Groundwater in sub-Saharan Africa: Implications for food security and livelihoods

Ghana Country Status on Groundwater

Final Report

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1 INTRODUCTION

1.1 Background

Freshwater constitutes less than 3 % of the world's water resources but it is one of the world's most important natural resources and an indispensable part of all terrestrial ecosystems. It is a necessary input for many sectors of the global economy. In many world regions, particularly in developing regions like Africa, availability and access to freshwater largely determines patterns of economic growth and social development (Odada, 2006). Freshwater resources are pivotal to key economic and social activities such as water supply and sanitation, agriculture, industry, urban development, hydropower generation, inland fisheries, transportation and recreation among others. These activities provide employment and generate revenue that sustains many economies of the world. Besides its economic value, freshwater plays an important role in addressing issues of health, poverty and hunger and has been rightly recognized in the formulation of the United Nations' millennium development goals.

Africa as a continent has an immense supply of rainfall, with an average annual of 744 mm, and relatively low withdrawals of water for its three major water sectors, namely agriculture, community water supply and industry (FAO, 2003). However, natural phenomena such as rainfall variability and global climate change, and human factors such as over-exploitation and pollution, create a serious threat to the sustainability of Africa's freshwater resources, and hence the livelihood of the many poor that inhabit the continent.

Ghana is well watered with high annual rainfall varying from 800 mm to 2200 mm and a dense system of rivers and streams with 10 major rivers and several perennial springs located in the forested highland areas. However, the rainfall is highly variable between the wet and dry season as well as from one place to another. The northern part of the country, for example, experiences a prolonged dry season of about 7 months with high evaporative losses and as a result many of the rivers and streams dry up before the dry season is over. For these reasons, surface water supplies are unreliable and insufficient to meet the water demand for socio-economic development. Besides, many of the surface water sources, particularly those used by small towns and rural communities have serious health risks with regard to water-related diseases such as bilharzias, cholera and guinea worm (WARM, 1998). Groundwater sources have become the preferred means of supplying water to meet the growing demand of the largely rural and dispersed communities and small urban towns in the country. Generally, the chemical and microbiological quality of groundwater is better than that of surface water. Groundwater supply is usually less expensive to develop than surface water and it is more easily expanded at a future date by simply adding new boreholes (Bannerman, 1975). Compared to surface water, groundwater responds more slowly to climate variability and change thereby making it less vulnerable to drought conditions. In addition, groundwater is much easier to protect from biological contamination and, in cases where such contamination has been identified, it is easy to disinfect (WARM, 1998).

Throughout Ghana, groundwater is mostly used for domestic water supply. However, the need for irrigation as a result of variability and change in the amount and pattern of the rainfall coupled with the demand for increased agricultural production to feed the growing population of the country has made it a necessity to diversify groundwater use to include dry season irrigation, poultry and livestock watering and fish farming. The use of groundwater in agriculture has the potential to alleviate poverty and improve the food security of the people involved.

This study is part of a 3-year research project being undertaken by The International Water Management Institute (IWMI). The project is entitled "Groundwater in sub-Saharan Africa:

Implications for food security and livelihoods”. One of the broad goals of the project relevant to this study is to assess groundwater availability and its current and potential use and impacts at the national scale across sub-Saharan Africa, and particularly in the AGRA countries. The specific objective of this study was to develop a clear and comprehensive report on the status of groundwater in Ghana.

1.2 History of Groundwater development in Ghana

Before Ghana came under colonial rule in 1844, individuals, companies (e.g., trading, mining and timber companies) and small communities were responsible for their own water supply. The sources of water supply at that time were traditional hand-dug wells, ponds, dugouts, streams and rivers, springs and rainwater harvesting from roofs. In the case of hand-dug wells, the interested parties or communities developed their own traditional techniques or methods of siting the wells. The wells were usually dug through overburden and weathered rock material and were up to 6 m deep (Gyau-Boakye and Dapaah-Siakwan, 1999). During the dry season when yields from hand-dug wells were very low and in some cases no yield at all, the wells were abandoned for other sources of water, mainly streams and rivers until the aquifers were recharged in the rainy season.

From about 1900, the colonial government assumed some responsibility for public water supply in the urban and rural areas due to periodic droughts, population growth and concentrations into larger communities. The first reference to a modern well in Ghana was in 1915 (Gyau-Boakye and Dapaah-Siakwan, 1999). This well was sunk at the Accra Railways Station in the capital of the country, Accra. The well was first dug through clay and shale to about 22 m depth and gave a yield of 90 l/h of brackish water. It was then drilled to a depth of 52 m through shale and hard rock. Fresh and potable water was struck in the interval of 40 to 52 m, with a yield of 450 to 545 l/h. Consequently a Public Works Department was formed at the turn of the century to investigate urban water supplies across the country.

In 1920, the Geological Survey Department was requested to assist in offering advice on where to site wells in the semi-arid northern territories where drought is frequent and the geology is complex. Further to this, a water supply division was set up in the Geological Survey Department in 1937 as a way to deal with the magnitude of water supply problems in northern and southeastern parts of the country (the driest areas of Ghana). Among other important tasks, the division was tasked to investigate new sources of water supply (both groundwater and surface water sources) and to advise medical officers and political administration personnel in well digging, lining and maintenance and the sanitary precautions to adopt against pollution.

In 1944, the political administrators of the country decided to set up a separate entity from the Geological Survey Department known as the Department of Rural Water Supply. This department was made to take sole charge and deal more effectively with the water supply problems in rural areas (Gyau-Boakye and Dapaah-Siakwan, 1999). It supplied water from wells, tanks, and other water sources in addition to training and supervising native administration staff. Rural communities with large population were provided with piped water from groundwater sources, mainly from mechanically drilled boreholes.

The progress and failure rate of groundwater supplies in the dry season became a source of concern to the government to the extent that it decided in 1951 to have the situation reviewed. To this end, a consultant was invited from the United Kingdom to advise on the work being done by the Department of Rural Water Supply, the groundwater potentialities of the country and the need to invite tenders for drilling by contract. Between 1952 and 1959 the efforts of the Department of Rural Water Development were supplemented with contract drilling placed with private drilling companies as had been recommended. In addition to the efforts of the Department of Rural Water Development, other agencies like the Department of Community Development of the Ministry of Social Welfare and Community Development and the Department of Agriculture also assisted with rural water supply. The technologies used were mainly hand-dug wells, with or without hand pumps, rainfall harvesting from roofs, infiltration galleries, dug-outs and small dams (Gyau-Boakye and Dapaah-Siakwan, 1999).

2 DESCRIPTION OF GHANA

2.1 Geography of Ghana

Ghana is situated on the west coast of Africa between latitude 4^0 44’N and 11^0 15’N and longitude 1^0 12’E and 3^0 15’W, and occupies a land area of about 239 460 km^2. It is boarded by Cote d’Ivoire on the west, the Republic of Togo in the east, Burkina Faso in the north and the Atlantic Ocean (gulf of Guinea) in the south (Figure 1). The country is divided into ten administrative regions (Table 1), which are further divided into 170 districts.

Figure 2: Location Map of Ghana showing administrative regions (UN, 2005)

Table 1: Administrative region by size and percent of total land area

Administrative region	Area coverage (km^2)	% total land area
Northern	70.38	29.5
Brong Ahafo	39.56	16.6
Ashanti	24.39	10.2
Western	23.92	10.0
Volta	20.57	8.6
Eastern	19.32	8.1
Upper West	18.48	7.7
Central	9.83	4.1
Upper East	8.84	3.7
Greater Accra	3.24	1.4

Ghana's topography consists mainly of rolling plains, escarpments and low hill ranges. Most of the land is of an elevation below 500 m and over half is less than 150 m (WARM, 1998). The terrain is predominately flat and gently undulating with slopes less than 5% and in many places less than 1% (Quansah, 2000). Surface drainage is dense and dendrite, with the Kwahu Plateau forming a watershed separating the South-West of Ghana from the Volta basin which covers a large proportion of the country.

2.2 Climate

The climate of Ghana is tropical and controlled by the movement of the so called Inter-tropical Convergence Zone (ITCZ) that dominates the climate of the entire West African region (Ojo, 1977). The ITCZ is the inter-phase of the warm, dry and dusty North-East Trade Wind (Tropical Continental Air Mass) that blows from the Sahara Dessert in the north of Africa and the cool and moist South-West Monsoon that blows over the sea from the South Atlantic (Gyau-Boakye et al., 2008; Barry *et al*., 2005). The ITCZ moves across the country in a complex manner resulting in a mono-modal rainfall season in areas that it crosses once within a year and a bi-modal rainfall seasons in areas that it crosses twice. The movement of the ITCZ is associated with vigorous frontal activities that influence the amount and duration of rainfall over the country (Andah *et al*., 2003). Except in the north of the country, the ITCZ crosses Ghana twice in a year giving rise to two main rainfall regimes that occur from April to July and from September to November. The northern part of the country experiences a single rainfall regime (starts in April/May and lasts until September) as the ITCZ crosses the north once in a year.

Generally, rainfall decreases towards southeast and north (Figure 2). Annual rainfall ranges from about 800 mm in the southeast along the coast in Accra to about 2,200 mm in the extreme southwest along the coast in Axim. The mean annual temperature is about 30^{o}C. For most parts of the country, temperatures are highest in March and lowest in August. The northern parts of the country experience hot days and cool nights between December and March (dry season) due to the movement of the Tropical Continental Air Mass (Harmatan). In the south, the effects of the harmattan are felt in January. Humidity is high in the south particularly at the coast where relative humidity could be 95-100% in the morning and about 75% in the afternoon (Andah et al., 2003). The north experiences low humidity with relative humidity values of 20-30% during the Harmatan period and 70-80% in the rainfall season. Annual potential open water evaporation has been estimated as ranging from about 1500 mm in the south to more than 2500 mm in the north (WB/UNDP/ADB, 1992). The conditions in the synoptic stations in Accra, Kumasi and Tamale (Table 2), summarises the climate in the southern, middle and northern belts of Ghana, respectively.

Table 2: Climatic data from North, middle and South Ghana (Agodzo et al., 2003)

Yearly averages	**Unit**	**South (Accra)**	**Middle (Kumasi)**	**North (Tamale)**
Rainfall regime	-	Bi-modal	Bi-modal	Mono-modal
Rainfall period	-	May-June, October	-	5-6 months
Drought period	-	-		6-7 months
Rainfall	mm	810	1,420	1,033
Temperature	oC	27.1	26.1	28.1
Relative humidity	%	81	77	61
Wind speed	km/day	251	133	138
Sunshine	hours	6.5	5.4	7.3
Solar radiation	MJ/m2/day	18.6	17.0	19.6
Potential evapotranspiration	mm	1,504	1,357	1,720
Aridity index*	-	0.54	1.05	0.60
Effective rainfall**	mm	659	1,081	782

* Aridity index = rainfall/potential evapotranspiration;

** Effective rainfall: estimated with USDA method in CROPWAT (FAO, various years).

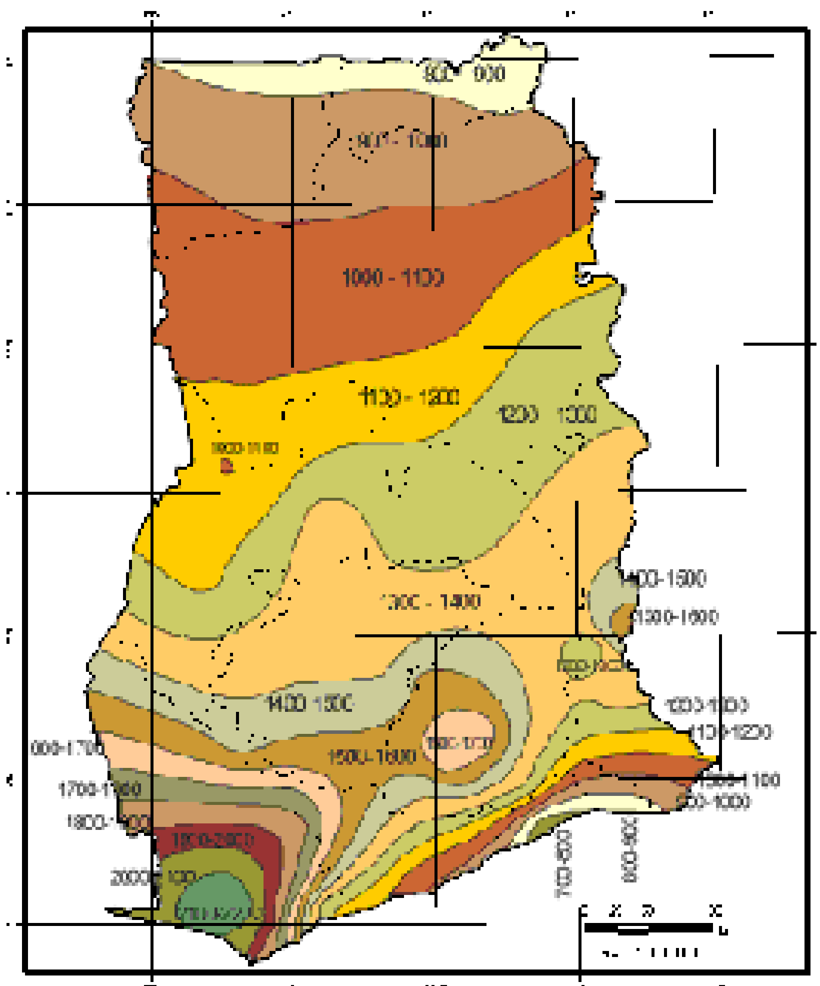

Figure 2: Mean annual Rainfall in Ghana (FAO, 2004)

2.3 Soils

The soils of Ghana have been formed from weathered parent materials of the mid Palaeozoic age or older (Andah et al., 2003) and have been leached over a long period (Benneh et al., 1990). The parent materials consist mainly of Siluro-Devonian sandstone, shale, igneous and granite among others. In the southern forest zone, where annual rainfall is high (1000-2000 mm), the dominant and important major soil types are the Acrisols (Figure 3). These soils are characterised by an accumulation of organic matter in the surface horizon. The rest, mainly in the wetter areas, are Lixisols or intergrades of Acrisols and Lixisols. Soils in the northern savannah consist mainly of Lixisols, Plinthosols, Luvisols, and Leptosols formed over granite and voltain shales. They contain much less organic matter and are lower in nutrient than the forest soils. In the coastal savannah, soils are younger and closely related to the underlying rocks. They are mainly a mixture of Lixisols, Acrisols, Luvisols, Planosols, Ferralsols and Leptosols and are generally poor largely because of inadequate moisture.

A sectional view of the soil profile reveals that many of the soils in the country have light textured surface horizons in which sandy loams and loams are common. The lower horizons have slightly heavier textures varying from coarse sandy loams to clays. Heavier textured soils occur in many valley bottoms and in parts of the Accra Plains. Many soils contain abundant coarse material either gravel and stone, or concretionary materials which affect their physical properties, particularly their water holding capacity (SRI *cited in* SRID, 2009).

