2006

Evaluation Of Alternative Water Resources For Cape Coast And Its Environs In Ghana

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EVALUATION OF ALTERNATIVE WATER RESOURCES FOR CAPE COAST AND ITS ENVIRONS IN GHANA

by

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A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science in Water Resources Engineering
in the Department of Civil and Environmental Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2006

ABSTRACT

Cape Coast once a national capital of Ghana and its environs in recent years have constantly suffered perennial acute water shortage. The Brimsu dam which takes its supplies from the Kakum River with current production capacity of 1.4×10^4 m^3/day cannot meet the water needs of the study area. The operating levels of the dam during crisis have reduced from 7.3 meters to 4.7 meters over the years with subsequent reduction in water production by 35%. Recently, the operating level has reduced further to about 3.5 meters with 60% reduction in water supply.

This study evaluated alternative water resources to augment water supply and mitigate the impact of perennial water shortage. Among the alternatives considered are surface water from Twifo Prasso on the Pra River, groundwater supplies, and the desalination technology. Mean annual streamflow of Pra River at Twifo Prasso was used to evaluate the continuous availability and reliance on surface water. Hydrogeological assessment of geology underlying the study area vis-à-vis the existing borehole and their yields was used to evaluate groundwater potential. Desalination technology which is not currently in existence in the study area was considered based on available literature. Since the implementation of projects of this magnitude are the responsibilities of the central government through grants and loans, the study focuses on the cost implications of water from these alternatives to the final consumer in terms of affordability.

In considering the cost of water from the various alternatives to per capita per day consumption in rural and urban settlements within the study area for a household of five, the cost of surface

water remains the most affordable means of water supply, followed by groundwater. Borehole yields indicate that intensive exploitation of groundwater even though more expensive than surface water sources could minimize the effect of perennial water shortage and over dependence on surface water. The cost comparison analyses have shown that the cost of desalination using reverse osmosis is still expensive and could not compare favorably with the existing water supply alternatives. The analyses have thus confirmed the long held perception that "desalination is expensive and cannot be used in study area".

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Ola Nnadi, for her academic and financial support and outstanding guidance. She offered invaluable criticism and insight which helped me throughout my studies at the University of Central Florida. I would also like to thank my committee members Dr. Marty Wanielista and Dr. Scott Hagen for the unmeasurable contributions to my education and this thesis.

I wish to extend my heartfelt gratitude to the sponsors of the West African Graduate Engineering Education Program (WAGEEP) for making it possible for me to benefit from graduate studies. I would also like to thank my sister, Beauty and brothers, Robert and Alfred Kumah for their selfless support and encouragement.

Finally, I would like to thank my wife, Mary, for her patience, understanding and support during my graduate studies. Her love gave me the strength I needed to complete my studies.

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LIST OF ABBREVIATIONS

ABBREVIATION	DEFINITION
CEDECOM	Central Region Development Commission
GWCL	Ghana Water Company Limited
PURC	Public Utility Regulatory Commission
GSS	Ghana Statistical Service
WSS	Water Supply System
PANAFEST	Pan-African Historical Theater Festival
ERP	Economic Recovery Program
MoWH	Ministry of Works and Housing
WRRI	Water Resources Research Institute
CSIR	Council for Scientific and Industrial Research
BWSS	Bekwai Water Supply System
CWSA	Community Water and Sanitation Agency
RO	Reverse Osmosis
MSF	Multi Stage Flush
lcd	Liter per capita per day

1 INTRODUCTION

Water shortages have economic, technical, social, cultural, physical, hydro climatic and political dimensions. In countries across the world, particularly in developing countries, governments face the problem of how to supply sufficient water of good quality to their citizens. In many cases, the supply of water cannot keep pace with the demand as a result of inadequate capital for expansion of water supply systems. In addition, rapid population growth and urbanization continue to widen the gab between the demand and supply of water. In many developing countries, the water needs exceed the capacity of government to finance new water infrastructure. It has also been established that annual growth rates of only 1% in developing countries impact significantly and almost negatively on existing infrastructure and increase demand for fresh water (Falkenman and Widstand 1992). Water shortages is said to affect 88 developing countries that are home to half the world's population. In these countries, 80% to 90% of all diseases and 30% of all deaths result from poor water quality.

Globally, demographic factor coupled with ever increasing per capita demand and the decreasing readily available resources, partly due to pollution, result in the era of global freshwater scarcity the world currently experiences. At present, 25 countries (Figure1-1) are suffering from water stress, thus withdrawals exceeding 20% of renewable water supply is expected to rise to 90% by 2020 (Falkenman and Widstand 1992). It has been estimated that about 20% of the World's

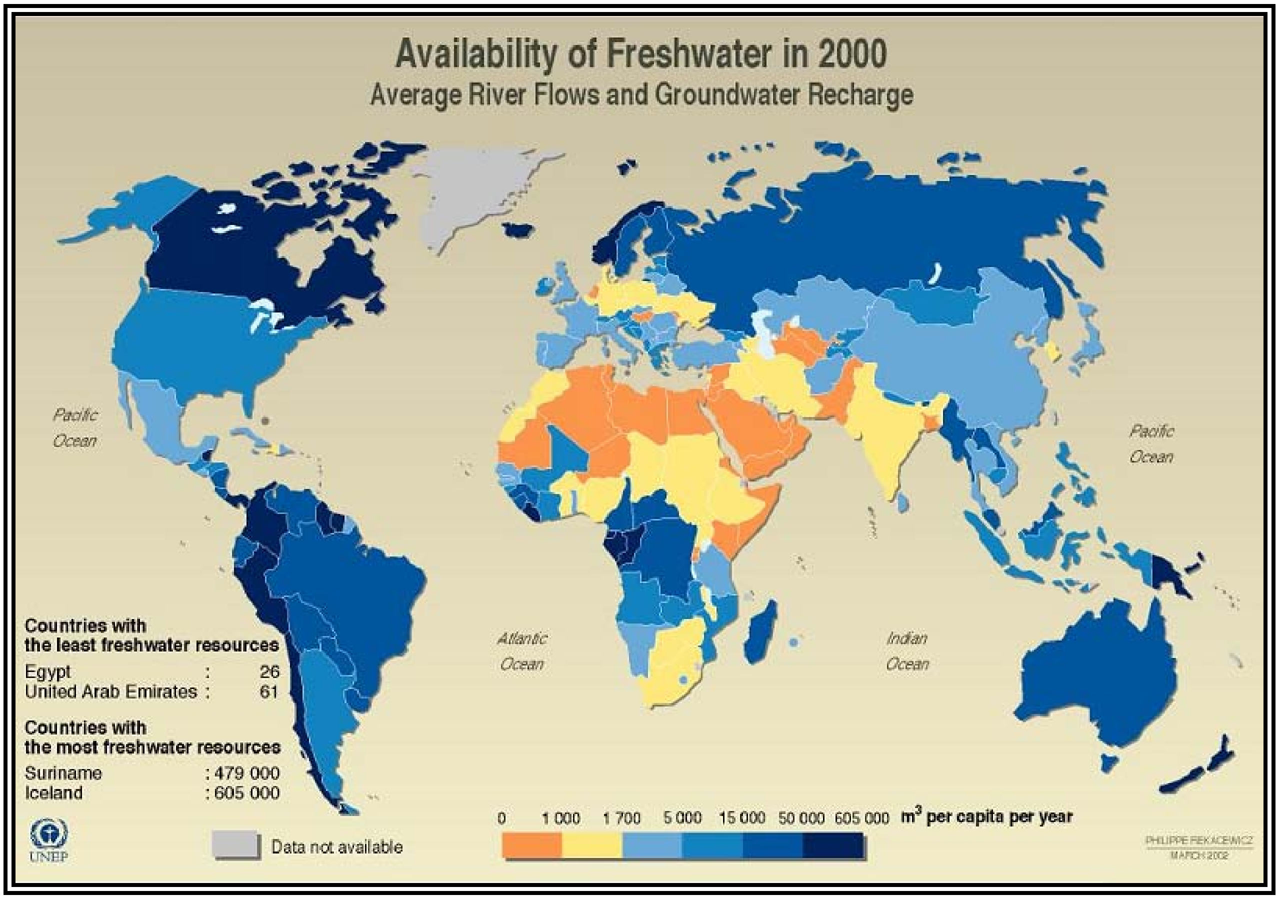

Figure 1-1: Availability of Freshwater in 2000

Source:http://maps.grida.no/go/graphic/availability_of_freshwater_in_2000_average_river_flows_and_groundwater_recharge

population does not have ready access to drinking water. The majority of those affected are in developing countries, and the United Nations has subsequently identified water use as a priority for international aid to developing countries. During the 4th World Water Day held in Mexico City recently, report prepared by Economic Commission for Africa and other partners on Water Resources Development in Africa revealed that about 300 million in Africa lack access to portable water and about 313 million also lack access to sanitation. Africa thus needs yearly estimate of about $20 billion in order to meet her 2025 water visions (http://www.uneca.org/cfm/2006/docs/ECANewsletter_ENG.pdf).

Ghana, one of the developing countries in Africa with annual population growth rate of 2.7%, also lack in adequate provision of urban and rural water supplies, thus creating a vast backlog. It is estimated that about 9 million people (nearly 50%) of the population lack access to adequate water supply (Ghana Statistical Service, 2000) and according to Central Region Development Commission (CEDECOM), an estimated capital cost to remedy the deficiency over the next five years varies between $1 billion and $1.2 billion.

Other estimates indicated that up to 40% of the Ghanaian population did not have direct access to clean and safe drinking water. Ghana Vision 2020, which aims at transforming Ghana into a middle income country with safe water supplies, high rates of industrial growth and an expanded and accelerated agricultural sector is based on the availability and efficient management of water resources, and would be expected to put further pressure on water use. Water brings three main issues in developing countries. These include public health, economic, socio-economic issues. It is estimated that about 4 million people die of water borne diseases, including 2 million children who die from diarrhea (UNFPA, 2002).

1.1 Project Area Description

Ghana is a country of an estimated population of about 21.4 million with 54% living in the rural areas and 46% in urban areas. It is situated within latitudes 4º 30' N and 11º N and longitudes 1º 10' E and 3º 15' W on the West Coast of Africa. It is bordered on the west by Cote d'Ivoire, on the north by Burkina Faso, on the east by Togo and the Gulf of Guinea and Atlantic Ocean on south (Figure 1-2). It has an area average of about 238,000 km^2, which is subdivided into ten administrative regions.

Cape Coast, the most historical city in Ghana is the capital town of the Central Region, is located 165 km west of Accra. It was the capital town of then Gold Coast (now Ghana) from 1700 to 1877. The Central Region is underlain by gently rolling terrain and mostly drained by short-lived rivers. The climate is tropical with a mean annual temperature of about 26.1º C and characterized by two rainy seasons. The map of Central Region is shown in Figure 1-3, while Figure 1-4 shows the downtown of Cape Coast.

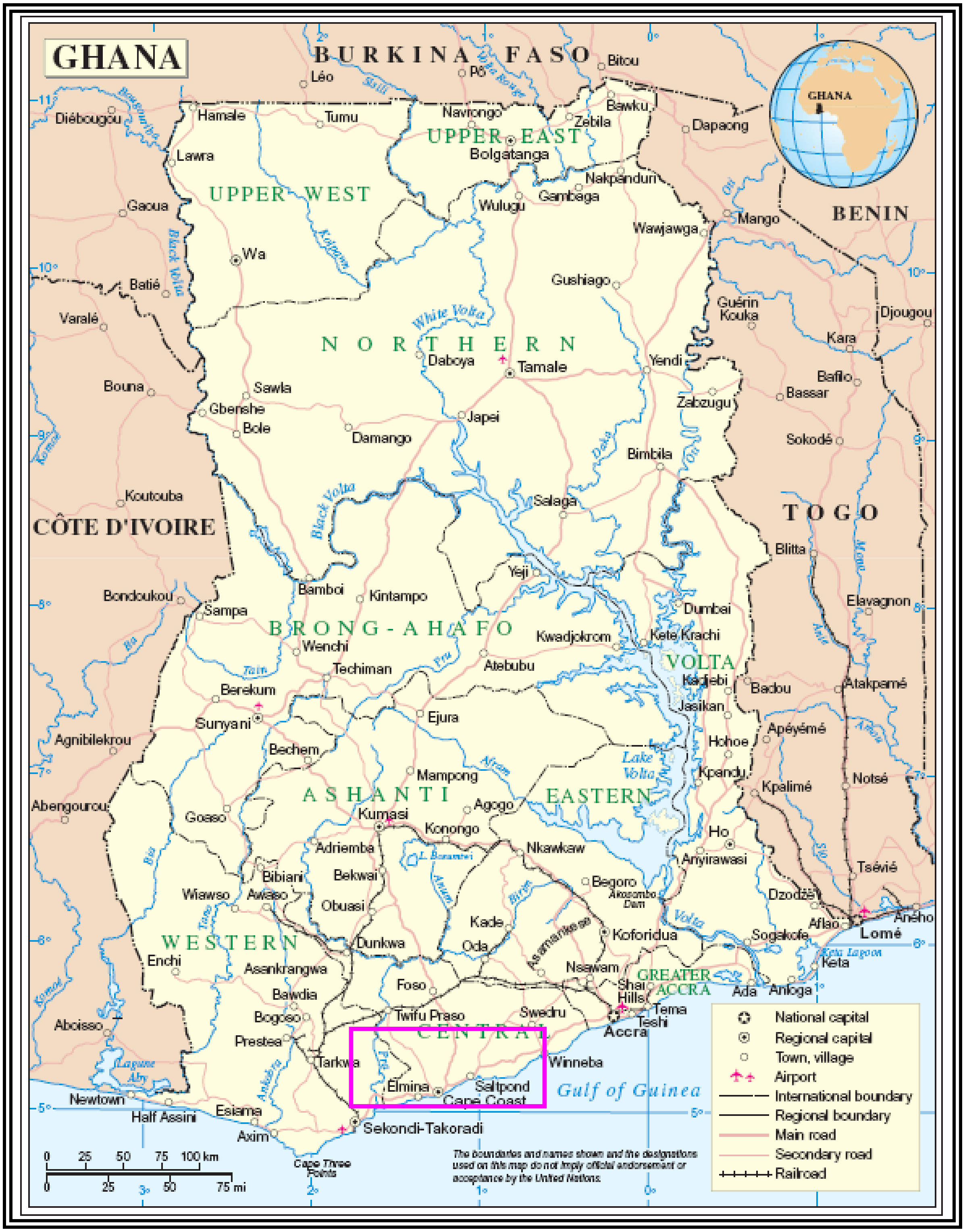

Figure 1-2: Map of Ghana

Source: http://www.un.org/Depts/Cartographic/map/profile/ghana.pdf

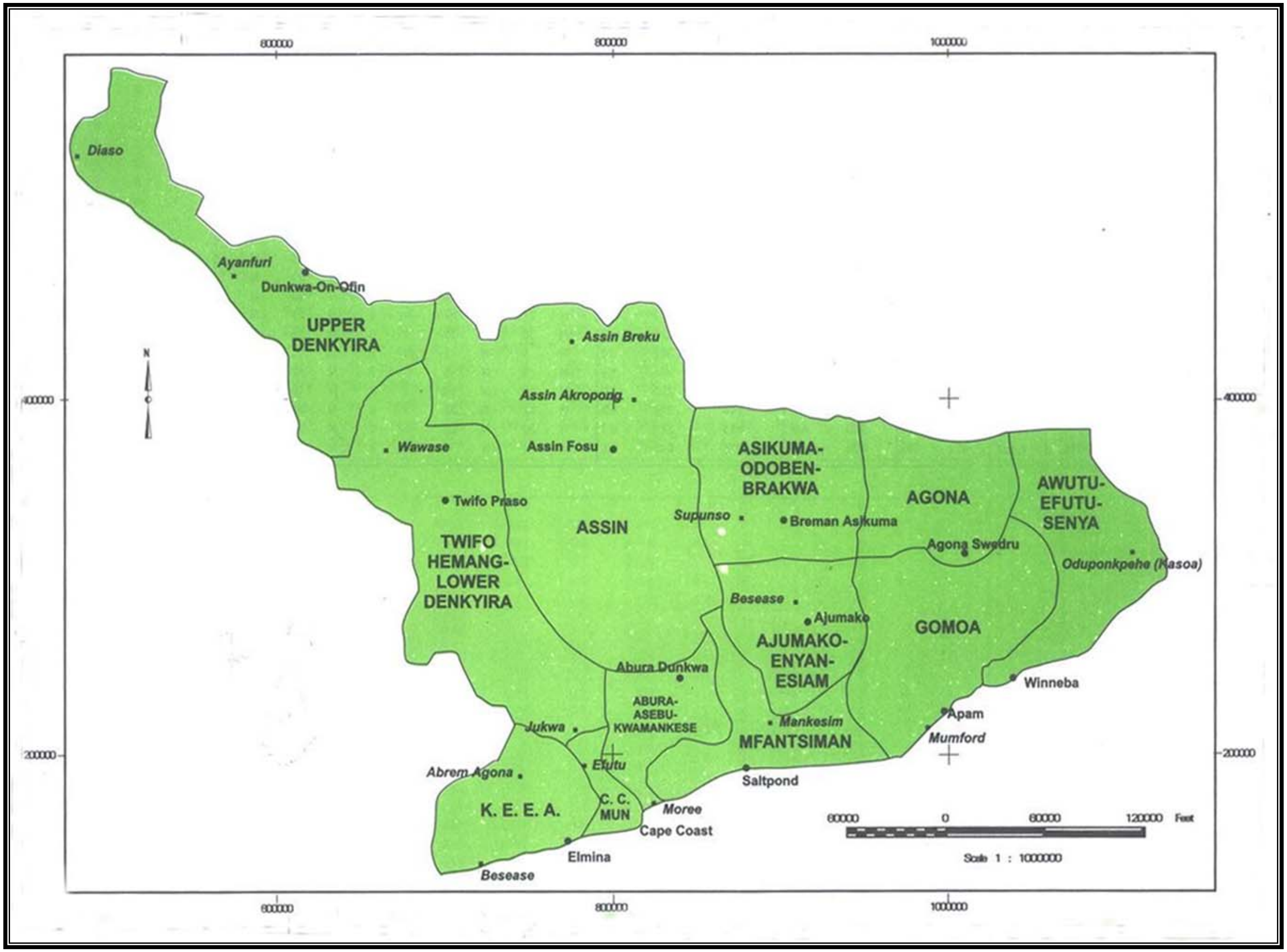

Figure 1-3: Map of Central Region

Source: Ghana Statistical Service, 2000

Figure 1-4: Cape Coast Downtown
Source: http://en.wikipedia.org/wiki/Cape_Coast

1.2 Population and Social Infrastructure

The total population of the Central Region is about 1.6 million, thus about 8.4% of Ghana's population (Water Supply and Sanitation Sector Assessment, 2000). Cape Coast and its environs has a total population of about 361,900 and population of about 58% received its water supply from Brimsu Water Supply System.

Cape Coast is the seat of the University of Cape Coast (UCC), Ghana's leading university in teaching and research, a hub of the country's tourist attraction sites and the oldest, best and efficient educational institutions. The existence of Forts and Castles (Figures 1-5 and 1-6) and other attractions such as the Cape Coast Center for National Culture, the Oguaa Fetu Afahye harvest festival and, the biennial Pan-African Historical Theater Festival (PANAFEST) have gradually made Cape Coast a tourist area since 1992. Tourism in Ghana is becoming number three foreign exchange earner apart from the country's traditional resources such as Gold and Cocoa. For Cape Coast and its environs to continue to play vital role in the socio economic development of Ghana, there is need to develop alternatives water resources to augment water supply to eliminate the perennial water shortage.

Figure 1-5: The Cannons of Cape Coast Castle (A Slave Trading Castle)
Source: http://en.wikipedia.org/wiki/Cape_Coast

Figure 1-6: Cape Coast Castle

Source: http://www.ghanaweb.com/GhanaHomePage/NewsArchive/photo.day.php?ID=56580

1.3 Problem Statement

Cape Coast and its environs started facing perennial water shortage since 1987 and no one thought it would become a problem in almost two decades. The Traditionalists claimed at the time, that the God of the river was angry and had caused the Kakum River to dry up, because rituals had not been performed for her for a couple of years.

The problem with Brimsu dam is its inability to store enough water due to silting of the reservoir. Consequently the intake demand cannot be met especially during the dry season of the year resulting to serious water shortage. The production capacity of the dam varies during the dry season. In recent years the operating levels of the dam during crisis time have reduced from 7.3 meters to 4.7 meters with subsequent reduction in water production by 35%. Recently operating level of the dam dropped significantly to as low as 3.5 meters and water supply in March and April was reduced by 60% (Ghana News Agency, May 9, 2006). It has also been anticipated that about $1.4 million would be spent on tanker services to augment water supply. The dam in addition is said to have high iron and manganese contamination levels. Based on the high levels of contamination, it has been anticipated that if steps are not taken to get a second source of water in the near future, the Cape Coast area would not be able to use this dam. It has been established that more than 2 in 5 citizens in the Central Region do not have access to improved water supply facilities resulting to 2001 coverage levels in water supply at 70% for urban areas and 55% for the rural areas (CEDECOM). The demand for water is on the increase and the population which is likely to be affected would increase from 1.6 million at present to about 3 million in the year 2020, with majority living in rural communities (CEDECOM).

The perennial water shortage impacts negatively on education and other social economic development of the project area. Cape Coast is widely regarded as the citadel of education in Ghana and has the major tourist attractions. The acute water shortage particularly during the dry seasons results in closure of educational institutions. This closure sometimes last as long as six (6) weeks. Some mitigation measures adopted to keep normal business running turns out to be more expensive. For instance, in 2004 when the shortage hits the project area, a contingency program of installing overhead reservoirs and other facilities to haul water cost $2.3 million.

This was put in place to alleviate the effect of water shortage on educational institutions. The tourism industry normally suffers sharp decline during the crisis time. The outbreaks of waterborne diseases such as cholera affect inhabitants in the project area and almost grind economic activities to a halt. According to Ghana News Agency report of January 14, 2006, there was an outbreak of cholera in Elmina and its surroundings due to lack of potable water. Elmina is located about 16 km west of Cape Coast which also depends on water supplies from Brimsu dam.

The sole major urban water producer Ghana Water Company Limited (GWCL) in Ghana suggested that greater efficiency in the management of existing systems, financial viability and increase in capital expenditures is the way of meeting the ever increasing water demands of Cape Coast and its environs and Ghana as a whole. The efforts made by the GWCL to minimize the effect of the perennial water shortages include short, medium and long term measures.

The short term include establishment of monitoring points in the affected areas particularly Cape Coast township. This will require daily checks on the water supply situation to help identify areas that are seriously affected and will require augmentation by tanker services. In medium term measure, four different sources of alternative treated water supply to the study area were identified for water supply in the event of the crisis. These sources include water from two boreholes (groundwater) from Dehia near Cape Coast, and hauling of water from Baifikrom, Apam Junction and Daboase with water tankers. The long term measure include dredging of the

Brimsu dam, and building of a treatment plant at Skyere-Hemang for the treatment of water from the Pra river, to augment water supply to cape Coast and its environs. The past years have seen the implementation of the short and medium terms in addressing the perennial water shortage problem in the area whiles the third remains a dream.

Thus this study intends, to explore the long term measure, develop and evaluate other alternative sources of water in addition to the treatment plant on Pra River to augment water supply to the study area. This effort will provide recommendation on how to eliminate or minimize the perennial water shortage in Cape Coast area.

2 LITERATURE REVIEW

2.1 Sources of Water

The inhabitants of central region have two (2) main sources of water. These sources are surface water, which include rivers and streams and groundwater, which also include boreholes, wells and dugouts. The sources of water in the study area fall predominantly within the surface water resources.

2.2 Overview of Surface Water Resources of Ghana

Ghana has a mean annual rainfall of about 1187 mm, renewable water resources of 53 km^3/year and total water withdrawals of 0.35 km^3/year resulting to 35 m^3/cap/year. The sources of water supply in Ghana are predominantly surface water; accounting for 95% withdrawal in year 2000 for urban supply. (www.fao.org/ag/agl/aglw/aquastat/countries/ghana/index.stm).

