Energy and Environment Research; Vol. 4, No. 3;2014
ISSN 1927-0569 E-ISSN 1927-0577
Published by Canadian Center of Science and Education

Groundwater Resources Assessment in Tain River Basin of the Black Volta of West Africa

D. F. Dramani[1], G. K. Anornu[1], A. T. Kabo-bah[2] & S. Oduro-Kwarteng[1]

[1] Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, PMB, Kumasi, Ghana

[2] Department of Energy and Environmental Engineering, University of Energy and Natural Resources, Box 214, Sunyani, Ghana

Correspondence: G.K. Anornu, Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, PMB, Kumasi, Ghana. E-mail: anoprof@hotmail.com

Received: October 13, 2014 Accepted: October 20, 2014 Online Published: October 29, 2014

doi:10.5539/eer.v4n3p96 URL: http://dx.doi.org/10.5539/eer.v4n3p96

Abstract

The Black Volta basin is one of the most important basins in West Africa that provides support for water supply, irrigation, hydropower and recreation for the communities within this basin. The Tain River basin is a sub-basin within the Black Volta. Most communities within this basin depend on groundwater resources as their main source of water supply. However, the over-growing dependence and limited assessment of the availability of groundwater resources in quality and quantity in the basin have become a worrying factor towards the sustainable management of the resources. The study therefore assessed the quality and quantity of groundwater resources in the Tain River Basin and showed that the total permanent groundwater reserve is estimated as 6.89 x 10^7 m^3 while the total recoverable groundwater as 2.59 x 10^7 m^3. The total recoverable groundwater forms 38 % of the total permanent groundwater reserve and this is the water available for abstraction and recharging of streams and springs. Both the quality and quantity of groundwater in the basin were found to be adequate according to national standards and World Health Organisation guideline values.

Keywords: quality and quantity assessment, transmissivity, specific water level, specific capacity, borehole depth

1. Introduction

Water is an essential natural resource that sustains the life of man and all living things on earth. It is central to many human activities such as industrial, domestic, animal watering, hydropower generation, transport services, tourism and recreation. There is increasing competition globally on the scarce water resources, especially surface water due to rapid population growth, urbanization and technological advancement. Current global climate change processes are expected to affect both the spatial and temporal available water resources (Arnell*et al*., 2011; Oki & Kanae, 2006; Reddad *et al*., 2013; Walther *et al*., 2002). In 2004, WHO estimated that 1.1billion people lacked access to improved water sources and about 3,900 children under the age of 5 years died from water related diseases (World Health Organisation, 2004). The lack of access to potable water negatively impacts health, girl-child right to education in developing countries, and availability of water for agriculture. These collectively affect a country's urge to meet the Millennium Development Goals (MDGs) (Bakker, 2007; World Water Council, 2006).

According to the Ghana Water Policy (Ministry of Water Resources, 2007), improving water services and uses are essential for improving and increasing hygiene and sanitation services levels that affect productive lives of people, enhance enrolment and retention of girls in school, enhance women's dignity and ability to lead, reduce morbidity and mortality, reduce pre and post-natal women's risks and prevent vector and water borne diseases. In view of the concerns raised and the rate at which surface water is under threat, the only alternative source is groundwater. However, good estimation of groundwater resources of the basins in Ghana have not been carefully conducted and documented. For instance, in the Tain basin of the Black Volta, access to clean and potable water is a challenge. This is because most inhabitants depend on water supply from nearby unprotected streams and unreliable hand-dug wells constructed by individuals.

Over the years, groundwater development has been taken as the only alternative source of water to supplement the erratic surface water supply in the sub-basin. However, most of the boreholes are either dry or low yielding over time making it difficult for some communities to have easy access to potable water. Information gathered from Wenchi Municipal Water and Sanitation Agency located in the basin indicates that out of the 27 boreholes drilled in communities in 2012, eighteen (18) were successful and nine (9) were dry. Even those which were productive (successful), seven were low yielding ranging between 7 *l*/min. This is below the marginal yield of 13 *l*/min for development as stated by Community Water and Sanitation Agency (Ofori-Agyemang*etal*., 2008). This might be connected to the lack of basic information on possible groundwater potential zones and the complex nature of the subsurface geology of the area prior to the drilling exercise. There is no baseline study into groundwater resources in the River Tain basin of the Black Volta. Therefore this study examined and investigated into the groundwater resources potential in the Tain basin of the Black Volta in terms of success rate and recoverable groundwater storage. It provides a baseline for the available and current status of the groundwater resources in the basin.