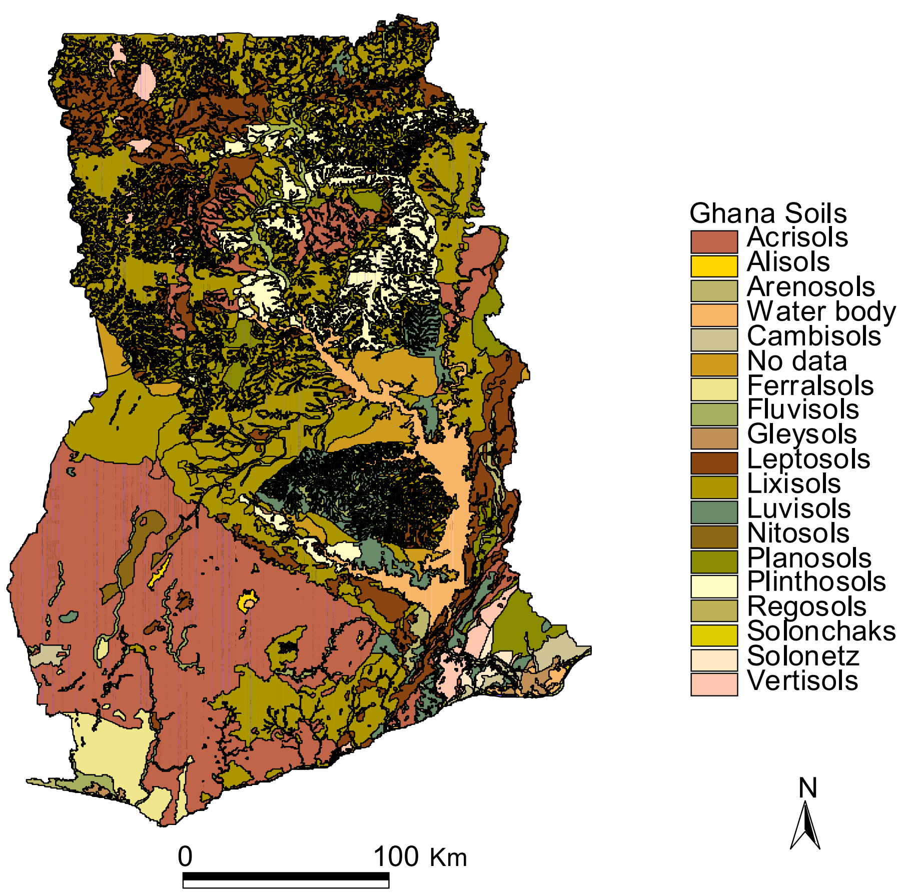

Figure 3: Soil map of Ghana (Data source: Ghana at Glance)

2.4 Agro-ecological zones and land use

The country is characterized by 6 distinct agro-ecological zones (Figure 4) defined on the basis of climate, reflected by the natural vegetation and influenced by the soils. These are the Rain forest of the cynometra-terrieta association, which covers a land area of 7,500 km^2; the deciduous rain forest of celtis-tripdochito association (66,300 km^2); transition forest of derived savannah and semi-deciduous forest (8,300 km^2); Guinea savannah woodland with scattered shrubs (147,900 km^2); Sudan savannah mainly tall grasses interspersed with fire resistant and scattered shrubs (1,900 km^2); and the costal savannah consisting of shrubs, thickets, grasses and packets of mangrove swamps covering an area of 4500 km^2 (FAO, 2005; Agodzo et al., 2003; WARM, 1998). Characteristics of the various agro-ecological zones in Ghana are presented in table 3.

Table 3: Characteristics of Agro-ecological zones in Ghana (FAO, 2005; Agodzo et al., 2003)

Zone	**Rainfall (mm/yr)**	**Portion of total area (%)**	**Dominant land use systems**	**Main food crops**
Rain forest	2,200	3	forest, plantation	roots, plantain
Deciduous forest	1,500	3	forest, plantation	roots, plantain
Transition zone	1,300	28	annual food and cash crops	maize, roots, plantain
Guinea savannah	1,100	63	annual food and cash crops, livestock	sorghum, maize
Sudan savannah	1,000	1	annual food crops, livestock	millet, sorghum, cowpea
Coastal savannah	800	2	annual food crops	roots, maize

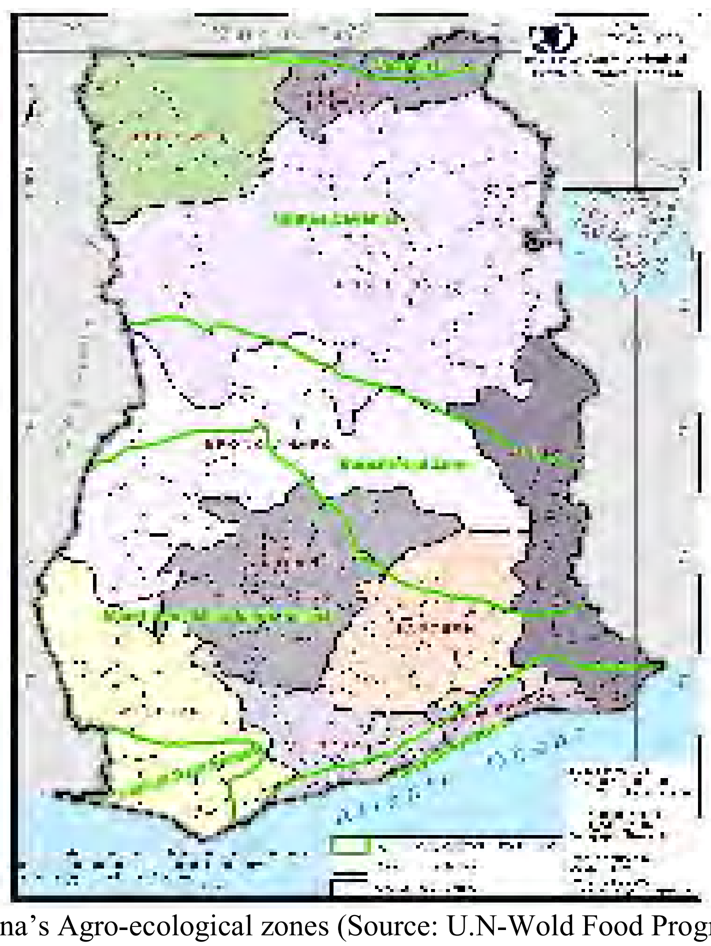

Figure 4. Ghana's Agro-ecological zones (Source: U.N-Wold Food Programme, 2009)

The general land use system in the country is presented in table 4. The dominant land use system is savannah woodland, which covers 30% of the total land area. This is followed by Bush fallow (25%), unimproved pasture (15%) and Forest reserves (11%). Unreserved forest is the least land use system in the country, covering only 2% of the total land area of the country.

Table 4: General Land use systems in Ghana (MTADP-MOFA, 1991 *cited* in SRID, 2009)

Land Use	**Area ('000 sq. km.)**	**% of Total**
Savannah woodland	71	30
Bush fallow and other uses	60	25
Unimproved pasture	36	15
Forest reserves	26	11
Tree crops	17	7
Annual crops	12	5
Wildlife reserves	12	5
Unreserved forest	5	2
Total	**239**	**100**

The dominant land use systems in the Guinea and Sudan savannah agro-ecological zones are extensive land rotation cultivation of food and cash crops with widespread grazing of livestock and cattle and compound cropping around settlements. The major food crops cultivated include sorghum, maize, millet, groundnut, beans and cowpea. The major land use system in the transition zone is agriculture with extensive bush fallow cultivation in some areas. Both annual food and cash crops are cultivated. They include maize, cassava, cocoyam, plantain, cocoa, coffee and oil palm. An important economic activity in this zone is charcoal burning which involves the cutting down of woody trees, leading to deforestation. The Rain and Deciduous forests land use systems are mainly forest and plantations. Annual food and cash crops are cultivated on small plots of lands. Major crops cultivated include Cassava, cocoyam, plantain, maize, coffee, cocoa and oil palm. The main land use in the coastal savannah zone is agriculture and involves the cultivation of annual food crops like roots and maize.

2.5 Water Resources

Ghana's surface water resources are concentrated in three main river systems. These are the Volta river system, which consists of the Black, White, Lower Volta, Oti and Daka rivers and other tributaries; the South-western river system, which comprise of the Bia, Tano, Ankobra, and Pra rivers; and the Coastal river system, which consists of the Tordzie/Aka, Densu, Ayensu, Kakum, Butre, Ochi-Amissa, and Ochi-Nakwa rivers. The Volta, South-western and Coastal river systems drain about 70, 22, and 8 percent, respectively, of the total land area of Ghana. The Volta river system contributes about 64.7% of the actual runoff generated in Ghana (WARM, 1998). The South-western and Coastal river systems contribute 29.2 and 6.1 percent, respectively. The Volta River is shared with Cote D'Ivoire, Burkina Faso, Mali and Benin. The Bia River is shared with Cote D'Ivoire, while the lower reaches of the Tano River forms the boundary with Cote D'Ivoire.

The total annual runoff from all rivers in Ghana (total actual renewable water resources) is estimated at 56.4 billion m^3 (Table 4). Of this, about 41.6 billion m^3 is accounted for by the Volta river system. The portion of the runoff originating from Ghana alone (internal renewable water resources) is about 40.0 billion m^3, representing 68.6% of the total annual runoff. The total water available from surface water sources is 39.4 billion m3 per annum (MWRWH, 2007). Internally produced groundwater is estimated at 26.3 billion m^3 and the overlap between surface and groundwater is estimated at 25 billion m^3 (Kundel, 2008).

Based on the 2008 population estimate of Ghana (22, 900,972), the total actual renewable water resources per inhabitant is 2,375. Compared to the so called Falkenmark indicator or "water stress index" (Falkenmark et al., 1989), which defines thresholds of 1700, 1000 and 500 m^3 per capita per year as water stress, water scarcity and absolute scarcity conditions, respectively, Ghana is currently not water stressed. However, available estimates reveal that the country will go into water stress condition by the year 2025 (UNEP, 2002) as a result of increasing population.

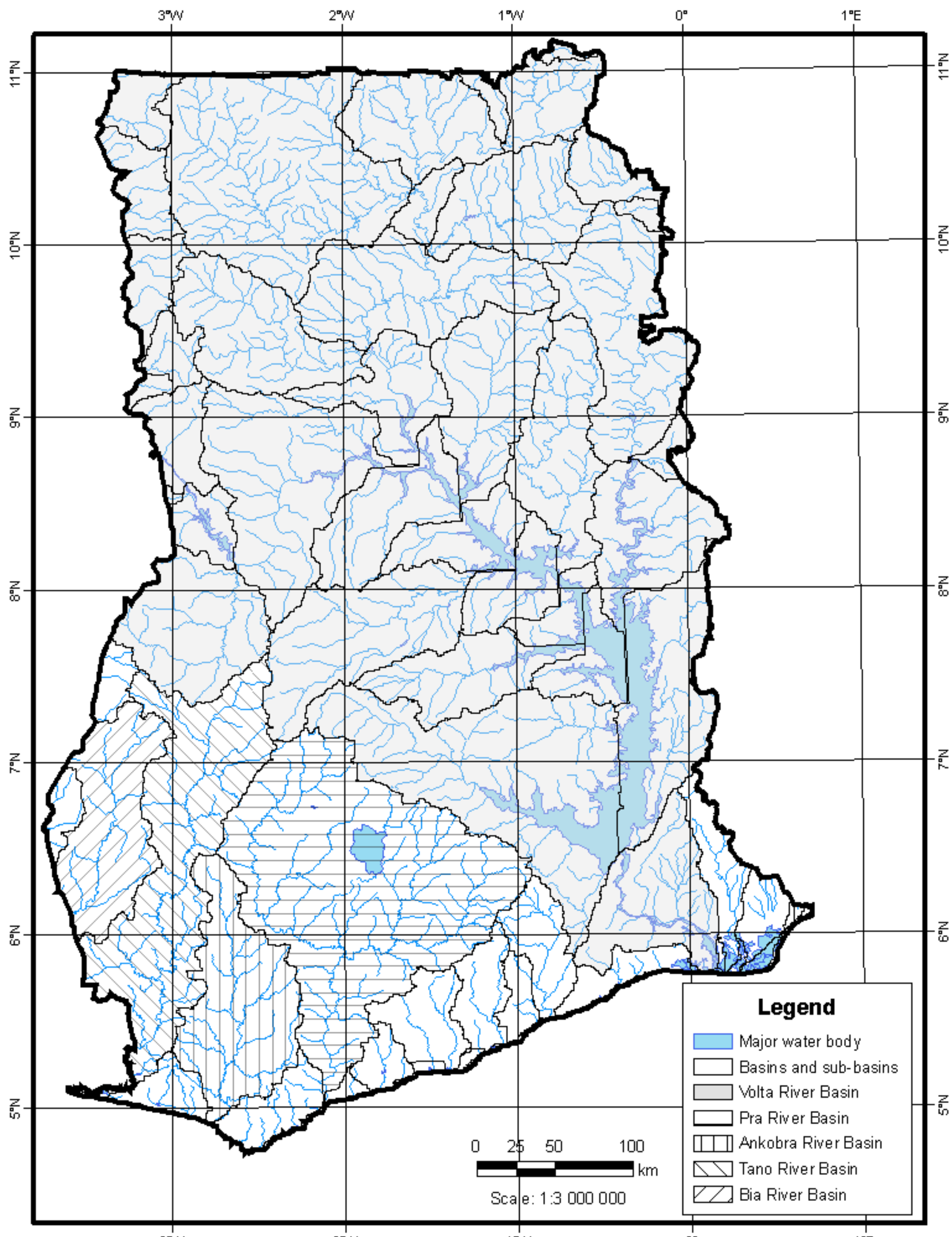

Figure 4: Major river basins in Ghana (HAP, 2006)

Table 5: Surface water resources in Ghana (FAO, 2008; MWRWH, 2007)

Renewable water resources	**Year data**		
Average precipitation		1,187	mm/yr
		283.1	m^3/yr
Internal renewable water resources		39.4	10^9 m^3/yr
Total actual renewable water resources		56.4	10^9 m^3/yr
Total actual renewable water resources per inhabitant	2008	2,375	m^3/yr
Water withdrawal			
Total water withdrawal	2000	982	10^6 m^3/yr
- Irrigation + livestock	2000	652	10^6 m^3/yr
- domestic	2000	235	10^6 m^3/yr
- industry	2000	95	10^6 m^3/yr
• per inhabitant	2000	50	m^3/yr
• as % of total actual renewable water resources	2000	1.8	%

Water withdrawals in Ghana are generally low. The major consumptive water sectors of the country are Agriculture, domestic water supply and industry. Agriculture and Industry are the largest and least users of water, respectively. In 2000, the agriculture sector, including livestock, withdrew 652 million m^3, accounting for 66% of the total water withdrawal for that year (Table 5). About 235 million m^3 of water, representing 24% of total withdrawals in 2000 was withdrawn for domestic water supply and 95 million m^3 (10% of total withdrawals) went to industry. The total water withdrawals in 2000 constitute only 1.8 % of the total renewable water resources available in the country.

2.6 Population distribution and growth

The population of Ghana has been counted in 4 censuses. The first was in 1960, the second in 1970, the third in 1984 and the fourth in 2000. The next population census will take place in 2010. Table 6 presents some characteristics of the population of Ghana as a whole and table 7 presents the distribution of Ghana's population by administrative region for the 1984 and 2000 censuses. According to the last census, the population of Ghana was about 18.9 million in 2000, with an inter-censual growth rate of 2.7% and an average population density of 79% (GSS, 2002).

Based on the population in the last census in 2000 and the inter-censual growth rate of 2.7%, the population is estimated to be 22.9 million in 2008 (UN-World Food Programme, 2009). The most populous region, according to the 2008 estimate, is Ashanti followed by Greater Accra (Table 8). The least populated region is the Upper West. The average rural population constitute 56% of the total population with highest rural population in the Upper East Region, followed by the Upper West and the Northern region. The highest population densities are found in the Greater Accra Region and in the Cocoa producing areas in the south of Ghana. Assuming an annual growth rate of 2.5% (average of all inter-censual growth rates), Ghana's population is projected to be about 30,172,000 by the year 2020 (Agodzo et al., 2003).