There are three distinct river systems, namely Volta basin, South-Western basin and Coastal basin. The largest is the Volta basin covering 70% of Ghana's landmass followed by South-Western basin 22% and Coastal basin 8% (Figure 2-3). The Volta basin is spread over six (6) West African countries (Figure 2-1). These three basins produce Ghana's mean total annual runoff of 54.4 billion m^3. The Volta basin has a total runoff of 38.3 billion m^3 (70.3%), whereas the South-Western and the Coastal basins have total annual runoffs of 13.9 billion m^3 (25.6%) and 2.2 billion m^3 (4.1%) respectively (Ministry of Works and Housing, 1998).

Ghana's estimated total water demand for the year 2000 is 1112.9 million m^3 as shown in Table 2-1, constituting about 2% of the available surface water resources. This water demand appears small compared to the available water resources.

Table 2-1: Year 2000 Consumptive Water Demand in Million m^3

River System	Domestic/ Industrial	Livestock	Irrigation	Total
Volta Basin	139.28	25.90	565.07	730.25
South-Western Basin	140.85	3.00	40.11	183.96
Coastal Basin	183.42	3.00	12.27	198.69
Total	463.55	31.90	617.45	1112.90

Source: Ministry of Works and Housing, 1998.

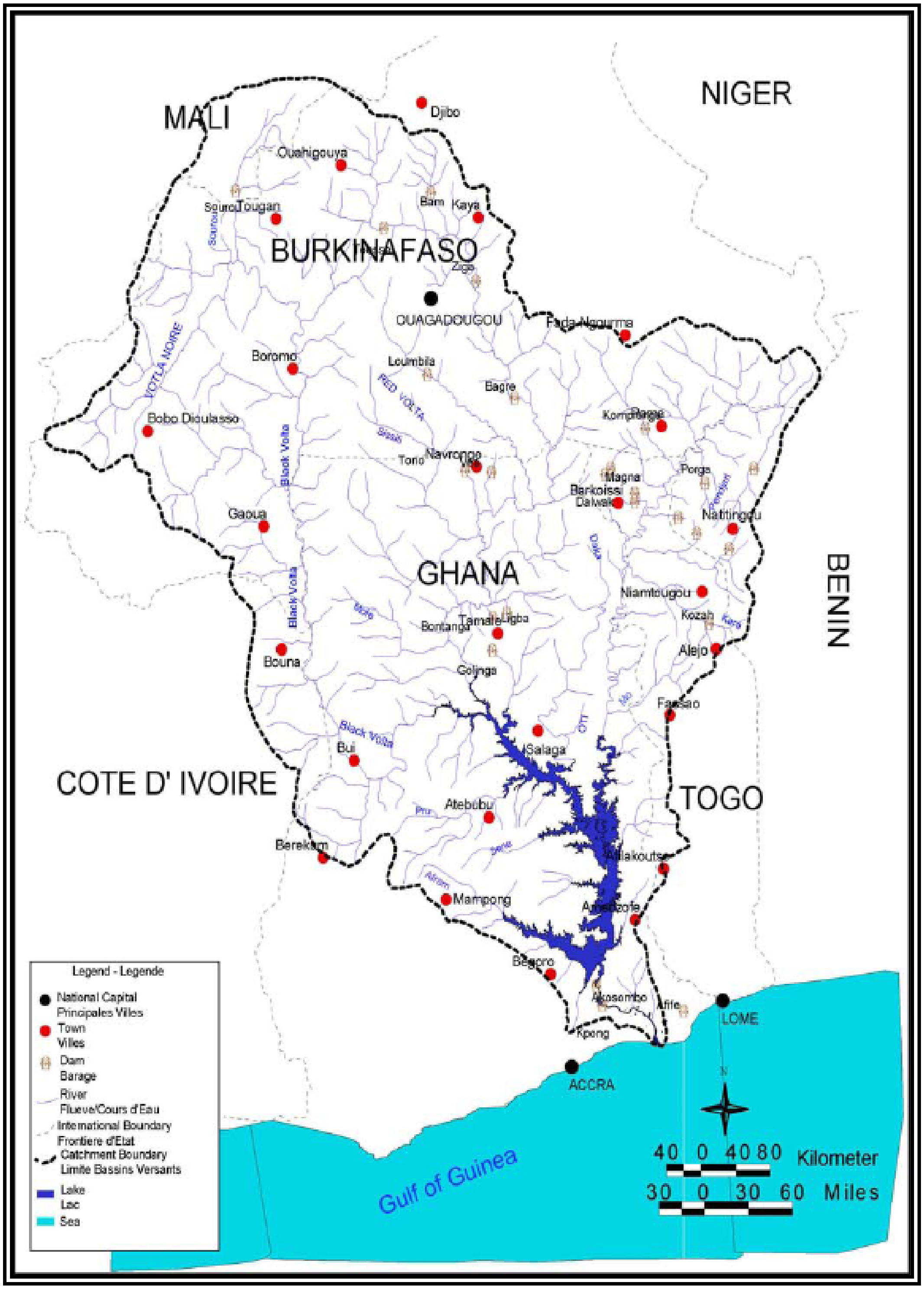

Figure 2-1: Location of Dams in the Volta Basin

Source: Barry et al., 2005.

Ghana's water demand keep rising as a result of rapid population growth and economic development, thus the government's Economic Recovery Program (ERP) and the Vision 2020, a program developed to help transform Ghana into a middle – income country by the year 2020. These plans are expected to put additional pressure on the country's water resources (Table 2-2).

Table 2-2: Year 2020 Projected Consumptive Water Demand Million m^3

River System	Domestic/ Industrial	Livestock	Irrigation	Total
Volta Basin	271.62	63.40	3605.29	3940.31
South-Western Basin	295.55	5.60	460.85)	762.00
Coastal Basin	369.87	5.80	48.28	423.95
Total	937.04	74.8	4114.42	5126.26

Source: Ministry of Works and Housing, 1998.

In spite of the projected increasing water demand shown in Table 2-2, the demand does not pose any threat in terms of water scarcity as demand remained small, thus less than 10% of the total annual runoff of the available water resources.

Ghana's source of power (electricity) is largely dependent on hydropower generation. The non-consumptive water demand for hydropower generation is at about 37.843 million m^3 at the two existing dams at Akosombo and Kpong. The evaporation losses from Lake Volta are estimated to be 4.5 billion m^3 per year. The proposed third dam, Bui hydropower plant at the Black Volta when built is expected to consume 6.843 million m^3 per year.

Though the above data create the scenario of “water abundance”, in reality the situation is contrary. Runoff is dependent on rainfall which has been prone to variations/fluctuation and could result to changes in the amount of runoff. Furthermore, Ghana has been grouped in category 2 of water scarcity in the twentieth century (Future Harvest, 1999). This means Ghana will face ‘economic water scarcity’; therefore Ghana must double her efforts to extract water to meet 2025 water needs but she will not have the financial resources available to develop these water supplies.

2.2.1 Sources of Water Supply in Central Region

The water resource for domestic water supply and irrigation in the central coastal region of Ghana is primarily surface water from four (4) rivers (Figure 2-2). Central Region thus has a total of about 8 operational water supply systems (WSS). The Cape Coast (Brimsu) WSS is the second largest in Central Region, with more than 70% of its consumers live in 5 towns with population more than 10,000. The Brimsu WSS obtains its raw water from the Kakum River for treatment and onward distribution to some coastal towns including Cape Coast and its environs (Table 2-3). There is a short fall in water supply by 53%, thus considering the design capacity and actual production of the dam at Brimsu. The shortfall in water supply worsens, particularly during the dry season when Brimsu dam capacity is further reduced by 35%. Furthermore, it is suggested that about 49% percent of actual production of water in March 2004 cannot be accounted for due to a combination of physical losses (leaks) and administrative loss (i.e. water that is consumed but not paid for).

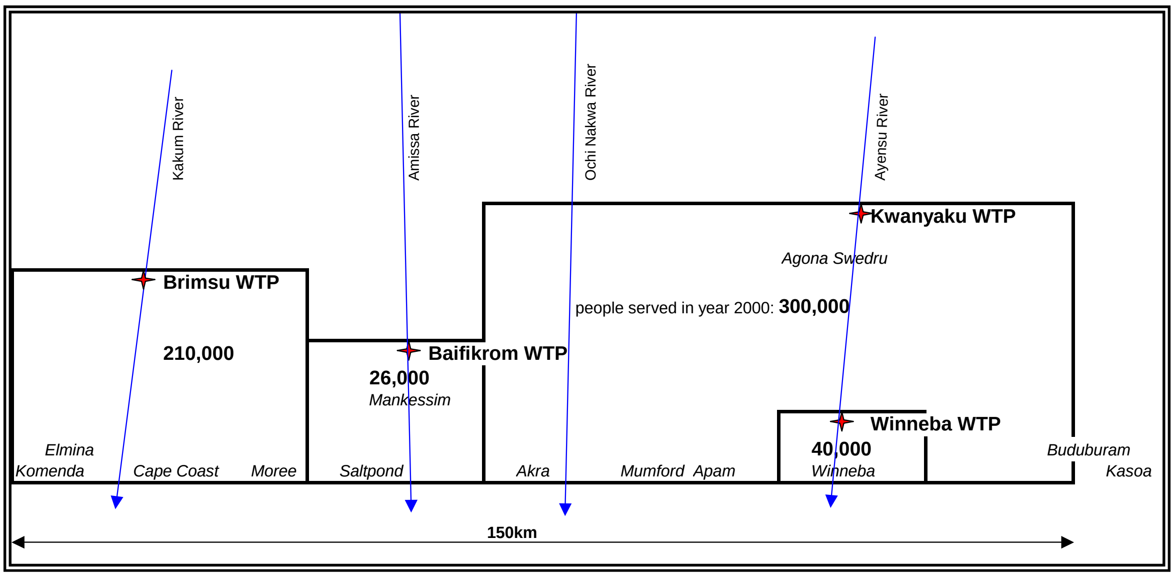

Figure 2-2: Schematization of Sources of Water Supply in the Central Region
Source: Water Supply and Sanitation Sector Assessment Part II, 2000.

Table 2-3: Water Supply Systems in Central Region

Source River	Design Capacity m^3/day	Actual Production m^3/day	Population Served	Towns Served*
Kakum River	29,200	13,600	210,700	Cape Coast, Elmina, Komenda, Saltpond, Moree
Amissa River	6,770	1,700	66,500	Assin Fosu, Mankessim
Ochi Nakwa River	660	180	22,600	Asikuma
Ayensu River	27,680	17,400	342,500	Agona Swedru, Buduburam, Awutu Senya, Bawjiase, Nyakrom, Besease, Apam

Source: Ministry of Works and Housing, 1998 and WSSSA, 2000.

* Towns with population more than 10,000

2.2.2 Water Demand in Central Region

The Ghana Water Company Limited (GWCL) recommends the unit water demand rates for planning purposes based on population. The per capita water demand which include non-domestic demand and an allowance for water losses is based on population as shown in Table 2-4.

Table 2-4: Projected Water Demand, l/c/d (inclusive of water losses at 15%)

Population	**Year**		
	1995	**2005**	**2020**
Greater than 50,000	85	105	120
20,000 – 50,000	75	85	95
10,000 – 20,000	65	75	85
5,000 – 10,000	45	55	65
2,000 – 5,000	30	30	35
Less than 2000	200 persons per water point		

Source: Ministry of Works and Housing, 1998.

The average water demands normally increase with population and delivery systems. In communities or settlements that obtain supplies from public stand pipes, the demand and usage is expected to be low compared to where every home is connected to the distribution system. The per capital consumption being low could be attributed to the effort to bring water home. Also, water from public stand pipes are relatively more expensive. Alternatively in urban communities, more homes are being connected to the distribution system, thus making water readily available and subsequently increase the water consumption.

The water demands in Cape Coast and its environs, similar to other communities is expected to increase with improvement in delivery systems, and when inhabitants have more money to spend on amenities to improve their water supply and shift from the use of public faucet to in-house.

2.2.3 Water Delivery Systems

The two main delivery systems of surface water in the Central Region include piped water and tanker services. According to 2000 population census conducted by Ghana Statistical Service, piped water delivery coverage accounts for about 50% whereas tanker services is 5%

2.2.3.1 Piped Water

In piped water delivery system, houses are connected with pipe network and inhabitants receive water through GWCL distribution system. This is supposed to be the most convenient and economical delivery system of water. Communities that lack GWCL distribution system or who have malfunction faucets rely on the remaining delivery systems of water such as tanker services for water supply.

2.2.3.2 Tanker Services

In this delivery system, water is hauled from GWCL designated stations to inhabitants using tanker services. The operators include GWCL, public institutions and other private individuals. This mode of delivery of water is however expensive, hence the patronage is perceived as the preserve of inhabitants normally in a high income bracket/group.

2.2.4 Assessment of Surface Water Resources of the Study Area

Cape Coast and its environs comprise of two hydroclimatic zones in the southern part of the country. These are South-Western basin and the Coastal basin systems (Figure 2-3). The rivers and streams draining the Coastal basin are Kakum, Amisa, Nakwa, Ayensu and Densu. The Coastal basin system is relatively the driest part of the country with annual mean rainfall less than 1000 mm (Opoku-Ankomah and Cordey, 1994). The South-Western basin is drained by Bia, Tano, Ankobra and Pra Rivers. The Pra basin is the biggest and covers an area of about 23,000 km^2. The South-Western basin on the other hand is humid with annual rainfall in the range of 1500 – 2000 mm.

Historical daily discharge data sets from 1950/1951 to 1990/1991 water years were used to compute the mean monthly and mean annual discharges for each gauging station. Established regression equations were used in assessing the surface water resources of the basin. As a result of the available gauge station recordings of the Pra River basin was used to establish the equation used in evaluating the total discharge or discharge at any site within the basin, whereas regional regression equations were used for other basins in either the South-western or Coastal basin systems due to inadequate gauging stations with reliable results.

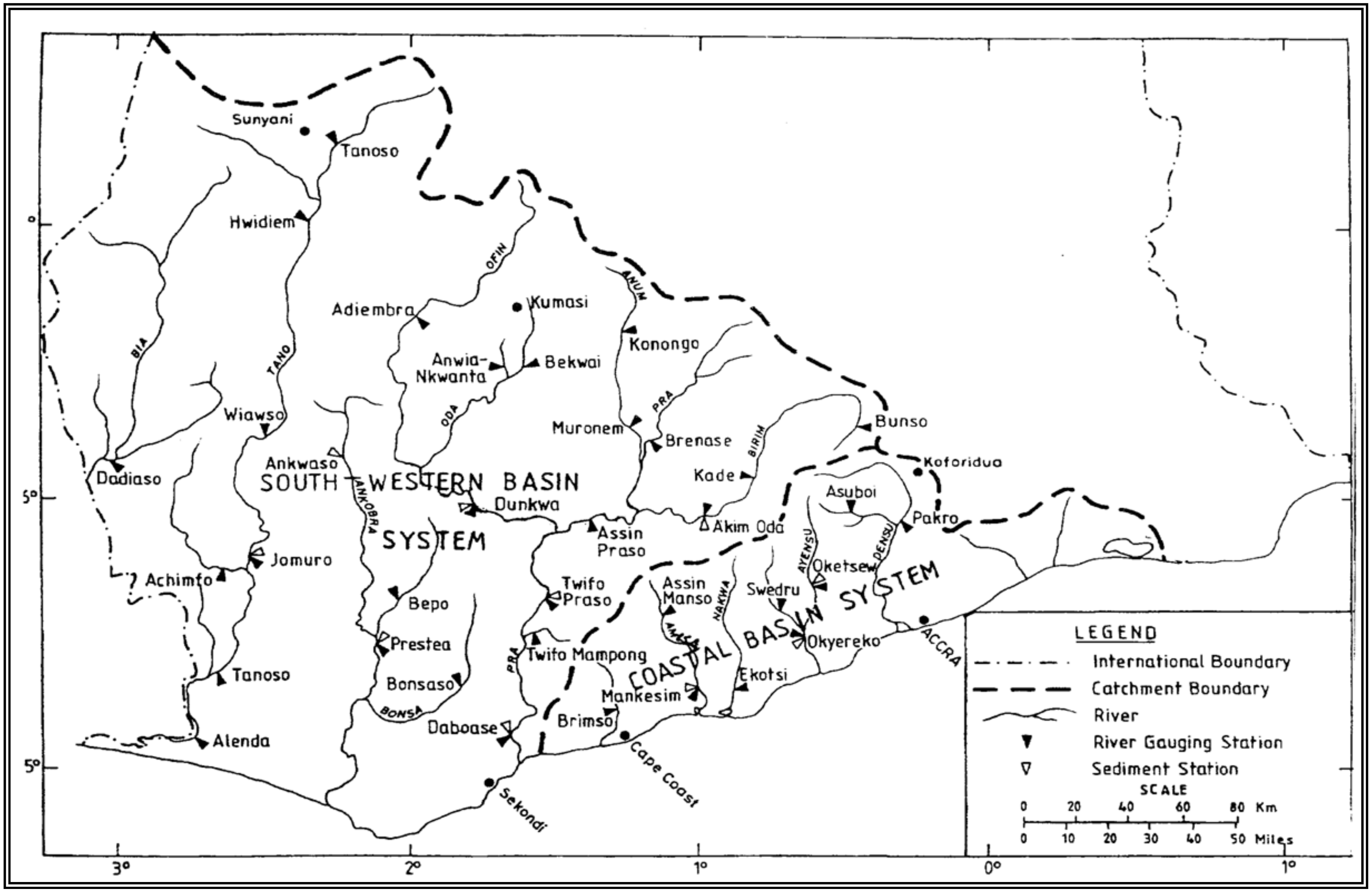

Figure 2-3: Discharge stations in the South-Western and Coastal basin systems of Ghana

Source: Opoku-Ankoma and Forson, 1998.

The plot of discharges against drainage areas in the Pra basin (Figure 2-4) gave correlation coefficient of 0.92 (Opoku-Ankomah and Forson, 1998). This therefore suggests that discharges from ungauged sites within the basin could be estimated using the regression equation inscribed in the graph (Figure 2-5) and resulted in estimated total basin discharge shown in Table 2-5.

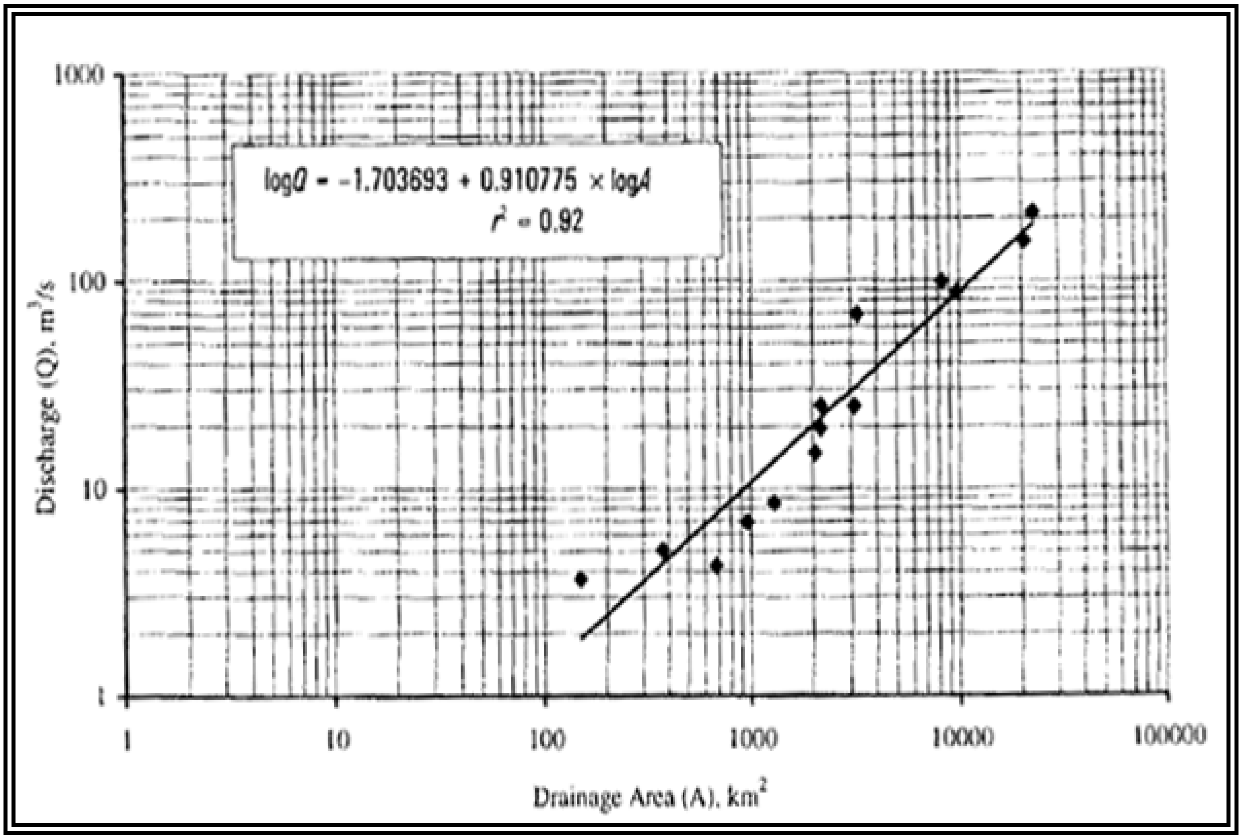

Figure 2-4: Discharge versus drainage area in the Pra Basin
Source: Opoku-Ankomah and Forson, 1998.

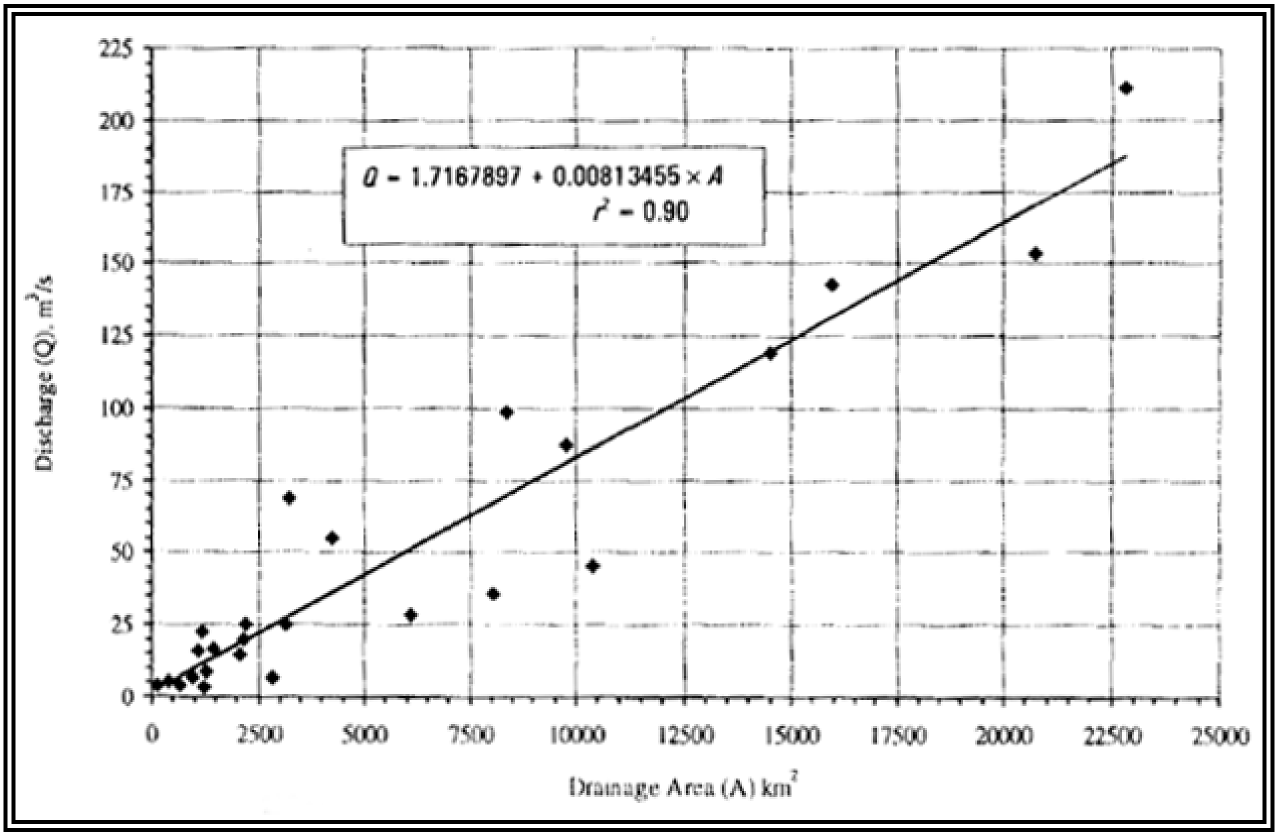

Figure 2-5: Discharge versus drainage area in the South-Western basin system (normal plot)
Source: Opoku-Ankomah and Forson, 1998

Table 2-5: Estimated Mean Annual Discharges of Drainage Basins in South-Western and Coastal basin Systems in Ghana

Basin	Drainage Area (km^2)	Estimated Mean Annual Discharge m^3/s
Kakum	984	5.8
Amisa	1,368	12.8
Nakwa	1,502	8.3
Densu	2,551	13.4
Ayensu	1,709	9.3
Bia	6,475	54.4
Tano	14,872	122.7
Ankobra	8,462	70.5
Pra	23,188	190.3

Source: Opoku-Ankomah and Forson, 1998.

