subsurface lithologic profiles at 63 sites over the study area are depicted in Figure 2. Although the rock types are different, they are all crystalline in nature and behave similarly under weathering and groundwater conditions. Thus the lithologies consist of lateritic clay with silty clay layers (aquitards) of thickness ranging from 1 - 27 m are present in the granites and Lower Birimian extending from South-eastern through eastern to the Northern part of the study area. Weathered and/or fractured granite, schist, tuff and phyllite are present beneath these aquitards, which are underlain by the second aquitard (that is, fresh bed rock). Thus, groundwater in this area exists under confined conditions which are justified by the fact that water levels in the boreholes rise several meters above the levels at which water was struck (Table 1). Transmissivity values calculated from the well pumping test results (Table 1) in the study area, which vary between 0.12 and 41.25 m^2/day, which confirms the conditions stated above.

Transmissivity expressed in m^2/s defined confine aquifers when the values are within the orders of x 10^{-3} and x 10^{-5} (Driscol, 1986). The depth to the confined aquifers increases towards the eastern boundary (i.e. from north-western part of the district) and its thickness varies between 5-18m. At the western part of the study area, however, the clay layers were missing which suggest a possible recharge area for these confined aquifers. This area is characterized by a densely tropical forest.

At the southern to South-western parts of the district around the vicinity of Achiase, gravel and sandy clay were found to be dominating and clay layer (aquitard) is missing. Such subsurface conditions suggest that unconfined aquifer is present in this area. The saturated thickness of the unconfined aquifer ranges from 7 - 26 m in this region.

The yield of a well is an important hydrogeological parameter which can be used with other factors to determine the groundwater recharge potential of an area. From Table 2 the Lower Birimian rocks have the highest yielding wells ranging from 10 to 180 l/min this is followed by the granites which have discharges ranging from 10 to 150 l/min, whereas the minimum and maximum productive wells in the Upper Birimian are 12 and 90 l/min

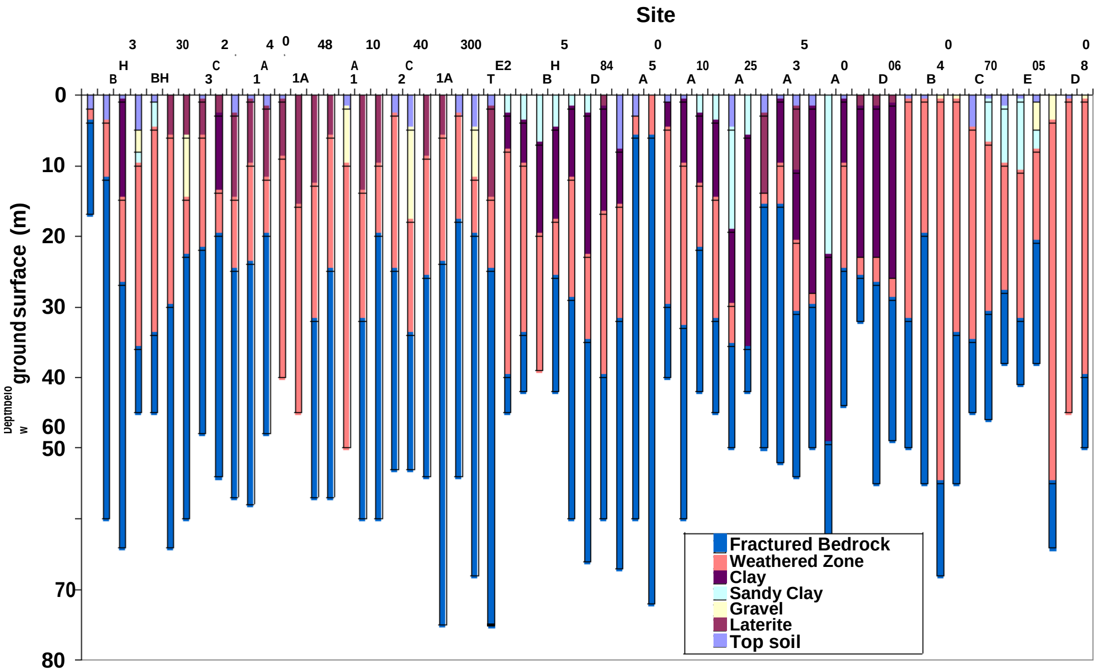

Figure 2. Geologic profile of the study area at 63 sites.