Table 6: Characteristics of Ghana population: 1960-2000 (GSS, 2002a, 2002b)

Population	1960	6,728,815
	1970	8,559,313
	1984	12,296,081
	2000	18,912,079
Increase (%)	1960-1970	27.2
	1972-1984	43.7
	1984-2000	53.8
Growth (%)	1960-1970	2.4
	1972-1984	2.6
	1984-2000	2.7

Table 7: Population characteristics by region: (Sources: GSS, 2002b; Agodzo et. al, 2003)

Administrative Region	**Area (1000 km2)**	**1984**		**2000**	
		Population (106)	**Population density (P/km2)**	**Population**	**Population density (P/km2)**
Ashanti	24	2.1	86	3.2	131
Greater Accra	3	1.4	441	2.9	897
Eastern	19	1.7	87	2.1	109
Northern	70	1.2	17	1.9	26
Western	24	1.2	48	1.8	77
Brong Ahafo	40	1.2	31	1.8	46
Volta	21	1.2	59	1.6	78
Central	10	1.1	116	1.6	161
Upper East	9	0.8	87	0.9	104
Upper West	18	0.4	24	0.6	31

Table 8: Estimated population for 2008 by region: (Source: UN-World Food Programme, 2009)

Administrative Region	**Population**	**Rural (%)**	**Urban (%)**
Ashanti	4,589,377	49	51
Greater Accra	4,057,434	12	88
Eastern	2,267,772	65	35
Northern	2,165,606	73	27
Western	2,424,139	64	36
Brong Ahafo	2,164,589	63	37
Volta	1,822,054	73	27
Central	1,801,520	63	38
Upper East	983,575	84	16
Upper West	624,861	83	18
Ghana	**22,900,927**	**56**	**44**

2.7 Economy

Ghana is one of the more economically sound countries in Africa even though it depends on international financial and technical assistance and remittances from the large Ghanaian community in the Diaspora. The Gross Domestic Product (GDP) per capita was in excess of USD 2,000 in 2006 and 2007 but declined to 1,400 in 2008 due to the huge expenditure made by the then Government on developmental projects and election activities. The economy is largely informal with about 91% of all the economically active people (age: 15-64 years) employed in the informal sector (UN-World Food Programme, 2009). Agriculture, particularly private-owned and small-scale, is the backbone of the economy accounting for 38% of the GDP in 2008 (Bank of Ghana, 2009) and employed 56% of the labour force in 2005 (CIA, 2010). The main agricultural export crop is cocoa, which generates about 30-40% of foreign exchange earnings. Other important agricultural export crops are Timber, horticultural products, fish/sea foods, Game and wildlife (SRID, 2009).

Over 90% of Ghana's agricultural production is done by peasant smallholders on plots less than 2 ha who produce most of Ghana's cocoa (UN-World Food Programme, 2009). About 20% of Ghana's estimated 136, 000 km^2 agricultural land is under cultivation (Seini, 2002). Agriculture is mostly rain fed, heavily dependent on the weather and thereby makes agriculture's performance highly unpredictable.

Table 9: Key economic indicators in Ghana (Source: Bank of Ghana, 2009; *cited* in UN-World Food Programme, 2009)

Economic indicator	**2008**	**2007**	**2006**
GDP per capita (USD)	1,400	2,700	2,500
GDP growth	6.2	6.3	6.2
Agriculture (share %)	38	34.7	35.8
Agriculture growth	4.9	4.3	4.5
Services (share %)	34	30.6	30
Services growth	6.9	8.2	6.5
Industry (share %)	28	26	15.4
Industry (Growth)	8.3	7.4	9.5
Current account deficit (% of GDP)	-22.3	-16.1	-13.1
Budget deficit (% of GDP)	11.5	8.1	7.8
Inflation	16.5	10.7	10.9
Depreciation of GHc (against USD)	GHc 1.09	GHc 0.97	GHc 0.92

The service sector is the second most important contributor to GDP and a key driving force to economic activities. It accounted for about 34% of GDP in 2008 (Table 9). The service sector comprises largely trade and public services. Financial services have improved in recent years with the introduction of a new stock market, the Ghana Stock Exchange, and several new financial institutions. Recent efforts to develop the tourism sector have led to a rapid growth in international tourists and there is still a considerable untapped tourism potential. Retail services, although still limited, are strong in the urban areas.

The industrial sector contributed some 28% to GDP in 2008. This is a slight increase over previous contributions in 2006 and 2007. The industrial sector is broad and diverse and includes mining, timber and agricultural processing plants, brewing, cement manufacture, oil refining, textiles, electricals, pharmaceuticals, and others. Gold and Timber exports are the two most important foreign exchange sources after Cocoa. Other sources of foreign exchange earnings include the export of Diamond, Bauxite and Manganese. The diamond industry is saddled with a history of corruption, smuggling and poor management, as there is extensive illegal mining and a thriving parallel market.

3. HYDROGEOLOGY

3.1 The Geology of Ghana

The Geology of Ghana is dominated by two major formations. Theses are the basement crystalline rocks associated with the West African Craton and covers 54% of the country and the Paleozoic consolidated sedimentary formation, which was formed in a depression of the West African Craton and covers about 45% of the country (Figure 5). The remaining 1% of the country is underlain by minor geological formations including Cenozoic, Mesozoic, and Paleozoic sedimentary strata along narrow belts on the coast, and Quaternary alluvium along the major stream courses.

The basement crystalline rocks are of Precambrian age and consist of granite-gneiss-greenstone rocks, phyllite, schist, quartzite, strongly deformed metamorphic rocks and amorogenic intrusions (Key, 1992). Generally, the structural trend in these basement rocks is influenced by the principal tectonic stress orientation and therefore follow a northeast-southwest (WNW-ESE) axis (Apambire, 1996). The basement crystalline formation is commonly subdivided into the Birimian group (with associated granitoid intrusions), Granite, Tarkwan group, Dahomeyan formation, Togo formation and the Buem formation (Figure 6). The Birimian group dominates the basement crystalline formation and covers densely populated areas including most of western, south-central, northeast and northwest of the country and can be as thick as 15,000 m (Key, 1992).

The Paleozoic consolidated sedimentary formations are locally referred to as the Voltaian formation and consist mainly of sandstone, shale, arkose, mudstone, sandy and pebbly beds, and limestone (WARM, 1998). Based on lithology and field relationships, the Voltaian formation can be sub-grouped into the upper, middle and lower Voltaian. The upper Voltaian consists of massive and thin-bedded quartzite sandstones, which are interbeded with shale and mudstone in some areas. The middle Voltaian (Obusum and Oti Beds) mostly comprise of shales, sandstones, arkose, mudstones and siltstones. The lower Voltaian consists of massive quartzite sandstone and grit (figure 7).

The Cenozoic, Mesozoic, and Paleozoic sedimentary strata (minor geological formations) are made up of two coastal formations, namely, the coastal Block-Fault and the coastal-Plain. The coastal Block-Fault consists of a narrow discontinuous belt of Devonian and Jurassic sedimentary rocks that have been broken into numerous fault blocks and are transected by minor intrusives. The coastal plain formation is underlain by semi-consolidated to unconsolidated sediments ranging from Cretaceous to Holocene in age in south-eastern Ghana and in a relatively small isolated area in the extreme south western part of the country (WARM, 1998). The other minor formation, Alluvia, comprises of narrow bands of alluvium of Quaternary age, occurring principally adjacent to the Volta River and its major tributaries and in the Volta delta (Dapaah-Siakwan and Gyau-Boakye, 2000).

The major geological formations in the country are overlain by the so-called regolith, which is a weathered layer that varies in thickness and lithology (Martin, 2005; HAP, 2006). The thickness of the regolith is influenced by lithology, structural characteristics, topography, vegetation cover, erosion, aquifer characteristics and climate. In the Precambrian formation the thickness varies widely with an average ranging form 2.7 to 40 m but can be upto 140 m in the extreme northwest of the country (Apambire et al., 1997; Apambire, 1996; Smedley, 1996). Generally, the regolith in the Voltaian formation is less thick compared to the Precambrian formation and ranges from 4 to 20 m in the southern part (Acheampong, 1996).

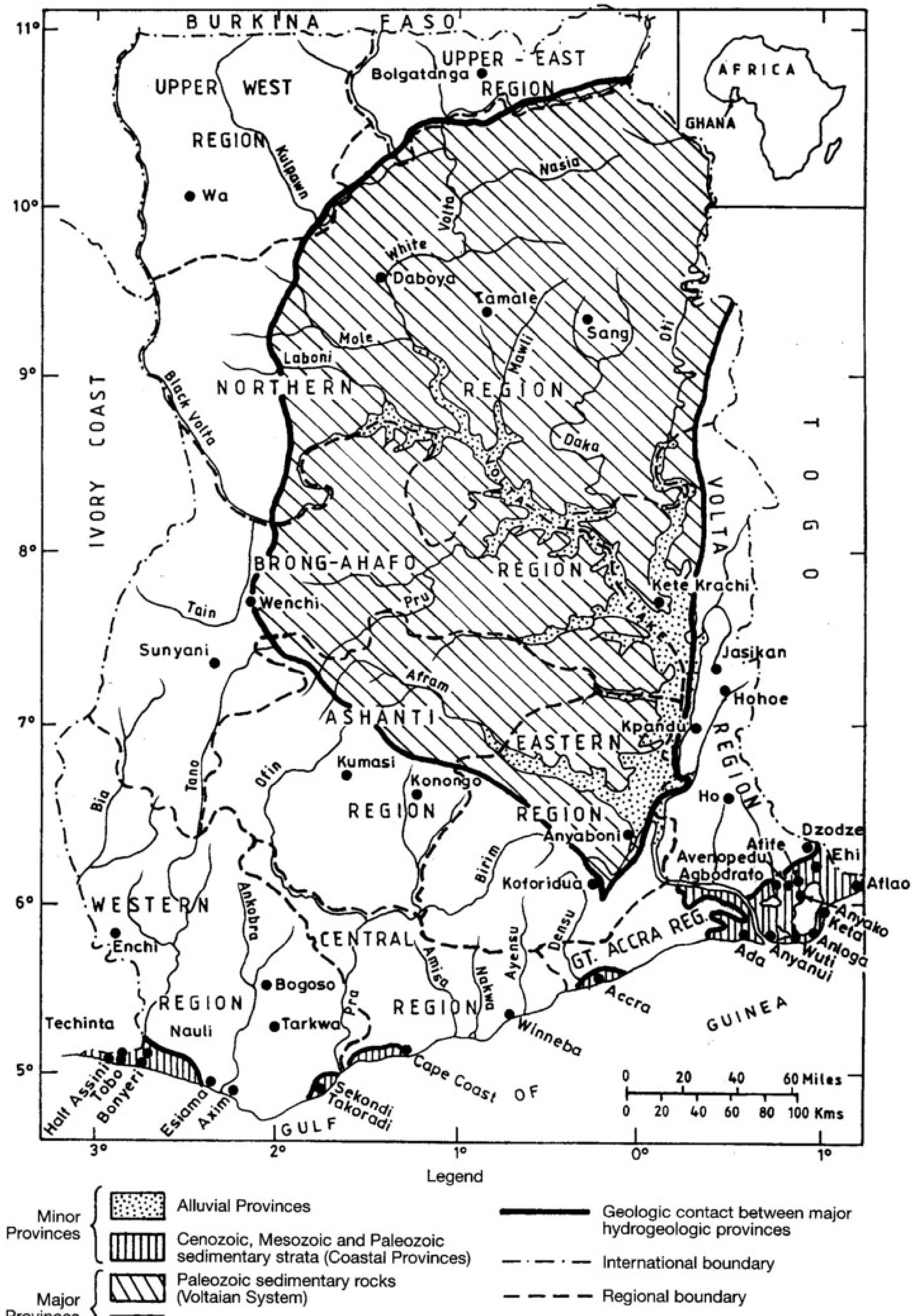

Figure 5: Geological groups and river systems of Ghana (Geological Survey of Ghana, 1969)

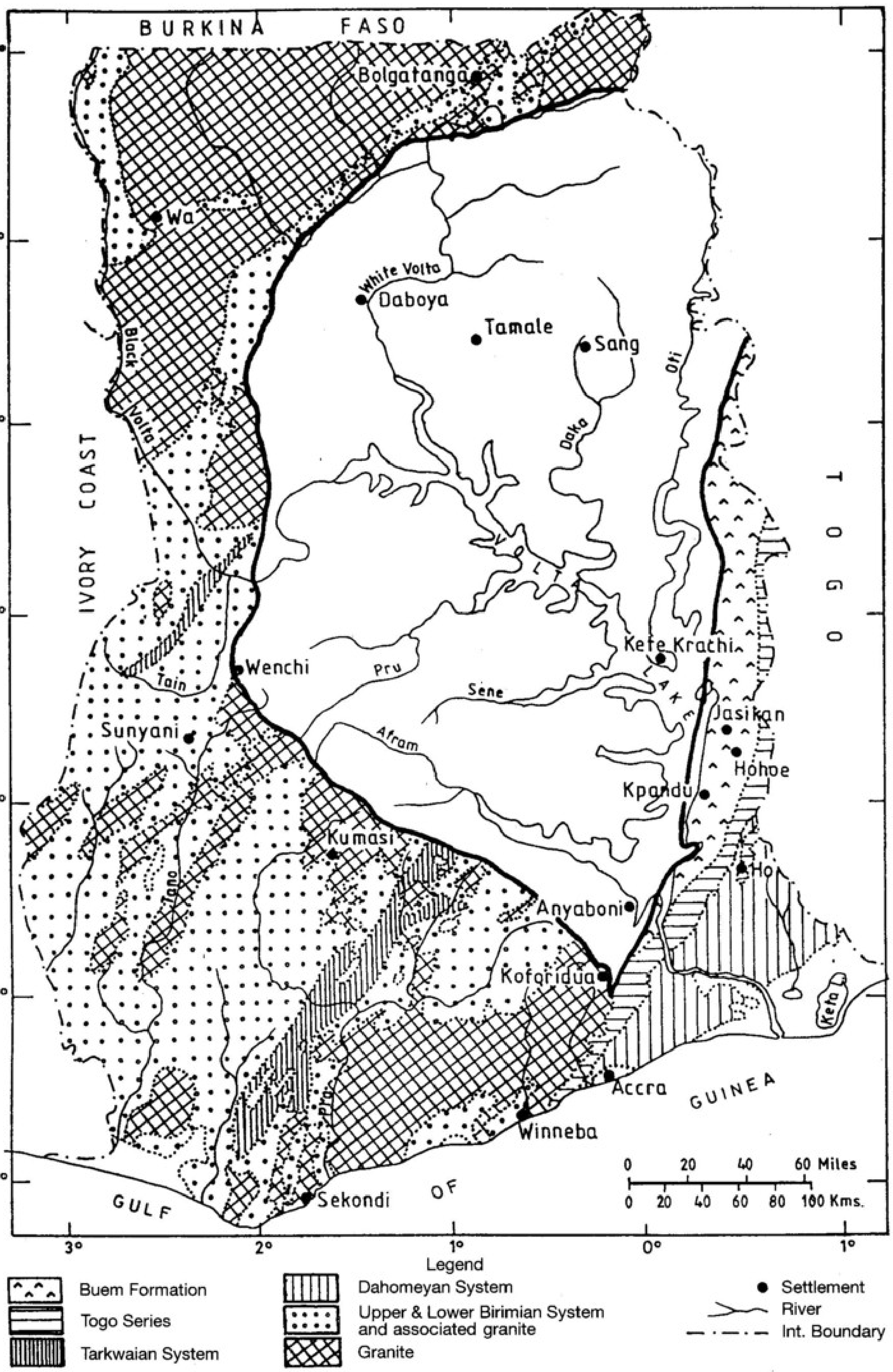

Figure 6: Geological subgroups of the Basement Complex (Ghana Geological Survey, 1969)