The results from Figure 2-4 when compared to Figure 2-5 show that flows within the Pra basin are better correlated with their drainage areas than all flows in the South-Western basin system put together and plotted against their corresponding drainage areas. Also, the linear plot (Figure 2-5) of results from South-Western basin system showed a higher correlation coefficient than the logarithmic plot (Figure 2-6).

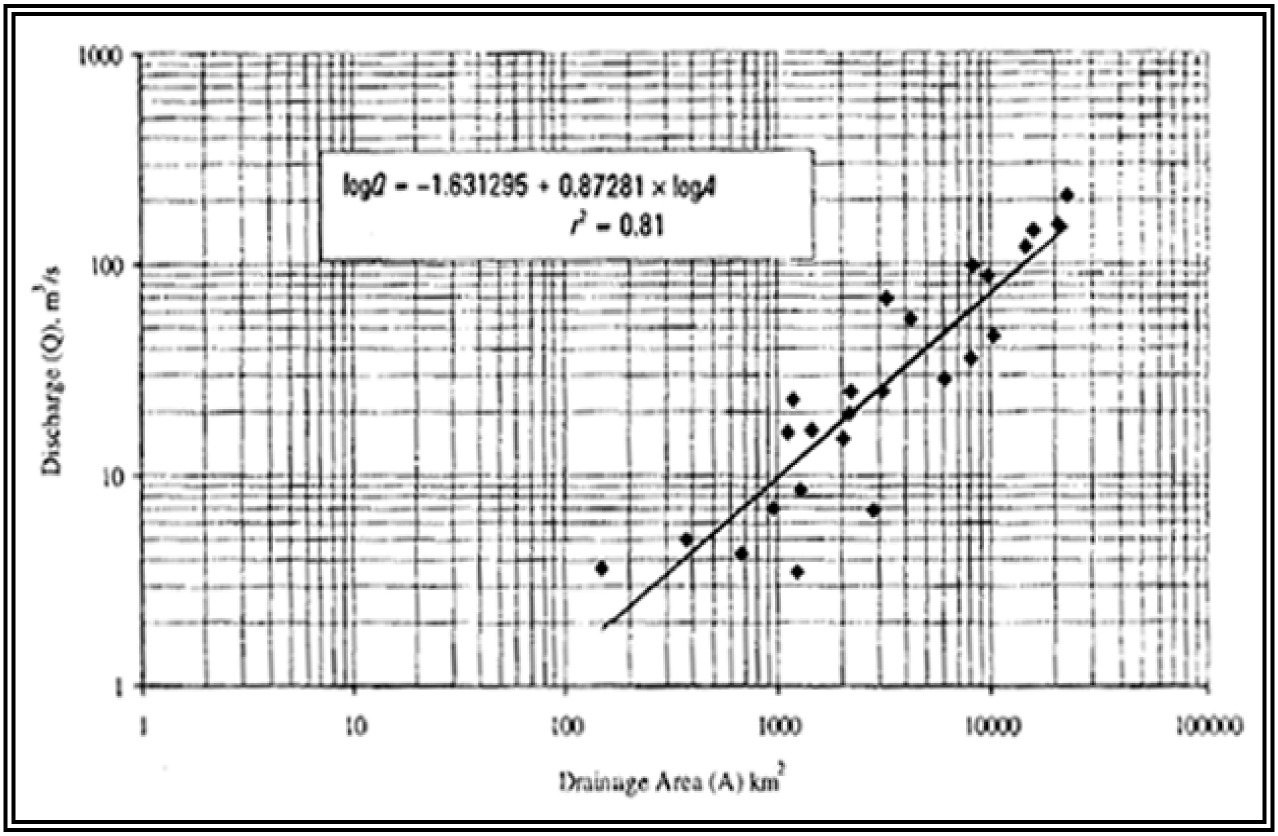

Figure 2-6: Discharge versus drainage area in the South-Western basin system (log plot)
Source: Opoku-Ankomah and Forson, 1998.

Significant correlations were shown between mean annual discharges and the drainage areas in the Coastal basin system (Figure 2-7). The correlation coefficient is lower than that of the South-Western basin system. The variance in correlation coefficient was attributed to the highly variable nature of rainfall in the Coastal basin system. The results obtained are important for assessing surface water resources by using the equation in Figure 2-6 to estimate discharges of rivers at specific sites where water resources developments are required.

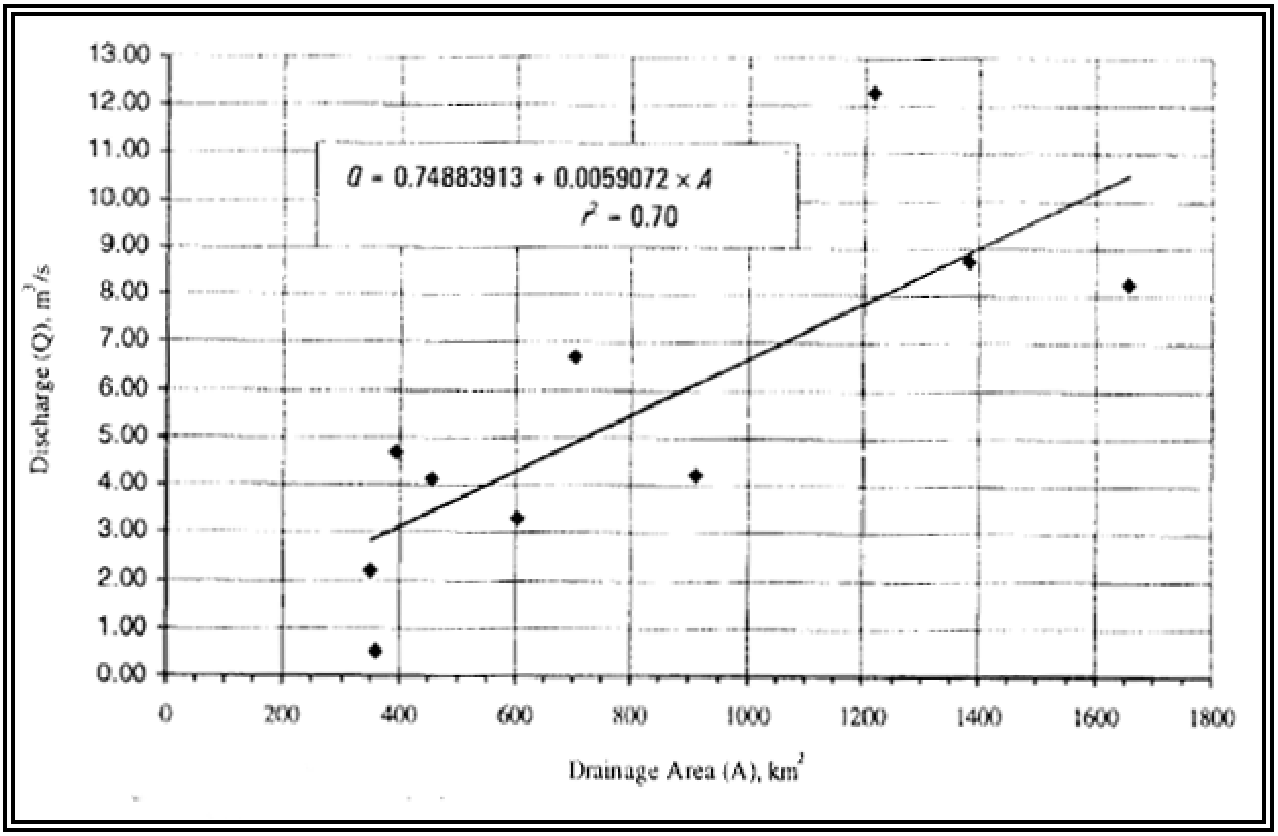

Figure 2-7: Discharge versus drainage area in the Coastal basin system
Source: Opoku-Ankomah and Forson, 1998.

2.2.5 Factors Affecting Water Supply

The factors affecting water supply in the Kakum basin include the following:

- Climatic variability
- Relative humidity
- Evapotranspiration

- Decline in annual rainfall and rainfall distribution
- Seasonal variation
- Sedimentation
- Deforestation and land use practices

2.2.6 Rainfall and Runoff Variability in South-Western Basin

Opoku-Ankomah and Amisigo in 1998 assessed rainfall and runoff variability in the southwestern river system of Ghana using two sets of data. These include daily discharges from Twifo-Prasso in the Pra basin and rainfall data from Kumasi. The distance between Twifo Prasso and Kumasi is about 97 kilometers (Figure 2-8). The discharge and rainfall data set from 1951 to 1991 were used for comparison. Missing daily discharge data were estimated from nearby stations where records were available and this was further converted to monthly mean discharges.

The plots of rainfall totals and discharges for the annual, wet and dry seasons are shown in Figures 2-9, 2-10 and 2-11 respectively. Each of these plots shows a decline in the time series beyond 1970, thus resulting to the data set being divided into two periods. The first period ranges from 1951 – 1970 and the second period ranges from 1971 – 1991. The decline observed in each case was however not continuous. The statistics computed for the rainfall and the discharges for the first and second periods are shown in Tables 2-6 and 2-7.

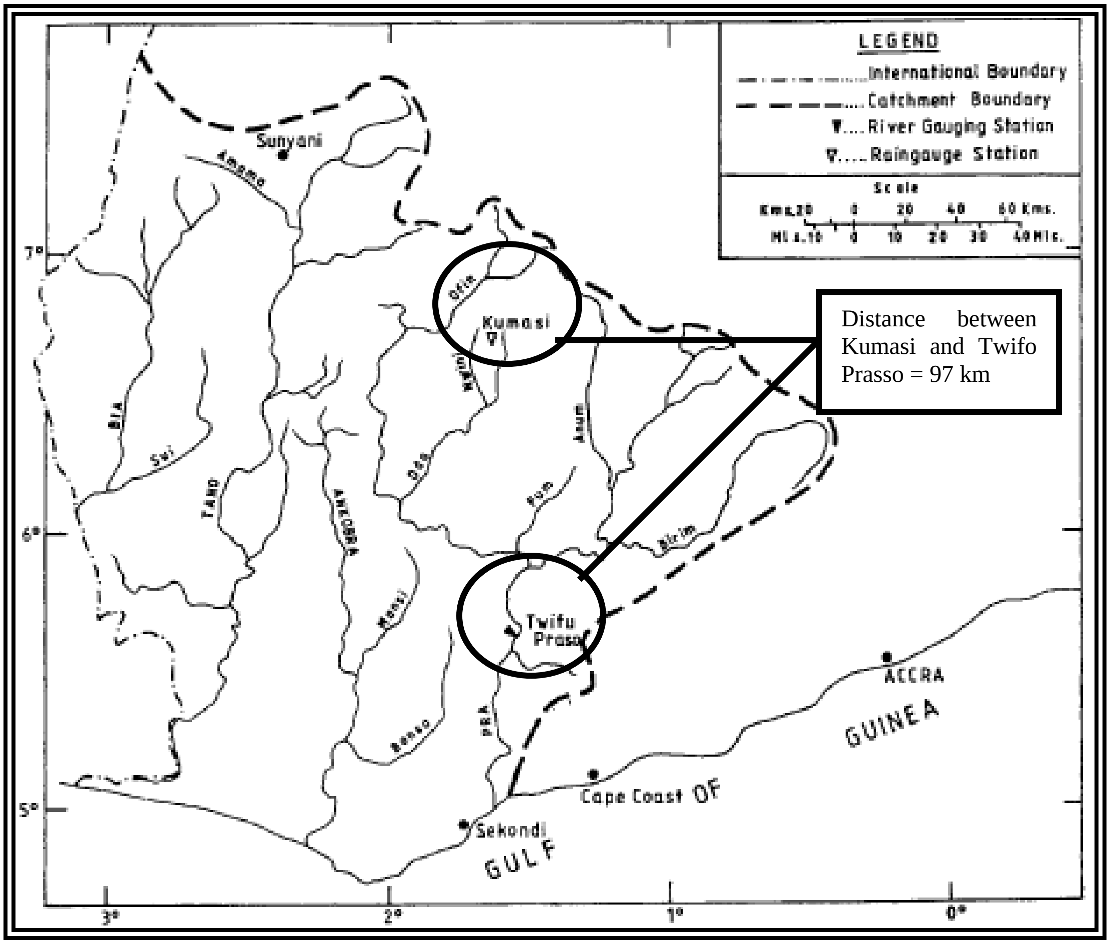

Figure 2-8: Discharge and rain gauge stations in the southwestern river systems of Ghana. Source: Opoku-Ankomah and Amisigo, 1998.

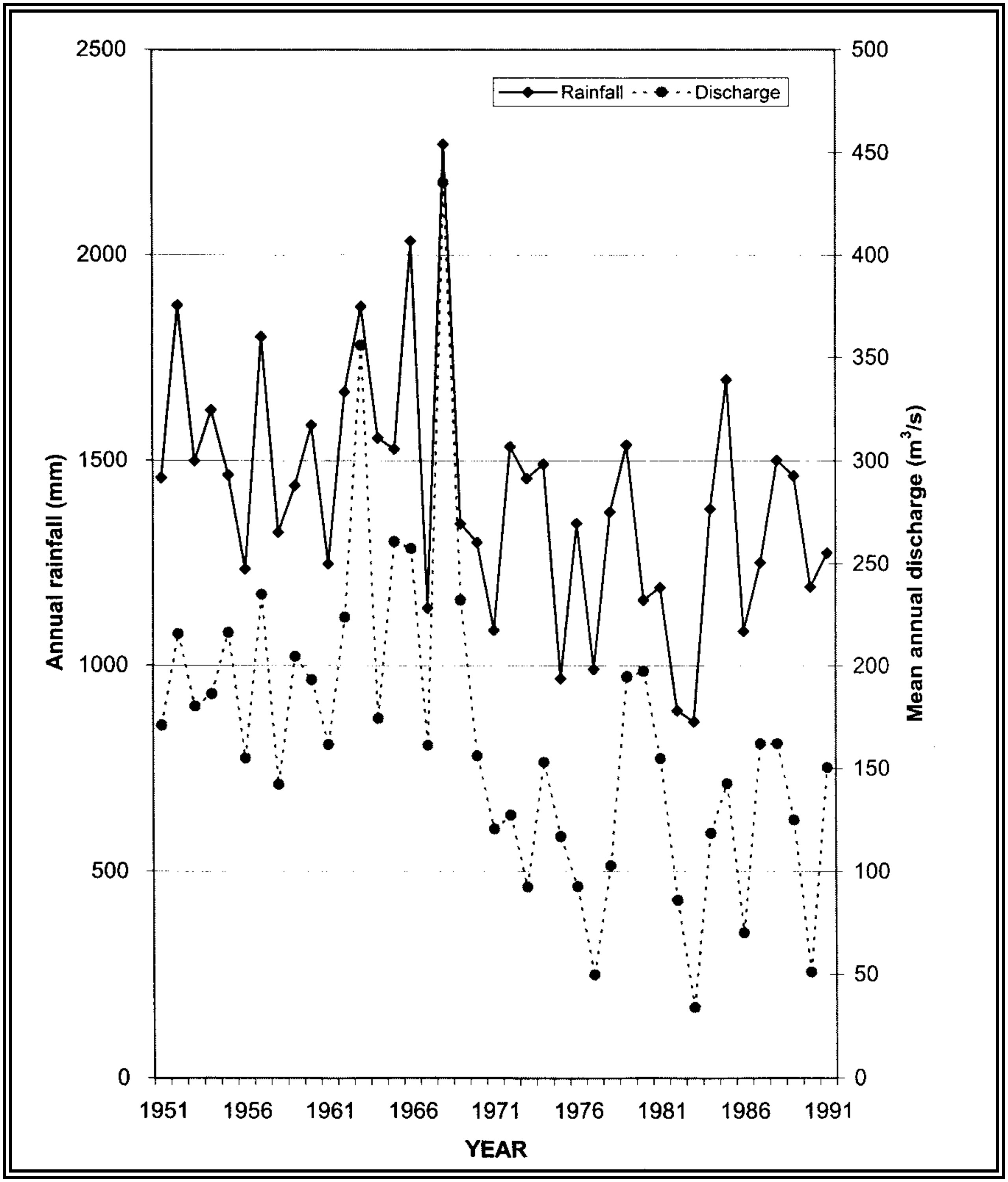

Figure 2-9: Annual rainfall and mean annual discharge of southwestern river systems of Ghana
Source: Opoku-Ankomah and Amisigo, 1998.

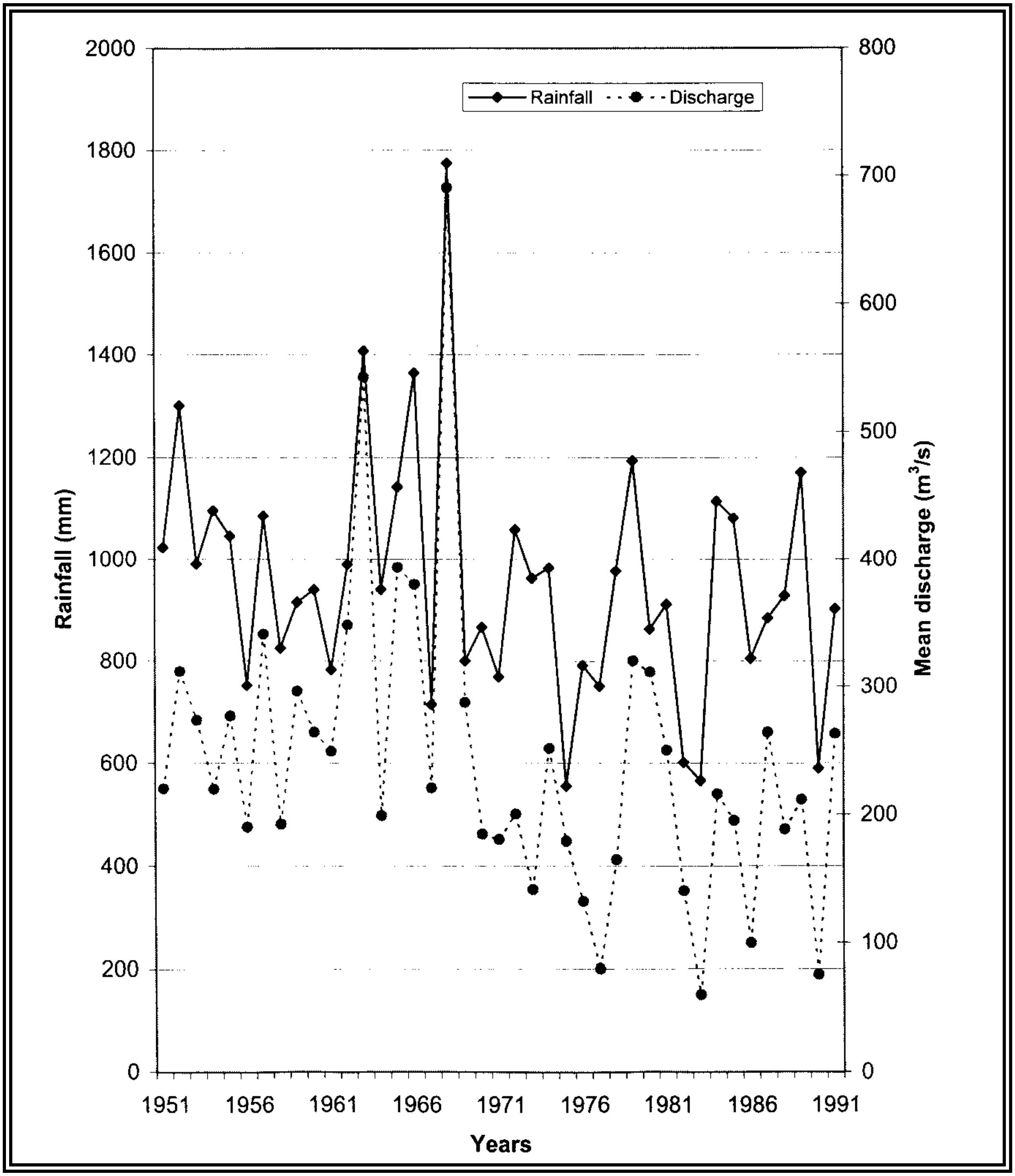

Figure 2-10: Rainfall and mean discharge for the wet season of southwestern river systems of Ghana

Source: Opoku-Ankomah and Amisigo, 1998.

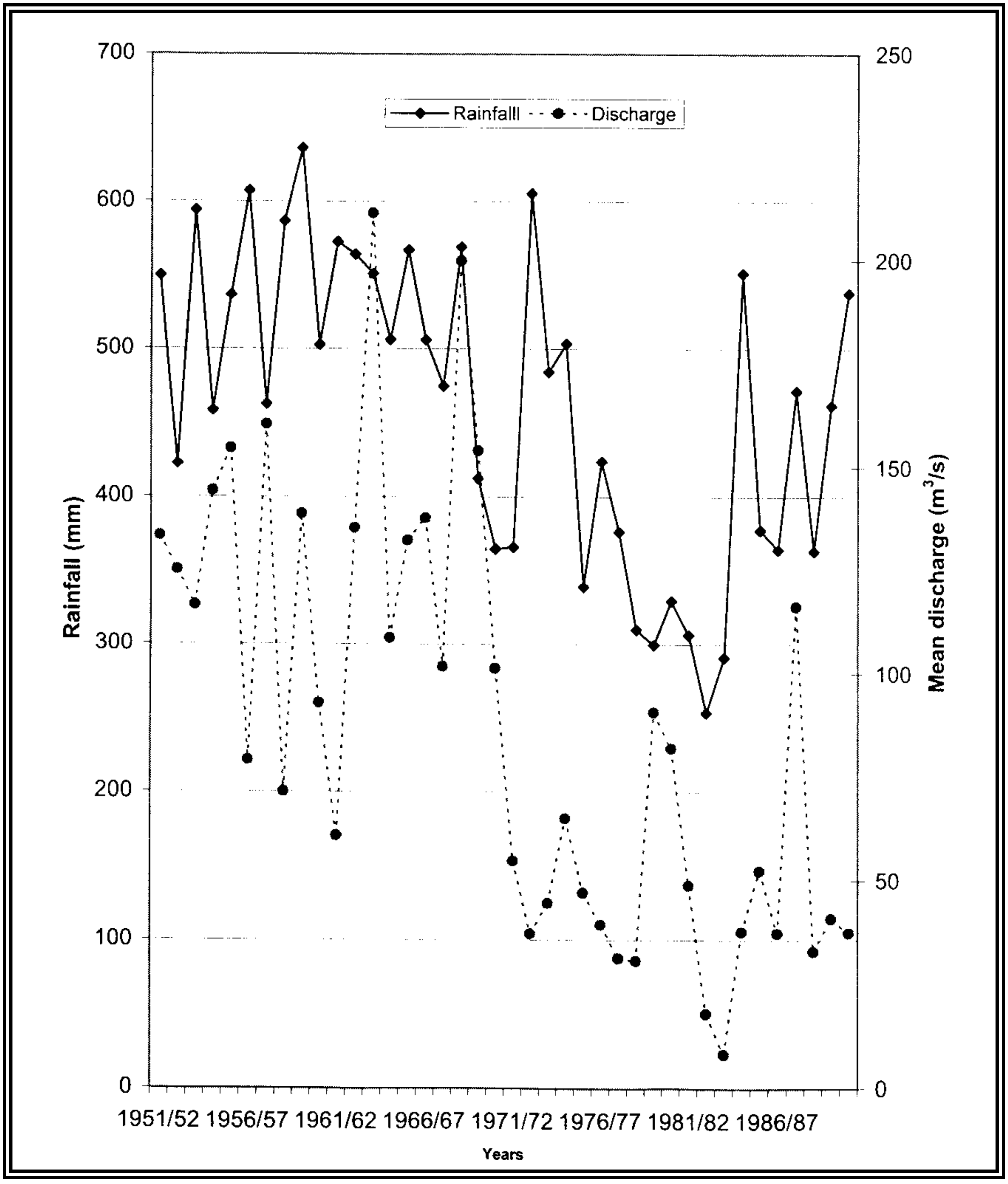

Figure 2-11: Rainfall and mean discharge for the dry season of southwestern river systems of Ghana

Source: Opoku-Ankomah and Amisigo, 1998.