2. Study Area, Materials and Methods

2.1 Study Area

River Tain basin of the Black Volta is located to the north-western part of BrongAhafo Region of Ghana within latitude 7°15′ N and 8°40′ N, and longitude 1°45′ W and 2°34′ W (See Figure 1). The basin covers four (4) administrative districts and four (4) municipalities in the region. These are Jaman North, Tain, Banda and Jaman South Districts, and Wenchi, Techiman, Sunyani and Brekum Municipalities. River Tain takes its source from the Republic of Cote d'Ivoire where it flows eastwards into Ghana through Jaman North and Jaman South, Brekum, Sunyani, and forms a boundary between Tain District and Wenchi Municipality. The river changes direction from the boundary towards the north and passes through Banda district and finally joins the Black Volta downstream of the Bui dam. The ground level elevation of the sub-basin ranges from 240 to 300 m above sea level with some few areas either undulating or rugged. Tain sub-basin of Black Volta lies in the Wet Semi-Equatorial climate region, which experiences bi-modal rainfall regime.

The major rainy season occurs between April and July with peak rainfall in June while the minor rainy season occurs between September and November, with its peak occurring in October. There is a short dry spell in August with the major one occurring between November and March. The mean annual rainfall is 1300 mm. The pattern of rainfall in the sub-basin follows the Inter-Tropical Convergence Zone (ITCZ) that shows distinction between the dry air from Sahara Desert and the moist monsoon wind from the Atlantic Ocean. The North-East trade wind, locally called the Harmattan brings in hot dry weather from December to February. The total mean evapotranspiration value for the sub-basin during the same period is 599.5 mm (Kortatsi, 1997). The mean monthly temperature is about 26 °C while average monthly humidity is 78 %.

The vegetation of the basin spans the moist-semi-deciduous forest and the Guinea Savanna woodland zones. The Guinea Savanna woodland represents an eco-climatic zone which has evolved in response to climatic and edaphic limiting factors and has been modified substantially through human activities. The original forest vegetation has been subjected to degradation, caused mainly by anthropogenic activities which include indiscriminate bush fires, slash and burn agriculture, logging and felling of trees for fuel over the years.