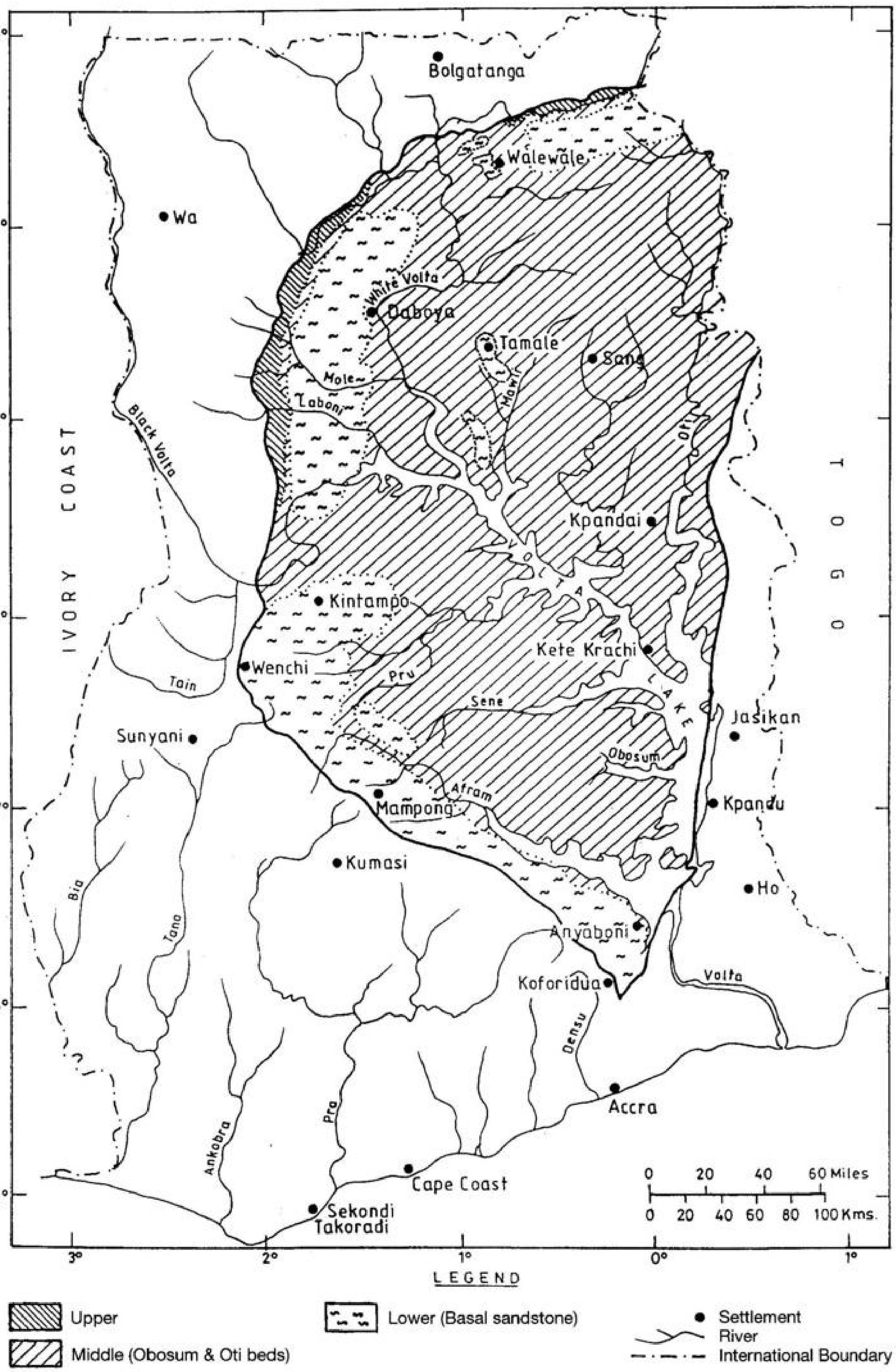

Figure 7: Geological subgroups of the Voltaian System (Ghana Geological Survey, 1965)

3.2 Groundwater aquifer system

The major geological formations of the country, the basement crystalline rocks and the Voltaian formation, are essentially impermeable and have little or no primary porosity. The occurrence of groundwater in these formations is associated with the development of secondary porosity as a result of chemical weathering, jointing, shearing, and fracturing (WARM, 1998). In both formations, two main aquifer systems can be identified: the weathered zone aquifer system (regolith aquifers) and the fractured zone aquifer system. The thickness and productivity of each aquifer system in the different formations vary but generally, the regolith aquifers occur at the base of the thick weathered mantle and have low permeability and high porosity due to high clay content. The fractured zone aquifers are normally discontinuous and limited in area.

Figure 8 is a conceptual model of groundwater occurrence in the Precambrian basement rocks in the Atankwidi sub-catchment of the Volta basin in Ghana and could represent the occurrence of groundwater in a larger part of the Precambrian formation in the country (Martin, 2006; HAPS, 2006). The most productive groundwater zone, according to the model, is the area around the lower parts of the regolith and the upper parts of the fractured bedrock. The depth of the productive zone varies greatly depending on location but generally ranges between 10 and 60 meters (WARM, 1998). Most boreholes in northern Ghana have depth less than 80 m (Agyekum, 2004) and are believed to be taping from the productive zone. Groundwater in the regolith aquifer occurs mostly under semi-confined or leaky conditions. The upper part of the regolith is sandy clay in nature and in some areas can allow for the development of discontinuous shallow perched aquifers (Martin, 2006) (Figure 8). Groundwater also occurs along lithologic contacts and fault zones in some areas of the Precambrian formations. According to WARM (1998), yield of aquifers in Precambrian formation rarely exceeds 6 m^3/h.

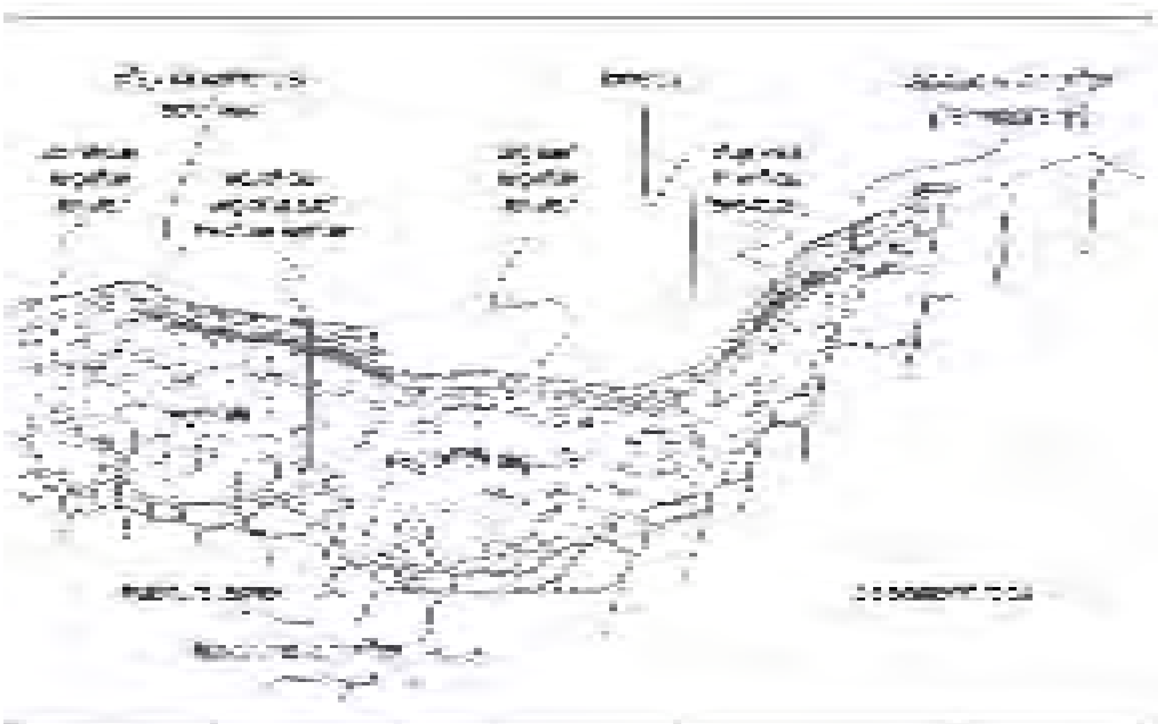

Figure 8: Groundwater occurrence in Basement rock in Ghana (HAP, 2006; Martin, 2006)

The Voltaian formation has lost its primary porosity as a result of consolidation and cementation. Groundwater in this formation occurs mainly in fracture zones in the bedrock and in some locations, also along bedding planes. According to Acheampong (1996), the fracture zones are mainly subvertical and are generally developed in bedrock at depths greater than 20 m below ground surface (HAP, 2006). The bedrock is characterized by high permeability and low porosity. The thickness of the fracture zone largely depends on depth, weathering intensity, lithology and structural history. The regolith layer in the Voltaian formation is thin and unsaturated in many areas and provides only scanty amount of groundwater.

Three aquifers occur in the cenozoic and mesozoic sediments formation (minor geologic formations) located in the extreme southeastern and western parts. The first aquifer is unconfined and occurs in the recent sand very close to the coast. It has a depth range between 2 m and 4 m and contains fresh meteoric water. The intermediate aquifer is either semi-confined or confined and occurs mainly in the red continental deposits of sandy clays and gravels. The depth of this aquifer varies from 6 to 120 m, and it contains mostly saline water. The third aquifer is the limestone aquifer, which varies in depth between 120m and 300 m and has an average yield of 148 m^3/h (WARM, 1998; Dapaah-Siakwan and Gyau-Boakye, 2000). The groundwater in this aquifer is fresh and occurs under artesian condition.

3.3 Characteristics of aquifers

Information that allows comprehensive understanding of the various aquifer systems in Ghana are lacking at the moment. Many of the groundwater exploration and borehole drilling activities in the country have been done in isolation and by NGOs whose main focus was to obtain water and not bothered much about the information produced in the process. The scanty information available are scattered in bits and pieces in several reports and publications. Table 10a and 10b present information on borehole success rates, depth, yield, transmisivity, specific capacity and storativity of the major aquifer systems in Ghana. The values in the table have been obtained from various sources that used different amount of datasets and estimation methods and for different study areas and area sizes and may exhibit inconsistencies or inaccuracies (HAP, 2006). Figure 9 shows the distribution of borehole yields estimated in 1994 by the Water Research Insttute, Ghana. The data used for preparing the map is already 26 years old and needs updating. Therefore, this map should only be considered as first hand information on yield for areas of the country where detailed and updated information on yields are lacking.

3.3.1 Precambrian Basement Province

Current information on the total number of boreholes drilled in all the Hydrogeologic Provinces in Ghana is not available. However, available information indicates that the total number of listed boreholes drilled in the Precambrian basement Province as at 2001 was 13,500. About 90% of these boreholes are located in the Birimian formation with its associated granitoids. Borehole success rate (defined as boreholes with a minimum yield of 0.78 m^3/h) is poorest in the Dahomeyan formation with an average value of 36%, and best in the Buem/Togo series ranging from 85% to 90% and averaging 87.9% (Dapaah-Siakwan and Gyau-Boakye, 2000). Depth of boreholes varies between 34 m and 62 m in the Tarkwaian and Birimian formations and the associated Granitoids, and between 30 m and 55 m in the Buem/Togo series.

Table 10a: Characteristics of major aquifer systems in Ghana (HAP, 2006)

Hydrogeologic provinces and sub-provinces	**No. of borehole[1]**	**Borehole success rate[2] (%)**		**Borehole depth (m)**		**Screen (m)**	
				Range	**Average**	**Range**	**Average**
Cenozoic-Mesozoic-Palaeozoic Province							
Alluvia Province	-	67	-	-	-	-	-
Coastal-Plain	-		-	-	-	-	-
-Sand and clays	380	78	70-90	3-100	-	-	-
-Limestone beds	100		60-75	100-609	-	-	-
Coastal Block-Fault	-	36	-	-	-	-	-
Voltaian Province							
Upper Voltaian		56					
Middle Voltaian	512	56	22-53	45-75	55	2-30	9.8
Lower Voltaian		55					
Precambrian Province							
Buem	300	87.9	85-90	30-45	-	1-28	10.6
Togo	350	87.9	85-90	33-55	-		
Tarkwaian	350	83	80-86	34-60	-		
Upper Birimian	5200	76.5	68-85	35-62	42	1-18	8.9
Lower Birimian		75					
Granotoids[3]	7000	68-85	59-76	35-55	50	4-33	12.9
Dahomeyan	300	36	28-40	45-70	55	1-31	11.4
Sources	(6)	(1)	(6)	(6)	(6)	(4)	(4)

Table 10b: Characteristics of major aquifer systems in Ghana (HAP, 2006)

Hydrogeologic provinces and sub-provinces	**Yield (m^3/h)**				**Transmissivity (m^2/d)**			**Specific capacity (m^3/h/m)**		**Storability**
	Range		**Average**		**Range**	**Average**		**Range**	**Average**	**Range**
Cenozoic-Mesozoic-Palaeozoic Province										
Alluvia	1-15	-	11.7	-	-	-	-	-	-	-
Coastal-Plain	4.5-54	-	15.6	-	-	-	-	-	-	-
-Sand and clays		-		-	0.7-1624	-	22.2	-	-	-
-Limestone beds		-		-	12-490	-	57.1	-	-	-
Coastal Block-Fault	1-5	-	3.9	-	-	-	-	-	-	-
Voltaian Province										
Upper Voltaian	1-9	0.3-72	8.5	7.3	0.3-267	-	11.9	-	-	-
Middle Voltaian	0.41-9		6.2			15.9		0.06-2.7	0.6-1.4	-
Lower Voltaian	1-9		8.5			-		-	-	-
Precambrian Province										
Buem	0.7-24.3	0.4-31.5	9.2	5.6	0.9-43	-	8.0	-	-	-
Togo	0.7-24.3		9.2			-		-	-	-
Tarkwaian	1.0-23.2	0.48-36	8.7	7.6	0.2-119	-	7.4	-	-	0.003-0.008
Upper Birimian	0.5-23.6		7.4			-		-	-	
Lower birimian	0.4-29.8		12.7			-		-	-	
Granitoids[3]	-	0.3-36.4	-	4.0	0.3-114	-	6.6	-	-	-
Dahomeyan	1-3	0.5-12	2.7	3.0	0.3-42	-	4.5	-	-	-
Sources	(1)	(2)	(1)	(2)	(6)	(3)	(6)	(3)	(3)	(5)

Note

- : No data available; 1: These represent the approximate total number of listed boreholes drilled in each subprovince as of 2001; 2: Successful boreholes are generally defined as boreholes with a minimum yield of around 13 L/min (or 0.78 m^3/h); 3: Granitoid intrusions associated with the Birimian System.

Sources

(1): Dapaah-Siakwan and Gyau-Boakye, 2000 (N.B.: values are based on ~ 11 500 boreholes); (2): Darko and Krasny, 2003 (N.B.: values are based on ~2 050 boreholes); (3): Acheampong, 1998 (N.B.: values are based on 28 boreholes); (4): Darko and Krasny, 2000 (N.B.: transmissivity range represents mean ± std deviation); (5): Bannerman and Ayibotele, 1984 (N.B.: values are base on ~ 2 500 boreholes in the Upper East & Upper West Regions); (6): Agyekum, 2004 (N.B.: values are based on ~ 14 500 boreholes).