Table 2-6: Statistics for rainfall

		1st Period	**2nd Period**	**2nd Period/ 1st Period (%)**
Annual rainfall	Mean (mm)	1563.6	1273.8	81.5
	CV	0.18	0.18	
	Max (mm)	2270.3	1696.5	
	Min (mm)	1140.5	684.9	
Wet Season	Mean (mm)	1037.6	879.1	84.7
	CV	0.25	0.22	
	Max (mm)	1774.4	1193.5	
	Min (mm)	714.3	555.8	
Dry Season	Mean (mm)	522.2	400.8	76.9
	CV	0.14	0.25	
	Max (mm)	636.3	605.5	
	Min (mm)	364.7	253.5	

Source: Opoku-Ankomah and Amisigo, 1998.

Table 2-7: Statistics for discharge

		1st Period	**2nd Period**	**2nd Period/ 1st Period (%)**
Annual rainfall	Mean (mm)	215.7	119.4	55.3
	CV	0.33	0.38	
	Max (mm)	435.1	197.6	
	Min (mm)	142.0	33.8	
Wet Season	Mean (mm)	304.0	186.9	61.5
	CV	0.41	0.40	
	Max (mm)	690.4	320.3	
	Min (mm)	185.2	59.4	
Dry Season	Mean (mm)	128.0	47.5	37.2
	CV	0.30	0.53	
	Max (mm)	211.3	116.3	
	Min (mm)	61.0	8.1	

Source: Opoku-Ankomah and Amisigo, 1998.

Opoku-Ankomah and Amisigo in comparing the changes in discharges among the seasons (Figures 2-10 and 2-11) indicated that dry season flows which are more critical to water resources system performance have undergone considerable changes resulting to the second period mean flow of 37% of the first period for the dry period (Table 2-7). It was further established that flows exceeded 95% of the time for the first and second periods are 71 and 17 m^3/s respectively. According to Opoku-Ankomah and Amisigo, the large decrease in the discharges when compared to the rainfall must be associated with infiltration, which needs to be satisfied before discharge. The decrease in rainfall amount could be considered as a primary factor causing the decrease in discharge. The decrease noticed in the study may also be assumed to be part of a periodic fluctuation normally inherent in climatic data (Lavender & Anderson, 1984).

2.3 Overview of Groundwater Resources of Ghana

Hydrogeologically, Ghana has two major provinces. These consist of the Basement Complex which underlies about 54% of the country composed of Precambrian crystalline igneous and metamorphic rocks, Paleozoic Sedimentary Formations locally referred to as the Voltaian Formation, which also underlies 45% of the country and Paleozoic Sedimentary strata (Coastal Provinces) underlying the remaining 1% of the country (Figures 2-12 and 2-13). The Basement Complex is further divided into sub-provinces on the basis of geologic and groundwater conditions (Figure 2-14) whereas the Voltaian Formation is further divided on the basis of lithology and field relationships into sub-provinces (Figure 2-15) (Dapaah-Siakwan and Gyau-Boakye, 2000).

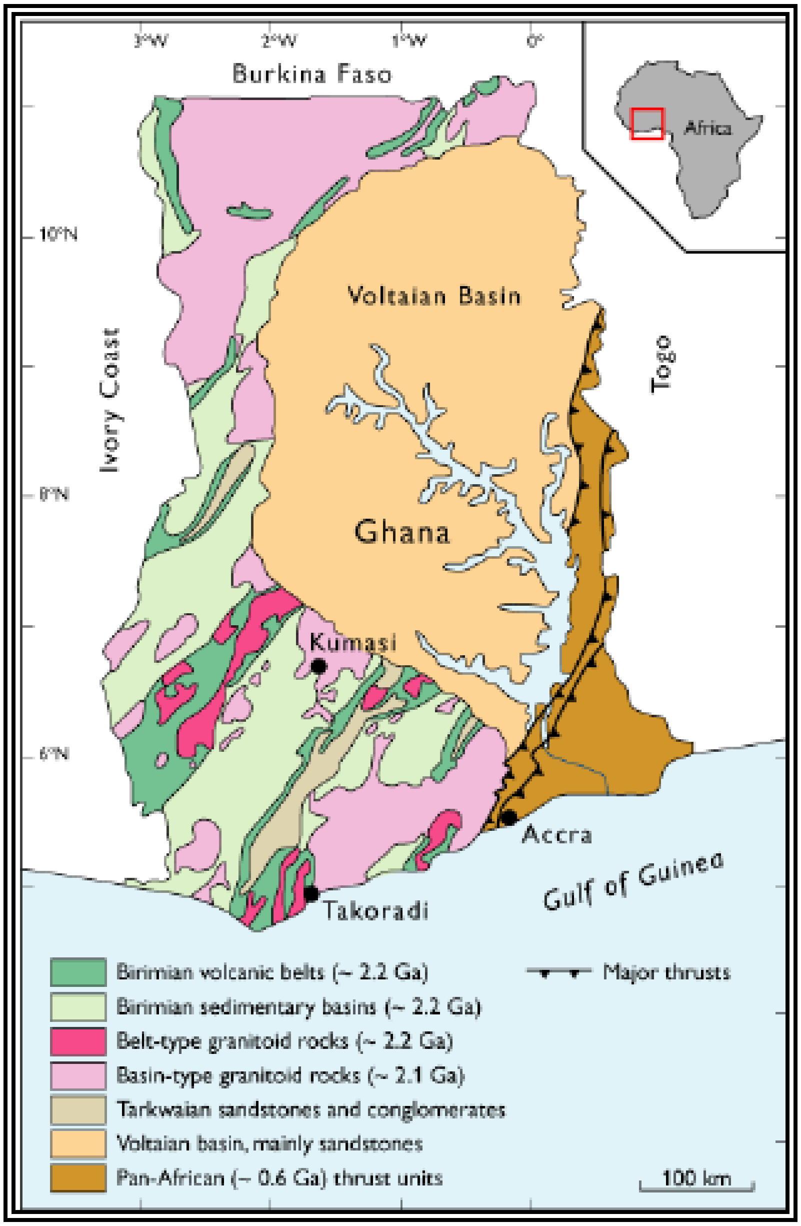

Figure 2-12: Geological Map of Ghana

Source: Modified from Kesse, 1985 by Hirdes et al., 1992.

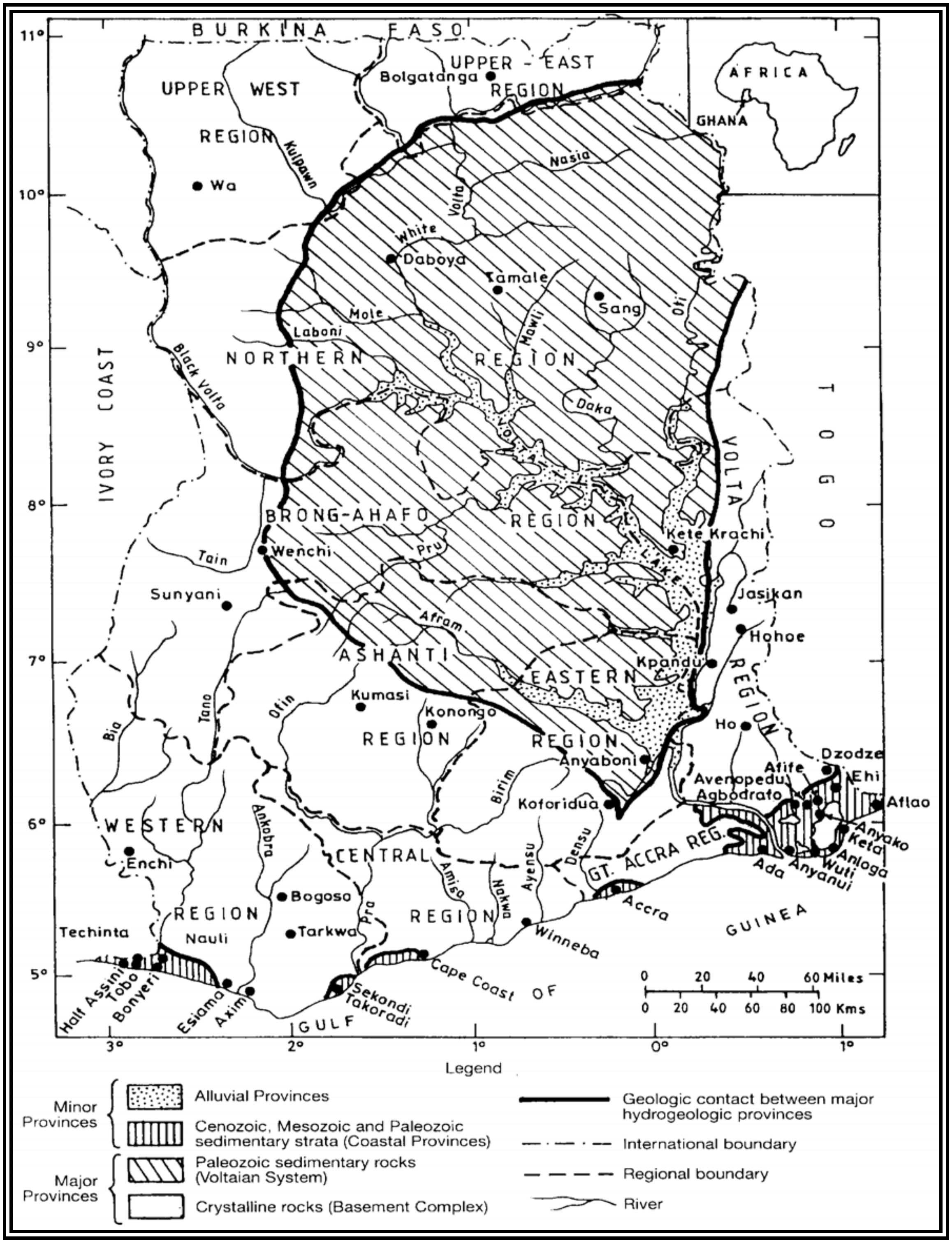

Figure 2-13 Hydrogeological provinces and river systems of Ghana

Source: Geological Survey of Ghana, 1969.

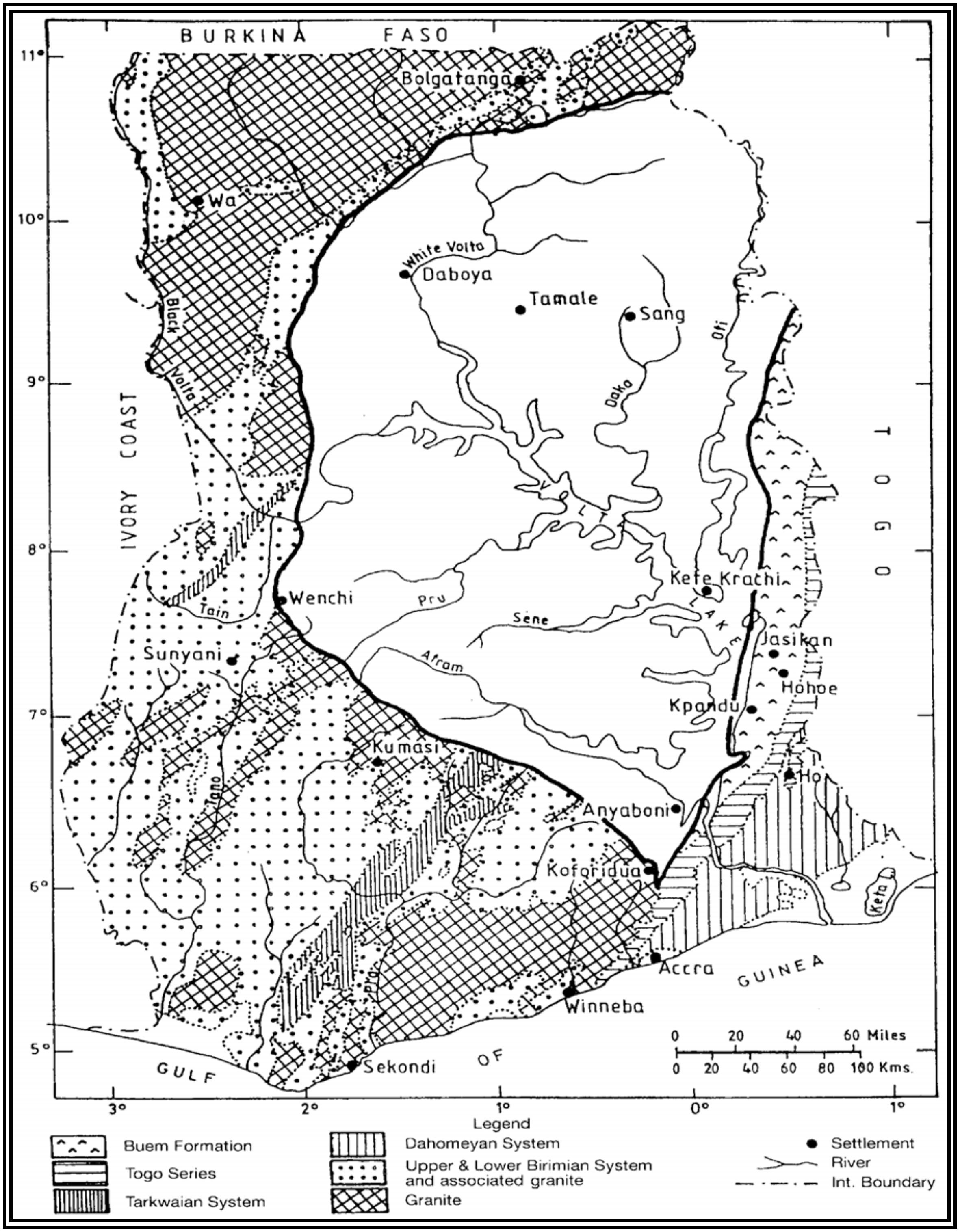

Figure 2-14: Hydrogeological sub-provinces of the basement complex in Ghana.
Source: Geological Survey of Ghana, 1969.

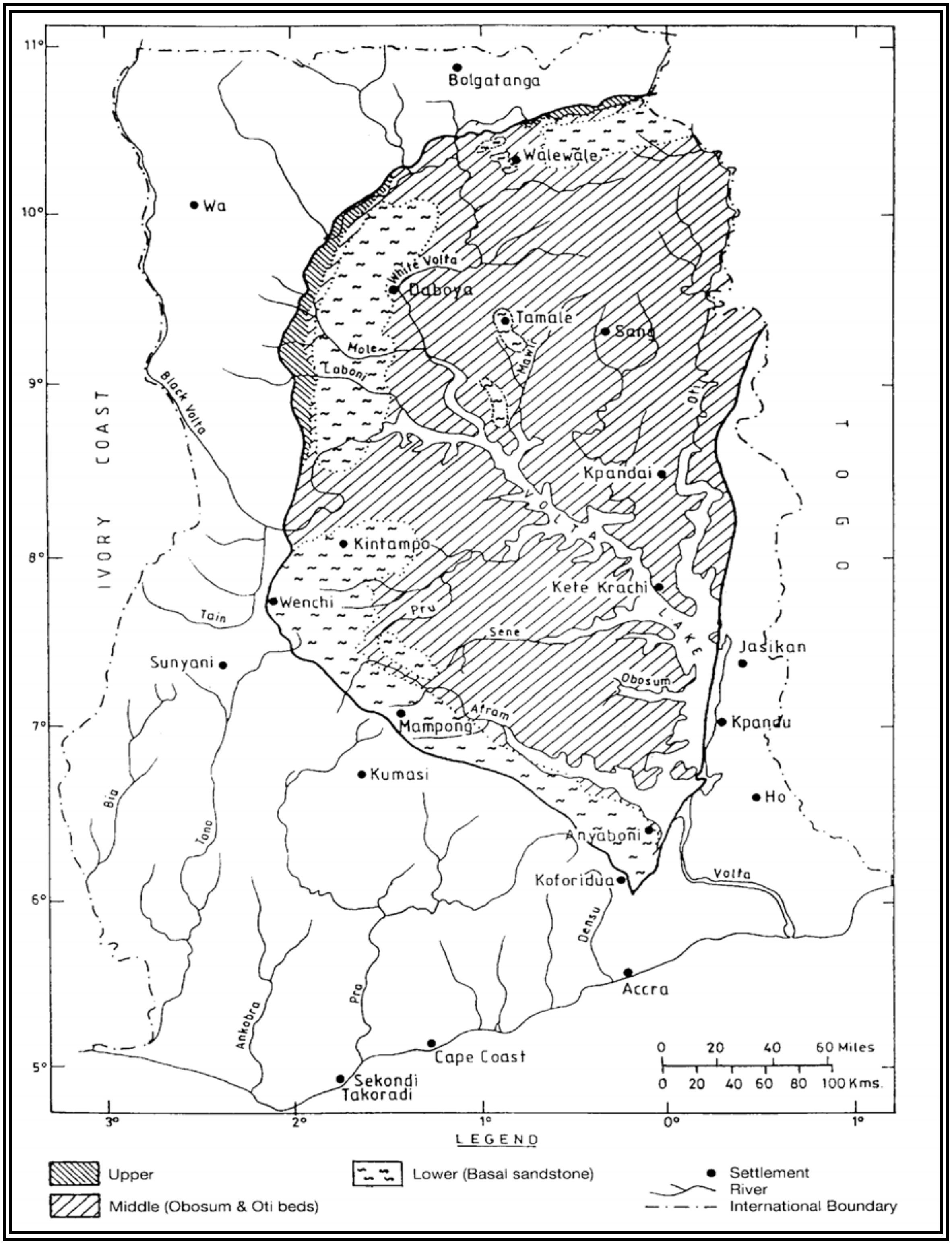

Figure 2-15: Hydrologeological sub-provinces of the voltaian system in Ghana

Source: Geological Survey of Ghana, 1969.

The Basement Complex and the Coastal Provinces have higher potential for groundwater than the Voltaian System. These underlie the most densely populated areas of the country and can therefore be exploited or tapped for human consumption. The Voltaian System is the least explored geologic unit owing to the low population density in the area it underlies.

Yields from boreholes are highly variable because of lithological varieties and structural complexities of rocks. The Water Resources Research Institute (WRRI) of the Council for Scientific and Industrial Research (CSIR) analyzed the borehole yields for various geologic formations in Ghana based on 11,500 boreholes drilled nationwide. A borehole yield map of Ghana was prepared based on available data on borehole yields, static water levels and other vital information (Figure 2-16). This map indicates borehole yield to be expected in any area within Ghana. Table 2-8 also gives a summary of data on borehole yields for the various hydrogeologic provinces and sub-provinces in Ghana.

Groundwater is mostly used in the rural areas of Ghana for drinking and other domestic purposes. The use of groundwater for livestock and poultry watering and for irrigation of crops is limited. Generally, groundwater use is determined by quantity available, its quality and unavailability of other alternatives. Owing to the low yield of boreholes and the relatively good quality of groundwater compared to surface sources, boreholes in almost the ten regions of Ghana with the exception of Greater Accra region are exclusively used to supply water for drinking and other domestic purposes

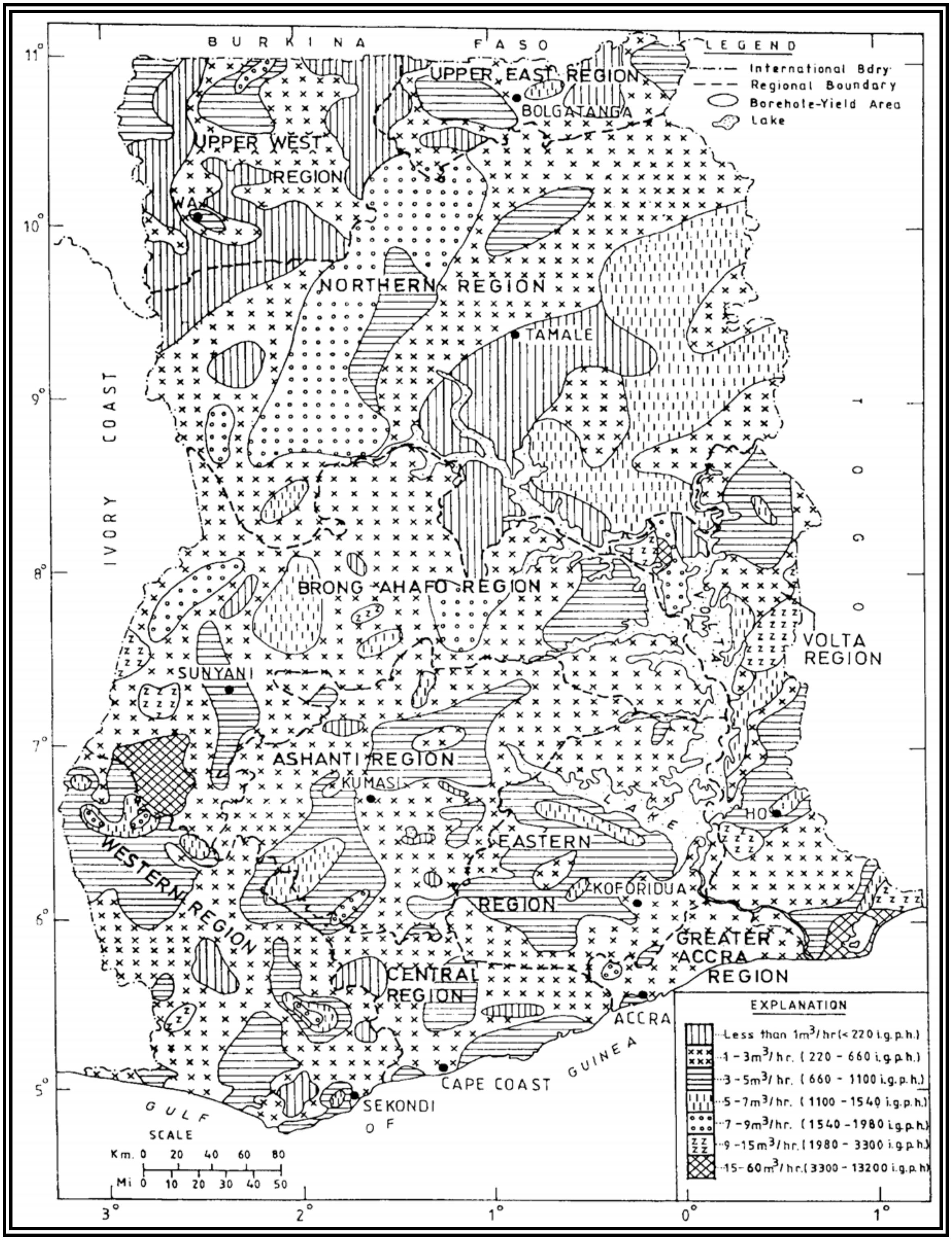

Figure 2-16: Distribution of borehole yields in Ghana

Source: Water Resources Research Institute, 1994.