Table 1. Summary of transmissivity values and static water levels in the study area.

Formation	No. of boreholes(analysed)	Static water level (m)		Transmissivity (m^2/day)	
		Range	Mean	Range	Mean
Granites	35	1.0 - 22	12.56	0.12 - 27.58	10.86
Lower Birimian	22	2.01 - 21.57	10.27	0.73 - 41.25	11.97
Upper Birimian	7	3.04 - 25.4	12.8	1.2 - 41.9	14.70

Table 2. Summary of borehole depths and yields in the study area.

Formation	No. of boreholes(analysed)	Depth (m)		Borehole yield (l/min)	
		Range	Mean	Range	Mean
Granites	35	17-75	53.2	10 - 150	46.99
Lower Birimian	22	40-68	53.3	10 - 180	52.61
Upper Birimian	7	35- 60	47.9	12-90	40.4

respectively.

From Figures 3a and 3b, it was found that there were poor correlations between yield and depth of the boreholes in the Upper and Lower Birimian. Further more it was observed in the relationship between depth and yield with regards to boreholes in the granites was poor (Figure 3c). This is consistent with the fact that both the Birimian and Granites are crystalline and behave similarly under weathering and groundwater conditions. Table 3 shows a summary of the parameters of the various formation of the basement complex of the Ejisu- Juaben District.

Permanent and recoverable groundwater reserves

The total and recoverable quantities of the groundwater storage in the district basin were determined from the borehole data. Measurements of average values of the levels from ground surface to well water surface (Static water level) and from well water surface to weathering front were taken from boreholes in the district (Table 3). The presence of groundwater zone at a sample site is regarded as a success (if yield is greater than 9 l/min) and a failure (unsuccessful) based on the drilled boreholes. Borehole parameters, such as unsaturated thick-

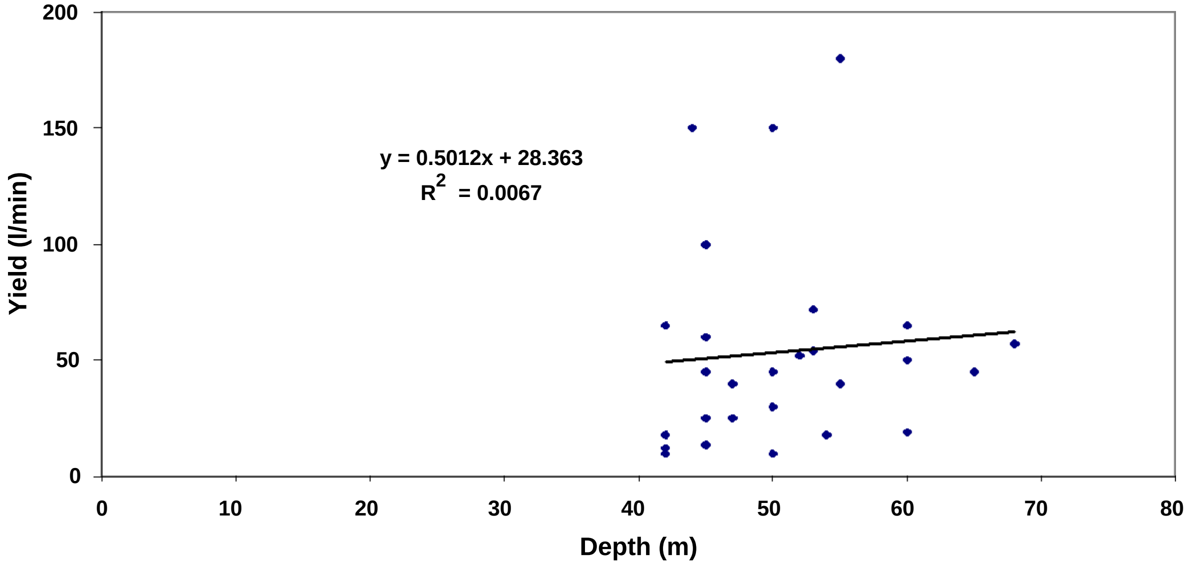

Figure 3a. Variation of well yield with depth in the Upper Birimian.