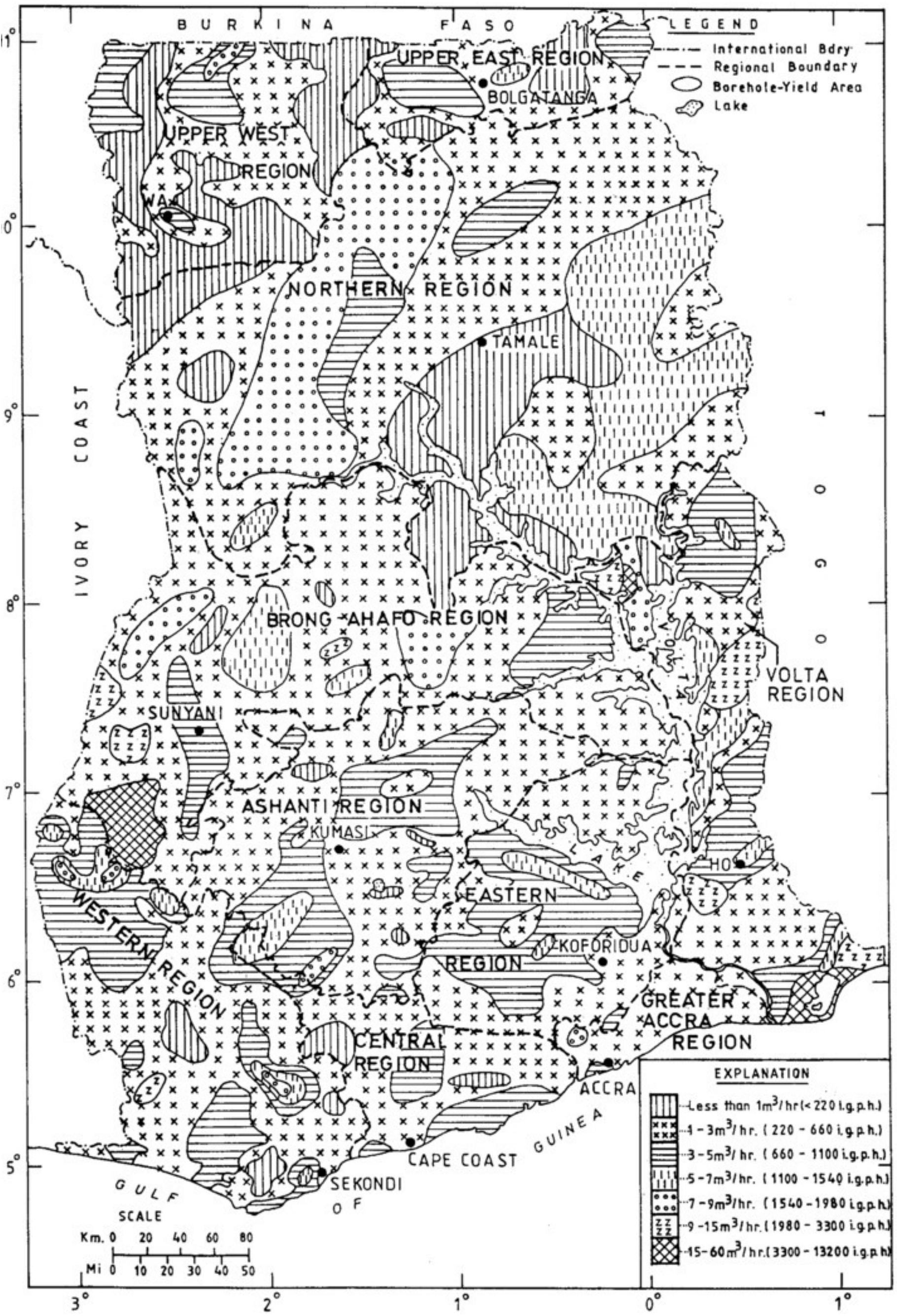

Figure 9: Distribution of borehole yield in Ghana (WRRI, 1996b)

There is hardly any data on the depth of the most productive zone in the Precambrian formation. However, the depths of the screen section of boreholes generally represent the thickness range of the productive zone. Screen depths range from 1 m to 18 m in the Birimian and Tarkwaian formations and vary from 1 m to 28 m in the Buem/Togo series. In the Granitoids and Dahomeyan formation, screen depths are in the range 4-33 m and 1-31 m, respectively.

Yields of boreholes in the Precambrian formation are low due to low transmissivities and low storativities (HAP, 2006). The best yields are obtained in the Birimian and Tarkwaian formations, ranging from 0.48 m^3/h to 36 m^3/h with an average of 7.6 m^3/h. Average yields in the Buem/Togo series and the Granitoids are 5.6 m^3/h and 4.0 m^3/h, respectively. Transmissivity values range from 0.2 m^2/d to 119 m^2/d in the Birimian (including Granitoids) and Tarkwaian formation, from 0.9 m^2/d to 40 m^2/d in the Buem/Togo series, and 0.3 m^2/d to 42 m^2/d in the Dahomeyan formation (Agyekum, 2004). Information on aquifer storativity is lacking. The only data available is for the Tarkwaian and Birimian formations and range from 0.003 to 0.008.

3.3.2 Voltaian Province

Hydrogeologically, the Voltaian terrain is the most complex and least understood of all the formations in Ghana. The number of listed boreholes as of 2001 was 512, much fewer compared to the Precambrian basement formation. Borehole success rates are low, between 22% and 53% (Agyekum, 2004) although slightly higher success rates (55-56%) have been reported in literature (Dapaah-Siakwan and Gyau-Boakye, 2000). The depths of boreholes range from 45 m to 75 m with an average of 55 m. Borehole yields lie in the range 0.41-9.0 m^3/h but could be up to 72 m^3/h in some areas (Darko and Krasny, 2003a). Average borehole yield is 6.3 m^3/h in the Middle Voltaian subprovince and 8.5 m^3/h in the Upper and Lower Voltaian sub-provinces. On average, transmissivity values are higher in the Voltaian province than in the Precambrian Province, ranging from 0.3 m^2/d to 267 m^2/d with an average of 11.9 m^2/d (Darko and Krasny, 2003b). Specific capacity values range from 0.06 $m^3/h/m$ to 2.7 $m^3/h/m$ (HAP, 2006).

3.3.3 Cenozoic, Mesozoic and Palaeozoic Province

Data on the total number of boreholes drilled in the Cenozoic-Mesozoic-Palaeozoic Province is not available. However, the number of listed boreholes drilled in the Costal-Plain sub-province, as of 2001, was 480 (380 in sands and clays and 100 in limestone beds). The success rate of Boreholes varies widely amongst sub-provinces, from an average of 36% in the Coastal Block-Fault to 78% in the Coastal-Plain. Information on borehole depths are available for the Coastal-Plain sub-province only and range from 3 m to 100 m in the sand and clay materials and 100 m to 600 m in the limestone beds. Yields are highest in the Coastal-Plain with an average yield of 16.6 m^3/h and lowest in the Coastal Block-Fault with an average of 3.9 m^3/h. Transmissivity values for the Cenozoic-mesozoic-Palaeozoic Province are the highest of all the hydrogeologic provinces in Ghana with average values of 22.2 m^2/d and 25.1 m^2/d in the sand/clay and limestone materials, respectively, of the Coastal-Plain sub-province.

3.4 Groundwater development and utilization

3.4.1 Abstraction structures and volume

Groundwater is abstracted from all the Hydrogeologic Provinces in the country. The main structures for accessing groundwater in Ghana are boreholes, hand-dug wells and dugouts. As of 1994, there were over 55,500 abstracting systems in the country. This was made up of about 10,500 boreholes, 45,000 hand-dug wells and some dugouts (Kortatsi, 1994). Distribution of boreholes by region is presented in Table 11. The number of abstraction systems increased to 71,500 in 2000 and comprised of 11,500 boreholes and 60,000 hand-dug wells (Dapaah-Siakwan and Gyau-Boakye, 2000). Currently, the number of boreholes in the country is over 15,000 (Gyau-Boakye et al., 2008) and the number of hand-dug wells have increased but there is yet to be an update of the figure. Boreholes abstract water from deep aquifers and are found in use in several areas in Ghana though the cost involve limit their usage. They are most used for abstracting groundwater from deep aquifers purposely for domestic uses. Boreholes are normally fitted with hand pump or motorized pump in the case where water is lifted into overhead water storage tank and supplied to homes for domestic uses. The types of hand pump commonly found in the country include Afridev, Ghana-modified India mark II and Nira. Most boreholes have been drilled through one project or the other for community use but few private organizations and very few individuals have drilled their own boreholes.

Hand-dug wells are cost effective structures for extracting shallow groundwater. They are used extensively as traditional water supply systems in many rural and urban communities throughout the country. There is limited data on the yields of hand-dug wells in the country, except for the Volta region (Extreme east of Ghana) where inventory of hand-dug wells has been documented in a study (Kortatsi, 1994a). Data from the study show that yields of hand-dug wells vary from 0 m^3/day to 26 m^3/day with an average of 6 m^3/day.

Assuming an average borehole yield of 5 m^3/h for the country (average of the averages in all the hydrogeologic provinces – See Table 10b), and 6 hrs of pumping per day (Authors' survey in northern Ghana in June 2010), the annual volume of groundwater abstracted by means of boreholes as of 2000 is estimated to be 126 million m^3. Similarly, the annual volume of groundwater abstracted from hand-dug wells as of 2000, based on an average yield of 6 m^3/day, is about 131 million m^3. The two together gives a total volume of 257 million m^3.

Table 11: Distribution of boreholes by region as at 1994 (Kortatsi, 1994a)

Administrative region	**Number of hand-dug well**
Northern	1350
Brong Ahafo	855
Ashanti	1310
Western	700
Volta	1140
Eastern	950
Upper West	1350
Central	925
Upper East	1680
Greater Accra	210
Ghana	**10,470**

3.4.2 Groundwater use for domestic water supply

Generally, groundwater usage is determined by the quantity available, the demand, the quality of the water and the unavailability of other alternatives. For various reasons including low yield of boreholes and the relatively good quality of groundwater compared to surface sources, groundwater abstracted from boreholes in 9 of the 10 administrative regions of the country (exception Greater Accra region) is exclusively used for domestic water supply. It is estimated that over 95% of groundwater use in the country is for domestic purposes (Gyau-Boakye et al., 2008). Data from the latest population census in 2000 reveal that groundwater sources (mainly boreholes and hand-dug wells) constitute 33% of the main sources of drinking water supply in Ghana (GSS, 2002). Table 12 gives information on the ratio of dependency on groundwater resources for domestic use by administrative region in 1994.

Rural areas and small towns are the major users of groundwater. As of 2004, portable water supply coverage in rural communities and small towns from groundwater sources is estimated to be 41% (CWSA *cited* in Dapaah-Siakwan and Darko, 2004). Martin and van de Giesen (2005) have reported that 11 of the 20 towns on the Ghana side of the Volta Basin, each with population of over 10,000 inhabitants, depend exclusively on groundwater for domestic water supply.

About 50% of the total number of hand-dug wells in the country is used solely for drinking water supply and about 66% is used for both drinking and other domestic purposes (Kortatsi, 1994b). The rest are used for irrigation and watering of livestock. In many communities, hand-dug wells are unprotected and easily get polluted.

Table 12: Dependency by region on groundwater supply for domestic use in 1994 (Sources: Gyau-Boakye and Dapaah-Siakwan, 1999; Authors' estimates)

Region	Regional Population (A)	Source of groundwater supply by population				Groundwater Dependency* (%)
		Borehole	Well	Dug-out	Total (B)	
Western	1,157,807	196,582	134,661	17,343	348,586	30.1
Central	1,142,335	146,800	129,502	31,358	207,660	18.2
Greater Accra	1,431,099	9,135	65,063	21,847	96,045	6.7
Eastern	1,680,890	248,232	224,463	80,596	553,291	32.9
Volta	1,211,907	130,609	232,033	36,110	398,752	32.9
Ashanti	2,090100	381,192	136,332	30,489	548,013	26.2
Brong Ahafo	1,206,608	103,458	146,439	57,187	307,084	25.5
Northern	1,164,583	23,203	207,009	100,613	330,825	28.4
Upper West	438,008	298,482	7,421	20,272	326,175	74.5
Upper East	772,744	491,177	86,982	15,206	593,365	76.8

*Groundwater dependency ratio = (A)/(B)

3.4.3 Groundwater use for irrigation

The use of groundwater for irrigation of crops and livestock and poultry watering is limited in Ghana. Data on the extent (area cultivated and number of farmers involved) of irrigation from groundwater sources is scanty. Generally, less than 5% of annual groundwater usage is attributed to irrigation and watering of livestock and poultry. Abstraction of groundwater for irrigation is usually done with hand-dug wells or dugouts that tape water from shallow aquifers though there are few mechanized boreholes used by commercial farmers. Groundwater irrigators are mostly small-scale farmers who produce vegetables like cabbage, spring onions, carrots, tomatoes, green pepper, okra and shallots on small plot sizes for readily available markets in nearby cities and towns.

Throughout the country, the use of shallow groundwater for irrigation is prevalent in the Volta, Upper East and Upper West Regions and the Accra Plains in the Greater Accra Region. In the Keta Basin in the southeast of the Volta Region, more than 60% of the shallow hand-dug wells drilled in the recent sands are used solely for irrigation. These wells have depth ranging from 1 m to 5 m and are spaced less than 100 m apart. The abstraction rate of wells in this area varies from 1.0 m^3/day to 22.6 m^3/day with an average rate of 2.7 m^3/day (WRRI/DANIDA, 1993). Water lifting devices including Ropes/buckets and low powered irrigation pumps are used to draw water from these wells to irrigate shallots and other vegetables on average farm sizes ranging from 0.08 ha to 1.5 ha on year round basis (Agodzo etal., 2003).

In the Upper East and Upper West Regions, hand-dug wells and dugouts are used to extract groundwater from alluvial channels along the courses of ephemeral streams during the dry season for vegetable production. Water is lifted from wells and dugouts by manual means using buckets and watering cans to irrigate between 0.04 and 0.1 ha vegetable farms (Kortatsi, 1994b). Laube et al, (2008) estimated that about 100-200 ha of land are cultivated in the dry season with groundwater by small-scale farmers in the Atankwidi-Anayare catchment area in the Upper East Region. Farmers using buckets for irrigation cultivate average plot size of 600 m² (0.06 ha), while those using pumps farm average plot size of 2000 m² (0.2 ha). Lands put under groundwater irrigation in this catchment are usually those along rivers or in floodplains where the groundwater table is high enough to allow easy access to the shallow groundwater.

Data from survey done by Laube et al (2008) revealed that, in 2006, groundwater irrigators in the Atankwidi-Anayare catchment area who apply water using buckets made an average profit of more than 150 Ghana Cedis (about 108 USD, based on August 30th 2010 exchange rate) from their farms while irrigators who use water pump made considerably more that 550 Ghana Cedis (about 393 USD). Some groundwater irrigators are full time farmers in the rainy season but many of them are employed in other sectors and therefore profits from groundwater irrigation are considered additional income. This additional income is substantive since according to GSS (2002b), more than 80 % of the population of the Upper East Region has an overall income below the official poverty line of 90 Ghana Cedis. It is only reasonable to conclude that, groundwater irrigation is one of the good adaptation strategies for overcoming poverty in the Upper East region.

In the Accra plains, about 70% of the boreholes were drilled for agricultural purposes and 33% are actually being used for irrigation (Kankam-Yeboah, 1987). Irrigation is limited to watering moderate to high salt tolerate vegetables such as cabbage, onion, tomatoes and carrot. A pilot groundwater irrigation project carried out in the Accra plains realised crop yields of 5 t/ha and 3 t/ha for cabbage and onion respectively. This compares well with the 5-8 t/ha and 2-5 t/ha for cabbage and onion grown in Ghana under similar agronomic practices but under more favourable climatic conditions and irrigation by river water (Andah, 1993).

Groundwater is used for growing leafy vegetables in urban and peri-urban areas of Accra, Kumasi, Tamale and Takoradi. Cornish and Aidoo (2000) reported on a study in agriculture in the peri-urban areas of Kumasi that 50% of 410 vegetable farmers interviewed mentioned that they irrigate their crops with shallow groundwater abstracted via dugouts some time during the crop season. The dugouts are shallow excavations of 1 to 2 m deep and about 1.5 m in diameter. The groundwater irrigators cultivate an average farm size of 0.9 ha.

3.4.4 Livestock watering

The watering of livestock with groundwater is much done in the Upper East, Upper West, Northern and Greater Accra regions. In the Northern, Upper East and Upper West regions, animals are not restricted but are allowed to range in search of food and water. Watering troughs are constructed between 5 and 10 m from boreholes. Spillways are constructed from the drainage aprons of the borehole to the watering troughs. Spilled water from the boreholes collect in these troughs for use by livestock mainly goat, sheep, cattle and pigs. About 70% of Ghana's 1.34 Million Heads (MH) cattle (2003 estimated figure) and 40% of other livestock and poultry (sheep-3.02 MH; goats-3.56 MH; pigs-3.03 MH; and poultry-2.64 MH) are produced in these 3 regions and are watered exclusively using groundwater (MOFA, 2004; Kortatsi, 1994b).

3.4.5 Industrial uses of groundwater

Industrial use of groundwater in Ghana is very recent but the interest to do so is steadily rising. A number of boreholes have been drilled purposely for the large scale commercial bottled water industries in the south of the country (Gyau-Boakye et al., 2008). Previous investigation on groundwater uses in the Densu Basin in the south of the country revealed that all the major commercial bottled water industries in Ghana got their water supplies from groundwater sources in the Densu basin and that industrial uses of groundwater constituted about 85% of all groundwater uses in the basin (Darko et al., 2003).