Table 2-8: Summary of Borehole Yields of Hydrogeologic Provinces and Subprovinces

Hydrogeologic Provinces and Subprovinces	Borehole-Completion Success Rate (%)	Range of Yield m^3/h	Average Yield m^3/h
Basement Complex			
Lower Birimian System	75	0.41 – 29.8	12.7
Upper Birimian System	76.5	0.45 – 23.6	7.4
Dahomeyan System	36	1 – 3	2.7
Tarkwaian System	83	1 – 23.2	8.7
Togo Series	87.9	0.72 – 24.3	9.2
Buem Formation	87.9	0.72 – 24.3	9.2
Voltaian System			
Lower Voltaian	55	1 – 9	8.5
Middle Voltaian	56	0.41 – 9	6.2
Upper Voltaian	56	1 – 9	8.5
Cenzoic, Mesozoic, and Paleozoic Sedimentary Strata (Coastal Provinces)			
Coastal Block-Fault Province	36	1 – 5	3.9
Coastal-Plain Province	78	4.5 – 54	15.6
Alluvial Province	67	1 15	1.7

Source: Dapaah-Siakwan and Gyau-Boakye, 2000.

From Table 2-7, the average borehole yields in the Basement Complex range from 2.7 – 12.7 m^3/h, Voltaian System from 6.2 – 8.5 m^3/h, Coastal Provinces 3.9 – 15.6 m^3/h and Alluvial Province is 11.7 m^3/h.

2.3.1 Groundwater Abstraction and Distribution

Groundwater is abstracted from all the geological formations in Ghana by means of boreholes, hand-dug wells and dug outs usually for most rural areas. In recent times, some borehole supplies are also tapped to supplement urban water supplies. There were over 45,000 abstracting systems in Ghana in 1994 made up of approximately 10,500 boreholes, 45,000 hand-dug wells and some dug outs, all over the country (Kortatsi, 1994). Due to population increase, which has resulted in higher demand for water for various uses particularly domestic, the available information shows increase in abstracting systems. The number of hand dug wells had risen to about 60,000 in 1998 whiles the number of boreholes reached 11,500 in the year 2000 (Dapaah Siakwan and Gyau-Boakye, 2000); making total of 71,500 systems. Based on borehole and well information, it was inferred that the rate of construction of wells in Ghana (1994-1998) and that of boreholes (1994-2000) were 10 per day and 1 every other day respectively.

A hand dug well is a cost effective means of extracting shallow groundwater bodies. Typically, a hand dug well in Ghana consists of three (3) components; the intake, a shaft and the wellhead (DANIDA, 1993). Boreholes are also found in use in several areas in Ghana though the cost limits its use. Most of the boreholes were dug for community use. Few private organizations and very few individuals however own their own boreholes. Generally, there are limited data on hand dug wells in Ghana, except in the Volta Region where an inventory has been done; and it could be inferred that a hand dug well yield varies from 0 (dry well) to 26 m^3/day with mean of 6 m^3/day (Kortatsi, 1994). The estimated total abstraction of hand dug wells per year is 1.3×10^8 m^3. The regional distribution of borehole and the estimated annual abstraction of groundwater based on 12 hour pumping a day are shown in Figure 2-17. The estimated total annual abstraction of borehole is 1.41×10^8 m^3.

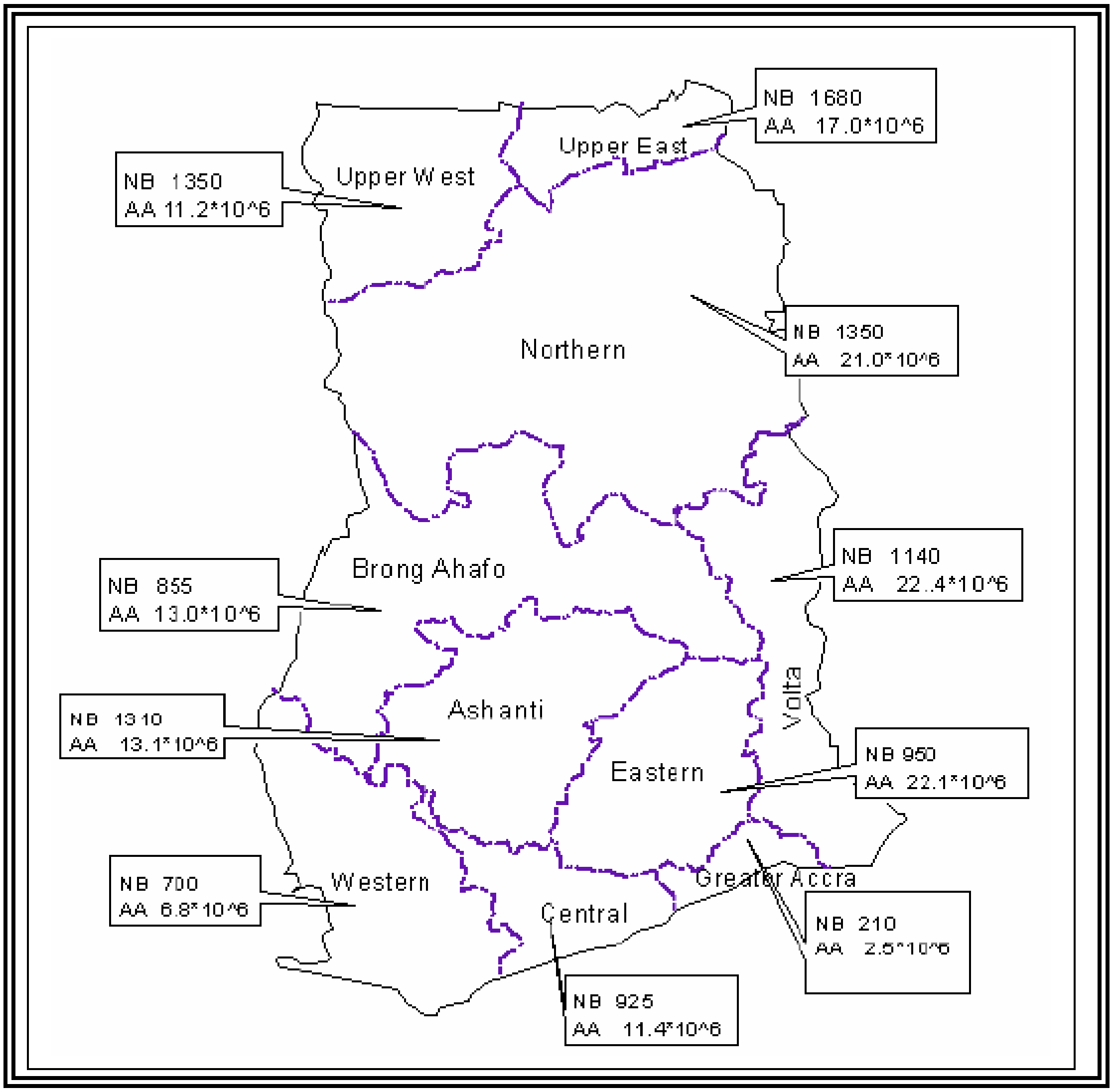

Figure 2-17: Regional distribution of borehole and annual abstraction in Ghana

Source: Barry et al., 2005.

2.3.2 Assessment of Groundwater Resources of Coastal Basin of Ghana

The Coastal basin of Ghana is predominantly underlain by the Basement Complex (crystalline rocks) which covers 54% of the country. Minor occurrences of more recent unconsolidated sands, clays and gravels are restricted to small areas along the coast. The Basement Complex is further divided to include the metamorphosed and folded rocks of the Birimian System, Dahomeyan System, Tarkwaian System, Togo Series and the Buem Formation (Figure 2-14) on the basis geologic and groundwater conditions (Gill, 1969). The granite and gneiss found with the Birimian rocks are of considerable importance in the water economy of Ghana. Cape Coast and its environs are being underlain by granite and upper and lower birimian system and associated granite.

The crystalline rock formations are not inherently permeable. However, the ability to store water results from secondary permeability and porosity that have developed as a result of shearing, jointing, fracturing and weathering activities thus giving rise to two main types of aquifers. Groundwater flow is mostly restricted to joints and fractures within the crystalline rock formations which often limit borehole yields. Areas with a thick or deep layer of weathered material overlies the crystalline basement turns to provide increased potential for groundwater storage and the converse is true for locations having shallow depth of weathered and fractured material. The thickness of the weathered zone varies from region to region. Weathering is generally shallow in the Accra Plains, Central and Upper regions where annual rainfall is low, 762 – 1143 mm The weathered layer can be in excess of 100 m in some places though typically it ranges from 1 – 70 m thick (Asomaning, 1993).

2.3.2.1 Groundwater Recharge

There is little information available on groundwater recharge in Ghana. Recharge to all the aquifer systems is mainly by direct infiltration of precipitation through fractures, faults and joints zones and through sandy portions of the weathered materials. There is also some recharge through seepage from ephemeral stream and river channels during the rainy season. Some indirect recharge principally occurs in the lower rainfall, low relief and low permeability areas. This happens as a result of runoff from watershed outside the areas or a particular storm event is of sufficient magnitude to cause runoff. The drainage courses or streams which act as conduit for these overland flows are generally weak fissured zones which allow a greater part of the runoff to infiltrate through their beds to the groundwater table.

The potential aquifers in the study area are located in two main types of rocks. The first being the high porosity and low permeability weathered basement rock type and the second relates to the fractured basement rock with low porosity and high permeability characteristics.

2.3.2.2 Groundwater Quality

Geology plays an important role in the determination of groundwater quality and potential water-quality problems. Previous studies (Nathan Consortium studies, 1970; Amuzu, 1978; Andah, 1993; Kortatsi, 1994; Ministry of Works and Housing, 1998) revealed that the quality of groundwater is generally good. As the Coastal basin is predominantly underlain by basement complex rocks and weathered derivatives, groundwater is mainly of low salinity and commonly acidic in composition (pH < 6.5), with low values of total hardness. It has been observed that along the south-east and the coastal margins, the hardness and the pH values are higher and the intrusion of seawater into coastal aquifers may increase groundwater salinity. The main groundwater quality problem observed in Ghana is high iron concentrations (Table 2-9).

Table 2-9: Summary of potential groundwater quality problems in Ghana

Determinant	**Potential Problem**	**Geology**	**Location**
Iron (Fe)	Excess, often significant	All aquifers	Many locations
Manganese (Mn)	Excess	All aquifers	Several locations
Fluoride (F)	Excess (up to 4 mg/l)	Granites and some Birimian rocks	Upper Regions
Iodine (I)	Deficiency (less than 0.005 mg/l)	Birimian rocks, granites, Voltaian	Northern Ghana (especially Upper Regions)
Arsenic (As)	Excess (> 0.01 mg/l)	Birimian	Especially south-west Ghana (Gold belt)

Source: http://www.wateraid.org/ghana.

It was established during an earlier study that groundwater quality in the southern Central Region generally is good for multi-purpose use except the presence of low pH (3.5 – 6.0) waters, high levels of iron, manganese and fluoride as well as high total dissolved solids (TDS) in the range of 1,500 – 2,000 mg/L (Ghana's Water Resources, 1998). There have been reported cases of saline water in the study area even though the average conductivity levels are within the standard acceptable limits. There have been isolated cases in which the values in the excess of 5000 µS/cm have been recorded. The high conductivity values are in most cases far from the sea and are underlain by crystalline rocks which are inherently impermeable which help in dismissing the possibility of seawater intrusion. Based on conductivity analysis, it was evident that the groundwater system in southern Central Region could be classified into four groups Table 2-10.

Table 2-10: Classification of groundwater systems based on conductivity

Groups	**Conductivity (µS/cm)**
Fresh Water	< 500 µS/cm
Marginal Water	500 – 1,500 µS/cm
Brackish Water	1,500 – 5,000 µS/cm
Saline Water	> 5,000 µS/cm

Source: Armah, 2000.

Figures 2-18 – 2-19 show Cape Coast Granite and Lower Birimian conductivity variation.

Cape Coast Granite Terrain

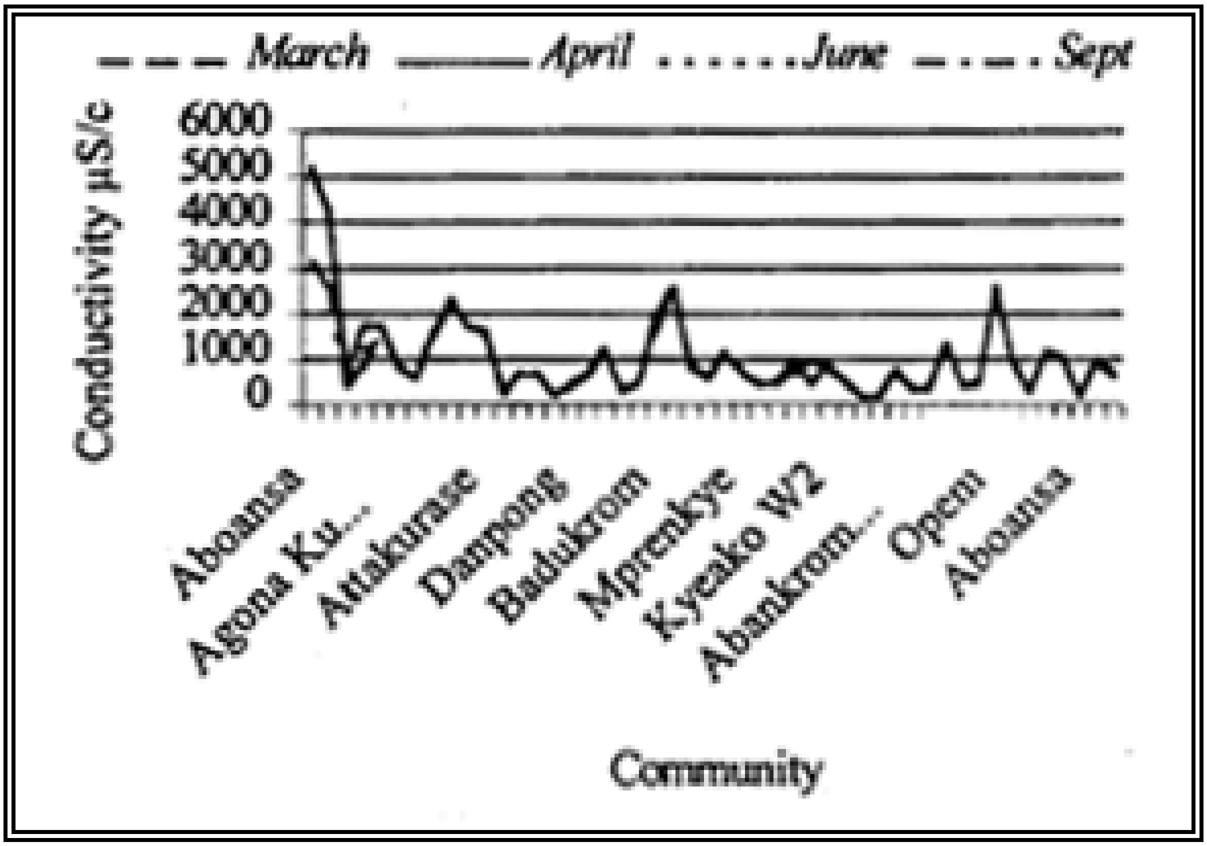

Figure 2-18: Cape Coast Granite Conductivity Variations

Source: Armah, 2000.

Lower Birimian Terrain

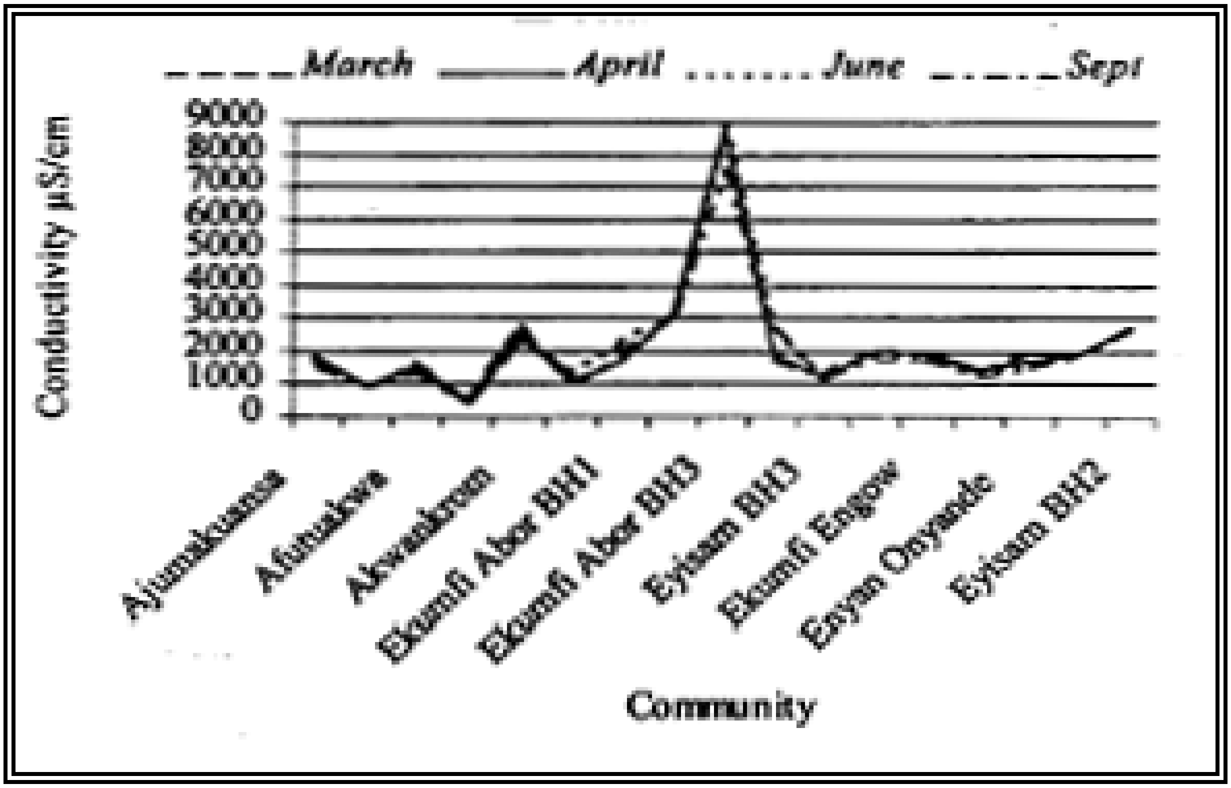

Figure 2-19: Lower Birimian conductivity variations
Source: Armah, 2000.

2.3.3 Wells and Boreholes

Wells (hand-dug) generally have a large diameter and are constructed using simple tools, such as pickaxes and shovels. Their depth ranges from 4.9 to 20 meters and could be lined with concrete cast on site, precast concrete rings, rock, or concrete blocks. Boreholes are hand- or machine-drilled wells. Machine-drilled wells are typically 0.1-0.2 meters in diameter and are sunk using relatively sophisticated equipment powered by diesel or electric motors. Machine drilling is suitable for depths of up to 50m, but the depth depends on the power of the rig and the geological conditions. Water is abstracted from these wells and boreholes by either hand or electrical pumps. The number of people that can be served by a drilled well depends on the capacity of the hand pump, but it is typically about 300. Until recently, wells and boreholes water source abstraction were done manually using bucket and rope and hand pumps. In modern practice, however, based on population and borehole yields among others, boreholes are mechanized with submersible pumps. Water from the wells and boreholes are pumped into overhead storage facility and later release to inhabitants through public stand pipes.

2.3.4 Groundwater Use

According to Gyau-Boakye and Siakwan-Dapaah (1999), about 52% of the rural inhabitants in Ghana have access to potable water mainly from groundwater sources. Of 19 million Ghanaian population, 56% live in rural areas (Ghana Statistical Service, 2002), with about 30% in the rural areas with access to groundwater as potable water source.

2.4 Need for Alternative Water Source

The primary aim of finding an alternative water source is to augment the current water supplies in the study area. Water is one of the main natural resources available to human beings. It is considered the most fundamental and indispensable resource because without water there is no existence. The scarcity of water in the study area is seen as the most limiting factor to economic growth and social development.

Since the inception of the perennial water shortage in Cape Coast and its environs, there has been both measurable and non-measurable loss. This to a very large extent has derailed efforts at marketing the area for investment. It is envisaged that continuous supply of water within the study area would help accelerate and boost the economic potential of Cape Coast and its environs especially in fishing, salt, tourism and vegetable production.

The available alternatives which this study wishes to consider include:

- Surface water (building of a new treatment plant on Pra river)
- Groundwater source
- Desalination of seawater

2.4.1 Dredging of Brimsu Dam and Building of a Treatment Plant on Pra River

According to the master plan report on the regional study for the improvement of urban water supply in the central region (2004), sedimentation at Brimsu dam has reduced storage capacity, thus leading to serious water shortage, particularly during the dry season. Dredging was considered as an interim measure, expected to make the Brimsu dam operates full capacity to augment water supply in the Cape Coast and its environs until a more permanent and long term measures such as increasing height of weir of the dam and building a new treatment plant at Hemang to pipe down about 6.6 million gallons of treated water a day from the Pra River are accomplished. Besides the capital cost of bringing water over a long distance from the supply area, there are also environmental concerns that need to be considered in evaluating this alternative.

Environmentally, the water draining from the dumpsite for sediment from dredging operations in the Brimsu reservoir may lead to increased turbidity in surface watercourses. Furthermore, the dredging works in Brimsu reservoir will disturb the bottom sediments in the reservoir and therefore have an adverse impact on the turbidity, in the lower parts of the lake. The new effort in the Pra basin will cause water pollution problems since the basin is in the mineral rich areas of Ghana where extensive artisanal mining activities are on-going. The Pra river basin in the southwestern Ghana is a site of on going application of metallic mercury in prospecting gold. Therefore any future reliance on the river for the provision of water such as the one under discussion may have to examine and take into consideration mercury (Hg) contamination in the different environmental compartments in its watershed.

2.4.2 Groundwater Source

The study of the possibility to augment water supply from groundwater sources in Cape Coast and its environs remain one of the available alternatives since hydrogeologically, the area is underlain by water bearing rock formations. Also the fact that during water shortage, water is hauled from boreholes to augment supply makes this alternative an option. In evaluating this alternative, critical attention will be given to the existing boreholes in the area and their respective yields and quality. Rainfall and local geology will be used in evaluating groundwater source as an alternative since recharge is mainly by direct infiltration. It is anticipated that groundwater source will be developed for communities with groundwater potential to rely on whereas areas that lack the ability to extract groundwater would continue their reliance on surface water alternative or the yet to develop desalination.

2.4.3 Desalination

The desalination technology is finding its outlets in supplying water to meet ever growing municipal domestic consumption needs in water scarce countries. It is normally used in water scarce countries with per capita availability freshwater below 1,000 m^3/year. Currently, there are eighteen (18) countries classified as water scarce countries using 1,000 m^3/year as the bench mark. These countries are mainly in the Middle East and Northern Africa with few found in Europe, Asia and the Caribbean. It is projected that approximately 29 countries in the world would experience water scarcity by 2025 (UN, 1995). The United Nation’s minimum population projections and data on renewable fresh water supplies estimated that one in three people world-wide will be living under inadequate freshwater supplies conditions by 2025 (The CWC Group, 2000).

One of the solutions for countries with water scarcity is the conversion of seawater and/or brackish water to potable water using desalination technology. The desalination of seawater and/or brackish water in coastal areas is increasingly becoming a feasible alternative in supplying water to meet the ever growing municipal domestic consumption needs in water scarce countries as the per capita availability of freshwater resources continue to decrease as the world population increases. Thus, the development of appropriate technology for the desalination of seawater in coastal communities where two-thirds of the world's population lives poses one of the biggest challenges of the new millennium. These challenges will include approaches necessary to limit the effects or impacts of water shortages by improving the efficiency of water use, implementing technologies and policies to encourage water use from non- conventional sources of water such as desalination, which has been a marketable technology over the last three decades for industries and urban centers (Ayoub and Alward, 1996).