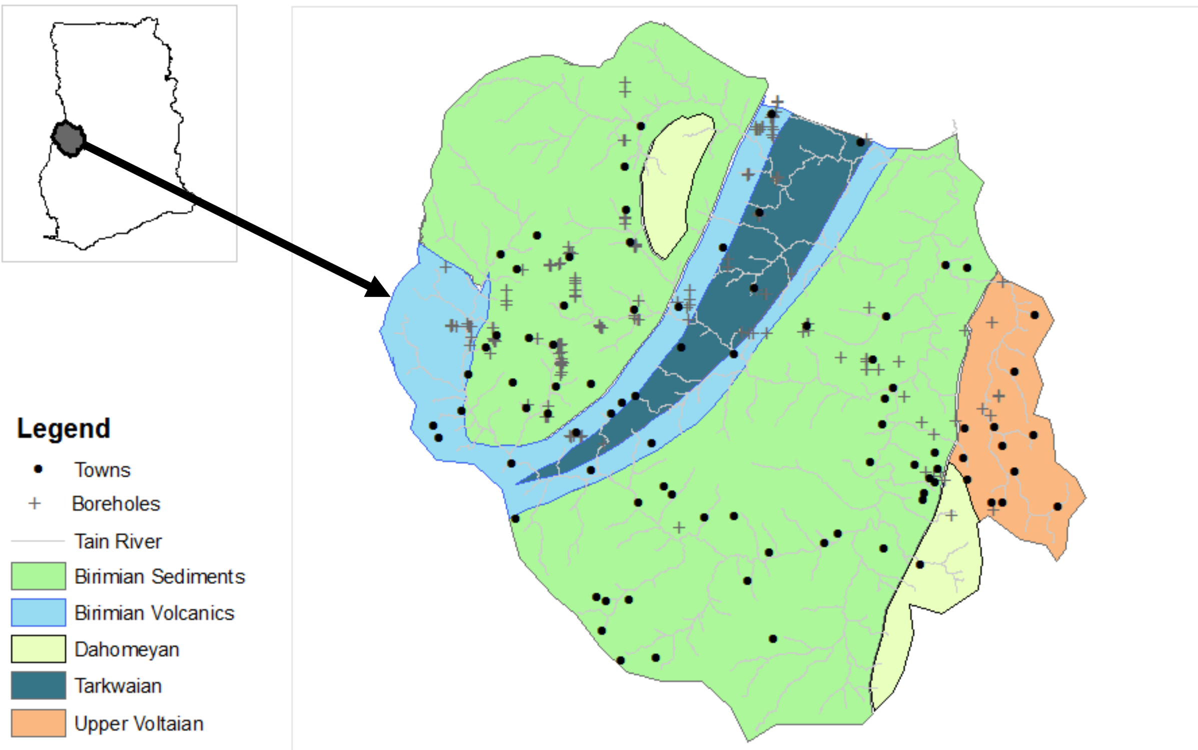


Figure 1. River Tain basin of the Black Volta showing borehole locations

2.2 Method

Geophysical data of boreholes and hydrological reports were used to identify local lineaments, the possible presence of aquifers, static water level, borehole logs, borehole yield, aquifer depth, thickness of the overburden and the aquifer zones pertaining to the basin. The study was also conducted by selecting specific communities in the sub-basin to locate all boreholes (wet and dry). The fundamental borehole parameters such as well depths, yield, static water level (SWL), dynamic water level (DWL) and geological logs were collated and analysed. The specific capacity was computed using the approach from Fetter (2001):

$$S_c = Q / s \tag{1}$$

Where

S_c = specific capacity (l/min/m);

Q = discharge in (l/mm);

s = Drawdown (m) = Dynamic water level (DWL) – Static water level (SWL);

Fifty eight (58) boreholes were selected based on the geological formations within the basin and their pumping test data analysed. For each borehole selected, a displacement-time graph was drawn and the widely used Cooper and Jacob's method employed to determine aquifer transmissivity (T) (Meier *et el.,*1998; Sánchez-Vila *et el.,* 1999).The aquifer transmissivity was then computed with.

$$T = \frac{2.303Q}{4\pi\Delta s} \tag{2}$$

Where;

T = Transmissivity;

Q = Discharge

Δs = Drawdown per log cycle

The water quality of the boreholes was assessed for their physicochemical parameters by evaluating thirty-two (32) boreholes. The distribution of the selection of the boreholes was done carefully to ensure that spatially each geological zone was represented. There were nine (9) in the Brimian Sedimentary, seven (7) in the Birimian volcanic, six (6) in the Upper Voltain, seven (7) in the Dahomeyan and three (3) in the Tarkwain formation zone. Relevant parameters for groundwater assessment were evaluated. These included calcium (Ca), Iron (Fe), Nitrate (NO_3^-), Magnesium (Mg), Sodium (Na), Flouride and pH.To ascertain the approximate total groundwater storage within the sub-basin, the approach used is as below (Asomaning, 1992; Schoeller, 1967):

$$Q_s = \omega\theta HA \tag{3}$$

Where

Q_s = Total groundwater storage;

ω = Percentage of study area underlain by groundwater zone;

ɵ = Porosity;

H = Mean thickness of the saturated zone;

A = Area of the hydrogeological basin.

The recoverable or usable storage capacity was also estimated to determine the amount of groundwater resource that could be withdrawn from a basin annually. The method used (Schoeller, 1967) is as below.

$$Q_r = \omega\beta HA \tag{4}$$

Where

Q_r = Recoverable groundwater storage;

ω = Percentage of study area underlain by groundwater zone;

β = Specific yield

H = Mean thickness of the saturated zone;

A = Area of the hydrogeological basin

Groundwater accessibility was assessed using 300 people per borehole threshold and a minimum yield of 13 l/min according to the Community Water and Sanitation Agency (CWSA) standard. The estimated 2012 population for the various communities were obtained from the Ghana Statistical Agency.