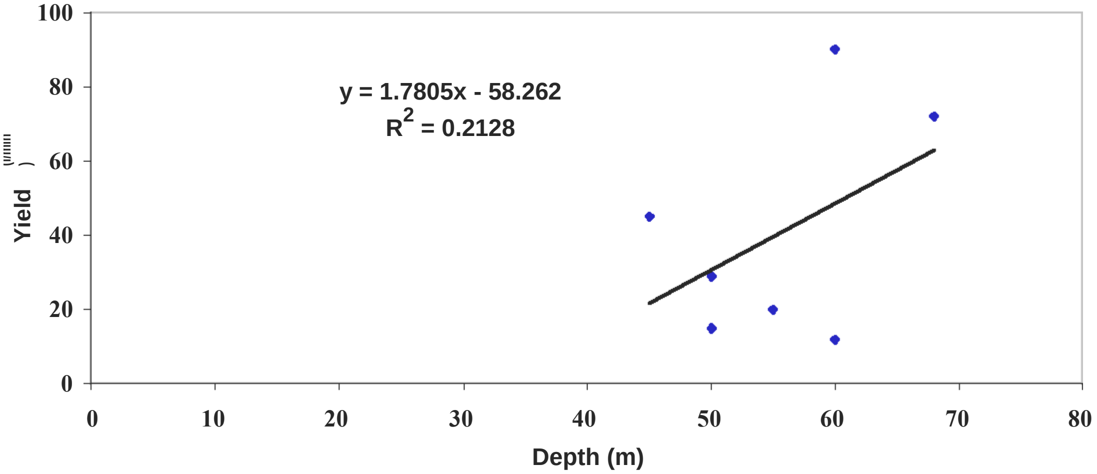

Figure 3b. Variation of well yield with depth in the Lower Birimian.

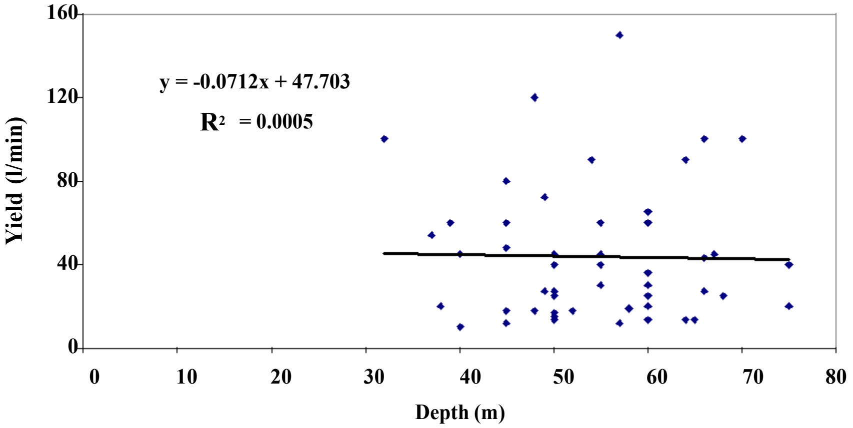

Figure 3c. Variation of well yield with depth in the Granite

Table 3. Borehole data in the weathered zone of the Basement Complex of Ejisu-Juaben district.

Parameter/ formation	Granite	Upper Birimian	Lower Birimian	Mean
Average depth total weathering front, D (m)	27.5	35.55	38.38	33.8
Average depth to water level surface, h (m)	17.92	22.06	20.51	20.16
Average saturated zone of weathering, H = D - h (m)	9.58	13.49	17.87	13.65
Total number of boreholes drilled, T	63	21	46	130
Number of successful boreholes, S	44	16	37	97
Number of unsuccessful boreholes, U	19	5	9	33
Probability of having groundwater zone, α = S/T	0.69	0.76	0.80	0.75

ness and saturated thickness of the weathered zone were determined from the borehole logs of the district.

Adopting the relative-frequency definition of probability, the probability that a randomly selected site in the study area is underlain by groundwater zone was computed by dividing the number of borehole sample sites underlain by saturated zone by the total number of borehole sample sites (Owolabi and Adegoke-Anony, 1988). Using the values for porosity and specific yield to be 5 and 2% respectively (Asomaning, 1993; Ogunkoya, 1987) and information from borehole logs in the study area (Table 3), the values of the permanent reserves Q_t and the recoverable quantity of the groundwater storage Q_r were determined.

The mean values of permanent reserves Q_t and the recoverable quantity of the groundwater storage Q_r were obtained to be approximately 326 064 38 x 10^3 and 130 425 75 x 10^3 m^3 respectively. The latter value representting the magnitude of groundwater reserve in the basin regolith of the district is that which can be abstracted by wells, becomes baseflow component of stream flow and seep out or flow out as spring where the local topography is favourable.