Once considered as an expensive and last option for marginal municipal domestic and industrial water supply, the practice over the years led to continuous improvements that rendered desalination technology remarkably efficient, reliable, and inexpensive and even affordable. It is finding new outlets in water scarce regions as a viable long term resource and alternative to major water transport schemes, supplying water to meet growing consumption and supply water to sea resorts. The difference between the cost of desalination and that of conventional supplies has narrowed in the past 10 years, resulting to current quoted prices for desalination brackish water and seawater as $0.2 – 0.35/m^3 and $0.7 – 1.2/m^3 respectively. The cost is however expected to reduce further below $0.5/m^3 for seawater in the near future (The CWC Group, 2000).

2.4.3.1 Global Desalination Capacity

According to a survey in 1998 on the application of the major technologies to desalination globally, multi-stage flash and reverse osmosis dominated the industry accounting for over 85% (Figure 2-20). Though capacity was almost the same between membrane and thermal processes, current trends suggest that the membrane processes are now preferred and will finally dominate the market (Miller, 2003).

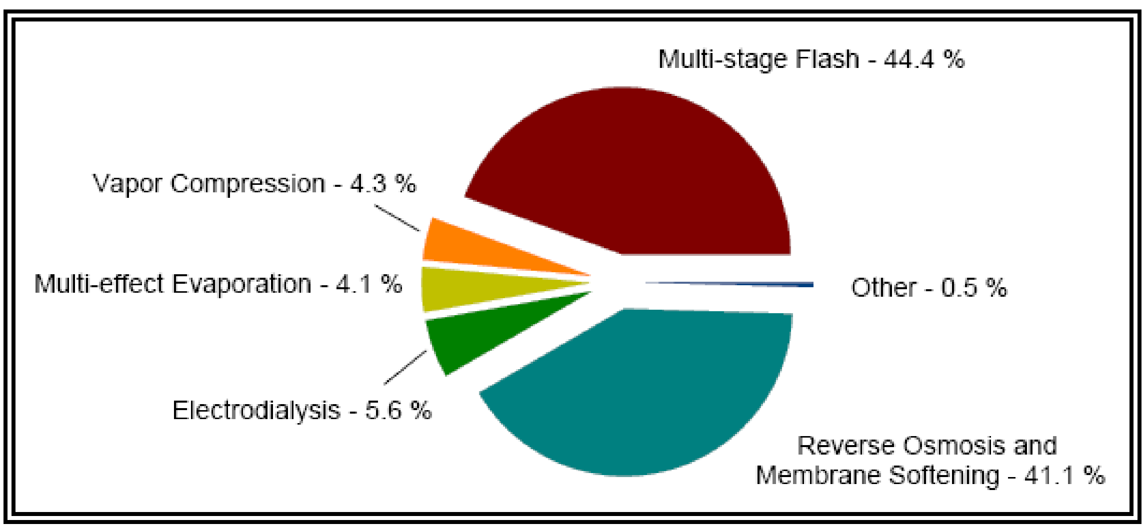

Figure 2-20: Global distribution of installed desalination by technology
Source: Mickley, 2001.

The distribution of desalination capacity by country presented in Table 2-11, shows that in 1998 eleven countries accounted for more than 75% of the global capacity. It was evident that thermal processes are dominant in countries located in the Middle East which has abundant energy resources and historical reliance on desalination prior to the development of modern Reverse Osmosis (RO) membranes. The United States, second to Saudi Arabia in desalination capacity uses membrane technology.

Table 2-11: Installed Desalination Capacity by Country (multiply m^3/day by 264 for gal/day)

Country	**Total Capacity (m^3/day)**	**% of Global Production**	**MSF**	**MEE**	**MVC**	**RO**	**ED**
Saudi Arabia	5,253,200.	25.9	65.7	0.3	1.2	31	1.9
United States	3,092,500	15.2	1.7	1.8	4.5	78	11.4
United Arab Emirates	2,164,500	10.7	89.8	0.4	3.0	6.5	0.2
Kuwait	1,538,400	7.6	95.5	0.7	0.0	3.4	0.3
Japan	745,300	3.7	4.7	2.0	0.0	86.4	6.8
Libya	683,300	3.4	67.7	0.9	1.8	19.6	9.8
Qatar	566,900	2.8	94.4	0.6	3.3	0.0	0.0
Spain	529,900	2.6	10.6	0.9	8.7	68.9	10.9
Italy	518 700	2.6	43.2	1.9	15.1	20.4	19.2
Bahrain	309,200	1.5	52.0	0.0	1.5	41.7	4.5
Oman	192,000	0.9	84.1	2.2	0.0	11.7	0.0
Total		76.9					

Source: Wangnick, 1998.

2.4.3.2 Desalination Processes (Technology)

Desalination processes based on the quality of energy inputs could be classified into two processes, thermal and membrane processes. The technologies such as Multi Stage Flush (MSF), Multi-Effect Evaporation (MEE) and Vapor Compression (VC) are typical of some thermal processes which require a relatively high thermal energy input to effect a phase change in the sea or brackish water. Thermal processes are said to be generally cost-effective since the unit cost of product is lower and are mainly used to supply municipal drinking water and have high commercial viability. In membrane processes, technologies such as Reverse Osmosis (RO), Electro Dialysis (ED) and Electro Dialysis Reversal (EDR) use high-grade electrical or mechanical energy inputs to produce fresh water without a phase change in the sea or brackish water. These technologies are adaptable to large and small scale applications and can be used to supply industrial process water, treat municipal waste water, and supply community potable water.

2.4.3.2.1 Multi-Stage Flash (MSF)

Multi-Stage Flash desalination process accounts for over 40% of the world's desalination capacity (Ettouney et al., 1999). The distillation process involves evaporation and condensation of water. Evaporation and condensation stages are coupled in design such that the latent heat of evaporation is recovered for reuse during preheating of incoming water. Each stage of MSF operates at a successively lower pressure. The schematic diagram of MSF desalination process is shown in Figure 2-21.

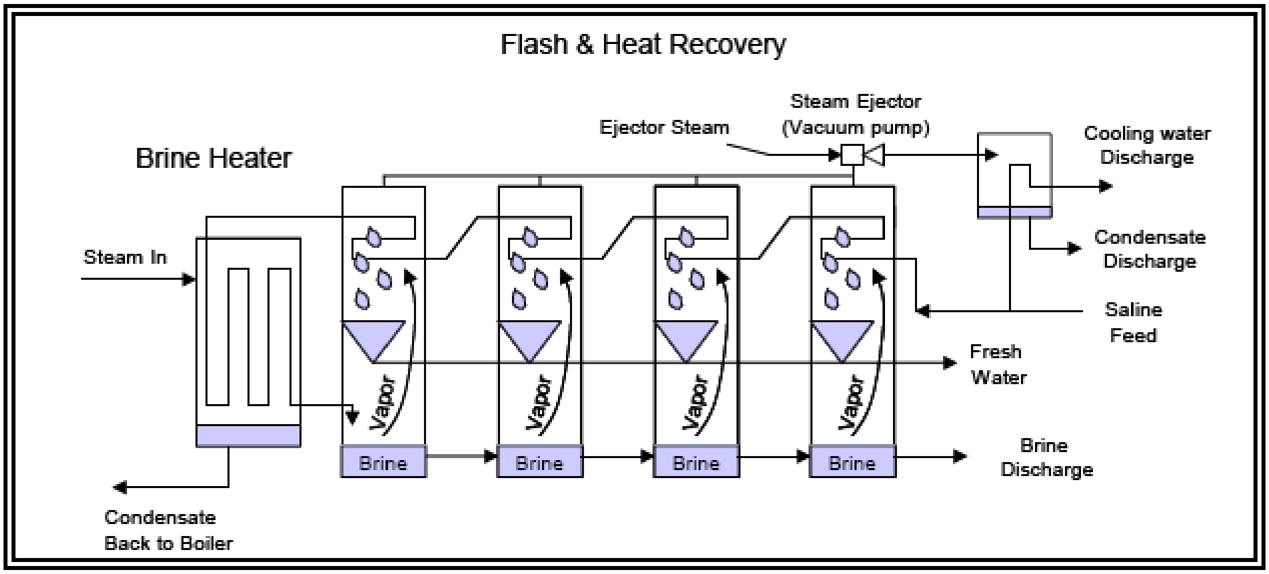

Figure 2-21: Multi-Stage Flash Desalination Process
Source: Miller, 2003.

2.4.3.3 Multi-Effect Evaporation (MEE)

The Multi-Effect Evaporation (MEE) (Figure 2-22) was among the early desalination technologies developed. The problems with scaling on the heat transfer tubes have resulted to its replacement with MSF (Al-Shammiri and Sofar, 1999). Though not widely use currently, it gained a lot of attention due to the better thermal performance compared to MSF. Vapor from each stage is condensed in the next successive stage resulting in using its heat to derive more evaporation. The MEE process can have several different configurations depending on the type of heat transfer surface. It can be combined with heat input between stages from a variety of sources such as mechanical vapor compression or thermal vapor compression.

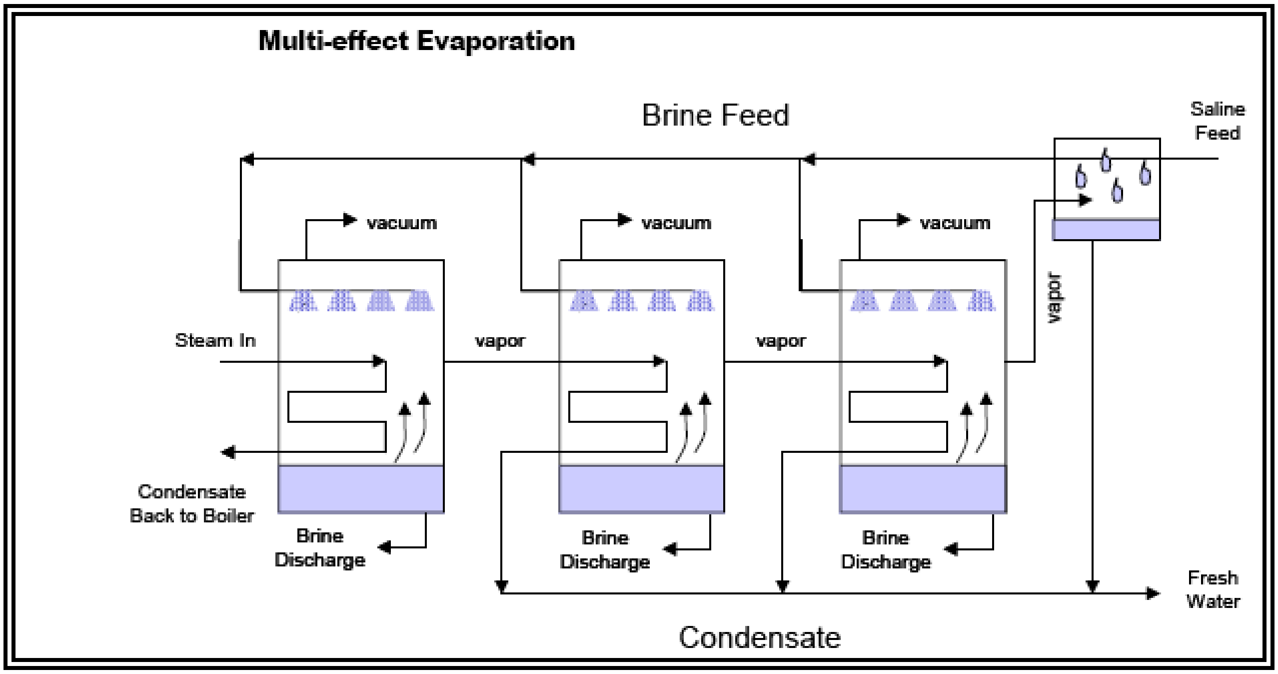

Figure 2-22: Multi-Effect Evaporator Desalination Process (Horizontal Tube – Parallel Feed Configuration)

Source: Miller, 2003.

2.4.3.4 Vapor Compression (VC)

The Vapor Compression desalination processes rely on pressure operation to drive evaporation, and the heat of evaporation is supplied by the compression of vapor either with mechanical compressor (Figure 2-23) or a steam ejector also known as thermal vapor compression. Vapor compression processes are particularly useful for small to medium installations (Buros, 2000).

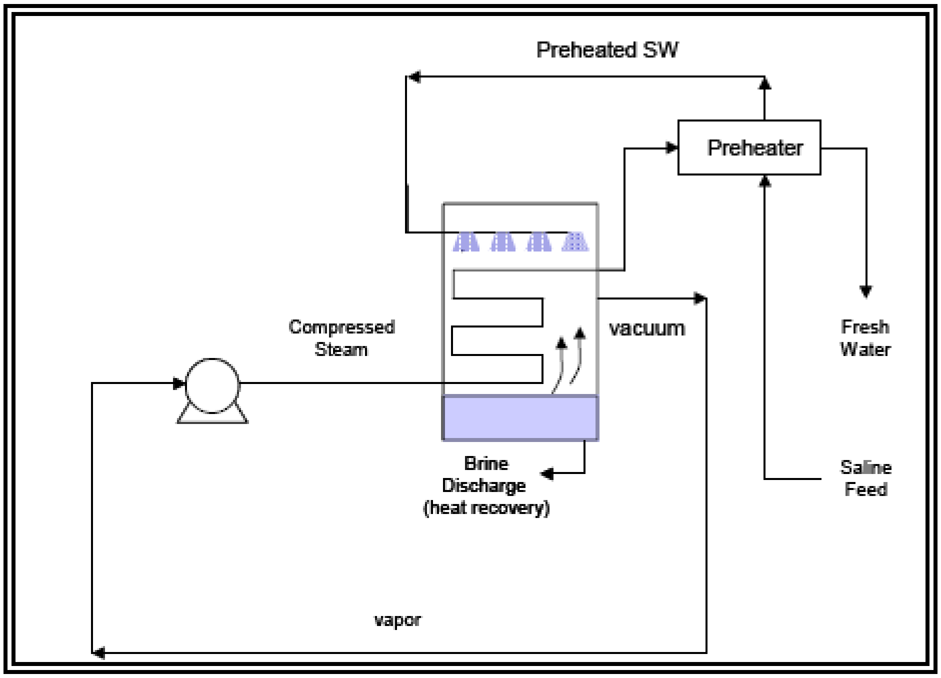

Figure 2-23: Single stage mechanical vapor compression desalination process
Source: Miller, 2003

2.4.3.5 Reverse Osmosis (RO)

Reverse osmosis is a membrane separation process that recovers water from a saline solution pressurized to a point greater than the osmotic pressure of the solution. The membrane filters out the salt ions from the pressurized solution, thus allowing only water to pass. According to Semiat (2000), the United States primarily rely on RO to treat brackish and surface water. In RO, considering that salt can be removed from the seawater to produce fresh water without having to undergo a change of state has made RO the most energy efficient processes. The schematic of RO process is shown in Figure 2-24.

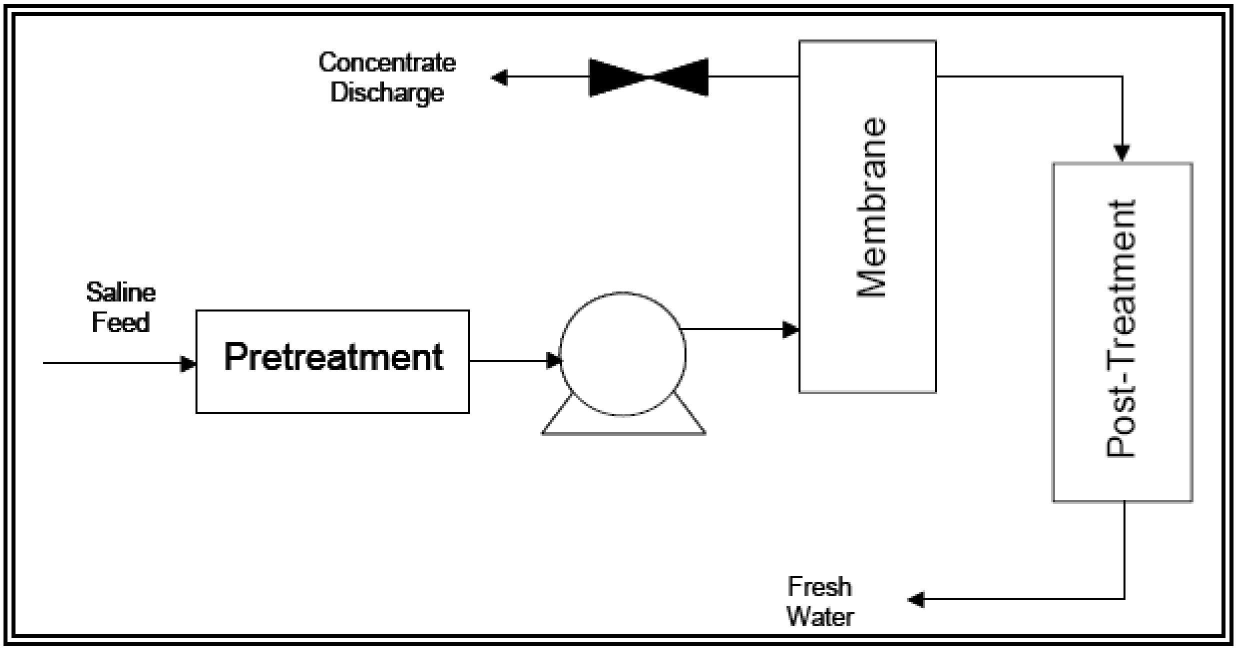

Figure 2-24: Block diagram of reverse osmosis operations – option pressure devices not Depicted

Source: Miller, 2003.

2.4.3.6 Electrodialysis (ED)

Electrodialysis (ED) uses direct current source and a number of flow channels separated by alternating anion and cation selective membranes to achieve separation of water and dissolved salts (Buros, 2000). The ED only removes ionic compounds from solution unlike RO or distillation, and an electric field serves as the driving force for the separation. In the process, saline water is fed in parallel to each of the separate channels. Ions migrate in opposite directions in response to an applied voltage and as a result of charge selectivity of the membranes, ion concentration increases and decreases in alternating channels of the apparatus. (Figure 2-25).

According to Spiegler and El—Sayed in 1994, separation carried out in a series of small steps process makes it more economical and easier to control.

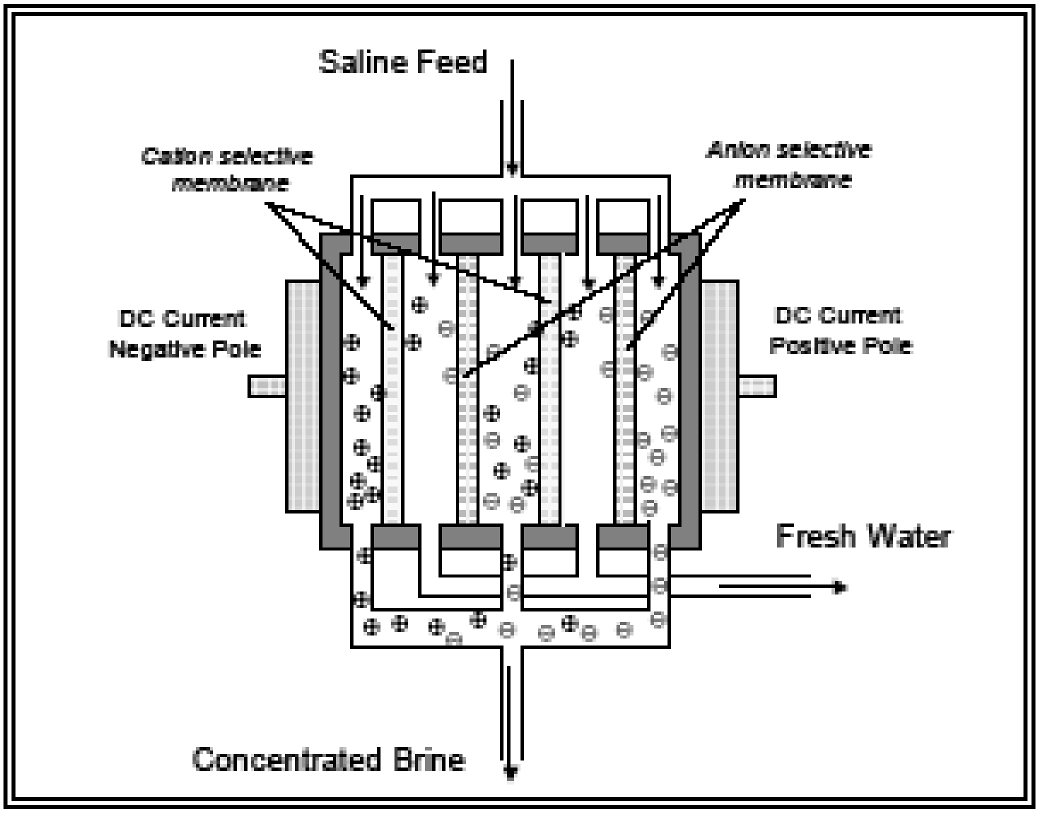

Figure 2-25: Schematic diagram of electrodialysis desalination process
Source: Miller, 2003.

Spiegler and El—Sayed (1994) established that the energy required to separate the ions from the solution increases with concentration. This restricted the use of ED for brackish waters containing fewer thousands parts per million (ppm) of dissolved solids as compared to seawater.

2.4.4 Reservoir

The construction of large surface reservoirs can lead to major transformations in temporal-spatial distribution river runoff and an increase in water resources during the low flow limiting periods and dry years. The uses of reservoirs include holding water for domestic and industrial supply, generating electricity, supplying water to canal or irrigation system and holding water that would have flooded a community. Reservoirs are promoted as an important way to meet water and energy needs and support economic development. During the 1990s, four-fifths of an estimated $32-46 billion spent annually on large reservoirs was in developing countries (WCD Thematic Review III). As of 1998, water supply from reservoirs in Africa constitutes 20%, with irrigation accounting for the majority use of about 52% (ICOLD, 1998).

Based on the fact that the study area is one of the country's driest location and the rivers do not possess features suitable for reservoir construction, such as deep and narrow river valleys where valley sides can act as natural wall suggest that reservoir could not be considered as an alternative in this study.

3 MATERIALS AND METHODS

This chapter presents data on the three alternatives being considered to augment water supply to the study area: These alternatives include: 1) Building of a new treatment plant at Pra River; 2) Groundwater supplies; and 3) Desalination of seawater or brackish water. The overview and analysis of data for the alternatives in this and preceding chapters would be used to assess continuous reliance on the alternatives to augmentation water supply to the study area and to minimize or eliminate the perennial water shortage.

There were some difficulties in obtaining streamflow and rainfall data from the relevant institutions in Ghana for the study, particularly in assessing continuous availability of surface water. Nevertheless, progress was made and as a result yearly streamflow data on various stations of the Pra River were obtained. This study also relied on data from previous works of others in the study area in the form of graphical presentations.

3.1 Data on Surface Water Alternative

In considering surface water alternative, the need to evaluate streamflow and rainfall data as well as the cost to the consumer for this water from GCWL becomes imperative.

3.1.1 Streamflow and Rainfall Data

The continuous dependence on surface water supplies to meet domestic and industrial water demands of the study area to a very large extent depends on quantity and quality of water available. Rainfall and streamflow data from both the coastal and southwestern basins of Ghana are significant in assessing the availability of surface water. The mean annual streamflow data for the various stations of the Pra River is presented in Appendix A. Rainfall and other climatic patterns are said to have changed dramatically in the study area. Rainfall and runoff variability in the southwestern river system of Ghana using two sets of data would be used in determining surface water availability (See Figures 2-9 – 2-11).

3.1.2 Cost of Water Supply Data by GWCL

The overriding factor in the determination of cost of water is energy. The data on the cost to consumers for water produced and distributed by the GWCL in Ghana in recent years (1996 – 2003) are shown in Table 3-1. The cost paid for water per cubic meter is based on operating statistics, energy analysis, and direct operating cost analysis. The data are also based on the specific volumes of water produced and sold in the respective years. In real terms the data have been derived using end of year consumer price index (CPI).