3. Results and Discussion

3.1 Aquifer Baseline Characteristic

The research conducted has shown that, the depths to aquifer in the sub-basin vary between 13-52 m with a mean value of 30.5 m as illustrated in Figure 2(a). Birimian Sedimentary which covers about 66.4 % of the sub-basin has depth to aquifer ranging from 16-43 m with a mean value of 27 m while Birimian Volcanic, Upper Voltaian and Tarkwaian formations, the depth to Aquifer varies from 22-52 m, 19-43 m and 25-35 m respectively. The deepest depth to aquifer values occurs in the areas where the regolith is thickest such as Botenso, Nchiraa, Seketia and Akete. The aquifer materials encountered in the Birimian Sedimentary include laterite with quartz veins, deep brown clay, and dry fine clay at a depth of between 0-55 m with high to moderately weathered black shale between the depths of 55-70 m. In the Upper Voltaian sandstone, fine-textured dry sand with clay was encountered at the depth of 0-55 m with highly weathered moist sandstone struck at the depth between 55-70 m. The data analyzed indicates that boreholes in the five geological formations ended in shale, sandstone or phyllite geological units. Groundwater occurrence in the basin depends mainly on secondary porosity through weathering, fracturing and fissuring. Fractured aquifers were encountered at Adadiem, Arkokrom, Abekwai, WalaNkwanta and Amoakokrom. In the Birimian sedimentary and volcanic formations, fissure zones were encountered underneath the thick regolith at KwabenaSuo, Kogua, Tadeakwae and Abekwai.

The aquifer transmissivity values for the Birimian sedimentary range between 1.32 and 25.61 m^2/day while in the Birimian volcanic, Upper voltaian and Tarkwaian formations, transmissivity values range between 1.019 and 16.6 m^2/day, 3.14 and 40.58 m^2/day and 1.54 and 20.34 m^2/day respectively. Table 1 summarises some borehole parameters considered in the study.

Figure 2(b) shows the specific water levels of the Tain river basin. The static water levels generally vary based on the type of the geological formation. The study indicates that Birimian volcanic recorded the deepest mean static water level of 26.1 m while the Tarkwain, Birimiansedimetary and Upper voltaian recorded the mean values of 16.4, 14.4 and 15.3 m respectively. Data on the Dahomeyan formation was not available for analysis during the study period. The shallowest static water level of 1.4 m occurred at GedengeNewsite in the

Birimianvolcanic with the deepest of 40.1 m occurred at Okyerekrom in the Birimian sedimentary formation.

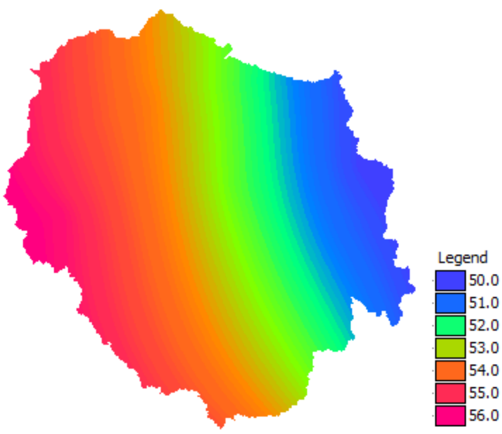
From Figure 2(c), the research revealed that Birimian sedimentary has a specific capacity range of 0.37-7.23 *l*/min/m with a mean value of 2.44 *l*/min/m while the specific capacities of the Tarkwaian, Birimian volcanic and Upper voltaian range from 1.89-2.33, 0.8-1.57 and 0.61-22.82 *l*/min/m respectively for a period of six (6) hour pumping and three (3) hour recovery periods. The low value of specific capacity in the sub-basin indicates that transmissivity in the various geological formations are generally low. However, the low values may be the effect of losses in the wells, geological boundaries and partial penetration of the aquifers by the boreholes.