3.5 Aquifer recharge

The quantification of groundwater recharge is a basic prerequisite for efficient and sustainable management of groundwater resources. For example, values of recharge are needed to estimate the sustainable yield of groundwater aquifers and the knowledge of sustainable yields are essential for rational and sustainable exploitation of the groundwater resource (Sanford, 2002; Sophocleous and Schloss, 2000). Recharge estimates are influenced by factors such as rate and duration of precipitation or irrigation, the antecedent moisture condition, geology, soil properties, the depth to water table, aquifer properties, vegetation and land use, topography and landform (Lerner et al., 1990).

Recharge to all the aquifer systems in Ghana is mainly by direct infiltration of precipitation through fractured and fault zones along the highland fronts and also through the sandy portions of the weathered zone (Kortatsi, 1994). Some amount of recharge also occurs through seepage from ephemeral stream channels and pools of accumulated runoff during the rainy seasons. Though there is some contribution from regional aquifers, the source of recharge to the aquifers in Ghana, particularly aquifers in north of the country is mainly precipitation (Obuobie, 2008; Martin, 2006). Groundwater hydrographs for more than 15 monitored wells in the Upper East Region give some indication that the groundwater system in the country is active and it is affected by significant recharge and discharge on an annual cycle (Obuobie, 2008). Recharge values in Ghana are generally low and characterized by high spatial and temporal variability. Low recharge values are typical of semi-arid areas where evapotranspiration dominates the water balance.

Available data on groundwater recharge for specific locations in the country are summarised in table 13. The recharge values in table 13 have been estimated using various methods including water balance, chloride mass balance, water table fluctuation and hydrological modelling. Based on data in table 13, the recharge for the country generally varies from 1.5% to 19% of the annual rainfall

Table 13: Groundwater recharge for specific areas in Ghana (Modified from HAP, 2006)

Study area	**Region**	**Rainfall (mm)**	**Recharge (% Rainfall)**	**Source**
Atankwidi River Basin	Upper East	910-1,138	4-13	Martin (2006)
Southern Voltaian Sedimentary Basin	Eastern	1,400	12	Acheampong (1996)
Pra River Basin	Ashanti, Eastern and Central	1,170-1,490	3.9*	Darko and Krasny (2003a)
Volta River Basin	Mostly all the Central and Northern	1,002	5*	Friesen et al. (2005)
Northeastern Ghana	Upper East	990	3-16	Obuobie et al. (2010)
White Volta Basin	Upper East, Upper West and Northern	824-1,294	2.5-19	Obuobie (2008)
	Upper East	1,233	8	Acheampong (1988)
Tamale, Yendi, Bole	Northern	1069-1192	2.5-11.2	Carrier et. al. (2008)
Wa	Upper West	1007	1.5	Carrier et. al. (2008)
Navrongo	Upper East	987	6.6	Carrier et. al. (2008)

NB: *Net recharge inside the basin was considered equal to discharge of groundwater across basin boundary (i.e. baseflow).

4.0 GROUNDWATER QUALITY

Available data from previous studies (e.g., Amuzu, 1975; Andah, 1993; Kortatsi, 1994; WARM, 1998; Darko *et al*, 2003) indicate that the quality of groundwater abstracted via boreholes in Ghana is generally of good chemical and microbiological quality and therefore suitable for domestic including drinking, agriculture and industrial uses (See table 14). There are, however, groundwater quality problems in certain localities. The problems include low pH (3.5-6.0) waters found mostly in the forest zones of southern Ghana, high concentration of iron in many places throughout the country, high concentration of manganese and fluoride mostly in the north of Ghana as well as high mineralization with TDS in the range 2000-14,584 mg/l in some coastal aquifers (Kortatsi, 1994). Most of these problems can be attributed to geochemical processes taking place in the bedrock of aquifers, anthropogenic activities or sea water intrusion in the case of high concentration of sodium chloride in coastal aquifers. A summary of potential groundwater quality problems in Ghana are presented in table 15.

4.1 pH

As mentioned earlier on, Ghana is dominantly underlain by crystalline basement rocks of Precambrian age. The groundwater associated with crystalline rocks is aggressive, usually acidic in composition ($pH < 7.0$) and have low values of salinity and total hardness (Langenegger, 1994). The pH of groundwater in the Upper Regions of northern Ghana was measured by Pelig-Ba (1998) to be in the range 5.20 - 8.06 with an average of 7.11. This average pH value is well within the range 6.5-8.0 recommended by the World Health Organization (WHO, 2004). In the Densu basin in the south of the country, the median of pH values obtained for groundwater ranged from 6.40 to 6.70 (Tay and Kortatsi, 2008). Though majority of the 68 wells sampled in the Densu basin had pH values higher than 6.5, groundwater in a significant number of the wells could be described as acidic with pH values less than 6.0. This was attributed to anthropogenic processes such as excessive use of ammonia and manure as fertilizers in farming activities. There is no direct health hazard related to the pH of water (HAP, 2006).

4.2 Iron (Fe) and Manganese (Mn)

A major groundwater quality problem in Ghana is the presence of high concentration of iron in nearly all geological formations in the country. High iron concentrations are normally associated with acidic or anaerobic groundwater. According to Ayibotele (1985), about 30% of all boreholes in Ghana have iron problem. High iron concentrations in the range 1-64 mg/l have been observed in boreholes in all aquifers in the country (WARM, 1998). Pelig-Ba (1998) reported an average Fe concentration of 0.825 mg/l in a study conducted in the Upper Regions of Ghana. In a study conducted in the Oyibi area of the Greater Accra Region in the south of Ghana, Fe concentrations as high as 57 mg/l where found in groundwater in some boreholes. Fe concentrations in the Precambrian basement formation in the Volta Region of Ghana are high, generally ranging from 0.3 mg/l to 4.2 mg/l but with some concentrations as high as 40 mg/l (Gill, 1969). The high concentrations of Fe in groundwater in Ghana have been partly attributed to the bedrock of aquifers as they have relatively high iron proportion (approximately 6%) and partly to corrosive pump parts as a result of the attack of low pH waters on those parts.

Manganese often occurs with Fe. However, the concentrations of Mn in groundwater in the country are much lower compared to Fe. Concentrations significantly above the WHO recommended limit of 0.1 mg/l for drinking water supply are found in several localities. In a study conducted in the Densu basin (Tay and Kortatsi, 2008), groundwater samples analyzed from 17 of the 68 communities have Mn concentrations above 0.2 mg/l.

High Fe and Mn concentrations in water do not have any direct health hazard for humans. However, concentrations above WHO recommended limits of 0.3 mg/l for Fe and 0.1 mg/l for Mn can cause decolourization of the water which in turn can result in staining of laundry and sanitary wares (WHO, 2004).

4.3 Fluoride

High fluoride concentrations in groundwater occur mostly in the Upper Regions of northern Ghana where the geology is dominated by granite. High fluoride concentrations in the range of 1.5-5.0 mg/l have been found in boreholes situated in granitic formations in the Upper East and West Regions (Pelig-Ba, 1989). In the Bolgatanga and Sekoti areas of the Upper east Region, Smedley et al. (1995) reported fluoride concentration in excess of the WHO (2004) guideline value of 1.5 mg/l with up to 3.8 mg/l in some boreholes. High fluoride concentrations are attributed mostly to the dissolution of mineral fluorite in a type of granite locally known as the Bongo granite (HAP, 2006). Other minerals such as apatite and some mica are known to contribute to the fluoride problem. In a groundwater study in the Upper East Region, Smedley et al. (1995) observed significant variation in fluoride concentration with depth in groundwater from the Bongo granite in the Bolgatanga area. Groundwater from shallow hand-dug wells was noted to have much lower fluoride concentrations compared to groundwater from boreholes due to dilution by recent recharge. Excess fluoride in drinking water (> 2.0 mg/l) can result in dental fluorosis and concentrations above 5.0 mg/l can cause skeletal fluorosis.

4.4 Arsenic (As)

The problem of high levels of As in groundwater is not widespread but a localized situation often found in gold mining areas. Arsenic comes mainly from arsenic-bearing minerals such as arsenopyrite and pyrite that occur in close association with gold (Smedley et al., 1995). In a study of As in groundwater samples taken from the gold mining areas in Obuasi in the Ashanti Region and the Bolgatanga area in the Upper East Region, Smedley et al (1995) reported few samples having concentrations above the WHO guideline value of 0.01 mg/l (WHO, 2004). As concentrations in the 78 samples taken from the Obuasi area ranged from < 0.001 mg/l to 0.064 mg/l. Fourteen of the samples, representing (18%) had concentrations > 0.01 mg/l. In the Bolgatanga area, As concentrations in water samples (a total of 118 samples) ranged from <0.001 mg/l to 0.141 mg/l. Only 2 of the samples (less than 2%) hand concentrations above the WHO guideline value.

4.5 Nitrate (NO_3-N)

Nitrate problems are mostly associated with the shallow groundwater, which is taped in hand-dug wells or dugout. In many hand-dug wells throughout the country, the groundwater looks turbid and polluted as they contain high levels of nitrate in the range of 30-60 mg/l and abundant coli form (Kortatsi, 1994). The WHO guideline value for nitrate is 50 mg/l (WHO, 2004). High nitrate concentrations have been found in shallow groundwater mostly near towns and villages and could have originated from anthropogenic sources including improper sitting of sanitation facilities and inadequate protection of well from contamination from surface runoff and animal droppings.

Table 14: Summary of water quality in geological formations of Ghana (Kortatsi, 1994)

	Gneiss	Granite	Phyllites	sandstone	Mudstone and shale	Sand and gravel	Limestone	Quartzite
pH	7.50	6.99	6.83	6.95	7.64	7.53	7.70	6.36
Total dissolved salts	4888.00	387.38	211.19	533.45	424.66	632.04	932.04	398.26
Calcium	595.00	49.38	32.09	25.08	26.10	68.72	58.08	42.05
Magnesium	207.20	19.06	15.67	7.57	9.12	33.50	36.14	23.37
Sodium	720.00	47.99	11.67	262.55	125.39	134.45	296.77	24.53
Chloride	1790	73.48	9.90	70.42	42.04	173.56	196.86	103.61
Sulphate	1800	10.60	7.16	65.17	11.18	101.19	77.25	60.06
Bicarbonate	34.00	81.17	104.14	97.49	189.29	154.59	149.66	67.05
Total iron	0.10	1.01	2.15	1.95	0.65	1.84	0.47	2.87
Manganese	0.05	0.44	0.39	0.17	0.10	0.22	0.16	0.45
Fluoride	0.25	0.35	0.32	0.78	0.57	0.60	1.76	0.23
Nitrate nitrogen	0.50	1.61	0.59	0.75	0.14	2.22	1.79	2.32
Total hardness	2340	172.49	123.70	70.76	222.77	230.35	229.94	179.61

NB: all values except pH are in mg/l

Table 15: Summary of potential groundwater-quality problems in Ghana (BGS)

Determinand	**Potential Problems**	**Geology**	**Location**
Iron	Excess, often significant	All aquifers	Many locations
Manganese	Excess	All aquifers	Several locations
Flouride	Excess (up to 4 mg/l)	Granites and some Birimian rocks	Upper Regions
Iodine	Deficiency (less than 0.005 mg/l)	Birimian rocks, granites, Voltaian	Northern Ghana (especially Upper Regions)
Arsenic	Excess (>0.01 mg/l)	Birimian	Especially south-west Ghana (gold belt)

5.0 COSTS OF GROUNDWATER DEVELOPMENT IN GHANA

In sub-Saharan Africa, the cost of constructing boreholes and wells are generally high, compared to China and India. The high cost has been attributed to factors such as (i) lack of economy of scales and competition in well construction, due to absence of a large private-sector market for domestic and irrigation wells (ii) high excise duties on imported drilling equipment and pumping plant, and no significant local manufacture even of spares (iii) corruption in the letting and execution of well drilling contracts and (iv) inappropriate well design and excessive drilling depth for some hydrogeological conditions (World Bank, 2006). In many of the countries in sub-Saharan Africa, high initial cost is one of the major set backs to the development of groundwater for the purpose of achieving the MDGs and for poverty reduction. Cost of more than 5,000-15,000 USD per well in sub-Saharan Africa have been reported in literature (World Bank, 2006).

The cost of developing a typical borehole in Ghana varies due to many factors including the type of pump installed. A typical cost estimate includes the cost of geophysical exploration, drilling of the borehole, pumping test, water quality test, pump acquisition and installation For the same type of geologic formation, the cost of a borehole fitted with a submersible pump ranges between USD 6,300 and USD 9,000. For a borehole fitted with a hand-pump, the cost ranges between USD 7,000 and USD 8,000. The breakdown of each of the major cost components are presented in the sections following. The figures provided are averages of figures from several drilling companies in Ghana, notably FBB Drilling and Country Drilling companies.

5.1 Cost of geophysical exploration

A geophysical exploration for groundwater involves looking for the presence of suitable aquifers and finding the best place for boreholes and wells from the standpoint of occurrence, quantity, quality and depth to groundwater. A typical geophysical exploration may involve resistivity and EM profiling, and Vertical Electrical Sounding (VES). The cost of geophysical survey, as of 2004, was quoted by a private company, FBB Drilling Company, to be about 2,000 USD for an alternative borehole. Average cost of geophysical exploration in 2010 is about 7 USD/m for resistivity/EM profiling and 143 USD per point for VES.

5.2 Cost of Borehole Drilling

For drilling purposes, a typical borehole in Ghana has a maximum depth of 60 m and a diameter of 140 mm. The cost components of Borehole drilling are drilling (including mobilization and demobilization), construction (mainly installing screens and pipes) and development (washing borehole to obtain clean water) of the borehole.

The average cost of drilling a borehole of 60 m deep and 140 mm diameter including pumping test is 3,500 USD (Table 16). Pumping test consists of 6 hours continuous pumping and 4 hours of recovery.

Table 16. Average cost for a typical borehole (depth: 60 m; diameter: 140 mm) in 2010

Particulars	**Cost (USD)**
-Borehole drilling and construction in any type of rock including borehole development (additional drilling cost 14 USD per meter)	3,215
-Pumping test	285
Total	**3,500**

Source: William Agyekum (Groundwater Division, CSIR-Water Research Institute), 2010. Figures are based on data from several drilling companies

5.3 Cost of pump and installation

Boreholes that are used for domestic water supply in Ghana are fitted with either a submersible pump or a hand-pump. Commonly used submersible pumps are the Pedrollo and Grundfos pumps and more recently China made pumps (Agyekum, 2010, personal communication). Grundfos is the most expensive and cost on average, about 3,200 USD. The Pedrollo pump is an Italian made pump and cost about 1,450 USD. The most common China made pump, Donyin pump, cost about 450 USD and is available in 1 and 1.5 horse powers. The 1 horse power Donyin pump draws water from a maximum depth of 90 m and the 1.5 can pump water from a depth upto 120 m.

The cost of installing each of these pumps cost about 180 USD (William Agyekum, 2010: personal communication). Average cost of installing a submersible pump is 180 USD. Aside the submersible pumps, a number of hand operated pumps are used for lighting water. The most widely used pumps and their associated costs are listed in Table 17.

Table 17. Average cost of Hand-pumps in 2010

Type of hand-pump	**Price (USD)**
Modified India Mark II with all accessories (depth: 30-35 m)	1,785
Nira (depth: 50-60 m)	2,100
Afridev with all accessories (depth: 30-35)	1,285
Cost of installation	100

Source: Average market prices as at July, 2010.

5.4 Cost of shallow well

5.4.1 Shallow tube well

The washbore technique is extensively used in Ghana for the construction of shallow tube wells especially in the riverine alluvium along rivers (Sonou, 1997). With the washbore technique, water is pumped at high velocity into the upper end of a vertical pipe and as the pipe is lowered into the ground the water jet at the bottom end of the pipe washes away all soil material. The main cost factors considered in the construction of a shallow tube well are: (i) Capital and depreciation; (ii) Operating and maintaining the equipment; (iii) Performance i.e. number of wells constructed per year; and (iv) Success rate. The last two factors depend on training and experience gained by the construction team. In estimating the cost of constructing shallow tube wells, (Sonou, 1997) made the following assumptions: (i) method of construction is mud washbore; (ii) average depth of tube well is 10 m; (iii) 140 successful tube wells completed by each team per year; and (iv) overhead allowance as 50 percent of manpower costs. Based on the above, the unit estimate cost of tube well in Ghana, as of 1992, was 313 USD.