Table 3-1: Cost of Water produced and distributed by GWCL (1996 – 2003) ($1 = ¢9,100.00)

Description	**Units**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Average Tariff	$/m^3$	0.05	0.05	0.10	0.13	0.15	0.26	0.39	0.50
Average Tariff (real)	$/m^3$	0.22	0.16	0.25	0.29	0.29	0.38	0.46	0.53
Direct Operating Cost (nominal)*	$/m^3$	0.05	0.07	0.12	0.17	0.16	0.31	0.46	0.54
Direct Operating Cost (real)*	$/m^3$	0.22	0.22	0.31	0.38	0.31	0.46	0.53	0.56
Direct Energy Cost (nominal)	$/m^3$	0.01	0.02	0.04	0.06	0.06	0.10	0.19	0.23
Direct Energy Cost (real)	$/m^3$	0.05	0.05	0.09	0.13	0.10	0.15	0.22	0.24
Direct Operating Cost (nominal)**	$/m^3$	0.04	0.05	0.09	0.11	0.11	0.21	0.27	0.31
Direct Operating Cost (real)**	$/m^3$	0.17	0.16	0.22	0.25	0.20	0.31	0.32	0.33

Source: Adapted from Public Utilities Regulatory Commission (PURC), 2005.

* Operating cost analysis including energy.
** Operating cost analysis excluding energy.

3.2 Data on Groundwater Supplies

Factors affecting augmentation through groundwater supplies include, availability, quantity, quality and cost of extracting the groundwater within the study area. The borehole data collated from the existing boreholes in the study are shown in Table 3-2. The current average cost of drilling a borehole in Ghana is about $6,700. This may however vary to a very large extent on the location and depth of the borehole. Due to the geographical location of the study area, the cost analysis has to anticipate deep boring to avoid salt water intrusion thereby guaranteeing the quality of water.

In 1998, water supply system was built for seven communities near Cape Coast using groundwater as its source. Water is pumped from borehole which is 180 m deep to the main storage tank that is combined with the iron removal plant. Water flows from the storage tank by gravity to six community storage tanks to be further distributed to nineteen (19) standpipes. The annual operation cost was given as shown below:

Pumping system:	US$ 1300 (excludes labor)
Pipe network:	US$ 1700
Fuel cost for pump:	US$ 3000

The data on boreholes shown in Table 3-2 were extracted from the database of the Central Region Community Water and Sanitation Agency (CWSA), which is government institutional body responsible for potable water supplies in rural areas of Ghana.

Table 3-2: Some borehole data within the study area

Name of Community	Lithology	Type of Aquifer	Depth m	Maximum Yield m^3/hr	Conductivity	pH
Cape Coast	Granite/Gneiss	Confined	25	2.7	-	-
Cape Coast	Granite/Gneiss	Confined	31	3.0	-	-
Cape Coast	Granite/Gneiss	Confined	25	1.08	-	-
Cape Coast	Granite/Gneiss	Confined	25	6.48	-	-
Aboransa	Weathered Sandstone	Semi-Confined	180	9.0	428	6.8
Aboransa	Weathered Sandstone	Semi-Confined	180	9.0	562	-
Dahia	Granite-Schist Contact	Semi-Confined	72	4.4	463	-
Esaaman	Granite/Gneiss	Semi-Confined	42	1.85	312	-
Abeyee	Granite/Gneiss	Semi-Confined	18	0.7	1544	-
Ankaful	Granite/Gneiss	Confined	28	1.35	-	-
Elmina	Granite/Gneiss	Semi-Confined	49	3.59	-	-

3.3 Data on Desalination Technologies

Generally, the cost of desalination water varies from \$0.75 to \$3/m^3. This variation depends largely on plant size, location and design requirements. Cost figures are inherently more variable and uncertain than energy consumption figures. Energy costs vary greatly over time, geography and concentration in terms of RO and ED. Other factors influencing cost include feed water quality vis-à-vis pretreatment costs and costs of transporting water to treatment site and disposing of concentrated brine costs. There is no agreed standard for computing and reporting water costs (Leitner, 1995). Whereas some authors have chosen to neglect capital costs, others have chosen to report all costs including delivery costs and the rest have reported design costs which do not reflect the actual operating expenses. The membrane processes such as RO and ED are adaptable to both large and small scale applications and can be used to supply industrial process water, treat municipal wastewater and supply community potable water. According to Buros in 2000, the RO and ED are amenable to a wide variety of capacities from 0.1 m^3/day to virtually any capacity. This could be the reason why RO has the highest market share among the various commercially available desalination processes (Table 3-3).

Table 3-3: Commercially available desalination processes

Process	Feed water Source	Capacity (m^3/d)	Power Source	Market share (%) (1991 figures)	1991 – Total installed or contracted desalting capacity (%)
Major Processes					
Thermal:					
• MSF	Sea	4,000 – 30,000	Natural gas	32	52
• ME	Sea	2,000 – 10,000	Natural gas	}	}
• VC	Sea	20 – 2,000	Electric	}	}
Membrane:					
• RO	Sea/Brackish	Various	Electric	50	33
• ED	Sea/Brackish	Various	Electric	}	}
• EDR	Sea/Brackish	Various	Electric	}	}
Minor Processes					
• Vacuum freezing	Sea	38– 750	Electric	Negligible	
• Solar distillation	Sea/Brackish	1.0 m^2 of collector area needed to produce 4 l/d of water	Solar	Negligible	

} ME, VC, ED and EDR share the remaining 18% and 15% of market share and total installed or contracted desalting capacity respectively

Source: Adapted and modified from Wangnick (1992), Buros(1980 & 1990), Malek et al (1992), Wangnick (1991), Spiegler (1962), Johnson (1993), Porteous (1983), Hamada (1992), Siwak (1992) and Spiegler (1966).

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From Table 3-3, reverse osmosis appeared to have better acceptance (i.e. 50% market shares). Also, favorable economics and lowest energy requirement make RO a preferred alternative for consideration under desalination.

3.3.1 Reverse Osmosis Cost Components

The reverse osmosis cost components are considered for both seawater and brackish water. Pittner (1993) and Semiat (2000) developed cost components which this study will use as the basis for its economic analysis of RO desalination technology. The breakdown for cost components are shown in the following figures. The two main differences between the two categories are the capital investment cost and energy cost

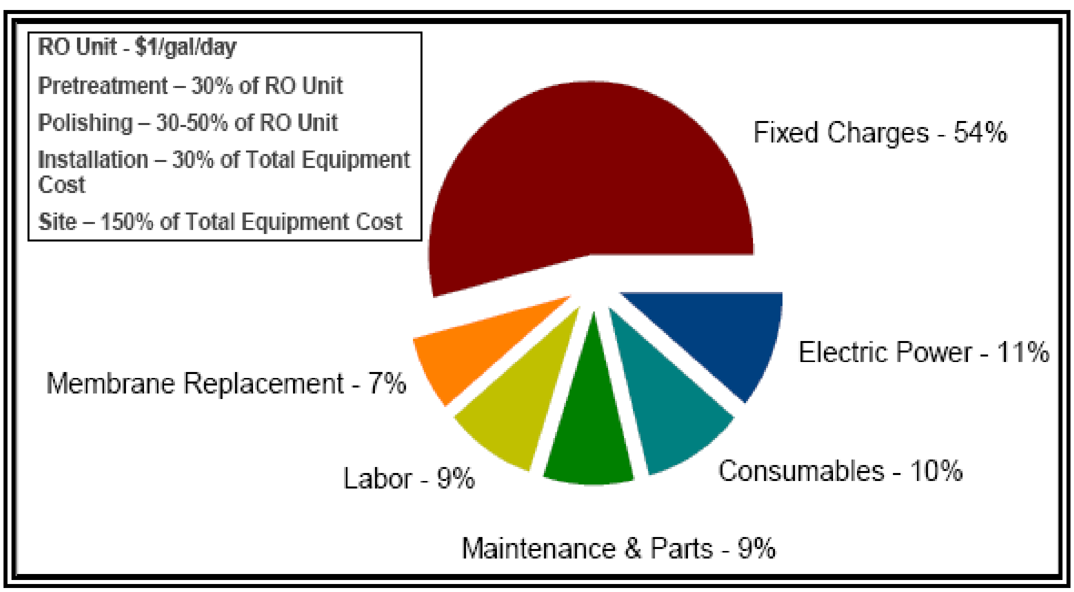

Figure 3-1: Cost breakdown for reverse osmosis desalination of brackish water
Source: Pittner (1993).

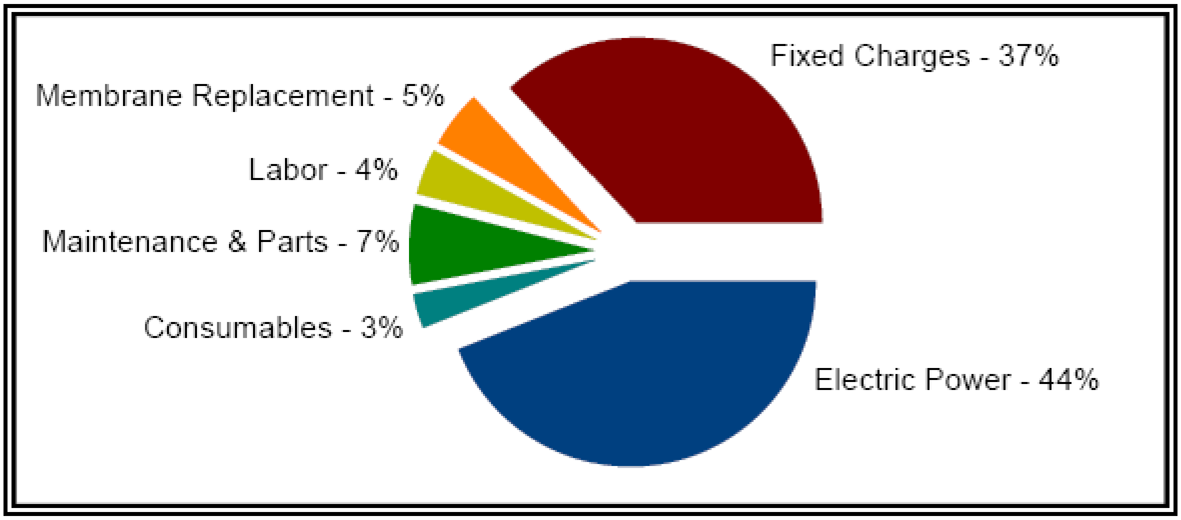

Figure 3-2: Cost breakdown for reverse osmosis desalination of seawater
Source: Semait (2000).

3.4 Methods

The approach used in this study would involve establishing a shortfall in water supply within the study area vis-à-vis minimum daily water requirement per capita. Population statistics given by GSS in 1984 and 2000 and water consumption per capita as given by both the Central Regional Office of GWCL and MoWH will be used to develop empirical predictive relationship between population and water demand from year 2005 to 2025. Cost analysis would be carried out to determine how much it shall cost a household with average of five (5) members to depend on each of the alternatives to augment water supply in both rural and urban settlements. The available data shall be analyzed to predict sustainability and continue reliance of the alternatives.

Analyses of the streamflow data would be carried out using Excel spreadsheet to determine relative variation of flow over the years.

4 ANALYSIS AND RESULTS

The chapter presents shortfall in water supply demand in the study area and the analysis and results of the alternatives under consideration.

4.1 Water Supply Demand

Prediction of future water consumption would normally take into consideration the population and per capita water requirement or consumption expected in the future. This study obtained projected water demand data from Ghana Water Company Limited Central Regional Office in Cape Coast, from 2005 to 2025. The study further used population census results of 1984 and 2000 respectively of the study area to develop projected water demand for the same period. Whereas the former has no available details or formula as to how these projections were developed, the later used population results of 1984 and 2000 to establish annual population increase of cities/towns with population more than 10,000 within the study area which take water supply from the Brimsu dam. The arithmetic growth rate ranges from about 229 to 2015 shown in Table 4-1.

Table 4-1: Cities/Towns with Population more than 10,000

Name of Cities/Towns	Population*		Arithmetic Growth
	1984	2000	
Cape Coast Municipality	79771	112009	2015
Saltpond	12552	16212	229
Komenda	5287	12278	437
Elmina	16970	21103	259
Moree	13061	17761	294

* Source: Ghana Statistical Service (1984 and 2000 Census Results)

Based on this arithmetic growth, population projections were developed from year 2005 to 2025 using arithmetic method with equation 4-1 (Clark and Viessman, 1966; Steel and McGhee, 1979; Viessman and Hammer, 1993) below. This projection is based upon the hypothesis that the arithmetic growth rate remains constant over the projection period

$$P_{2005} = P_{2000} + \left(R_a \times N\right) \qquad \text{Equation 4-1}$$

where

P_{2005} = Population projection for year 2005

P_{2000} = Population at year 2000

R_a = Arithmetic growth rate constant

N = Number of years

The projected population for Cape Coast Municipality in year 2005 thus becomes 122,083. Similarly, the above calculation was done to project population for the various cities/towns and the results are shown in Table 4-2. The projected water demand guideline developed by Ministry

Table 4-2: Population Projections for Cities/Towns from 2005 to 2025

Name of City/Town	Population Projections (2005 to 2025)				
	2005	**2010**	**2015**	**2020**	**2025**
Cape Coast Municipality	122083	132158	142232	152307	162381
Saltpond	17365	18518	19671	20825	21978
Komenda	14463	16647	18832	21017	23201
Elmina	22395	23686	24978	26269	27561
Moree	19230	20699	22167	23636	25105

of Works and Housing in 1998 (Table 2-4) based on population was used to quantify water demand for each of these cities/towns from year 2005 to 2025. The data in Table 2.4 was extrapolated to obtain projected water demand for years 2010, 2015 and 2025. The projected water demand used in this study is shown in Table 4-3. This was used to establish the projected water demand by multiplying the per capita consumption and population using equation 4-2.

Table 4-3: Projected Water Demand lcd (inclusive of water losses at 15%)

	Year				
Population	**2005**	**2010**	**2015**	**2020**	**2025**
Greater than 50,000	105	110	115	120	125
20,000 – 50,000	85	88	92	95	98
10,000 – 20,000	75	78	81	85	88

$$Q_{2005} = P_{2005} \times q_{2005}$$ Equation 4-2

where

Q_{2005} = Projected water demand in year 2005

q_{2005} = Per capita water consumption in year 2005

Cape Coast Municipality with a population of 122083 in 2005 will require that per capita consumption of 105 liters is used to calculate its projected water demand. From equation 4-2, the projected water demand for Cape Coast Municipality will be 1.28×10^7 liters per day. Similarly, water demand was projected for other cities/towns within the study area and the result is shown in Table 4-4.

Table 4-4: Water Demand Projections, lcd (2005 to 2025)

Name of City/Town	**Water Demand Projections, lcd (2005 to 2025)**				
	2005	**2010**	**2015**	**2020**	**2025**
Cape Coast Municipality	12818754	14537353	16356694	18276780	20297609
Saltpond	1302384	1444424	1593381	1978328	2153807
Komenda	1084702	1298495	1525397	1996591	2273741
Elmina	1903538	2084379	2297947	2495579	2700960
Moree	1442231	1821468	2039387	2245420	2460266

It could be demonstrated that based on this study water demand which is population dependent within Cape Coast and its environs may reach 29,887 m^3/day by the year 2025 with yearly average increase of about 2.0 %. There will be continuous reliance on Brimsu water source with the current capacity of 15,960 m^3/day. In extreme circumstances, particularly during the dry seasons production capacity of Brimsu water source will be further reduced by 35%. This implies the actual water supply to consumers is at 65% of the daily production capacity of the day (i.e, 10,374 m^3/day). Water demand and supply analysis using both the GWCL and this study projections are summarized in Table 4-5 and graphically presented in Figure 4-1. A predictive equation to estimate projected daily water demand shortage based on water demand projections in this study is presented in Figure 4-2. This is based on population and water projections in the study.

Table 4-5 Summary of Water Demand and Supply Analysis

Year	2005	2010	2015	2020	2025
Daily Water Demand, m^3/day (GWCL, 2005)	23328	25878	28407		37542
Daily Water Demand, m^3/day	18552	21187	23813	26993	29887
Daily Water Supply, m^3/day	15960	15960	15960	15960	15960
Daily Water Supply at 65%, m^3/day	10374	10374	10374		10374
Daily Shortfall in Water Supply, m^3/day (GWCL, 2005)	7368	9917	12447		21581
Daily Shortfall in Water Supply, m^3/day	2592	5227	7853	11033	13927

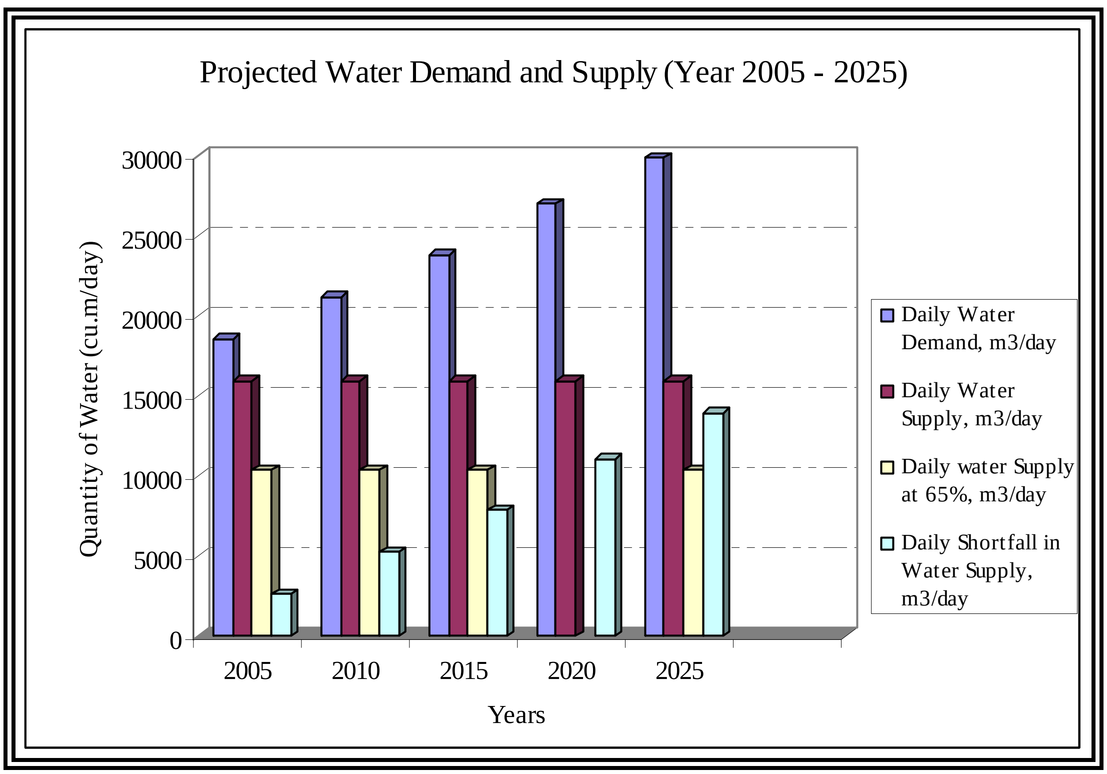

Figure 4-1: Projected Water Demand and Supply in the study area (Year 2005 – 2025)

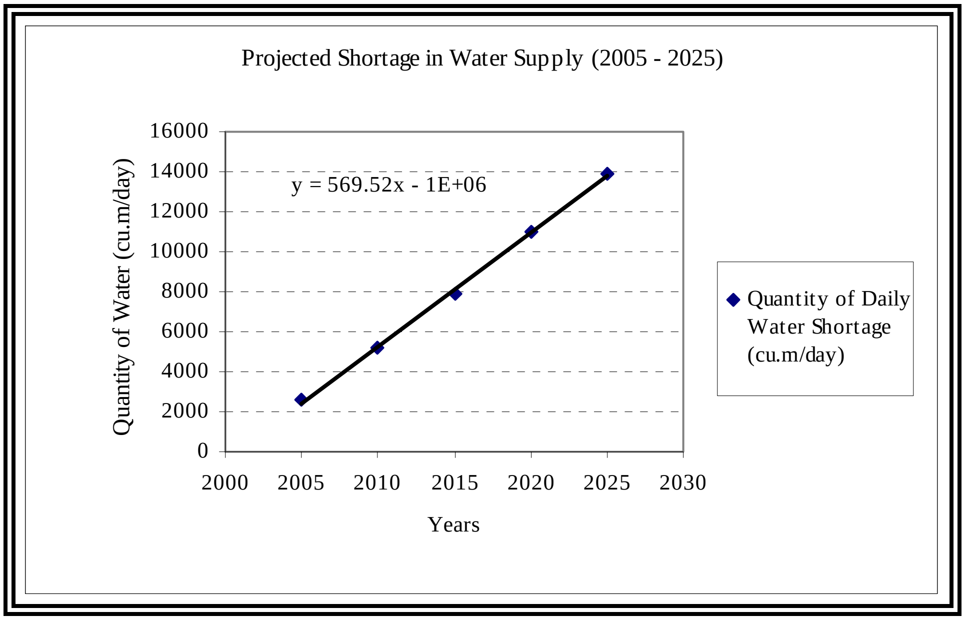

Figure 4-2: Projected daily water shortage in water supply within the study area (2005-2025).

Alternatively, water consumption estimates given by GWCL in 2005 shows that the daily water requirement ranges from 23,328 – 37542 cubic meters. The water demand and supply analysis shows that all the estimates deduced in this study are less than that given by GWCL.

The analysis further indicates that water requirement correlates perfectly with the population increase and the equation developed could be used as a tool in estimating water requirement of the area in any given year (Figure 4-3).

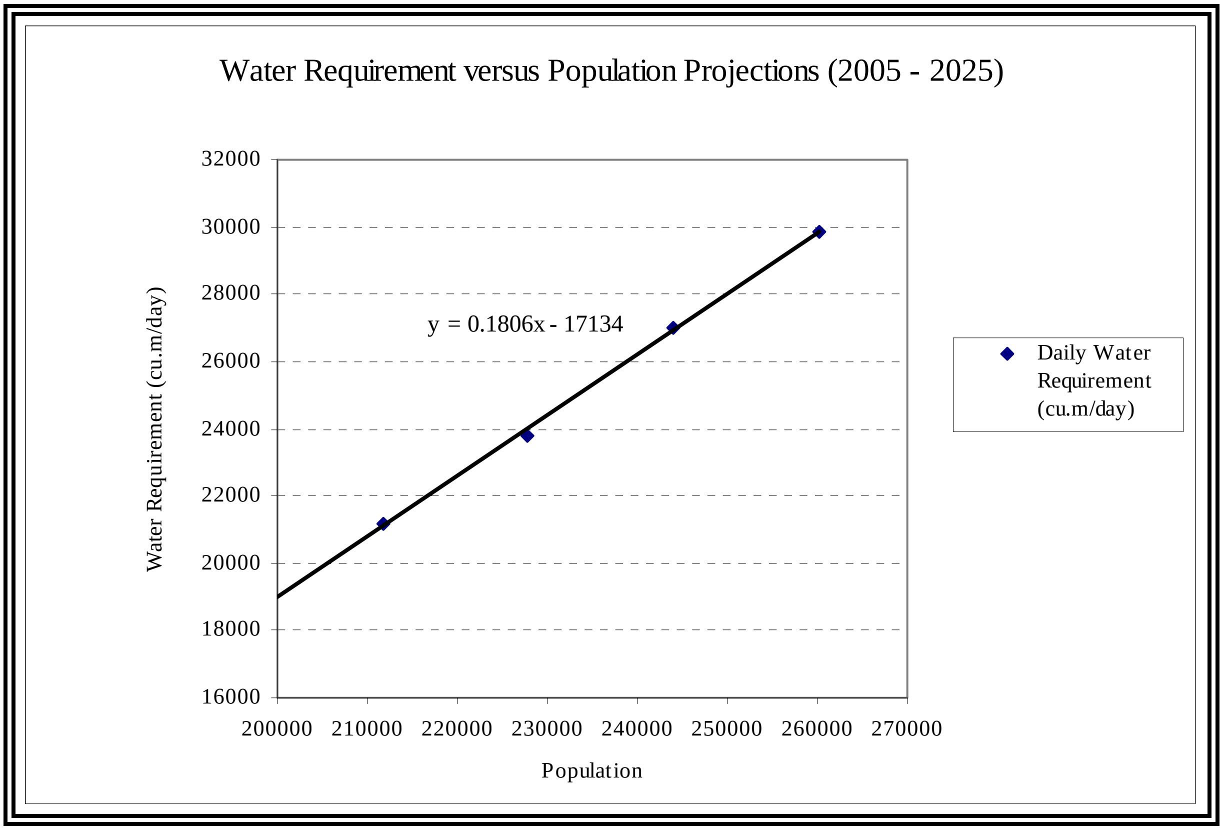

Figure 4-3: Water requirement versus population projections for the study area (2005 - 2025).