Recharge rate

Evaluation of groundwater recharge has significant implications for not only the study of groundwater quantity, but also the quality. Groundwater recharge using this method was estimated as follows. The mean chloride concentration value precipitation (T_P) (Table 4) was found to be 2.62 mg/l and that of groundwater (T_R) from data collected on boreholes in the district was found to be 29.76 mg/l.

Hence equation (1) has reduced to:

$$GWR = 0.088P \quad 7$$

A long term (1968 - 2003) mean annual precipitation of 1874 mm in the area was used in the calculation. The result from the chloride balance method using equation (7) shows that the groundwater recharge rate in the area is about 165 mm/year. This is about 8.8% of the long term mean annual rainfall. Using the simplified water balance equation method (Equation 3), with mean annual evapotranspiration value (1968 - 2003) of approximately 1406 mm and mean annual runoff (1968 - 2003) of 599 mm, the direct mean annual recharge for the area was computed to be 131 mm, which is approximately 7.0% of the mean annual precipitation. This shows a close agreement between the results of the two methods.

Finding from a similar study by Asumaning (1993) using the Base Flow Discharge Methods in the same geological formation gave an output of 172 mm/year which gives about 9.2% of the long term mean annual rainfall is in agreement with these results. Therefore areas with similar characteristics in terms of hydrogeo-logical formation and similar climatic conditions may give similar results regardless of methods used.

The evapotranspiration data obtained from District Meteorological Services Authority is a measure of water loss from the surface of the soil through evaporation and transpiration. Relating the mean monthly evapotranspiration and rainfall for the 35 years period (Figure 4), indicates that, there are some months when rainfall exceeds water loss. These months mainly, April, May, June, July, September and October are expected to be the months, during which groundwater recharge takes place.

Water quality

The summary statistics of the physico-chemical and bacteriological constituents and parameters of groundwater within the steady area presented in Table 4.

The water quality standard adopted for this project is WHO (2004) guidelines limits. The results from water quality analysis shows that the values for most of the parameters and constituents analysed were within WHO (2004) guidelines limits for drinking water. However, about 20% of the wells had iron values above the acceptable limit of 0.3 mg/l and approximately 4% had manganese values above the acceptable limit of 0.5 mg/l. The groundwater sources in the district can be said to be quite aggressive and may corrode reactive metal fixtures as water from over 58% of the wells sampled in the district had pH values below the 7.0 pH units. Genera the results of bacteriological parameters (*E. coli*; faecal and

Table 4. Statistics summary of physico-chemical and bacteriological constitutes and parameters in groundwater in the

Parameter	Minimum	Maximum	Mean	Median	Standard deviation	WHO (2004) guideline
Temp (°C)	23.90	29.30	26.32	26.30	0.81	
pH (pH units)	4.11	7.90	6.66	6.55	0.52	6.5-8.5
Eh (mV)	221.00	511.00	360.22	377.00	80.04	
DO	0.10	4.40	0.75	0.10	1.17	
Conductivity (µS/cm)	39.00	649.00	175.71	146.30	104.74	
Ca	0.49	78.36	13.14	7.63	14.67	200
Mg	0.55	35.49	5.05	3.98	4.62	150
Na	2.20	31.80	13.66	13.80	6.03	200
K	0.10	10.72	1.24	0.58	1.70	30
HCO_3	0.09	258.00	82.21	68.15	61.05	
SO_4	0.09	198.00	4.10	0.48	23.93	250
Cl	2.00	43.00	8.13	6.01	6.83	250
NO_3-N	0.19	17.60	1.39	0.19	2.63	10
Si	3.55	39.40	20.23	20.49	9.78	
F	0.24	0.47	0.30	0.10	0.06	1.5
Mn	0.19	0.92	0.26	0.24	0.01	0.5 0(P)
Fe	0.02	4.18	0.34	0.28	0.47	0.30
DOC	0.58	7.41	2.98	2.91	1.69	
E. coli (count/100ml)	0.00	0.00	0.00	0.00	0.00	0
Faecal Coliform (count/100 ml)	0.00	0.00	0.00	0.00	0.00	0
Total Coliform (count/100 ml)	0.00	4.00	1.00	0.00	0.20	0