Figure 2(d) shows that the borehole yield is between 20 *l*/min and 113 *l*/min. However, it can be deduced that Upper voltaian recorded the highest average yield of 26.7 *l*/min followed by Birimian sedimentary with a mean value of 26.6 *l*/min while Birimian volcanic and Tarkwaian formations recorded mean values of 15 and 16 *l*/min respectively. The values suggest that most of the boreholes in the sub-basin are low yielding and this is very characteristic of sedimentary formations. It is however important to note that most of the boreholes were drilled purposely for rural water supply and therefore drilling was completed anytime yield was adequate to meet rural demands and this may justify the reason for low yielding wells. Since the purpose of the drilling was geared towards the meeting of rural water supply, the optimum yielding capacities were not attained for each borehole. This explains why the Birimian Sedimentary and Upper Voltaian have different mean transmissivities but similar yield.

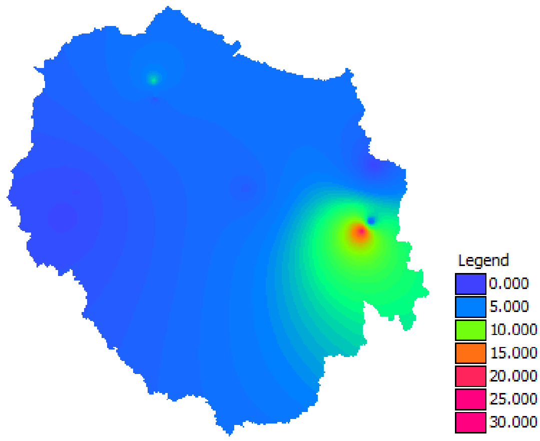
Table 1. Summary of boreholes parameters in the river Tain basin

Geological formation	No. of Borehole	Depth (m)		Yield (l/min)		SWL(m)		Transmissivity (m^2/day)	
		range	mean	range	mean	range	mean	range	mean
Birimian Sedimentary	25	30-75	48.9	7-113	26.6	4.8-24.7	14.4	1.3-25.6	0.63
Birimian Volcanic	16	39-69	45.8	9-21	15	12.6-38.2	26.1	1.02-16.6	10.44
Dahomeyan*	2	40-70	55	*	*	*	*	*	*
Tarkwaian	6	40-56	47.2	12-20	16	4.9-27.8	16.4	1.5-20.3	7.29
Upper Voltaian	11	30-60	49.3	12-55	26.7	2.4-34.2	15.3	3.1-40.6	20.15

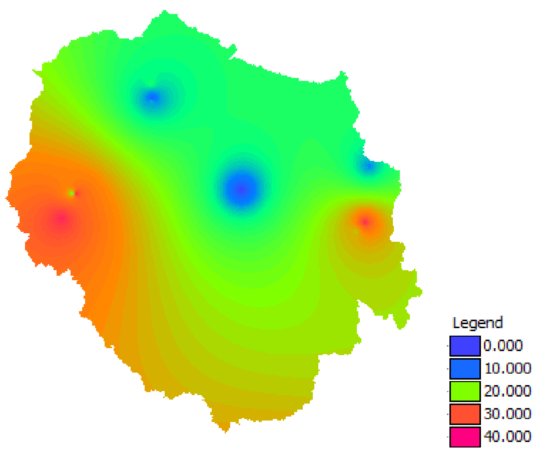
*pumping test has not been performed on the boreholes due to inaccessibility.



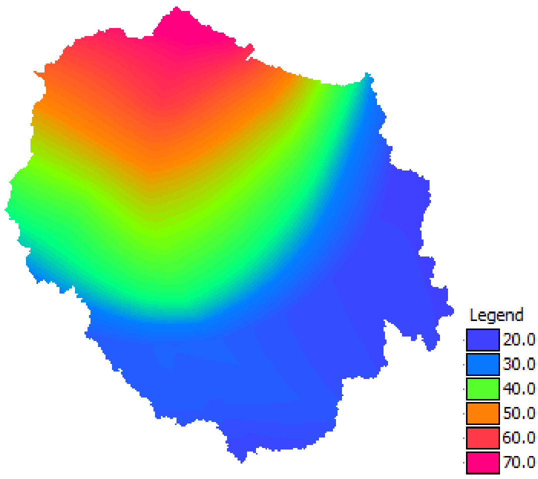
A) Borehole depths (m)



c) Specific Capacity (l/min/m)



b) Static Water level (m)



d) Borehole Yield (*l*/min)