5.4.2 Hand-dug well

Inferring from Agodzo (2003) and Kortatsi (1995), the estimated cost of a hand-dug well in Ghana could be as low as 40 USD and as high as > 1,300 USD. Low cost of drilling wells has been reported in the Keta Basin where the geological formation is mainly sand and the water table is very high, making excavation not difficult.

5.5 Cost of water quality analysis

Analysis of groundwater quality is compulsory for every borehole that is constructed for drinking and domestic uses in Ghana. Water quality parameters that are usually analyzed in water for drinking purpose are physical and chemical (physico-chemical), and biological. The physico-chemical constituents are temperature, pH, total dissolved solids, total suspended solids, odour, turbidity, colour, sodium, potassium, calcium, magnesium, chloride, total hardness, nitrate-nitrogen, nitrite-nitrogen, total iron, ammonium-nitrogen, sulphate, manganese, fluoride, carbonate, bicarbonate, lead, cadmium, zinc, chromium, copper, cynide, and arsenic. The biological parameters are total coliforms, faecal coliforms, E.coli and total heterotrophic bacteria.

The total cost of a complete analysis of water for drinking purpose is about 205 USD per sample. The breakdown of this figure is given in table 18.

Table 18. Cost of water quality analysis in 2010

Type of analysis	Cost (USD)
-Physical-chemical	155
-Bacteriological	50
Total	165

Source: CSIR-WRI Laboratory (2010 prices)

5.6 Comparative cost of supplying groundwater and surface water for drinking purpose

Bannerman (1975) provides a comparative cost analysis of groundwater and surface water supplies to support the argument that groundwater offers a cost-effective way of supplying water for drinking and domestic purposes. Though this literature is already 35 years old and the figures have changed, the ratio of the cost of water supplies based on surface water sources to that of groundwater sources may largely hold for today.

The cost of a pre-assembled treatment plant of a capacity of 10 m^3 (2,000 gph) and a borehole of equal yield are 40,000 USD and 17,200 USD, respectively. Boreholes can be drilled very close to the place they serve but the intake structures for surface water treatment plants are on average located about 3.2 km from the site of the plant. The cost of conveying raw water to the treatment plant alone could cost between 11,500USD and 28,750 USD. This brings the total cost of surface water supply to a figure in the range of 51,000-68,000 USD. This amount could drill up to 4 boreholes with a total yield of 30-40 m^3/h (8,000-10,000 gph). Additional cost associated with surface water supplies is the operation and maintenance cost arising from the processes of coagulation and sedimentation due to high suspended solids. Groundwater is generally low in suspended solids and therefore the processes of coagulation and sedimentation are not necessary.

6.0 INSTITUTIONAL AND LEGAL FRAMEWORK

6.1 Institutions

The Government ministry responsible for the water sector in Ghana is the Ministry of Water Resources, Works and Housing. This ministry discharges its responsibility in the water sector through one of its departments known as the Water Directorate. Activities of the water Directorate are focused on overall water resources management and drinking water supply. It also oversees the activities of 3 key Agencies in the water sector, namely the Water Resources Commission, Ghana Water Company Limited, and Community Water and Sanitation Agency.

6.1.1 Water Resources Commission (WRC)

The Water Resources Commission (WRC) was established by an Act of Parliament (Act 522 of 1996) with the mandate to regulate and manage Ghana's Water Resources and co-ordinate government policies in relation to them. The Act stipulates that ownership and control of all water resources are vested in the President on behalf of the people, and clearly defines the WRC as the overall body responsible for water resources management in Ghana. The WRC is composed of the major stakeholders involved in the water sector and provides a forum for integration and collaboration of different interests. The responsibilities of WRC, which are spelt out in Section 2 (2) of the Act, can be categorized as (www.wrc-gh.org):

- Processing of water rights and permits;
- Planning for water resources development and management with river basins (catchments) as the natural units of planning
- Collating, storing and disseminating data and information on water resources in Ghana; and
- Monitoring and assessing activities and programmes for the utilisation and conservation of water resources.

As part of its monitoring responsibility, the WRC has been monitoring the quantity and quality of both surface and groundwater resources in the country in collaboration with the Water Research Institute of the Council for Scientific and Industrial Research (CSIR-WRI). The CSIR-WRI has the needed human capacity and equipments for the monitoring of water quantity and quality. With Grant from Development partners such as DANIDA and CIDA, the WRC has drilled a number of monitoring wells in the various river basins across the country and equipped them with automatic water level monitoring equipment (Pressure Tranducers) to record temporal and spatial variations in water levels. Most of the monitoring wells were drilled through one project or the other and the main challenge now is how to maintain them after the various projects come to an end as the commission does not have regular funds for such activities. Currently, WRC is discussing with stakeholders on how to overcome this difficulty.

The WRC has its Head office in Accra and 3 basin-based support offices at Bolgatanga in the Upper East Region, Tarkwa in the Western Region, and Koforidua in the Eastern Region. The office at Bolgatanga provides support for integrated water resources management in the White Volta River Basin; the Tarkwa office supports the Ankobrah basin and the Koforidua office supports the Densu Basin.

6.1.2 Ghana Water Company Limited (GWCL)

The Ghana Water Company Limited (GWCL) was established in 1999 as a state owned limited liability company with the responsibility to supply water in urban areas of Ghana. Before 1999, this organization was known as the Ghana Water and Sewerage Corporation (GWSC) established in 1965 under an Act of parliament (Act 310) as legal public utility entity (www.gwcl.com.gh). The GWSC was responsible for water supply and sanitation in rural as well as urban areas, conducting research on water and sewerage, making of engineering surveys and plans, construction and operation of water and sewerage works, setting of standards and prices and collection of revenues.

The GWCL exercises management functions over water sources that it abstracts for treatment and subsequent distribution to consumers. In some situation, it builds dams on which water supply schemes for big cities are based. It has the mandate to manage such water sources, including the relevant catchment areas.

6.1.3 Community Water and Sanitation Agency (CWSA)

The Community Water and Sanitation Agency is one of the agencies created as part of the restricting exercise in the water sector. It was established by an Act of Parliament, Act 564 in 1998 with a mandate to facilitate the provision of safe drinking water and related sanitation services to Rural Communities and Small Towns in Ghana. Since its establishment the CWSA has been facilitating the implementation of the so called National Community Water and Sanitation Programme (NCWSP) using the decentralized structures at the district and community levels as prescribed in the Act that brought the agency into being. The NCWSP is a strategic programme prepared in 1991 by the Government of Ghana for the rural water and sanitation sector with support from the water and sanitation sector institutions and external support agencies.

6.1.4 Collaborating Institutions

Since water resources have strong link with the environment, the Ministry of Water Resources, Works and Housing, together with the agencies under it, have strong collaboration with the Ministry of Environment, Science and Technology (MEST). Two important institutions under MEST that play important roles in the water sector are the Environmental Protection Agency and the Water Research Institute of the Council for Scientific and Industrial Research.

6.1.4.1 Environmental Protection Agency (EPA)

By virtue of its mandate and functions, the EPA is one of the institutions that are involved in some aspects of water resources management. Established in 1994, the EPA has the responsibility to ensure that water operations did not cause any harm to the environment. Among other things, EPA maintains and enforces standards for wastewater discharge into water bodies, and ensures, through the concept of Environmental Impact Assessment, that the negative impact of development projects are reduced. EPA has prosecuting powers to take offenders to court.

6.1.4.2 Water Research Institute (WRI)

The WRI was formed in 1996 from the merger of the Institute of Aquatic Biology and the Water Resources Research Institute, all part of the Council for Scientific and Industrial Research (CSIR). It has a mandate to conduct research into water and related resources. In pursuance of this mandate, it generates and provides scientific information, strategies and services towards the rational development, utilization and management of Ghana's water resources in support of the socio-economic advancement of the country, especially in the agriculture, health, industry, energy, transportation, education and tourism sectors. WRI has 5 technical divisions, namely, surface water, groundwater, fisheries and aquaculture, environmental chemistry, and environmental biology. WRI's role in the water sector is mainly to provide decision support for effectively and efficiently managing Ghana's water resources.

6.2 National Water Policy

Before the promulgation of the Water Resources Commission Act 522 of 1996, the institutional and legal framework for planning and managing Ghana's water resources were inadequate. Planning of the use of water resources were done at sectoral level without any coordination at the national level. Various aspects of the management of the freshwater resources were undertaken by different water agencies within the context of their institutional or established mandates to serve individual sectors of the economy. Most of the water agencies were unable to work efficiently and effectively due to inappropriate policies for water resources management, unclear definition of institutional mandates, inadequate or total lack of resources, lack of enabling environment, lack of institutional mechanism for monitoring, enforcing and prosecuting offenders, inadequate education and training facilities, and lack of community participation and commitment among others.

Prompted by the challenge of lack of a comprehensive water policy focusing on all aspects of water resources management and the need to integrated and harmonize the activities and interest of the key water stakeholders, the ministry of water resources, works and housing, together with stakeholders, initiated a broader consultation process in 2004 for the formulation of a national water policy (MWRWH, 2007). This policy was based on a draft policy prepared by the Water Resources Commission in 2002. The process yielded a national water policy document which was prepared in 2007. This policy is strongly based on the principles enunciated in the Ghana Poverty Reduction Strategy, the Millennium Development Goals and the "Africa Water Vision" of the New Partnership for Africa's Development (NEPAD) and contains sections on integrated water resources management (including water for energy, food security and transportation), urban and community/small town water delivery. The policy also highlights the international legal framework for the domestic and trans-boundary utilization of water resources (MWRWH, 2007).

The key principles within the policy that guide water resources management in the country are:

i. the principle of fundamental right of all people without discrimination to safe and adequate water to meet basic human needs;
ii. the principle of meeting the social needs for water as a priority, while recognizing the economic value of water and the goods and services it provides;
iii. the principle of recognising water as a finite and vulnerable resource, given it multiple uses;
iv. the principle of improving equity and gender sensitivity;
v. the principle of integrating water resources management and development with environmental management in order to ensure the sustainability of water resources in both quantity and quality;
vi. the precautionary principle that seeks to minimise activities that have the potential to negatively affect the integrity of all water resources;
vii. the principle of coordinating water resources planning with land use planning;
viii. the principle of adopting the river basin (or sub-basin) as a planning unit;

ix. the principle of polluter pays, to serve as a disincentive to uncontrolled discharge of pollutants into the environment;
x. the principle of subsidiarity in order to ensure participatory decision-making at the lowest appropriate level in society;
xi. the principle of solidarity, expressing profound human companionship for common problems related to water;
xii. the principle that international cooperation is essential for sustainable development of shared basins;
xiii. the principle of integrating river basin management with management of the coastal zones and wetlands; and
xiv. the principle of the greatest common good to society in prioritising conflicting uses of water.

6.3 Water laws and water rights

The major laws that guide the regulation and management of water resources in Ghana, including groundwater, are the Water Resources Commission (WRC) Act, (No. 522 of 1996), the Water Use Regulations Legislative Instrument (LI 1692 of 2001) and the Water Drilling License and Groundwater Development Regulations (LI 1827 of 2006). Before the Act and the two LI came into being, organisations and individuals wishing to abstract water for any use were not required to follow any procedure or seek any permission to do so. The granting of water use permit is considered a tool to regulate water abstraction and control pollution of water bodies in Ghana. Previous laws concentrated on surface water only. The WRC Act, which addresses water resources in its entirety, has filled the gap in the regulation of ground water use (www.wrc-gh.org).

According to section 12 of Act 522, "the property in and control of all water resources is vested in the President on behalf of, and in trust of the people of Ghana." This implies that there is no private ownership of water in Ghana, but the president, or anyone so authorised, may grant right for water use (www.wrc-gh.org). Through the enactment of the LI 1692 of 2001, the WRC is mandated to regulate and control the use of water resources, through granting of water rights and water use permits. Individuals, agencies and authorities may obtain a permit for surface water abstraction (for domestic, commercial, industrial and agricultural use); groundwater (for domestic, commercial, industrial and agricultural use); hydraulic works construction (diversion, damming, etc.); engaging in the business of drilling for water; hydro-power generation; water transportation, fisheries (aquaculture); recreational use, etc (www.wrc-gh.org). Water rights granted by the commission are not transferable except with a written approval of the Commission. Water right may also be suspended, varied or terminated in the public interest in which event compensation is payable to the holder of the right. Act 522 recognises all existing uses of water prior to the enactment of the Act. However, all existing claims to water uses not submitted to the commission within twelve months after the Act came into force are now extinguished.

Individuals, institutions, NGO's, agencies and authorities who are required to apply for water right and water use permit from the WRC include industries with their own water supply such as mineral water producers, breweries, fruit juice and soft drink factories, textile and paper factories, hospitals, the army, schools, prisons, churches, and farmers; persons and companies with motorised water pump which whether temporary or permanently pumps water from river/stream or a borehole; persons or companies (including road contractors and construction firms) who construct weirs, dams, tanks or other works capable of diverting or impounding water inflow of more than 5 l/s (432 m^3 in any period of 24 hours).

Categories of water use that are exempted from the requirement of permit include: preventive use of water for the purpose of fighting fire, and any water abstraction by manual means. For some water uses, even though exempted from permit requirements, have to be registered. These include water abstraction by mechanical means for use where abstraction level does not exceed 5 l/s and subsistence agriculture water use for land not exceeding 1 ha.

The LI 1827 of 2006 was enacted to regulate and ensure safe development of groundwater resources in the country through licensing of water drilling companies. This LI has two parts. The first part stipulates the processes for obtaining a drilling licence, including requirements on personnel and equipments while the second part deals with the details of the notification to the WRC on ones intention to construct water well. This LI grants exemption to communities and individuals who construct hand dug wells for domestic water supply.

6.4 Traditional Water Regulations

Apart from the statutory laws, there are customary laws and practices, which govern water in Ghana. These laws and practices cover water conservation, pollution control, protection of catchments and protection of fisheries. These are enforced through various sanctions usually dictated by fetish priests and priestesses. The laws are appropriate for small communities where traditional authority is strong but will not be applicable in urbanized settlements. It is difficult to identify any features of customary law which are common throughout the country beyond the priority given to water for domestic use. This priority is contained in existing statutes.

6.5 Integrated Water Resources Management

As part of strategy to ensure sustainable utilization and management of water resources in Ghana including trans-boundary water bodies and aquifers, the Water Resources Commission has adopted the process of integrated water resources management (IWRM) with the river basin as the unit for planning. Already, IWRM has been infused into the national water policy that was prepared in 2007. Currently, river basin IWRM plans are being developed to provide direction for the utilization and management of both surface and groundwater resources.

7.0 SUMMARY

The interest in groundwater use in Ghana is relatively recent, prompted by the realization that surface water resources have been unable to satisfy the water demand for socio-economic development everywhere in the country and the increasing concern about the health of the population. The need for irrigation as a result of the recent erratic pattern of rainfall coupled with the demand for increased agricultural production to feed the ever growing Ghanaian population has made it a necessity to diversify groundwater use to include dry season irrigation, livestock watering, fish farming, poultry, etc.

The hydrogeologic units of Ghana can be generally classified as (i) the basement complex (crystalline rocks), which covers about 54% of the country; (ii) the Voltaian system, which covers about 45%; and (iii) the Cenozoic, Mesozoic and Paleozoic sedimentary strata which underlie the remaining 1% of the country. In terms of aquifer type, the basement complex and the Voltaian system (99% coverage of Ghana) have virtually no primary porosity with average yield of boreholes ranging from 2.7-12.7 m^3/h and 6.2-8.5 m^3/h respectively. Average thickness of these aquifers range between 10 and 60 m. Borehole yields in the remaining 1% of the country range from 3.9-15.6 m^3/h. Groundwater recharge is generally low and the source is mainly rainfall. Based on available data, recharge varies from 1.5% to 19% of the annual rainfall.