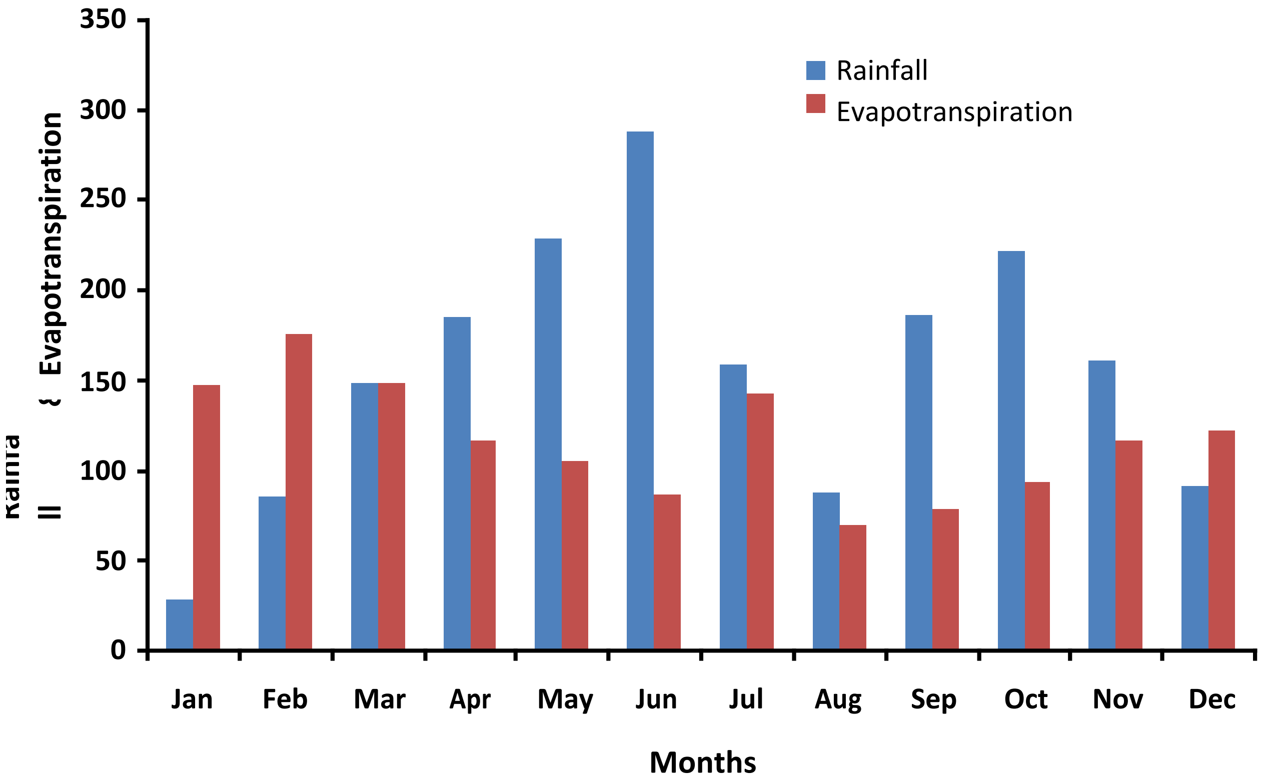

Figure 4. Mean monthly variation of rainfall with evapotranspiration from 1968 - 2003.

total coliform) analyses of groundwater in the district indicate satisfactory water quality thus the groundwater is bacteriologically safe for human consumption.

Conclusion

Recharge is mainly by direct infiltration of rainwater through out-crops of the crystalline rocks that have underlain the district. The annual groundwater recharge rate in the District estimated from the chloride balance and the water balance equations have been found to be 165 mm/year and 131 mm/year respectively. This value is approximately 45.6 x 10^6 m^3/year and it is about 7 - 9% of the long terms mean annual precipitation of 1874 mm taking climate change variability into consideration. The total permanent groundwater storage and recoverable groundwater storage of the district were found to be approximately 326.1 x 10^6 m^3 and 130.4 x 10^6 m^3 respec-tively. The quality of groundwater in the district is generally good as most of the physico-chemical parameters analysed fell within the WHO (2004) guideline limits for drinking water. However, there are localities where iron and manganese may pose water quality problem. It is envisaged that the utilization of adequate exploitation methods and development techniques will be employed to achieve optimum yield.

Recommendations

Although groundwater resources of the district are currently adequate, traditional methods for water conservation practices like rainwater harvesting, may be necessary in order to curtail any unexpected water demand as a result of population increase or industrialization

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