Figure 2. Spatial borehole yield, static water level, borehole depths and specific capacity

The borehole success rate in the various geological formations in the river Tain basin of the Black Volta is shown in Figure 3. It could be taken as the groundwater potential of the individual geological units which form the basin. Based on this, the Tarkwaian formation which records 94 % success rate is the richest in terms of groundwater in the study area. Birimian volcanic is next with about 89 % success rate and Birimian sedimentary which forms the largest formation in the sub-basin records about 70 % success rate. Most of the high yielding boreholes are found in the Birimian sedimentary, hence making it quite complex to conclude that it contains low yielding aquifers. Upper voltaian which is composed mainly of sandstone has a success rate of about 70 % and Dahomeyan formation recorded the highest failure rate of 50 %. This is due to the fact that Dahomeyan formation has impervious weathered zone and massive crystalline structure with limited fractured zones which limit its groundwater yielding capacity.

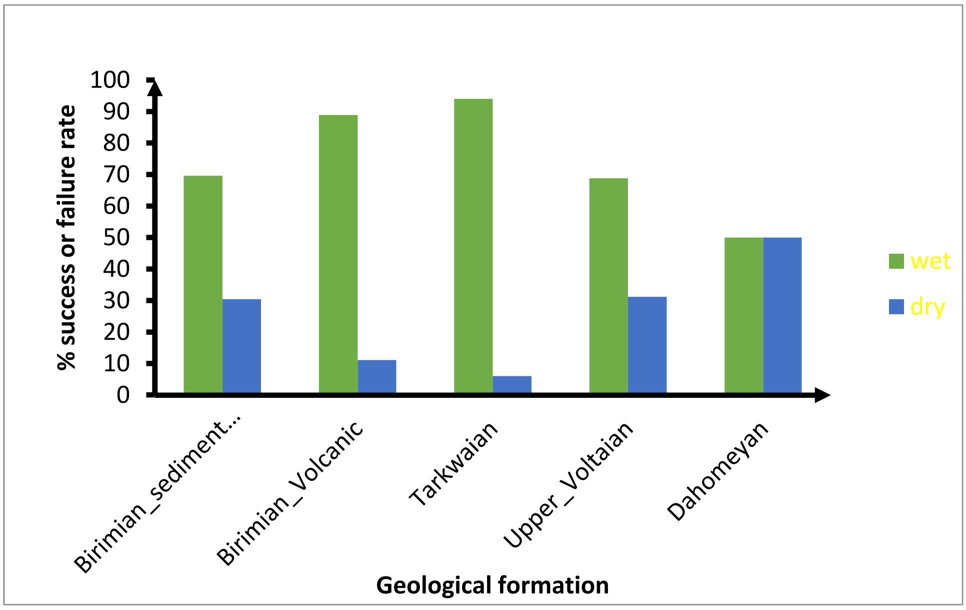


Figure 3. Borehole success and failure rate in the river Tain basin

Evaluation of the relationship between the borehole depth and yield was conducted but the study revealed no strong correlation ($R^2 < 0.2$). Therefore, there is no empirical relationship between yield and borehole depth and this can be attributed to early completion of drilling when yield is enough for water supply. The total permanent groundwater reserve was estimated at 6.89 x 10^7 m^3 whiles the total recoverable groundwater as 2.59 x 10^7 m^3 which is about 38 % of the total permanent groundwater reserve and this is the water for abstraction, recharging of streams and springs. The permanent groundwater reserves and recoverable groundwater storage for the various geological formations is summarized as in Table 2.