Groundwater is abstracted from all the geological formations in the country. Currently, there are over 75,000 abstracting systems all over the country. These are made up of > 15,000 boreholes, and > 60,000 hand-dug wells and some dugout. About 95% of all groundwater uses in the country is for domestic purpose including drinking. About 50% of the total number of hand-dug wells is used for drinking purpose while about 66% are used for both drinking and other domestic purposes. Less than 5% of groundwater uses in the country is attributed to irrigation of vegetables and livestock watering mostly in the Volta Region, Upper East, Upper West, and Greater Accra Regions

The quality of groundwater in Ghana is generally good for multi-purpose use except for the presence of low pH (3.5-6.0) waters, high iron concentration (ranging 1-64 mg/l), manganese and fluoride in certain localities as well as high mineralization with TDS in the range 2000-14,584 mg/l in some coastal aquifers particularly in the Accra plains. About 30% of all boreholes in the country have iron problems. This has been attributed to high iron concentration in bedrock aquifer and corrosive pump parts as a result of the attack of low pH waters.

The cost of construction of a typical borehole in Ghana (depth: 60 m; diameter: 140 mm) ranges between USD 6,300 and USD 9,000 for a borehole fitted with submersible pump. For a borehole fitted with a hand-pump, the estimated cost ranges between USD 7,000 and USD 8,000. Hand-dug well and shallow tube well cost about 313 USD and 40 - 1,300 USD, respectively. Compared to India and China, the cost of groundwater development in Ghana is very high. However, compared to the cost of water supplies from surface water sources, groundwater is less expensive and has other additional advantages.

Ghana now has a national water policy, which is underpinned by the principles in the Ghana Poverty Reduction Strategy, the Millennium Development Goals and the “Africa Water Vision” of the New Partnership for Africa’s Development (NEPAD). The policy gives direction for sustainable development, management and use of water resources in the country. The Water Resources Commission, under the Water Directorate of the Ministry of Water Resources, Works and Housing, has the overall responsibility of the water sector of Ghana. The regulation and management of Ghana's water resources including groundwater is guided by the Water Resources Commission (WRC) Act, (No. 522 of 1996) and the Water Use Regulations Legislative Instrument (LI 1692 of 2001). The granting of water use permit is considered a tool to regulate water abstraction and control pollution of water bodies in Ghana.

REFERENCES

Acheampong, S.Y., 1996. *Geochemical evolution of the shallow groundwater system in the Southern Voltaian Sedimentary Basin of Ghana*. PhD dissertation, University of Nevada, Reno.

Acheampong P.K., 1988. Water balance analysis for Ghana. Geography 73 (2): 125-131

Agodzo, S.K., 2003. Shallow well irrigation for shallot farming in the Keta Lagoon Area of Ghana. *Journal of the Ghana Institution of Engineers*. Volume 1, Number 1:pp1-6.

Agodzo, S.K., Huibers, F.P., Chenini, F., van Lier J.B., Duran, A., 2003. Use of wastewater in irrigated agriculture. Country studies from Bolivia, Ghana and Tunisia. Volume 2: Ghana. Wageningen: WUR-(W4F-Wastewater).-ISBN 90-6754-704-2.

Agyekum, W.A., 2004. *Groundwater resources of Ghana with the focus on international shared aquifer boundaries*. UNESCO-ISARM International Workshop – Managing shared aquifer resources in Africa. B. Appelgreen. Tripoli, Lybia, June 2002. United Nations Educational, Scientific and Cultural Organisation, IHP-VI Series on groundwater no.8, 600 p.

Amuzu, A. T., 1975. *A survey of the water quality of the River Densu*. WRRI Technical Report. Accra, Ghana.

Andah, A.I., 1993. *Groundwater Utilization for small-scale Irrigation in the Accra Plains: Kponkpo and Ablekuma pilot schemes*. Water Resources Research Institute (C.S.I.R). Accra, Ghana.

Andah, E.I., van de Giesen, N., Biney, C.A., 2003. Water, climate, food, and environment in the Volta Basin. Adaptation strategies to changing environments. Contribution to the ADAPT project. http://www.weap21.org/downloads/ADAPTVolta.pdf.

Apambire, W.B., 1996. *Groundwater geochemistry and the genesis and distribution of groundwater fluoride in the Bolgatanga and Bongo districts, Ghana*. MSc Thesis. Carleton University, Ottawa, Ontario, Canada.

Apambire, W.B., Boyle, D.R., Michel, F.A., 1997. Geochemistry, genesis and health implications of fluoriferous groundwaters in the upper regions of Ghana. *Environmental Geology* 33 (1) : 13-24.

Ayibotele, N. B., 1985. *Development and management of groundwater resources in Ghana — some current problems*. Lecture IV, 2nd International Advanced Course on Water Resources Management, Centre for International Studies, Perugia, Italy.

Bannerman, R.R., 1975. The role of groundwater in rural water supplies in Ghana. *Hydrological Sciences Bulletin*, 20, 191-201.

BGS-British Geological Survey. Groundwater quality: Ghana. Accessed on March 12, 2010 at https://www.wateraid.org/documents/ghanagw.pdf

Barry, B., Obuobie, E., Andreini, M., Andah, W. and Pluquet, M., 2005. The Volta river basin. Comprehensive assessment of water management in agriculture. Comparative study of river basin development and management. Available at http://www.iwmi.cgiar.org/assessment/research_projects/river_basin.

Benneh, G., Agyepong, G.T., Allotey, J.A., 1990. *Land degradation in Ghana*. Food production and rural development division. Commonwealth Secretariat, Marlborough House. Pall Mall. London

Carrier, M.A., Lefebvre, R., Racicot, J., Asare, E.B, 2008. Access to sanitation and safe water : Global partnership and local actions. Northern Ghana Hydrogeological Assessment Project. 33rd WEDC International conference, Accra, Ghana. Pp 353-361. Accessed in May, 2010 at http://wedc.lboro.ac.uk/resources/conference/33/Carrier_MA_GHA.pdf

CIA, 2010. World Factbook. Available at http://globaledge.msu.edu/ibrd.

Cornish, G.A., Aidoo, J.B., 2000. *Informal Irrigation in the peri-urban zone of Kumasi, Ghana: Findings from an initial questionnaire survey*. Report OD/TN 97. HR Wallingford, UK.

Dapaah-Siakwan, S., Gyau-Boakye, P., 2000. Hydrological framework and borehole yields in Ghana. *Hydrogeology Journal* (2000) 8:405-416. Springer-Verlag.

Darko, P.K., Dua, A.A., and Dapaah-Siakwan, S. 2003. *Groundwater Assessment: An element of integrated Water Resources Management: the case of Densu River Basin*. Technical Report for the Water Resources Commission, Accra, Ghana.

Darko, P.K., Krasny, J., 2003a. *Quantitative limits for groundwater exploitation under natural conditions in southwest Ghana*. Proceedings of the IAH International Conference on Groundwater in fractured rocks, Czech Republic, Sept. 2003, p. 141-142.

Darko, P.K., Krasny, J., 2003b. Regional transmissivity distribution and groundwater potential in hard rocks of Ghana. *Proceedings of the IAH International Conference on Groundwater in fractured rocks*, Czech Republic, Sept. 2003, p. 45-46.

Falkenmark, M., Lundqvist, J., Widstrand, C., 1989. Macro-scale water scarcity requires micro-scale approaches: Aspects of vulnerability in semi-arid development, *Natural Resources Forum* 13 (4): 258-267.

FAO, 2003. Aquastat: information system on water and agriculture. Ghana, version 2003. Available at ftp://ftp.fao.org/agl/aglw/aquastat/aquatat2003.xls

FAO, 2005. Aquastat: information system on water and agriculture. Ghana, version 2005. Available at http://www.fao.org/nr/water/aquastat/countries/ghana/index.stm

FAO, 2004. Gateway to land and water information: Ghana national report. Food and Agriculture Oorganization's Land and Water Development Division, on-line resource. Available at http://www.fao.org/ag/agl/swlwpnr/swlwpnr.htm.

Friesen, J., Andreini, M., Andah, W., Amisigo, B., Van De Giesen, N., 2005. *Storage capacity and long-term water balance of the Volta Basin, West Africa*. IAHS Publication no. 296: 138-145.

Geological Survey of Ghana, 1969. Geological Map of Ghana. Survey of Ghana, Accra, Ghana

Gill, H.E., 1969. *A ground-water reconnaissance of the Republic of Ghana, with a description of geohydrologic provinces*. US Geological Survey Water-Supply paper 1757-K.

GSS (2002a). 2000 Population and Housing Census. Special Reports on 20 Largest Localities. Ghana Statistical Service, Accra.

GSS, 2002b. 2000 Population and Housing Census. Summary Report of Final Results. Ghana Statistical Services, Accra.

Gyau-Boakye, P., Dapaah-Siakwan, S., 1999. *Groundwater: solution to Ghana's rural water supply industry?* Water Resources Research Institute, Accra, Ghana.

Gyau-Boakye, P., Kankam-Yeboah, K., Darko, P.K., Dapaah-Siakwan, S., and Duah, A.A., 2008. Groundwater as a vital resource for rural development: An example from Ghana. *In*: S. Adelana, A. MacDonald, T.A. Alemayehu and C. Tindimugaya, eds. *Applied groundwater studies in Africa, IAH selected papers Q3 on hydrogeology*. vol. 13.

HAP, 2006. Hydrological assessment of the Northern Regions of Ghana: A bibliographical review of selected papers. CIDA, WRC, SNC-LAVALIN International.

Kankam-Yeboah, K., 1987. *Status Report on the pilot scheme in Groundwater Utilization in the Accra plains*. WRRI-CSIR Accra, Ghana.

Key, R.M., 1992. An introduction to the crystalline basement of Africa. *In : The hydrogeology of crystalline basement aquifers in Africa*, E.P., Wright, W.G., Burgess. Geological Society Special Publication 66: 29-57.

Kortatsi, B.K., 1995. A consultancy report on preliminary groundwater resources assessment of pineapple farms. Amex international Inc.

Kortatsi, B.K., 1994a. *Management of Groundwater Supply for the urban areas: Groundwater exploration and techniques for sitting of high yielding borehole in the Accra plains of Ghana*. Advanced International Training Programme in Goteborg, Sweden, 29th August-6th October, 1994.

Kortatsi, B.K., 1994b. Groundwater utilization in Ghana. *In: Future groundwater resources at risk (proceedings of the Helsinki conference)* Wallingford: IAHS Press, IAHS Publ. No.222, 149–156.

Kundell, J (topic editor), 2008. "Water profile of Ghana." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). Last revised August 24, 2008. Available at http://www.eoearth.org/article/Water_profile_of_Ghana

Langenegger, O., 1994. Groundwater quality and handpump corrosion. World Bank Water and sanitation report no. 8.

Laube, W., Awo, M., Schraven, B., 2008. *Erratic Rains and Erratic Markets: Environmental change, economic globalisation and the expansion of shallow groundwater irrigation in West Africa.* ZEF Working Paper Series, ISSN 1864-6638. Department of Political and Cultural Change Center for Development Research, University of Bonn.

Lerner, D.N., Issar, A.S., and Simmers, I., 1990. Groundwater recharge. A guide to understanding and estimating natural recharge. International contributions to hydrogeology. Verlag Heinz Heise.

MOFA, 2004. Projected livestock population for 1997-2007. Ministry of Food and Agriculture, Accra, Ghana

Martin, N. and van de Giesen, N., 2005. Spatial distribution of groundwater use and groundwater potential in the Volta River basin of Ghana and Burkina Faso. *IWRA Water International*, 30 (2), 239–249.

Martin, N., 2006. *Development of a water balance for the Atankwidi catchment, West Africa – a case study of groundwater recharge in a semi-arid climate*, Ecology and Development Series, No. 41, Cuvillier Verlag Go¨ttingen, 168 pp.

MWRWH (Ministry of Water Resources, Works and Housing), 2007. National water policy. Available at

Obuobie, E., Diekkrüger, B., Reichert, B., 2010. Use of chloride mass balance method for estimating Groundwater recharge in northeastern Ghana. *The International Journal of River Basin Management,* (in press).

Obuobie, E., 2008. *Estimation of groundwater recharge in the context of future climate change in the White Volta River Basin, West Africa*. Ecology and Development Series. No. 62. 168 pp. Available from: http://www.glowa-volta.de/publ_theses.html.

Odada, E.O., 2006. Freshwater resources of africa: major issues and priorities. Global Water News, No. 3. Available at http://www.gwsp.org/downloads/GWSP_NL3_Internet.pdf.

Ojo, O., 1977. *The climate of West Africa*. Heibemann, UK.

Pelig-Ba, K.B., 1998. Trace elements in groundwater from some crystalline rocks in the Upper Regions of Ghana. *Water, Air and Soil Pollution* 103 (1-4): 71-89.

Quansah, C., 2000. Country case study: Ghana. *In FAO: Integrated soil management for sustainable agriculture and food security.* FAO-RAF 2000/01, Accra, p. 33-75

Sanford, W., 2002. Recharge and groundwater models: An overview. *Hydrogeol. J.*, 10:110-120.

Seini, A.W., 2002. *Agricultural growth and competitiveness under policy reforms in Ghana:* ISSER Technical Publication No. 61. University of Ghana, Legon

Smedley, P.L., 1996. Arsenic in rural groundwater in Ghana. *Journal of African Earth Sciences* 22 (4) : 459-470.

Smedley, P.L., Edmunds, W.M., West, J.M., Gardner, S.J. and Pelig-Ba, K.B., 1995. *Health problems related to groundwaters in the Obuasi and Bolgatanga areas, Ghana*. British Geological Survey Technical Report, WC/95/43, 122 pp.

Sonou, M., 1997. Low-cost shallow tube well construction in West Africa. *In: Irrigation Technology Transfer in Support of Food Security (Water Reports-14). Proceedings of a subregional workshop*. Harare, Zimbabwe, 14-17 April 1997.

Sophocleous, M.A., Schloss, J.A., 2000. Estimated Annual Groundwater Recharge. Avilable at http://www.kgs.ukans.edu/HighPlains/atlas/atrch.htm, Lawrence, Kansas.

SRID (Statistics, Research and Information Directorate), 2002. *Agriculture in Ghana: facts and figures.* Ministry of Food and Agriculture, Accra, Ghana.

Tay, C., Kortatsi, B.K., 2008. Groundwater quality studies: A case study of the Densu basin, Ghana. *West African Journal of Applied Ecology*. Vol. 12

UN, 2005. http://www.un.org/Depts/Cartographic/map/profile/ghana.pdf

UNEP, 2002. Freshwater stress and scarcity in Africa by 2025. UNEP/GRID-Arendal Maps and Graphics Library. Available at http://maps.grida.no

UNEP, 2002. State of the environment and policy retrospective: 1972-2002. In: Global environment outlook 3: past, present and future retrospectives. Available at http://www.grid.unep.ch/geo/press.htm.

UN-World Food Programme, 2009. Comprehensive food security and vulnerability analysis, Ghana. Available at www.wfp.org/food-security.

WARM, 1998. *Water resources management study, information 'building block' study. Part II, Volta basin system, groundwater resources*. Accra: Ministry of Works and Housing.

WRI, 2002. Info Water. Quarterly Newsletter of the CSIR Water Research Institute. Volume 1, Issue 1. June 2002.

WRRI, 1996b. Borehole yield map of Ghana, WRRI publication, Accra, Ghana.

Water Resources Commission (Ghana) webpage (www.wrc-gh.org). Accessed on May 10, 2010

WB/UNDP/ADB, 1992. Sub-Saharan Africa: Hydrological Assessment of West African Countries. Country Report: Ghana.

World Bank, 2006. *Groundwater Development in Sub-Saharan Africa: A Strategic Overview of Key Issues and Major Needs*. Case Profile Collection Number 15.

WHO, 2004. Guidelines for drinking-water quality - Volume 1: Recommendations. WHO publication, 3rd Edition, 515 p.

WRRI/DANIDA, 1993. Rural Drinking Water Supply and Sanitation Project in the Volta Region: Inventory and assessment of potential for hand dug wells in the Volta region.