Table 2. Total and recoverable groundwater reserves in the five geological formations

Geological formation	**Area covered (km^2)**	**Mean Specific capacity (m^3/min/m)**	**Percentage of saturated zone in the formation**	**Mean Saturated Thickness (m)**	**Total groundwater reserves (m^3)**	**Total recoverable groundwater reserves (m^3)**	**Percentage of recoverable groundwater as the total groundwater vol. (m^3)**
Birimian Sedimentary	3865	2.44	75.9	17.32	5.08 x 10^7	1.2 x 10^7	23.6
Birimian Volcanic	731.9	1.3	88.2	15.71	1.01 x 10^7	1.3 x 10^6	12.9
Upper Voltaian	217.2	3.62	68.8	18.42	2.7 x 10^6	9.96 x 10^5	36.9
Dahomeyan	342.4	**	**	**	**	**	**
Tarkwaian	667.1	2.14	66.7	14.75	6.56 x 10^6	1.40 x 10^6	21.3

**pumping test has not been performed on the boreholes due to inaccessibility.

Available data from sampled boreholes in the river Tain basin indicates that the quality of groundwater abstracted through boreholes is generally of good physicochemical quality and therefore suitable for domestic uses including drinking, agriculture and industrial purposes. The groundwater quality of the Tain basin is within the WHO guidelines limits (WHO, 2004; WHO, 2011). Table 3 presents the various water quality parameters that were measured.

Table 3. Water quality ranges in the various geological formations in the sub-basin

Parameter	Unit	Geological formation/Quality range				WHO Standard
		UV	BS	BV	TAR	
Calcium	ppm	12-28	21-108	4-14	9.6	-
Magnesium	ppm	1.5-8.5	2.7-12.2	8.5-9.6	3.9	-
Sodium	ppm	4.0-23	5.0-30	10-17	3.0	300
Nitrate	ppm	0.2-12	0.3-3.0	0.4-7.0	0.3	50
Iron	ppm	0.01-0.2	0.003-0.15	0.003-0.01	0.03	0.3
Nitrite	ppm	0.001-0.9	0.003-0.14	0.01-0.3	0.14	3.0
Sulphate	ppm	0.0-15.0	0.5-20.0	0.5-9.0	0.0	250
Manganese	ppm	0.0-0.5	0.0-0.001	0.0-0.1	0.00	-
Potassium	ppm	2.0-13.0	0.0-5.0	0.0-6.5	1.0	30

UV= Upper Voltaian, BS=Birimian Sedimentary, BV= Birimian Volcanic, TAR= Tarkwaian.

WHO recommended pH value for domestic drinking water is in the range of 6.5-8.5. Water sampled from the boreholes in the river Tain sub-basin indicates that their pH values fall within the recommended WHO value except a borehole at Wurumpo which has a value of 6.4. It falls within the Upper Voltaian formation.

3.2 Bacteriological Quality Analysis

The results from the test indicated that out of 17 boreholes sampled in the sub-basin, 7 samples contain coliforms levels above the WHO recommended limit of 0.0 MPN Index/100 ml. The boreholes were located at Birimian Sedimentary, Shale and Sandstone formations.

3.3 Groundwater Accessibility

The study revealed that quality of groundwater abstracted through boreholes is generally of good physicochemical quality and therefore suitable for domestic including drinking, agriculture and industrial uses. However, based on the CWSA standard, majority of the population has no access to groundwater. A population of 2496 at Amponsahkrom depend on one (1) borehole instead of eight (8) with average yield of 10 *l*/min. Geological formations such as Birimian Sedimentary and Birimian Volcanic had the required number of boreholes based on their population threshold but still face water crisis due to frequent breakdown and drying of boreholes. Sixty percent of the communities have less than the required number of boreholes based on the CWSA threshold of 300 persons per a borehole, 16 % exceeded their threshold whiles 24 % have the exact number of boreholes based on their population.

4. Conclusion

Groundwater resources assessment is an important requirement for efficiently managing the quality and quantity of water resources in a basin. The study assessed the quality and quantity of groundwater resources in the river Tain basin of the Black Volta in West Africa. The study showed that the borehole yield in the basin does not depend on the depth. This is because boreholes with depth range between 20 and 30 m at Ampieni, Agubie, Kenasi, Abotereye and Ohiampeanika gave average yield of 40 *l*/min while boreholes with depth range between 50 and 80m at Adadiem, Kodua and Damaabi gave an average yield of 8 *l*/min.

The aquifers in the sub-basin are low yielding because average aquifer yield is 32 *l*/min with a range between 7 and 113 *l*/min and it varies from one geological zone to another. The geological formation with the best yield is the Tarkwaian formation with a success rate of 94% while Dahomeyan formation recorded highest failure rate of 50%. About 60 % of the communities did not have the recommended WHO standard of 300 persons per borehole leading to perennial water problems in such communities. Groundwater quality in the sub-basin falls within the WHO (2004) recommended limits for domestic water use, except for 30 % of the sampled communities. It is envisaged that findings in this study would support decision making in the integrated water resources management in the Black Volta.

Acknowledgments

We are most grateful to the critical review from Mary Magdalene Tanguo, an office assistant at the GEONETCast Centre of the University of Energy and Natural Resources-Sunyani-Ghana; and all anonymous reviewers for their time and commitment.

References

Arnell, N. W., van Vuuren, D. P., & Isaac, M. (2011). The implications of climate policy for the impacts of climate change on global water resources. *Global Environmental Change, 21*(2), 592–603. http://dx.doi.org/10.1016/j.gloenvcha.2011.01.015

Asomaning, G. (1992). Groundwater resources of the Birim basin in Ghana. *Journal of African Earth Sciences (and the Middle East), 15*(3), 375–384. http://dx.doi.org/10.1016/0899-5362(92)90022-5

Bakker, K. (2007). The "Commons" Versus the "Commodity": Alter-globalization, Anti-privatization and the Human Right to Water in the Global South. Antipode. http://dx.doi.org/10.1111/j.1467-8330.2007.00534.x

Fetter, C. W. (2001). Applied hydrogeology (Vol. 3). Prentice Hall Upper Saddle River, NJ.

Kortatsi, B. (1997). Ghana Water Resources Management study. Information Building Block.

Meier, P. M., Carrera, J., & Sánchez-Vila, X. (1998). An evaluation of Jacob's method for the interpretation of pumping tests in heterogeneous formations. *Water Resources Research, 34*(5), 1011–1025. http://dx.doi.org/10.1029/98WR00008

Ministry of Water Resources, W. and H. (2007). Ghana Water Policy.

Ofori-Agyeman, M. C., Kpordze C. S. K., & Anornu, G. K. (2008). *Viability of marginal yield boreholes in selected geological formations in Ghana*. Proceedings 33rd WEDC International Conference, Accra, Ghana, April, 2008.

Oki, T., & Kanae, S. (2006). Global hydrological cycles and world water resources. *Science, 313*(5790), 1068-1072. http://dx.doi.org/10.1126/science.1128845

Reddad, H., Etabaai, I., Rhoujjati, A., Taieb, M., Thevenon, F., & Damnati, B. (2013). Fire activity in North West Africa during the last 30,000 cal years BP inferred from a charcoal record from Lake Ifrah (Middle atlas--Morocco): climatic implications. *Journal of African Earth Sciences.* http://dx.doi.org/10.1016/j.jafrearsci.2013.03.007

Sánchez-Vila, X., Meier, P. M., & Carrera, J. (1999). Pumping tests in heterogeneous aquifers: An analytical study of what can be obtained from their interpretation using Jacob's method. *Water Resources Research, 35*(4), 943–952. http://dx.doi.org/10.1029/1999WR900007

Schoeller. (1967). Quantitative evaluation of groundwater resources. Methods and Techniques of Groundwater Investigation and Dev. *Water Reso, 33*, 21–44.

Walther, G. R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C., … Bairlein, F. (2002). Ecological responses to recent climate change. *Nature, 416*(6879), 389–395. http://dx.doi.org/10.1038/416389a

WHO (2011). *Guidelines for drinking-water quality* (4th ed.). World Health Organization. Retrieved from http://whqlibdoc.who.int/publications/2011/9789241548151_eng.pdf

World Health Organisation. (2004). Water, sanitation and hygiene links to health. Retrieved from http://www.who.int/water_sanitation_health/publications/facts2004/en/

World Water Council. (2006). The right to water, from concept to implementation (p. 8:405).

Copyrights