4.2 Water Resources Availability

4.2.1 Surface Water

The study area comprises of short-lived rivers most of which suffers drastic drop in flow levels during the dry season (December – March). According to the regional study for the improvement of urban water supply in the Central Region of Ghana, the statistics on average and minimum monthly flows of Kakum River at Brimsu resulted to 1.9×10^5 m^3/day and no flow respectively and serves as an indication of general water availability. Twifo Prasso station on

Pra River with average and minimum monthly flows of 1.3×10^7 m^3/day and 8.8×10^4 m^3/day thus becomes an alternative surface water source to augment water supply in the study area.

A mean annual streamflow data of Pra River at Twifo Prasso was obtained from the Hydrological Services Department, Ghana for the period of 52 years (i.e.1945 -1997) and the time series mean annual flows was plotted (Figure 4-4). It is shown that there has been considerable decrease in the flow data after 1970.

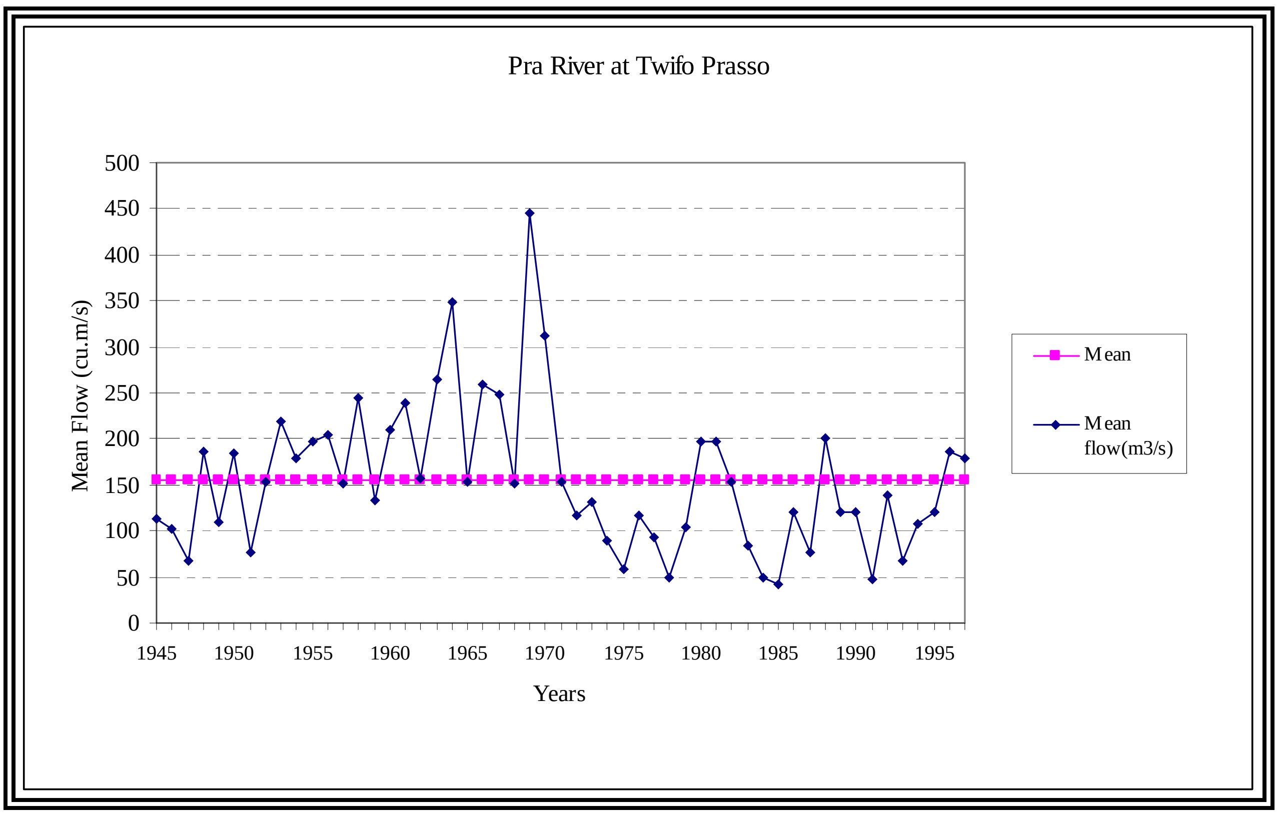

Figure 4-4: Time series plot of mean annual flow of Pra River at Twifo Prasso (1945-1997)

It can be suggested from Figure 4-4 that prior to 1970, majority of the yearly records show that mean flows are above the mean for the period 1945 to 1997 which is an indicative of more rains and the converse is true for the period after 1970. The decrease in streamflow noticed in the flow analysis after 1970 could be attributed to low rainfall occurrence within the Southwestern Coastal basin

These plots have to a very large extent confirmed widely held view that rainfall patterns have been fluctuating resulting to limited availability of water resources for development. Even though the causes are not well understood, it is perceived that the two complementary processes of desertification and deforestation are combining to push the frontiers of desert further south in West Africa (World Commission on Water, 2000). In Ghana, it is believed that 70% of the forest cover disappeared between 1954 and 1972.

It was subsequently observed that in the past 30 years the temperature had risen by about 33.8º F and the corresponding reduction in rainfall and streamflows were 20% and 30% respectively. Runoff was also found to be sensitive to changes in precipitation and temperature, and 10% change in precipitation or 1º C increase in temperature causes a reduction of more than 10% in runoff. Simulations on climate change scenarios for years 2020 and 2050 observed flow reductions of between 15-20% and 30-40% respectively.
(http://www.fao.org/ag/agl/aglw/aquastat/countries/Ghana/index.stm).

In spite of fluctuating nature of streamflow pattern, Pra River at Twifo Prasso still has appreciable flow levels that could be relied on in terms of quantity to augment water supply to Cape Coast and its environs.

4.2.1.1 Cost of Surface Water Supplies

Ghana Water Company Limited produces and distributes surface water throughout Ghana. The cost of water per cubic meter over the period of 1996 – 2003 is plotted as shown in Figure 4-5. The regression equation shown has correlation coefficient of 0.91 and could be used to forecast price levels in future for specific years. Factors that contributed to this cost or price build up include operating, capital maintenance and return on capital costs. These costs have also to a very large extent depended on volume of water produced and sold. The cost of water to the end-user includes:

- Direct operating cost of water (including overheads)
- Direct energy cost of water
- Depreciation calculated on a current cost basis divided by expectations of water sold and paid for.
- Return on capital.

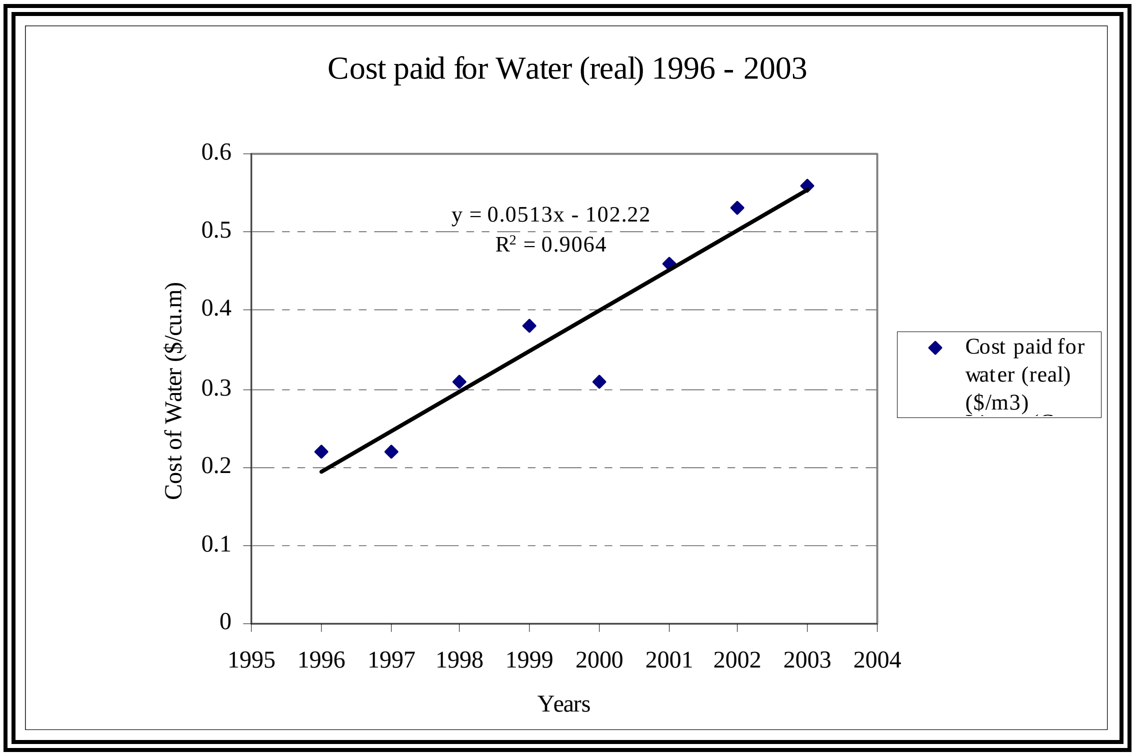

Figure 4-5: Cost of water per cubic meter (1996 – 2003)
Source: Adapted from PURC, 2005.

Based on these price levels, for instance in year 2003, the cost of water for per capita consumption per person per day are $0.02 and $0.05 respectively for rural and urban settlements. The rural and urban are considered to determine the cost impact of water consumption in the two distinct population categories. These translate to daily cost of water for an average household of five (5) in the study area (GSS 2000 Population Census) as $0.08 and $0.24. Thus the costs of water using Ministry of Works and Housing projected water demand guideline (Table 2-4) developed in 1998 of any household size could be estimated.

4.2.2 Groundwater Availability

Groundwater in Cape Coast and its environs is predominantly found within granite/gneiss lithology constituting about 73% of the existing and operational boreholes found in the study area (Table 3-3). According to Table 2-8 and the geology of the study area, borehole completion success rate is about 75 percent. The maximum yields ranges between 0.7 – 9 m^3/hr with groundwater found in weathered sandstone lithology recording the highest maximum yield of 9 m^3/hr. The two boreholes in Aboransa, a village near Cape Coast for instance produce 216 cubic meters for 12 hour pumping period. With total population less than 2,000, water consumption is about 30 liters per capita day (MoWH, 1998), leaving an excess of about 156 cubic meters of water unused/untapped.

The relationship between depth and yield of the boreholes found in Cape Coast and its environs is not well correlated (Figure 4-6). However, in exception to groundwater occurrence in weathered sandstone in Aboransa, the remaining boreholes are found in less than 91 m depth below ground surface. The Aboransa borehole yield and depth are significant and collaborate the fact that groundwater occurrence largely depend on secondary porosity such as fissuring, fracturing and weathering and permeability.

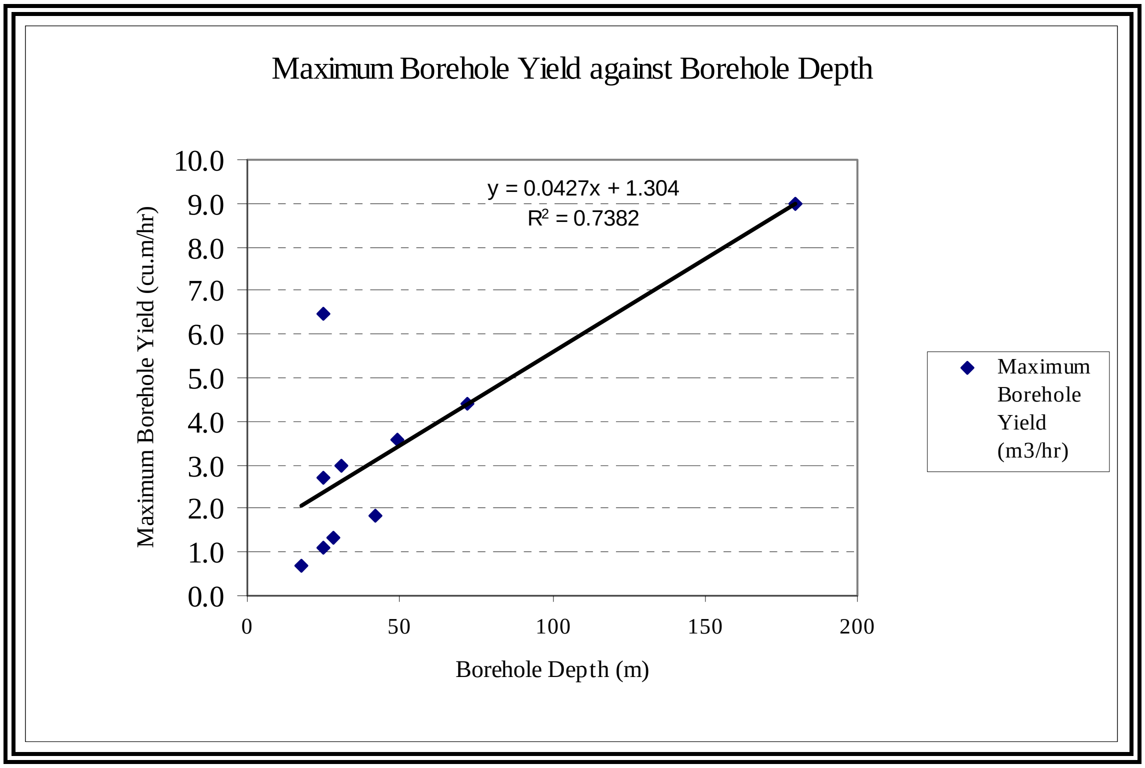

Figure 4-6: Plot of maximum borehole yield against borehole depth in the study area.

The groundwater occurrence based on borehole depths shows that the thickness of weathered zone is shallow attributable to annual low rainfall, ranging between 762 - 1,143 millimeters and little forest cover.

4.2.2.1 Cost of Groundwater Supplies

Groundwater supplies take two forms in the study area. These involve borehole fitted with hand pumps and borehole distribution by pipe network through standpipes. Most of the boreholes drilled are funded from projects sponsored by grants and multi-lateral aids. This trend is however changing gradually where beneficial communities are being requested to contribute 5% of the overall cost towards water facilities.

The consumers' cost for groundwater supply suggested by Vicco Ventures Limited under Bekwai Water Supply System (BWSS) is shown in Table 4-6.

Table 4-6: Cost of groundwater supply (2002 – 2004)

Year	**Private Connections $/m^3$**	**Public Standpipes $/m^3$**	**Standpipes $/0.019 m^3$**
2002	0.60	0.61	0.011
2003	0.79	0.80	0.014
2004	0.87	0.88	0.016

Source: Adapted from Vicco Ventures Limited water tariff review proposal, 2005.

This water tariff (cost) changes with economic indicators such as price of electricity, minimum daily wage and price of diesel. The annual water tariff is thus determined using the formula in equation 4-3 below in accordance with Article 25 of the Operations and Maintenance contract document between Vicco Ventures Limited and District Assemblies.

$$P_m = P_o\left(0.2 + 0.2\frac{E_m}{E_o} + 0.4\frac{W_m}{W_o} + 0.2\frac{F_m}{F_o}\right) \qquad \text{Equation 4-3}$$

where

P_m = revised tariff/cost for current year

P_o = tariff/cost of previous year

E_m = price of kWh of electricity for the domestic consumer in current year

E_o = price of kWh of electricity for domestic consumer in previous year

W_m = price of minimum daily wage for current year

W_o = price of minimum daily wage for the previous year

F_m = price of gallon of diesel for current year

F_o = price of gallon of diesel for the previous year

Assuming consumption rate of 30 liters per capita per day for a community such as Aboransa in the study area, daily water cost per capita in a day would be \$0.03. An average household of five (5) members may spend \$0.13 on water daily. If the system however operates in an urban center where population ranges from 20,000 – 50,000 with an average of 85 liters per capita per day consumption, it would translate to \$0.08 per person. Also a household of five (5) may spend \$0.37 on water consumption a day.

4.2.3 Seawater/Brackish Water Availability

The study area is bounded in the south by the Atlantic Ocean hence seawater and brackish water are abundant.

4.2.3.1 Cost of Seawater/Brackish Water Supplies

The energy and cost required for desalination appears to be the major concerns for proponents of the use of desalination technology to augment water supply in the study area. These concerns range from availability, reliability and cost of energy to ensure smooth running of the desalination plant and also to ensure affordable water rates. The concerns on availability and reliability of energy in the study area would soon be resolved when the West African Gas Pipeline Project, which is expected to transport gas from Nigeria to the coastal West African countries, is completed and becomes operational in year 2007. In spite of this, 44% of required energy for RO desalination of seawater would remain an overriding factor in determining the cost of water to consumers. The fixed cost, thus procurement and installation of desalination unit and energy cost form 65% and 81% of cost components for RO desalination respectively

Cost estimates are more variable and uncertain and as a result there are no standard for computing and reporting water cost (Leitner, 1995). The distribution costs in desalination are significant, and must be added to the treatment cost to determine the cost of water to the user (http://resources.ca.gov/ocean/97Agenda/Chap5Desal.html). For the purpose of this study, the cost estimates for seawater RO currently used in the U.S, $2.50/m^3 shall be used in this analysis. It should however be noted that costs in less developed countries such as the study area will be greater.

From the above, the lower bound water cost for rural and urban settlements per capita per day consumption rates are $0.08 and $0.21. The choice of 30 and 85 liters consumption rates are considered to determine the cost impact of water consumption in rural and urban settlements in the two distinct population categories respectively. Using the upper bound water cost of $4.60/m^3, the rural and urban settlements consumptions may result to $0.14 and $0.39. The range of cost for water in a five (5) members household in the two consumption categories are $0.38 - $1.06 for rural, and $0.69 - $1.96 for urban.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results of the economic evaluation of the alternatives are summarized in Table 5-1. This evaluation is based solely on cost of water to the consumer or end user. The capital and installation costs were not considered since these are normally taken off by the central government through grants, loans, multi-lateral agreements and other non-governmental organizations through special funding.

Table 5-1: Cost of water based on the alternatives.

	Surface Water	**Groundwater**	**Desalination**	
			Minimum	**Maximum**
Cost of water ($/rural)	0.02	0.03	0.08	0.14
Cost of water ($/urban)	0.04	0.08	0.21	0.39
Cost of water for average Household number 5 ($/rural)	0.08	0.13	0.38	0.69
Cost of water for average Household number 5 ($/urban)	0.24	0.37	1.06	1.96

Based on this study and the cost analysis, the cost of surface water remains the most affordable means of water supply, followed by groundwater. The cost of desalination is more expensive than the existing sources of water supply.

The existences of boreholes in the study area are few even though the hydrogeologic conditions show that the area has groundwater potentials. Borehole yields indicate that intensive exploitation of groundwater even though more expensive than surface water sources could minimize the effect of perennial water shortage and the over dependence on surface water.

The cost comparison analyses have shown that the cost of desalination using reverse osmosis is still expensive and could not compare favorably with the existing water supply alternatives. The analyses have thus confirmed the long held perception that "desalination is expensive and cannot be used in study area".

5.2 Recommendations

To find a long lasting solution to perennial water shortage within the study area, the alternative of augmenting supply by building a treatment plant on the Pra River at Twifo Prasso to pipe down water to Cape Coast and its environs remains a viable option. Groundwater exploratory activities even though expensive need to be intensified to develop and improve access to portable water supply in the study area where adequate supply from Pra River is not available. It is recommended that the central government through the municipal and district assemblies should intervene and subsidize the cost of developing groundwater to bring its cost at par with surface water in those areas. This investment may go a long way to reduce government expenditure on importation of drugs to control waterborne diseases. With regular and reliable source of water supply, government may in turn derive maximum benefit from tourism, and the academic calendars of the educational institutions may not be disrupted. However since surface water and groundwater are directly dependent on precipitation, and the fact that precipitation generally in Ghana is on the decrease, pragmatic efforts should be made towards the possibility of using the desalination technology. This effort will help to augment water supply when the costs due to technological improvement have reached an acceptable limits. A successful installation of such a system could help improve portable water supply not only to Cape Coast and its environs but also to other cities/towns, such as Accra and Tema.

APPENDIX A:

MEAN STREAMFLOW DATA ON PRA RIVER AT TWIFO PRASSO

Year	Water Year	Mean flow (m^3/s)
1945	44-45	113.1
1946	45-46	102.7
1947	46-47	68.4
1948	47-48	186.4
1949	48-49	109.6
1950	49-50	184.7
1951	50-51	77.4
1952	51-52	153.1
1953	52-53	218.8
1954	53-54	179.2
1955	54-55	196.9
1956	55-56	204.3
1957	56-57	151.3
1958	57-58	243.7
1959	58-59	133.2
1960	59-60	209.4
1961	60-61	238.4
1962	61-62	157.1
1963	62-63	264.9
1964	63-64	348.4

1965	64-65	154.1
1966	65-66	258.7
1967	66-67	247.7
1968	67-68	151.3
1969	68-69	445.7
1970	69-70	311.6
1971	70-71	152.9
1972	71-72	116
1973	72-73	132.2
1974	73-74	90
1975	74-75	58.6
1976	75-76	117.4
1977	76-77	92.2
1978	77-78	49.8
1979	78-79	104
1980	79-80	197
1981	80-81	196.8
1982	81-82	153.4
1983	82-83	84.7
1984	83-84	49
1985	84-85	42.1
1986	85-86	119.9

1987	86-87	76.3
1988	87-88	201
1989	88-89	119.9
1990	89-90	119.8
1991	90-91	48.3
1992	91-92	139.2
1993	92-93	68
1994	93-94	107.1
1995	94-95	120
1996	95-96	185.9
1997	96-97	179.3

LIST OF REFERENCES

Al-Shammiri, M. and Safar, M, (1999), Desalination, 126, 45.

Amuzu, A. T, (1987), Prototype Iron Removal System Suitable for Small-scale Groundwater Supplies, Accra, Water Resources Research Institute (CSIR).

Andah, A. I. (1993), Groundwater Utilization for Small-Scale Irrigation in the Accra Plains: Kponkpo and Ablekuma pilot schemes. Water resources Research Institute (CSIR), Accra, Ghana

Armah, T. E. K (2000), Groundwater Salinization in Parts of Southern Ghana, Groundwater: Past Achievements and Future Challenges, 30, 445 – 449.

Asomaning, G. (1993), Groundwater Resources of the Birim Basin in Ghana, Journal Africa Earth Science, 15, 375 – 384.

Ayoub, J. and Alward, R. (1996), Water Requirements and Remote Arid Areas: The Need for Small-Scale Desalination, 107, 131 – 147.

Barry, B, Obouebi, E., Andreini, M., Andah, W. and Pluquet, M (2005), Comparative Study on River Basin Development and Management.

Buros, O. K. (2000), The ABCs of Desalting, Second ed., International Desalination Association, Topsfield, Mass.

Central Regional Development Commission, Water Infrastructure Project.

Clark, J. W and Viessman, W. Jr., (1966) Water Supply and Population Control, New York: A Dun-Donnelley

Dapaah-Siakwan, S. and Gyau-Boakye, P. (2000), Hydrogeologic Framework and Borehole Yields in Ghana, Hydrogeology Journal, 8, 405 – 416.

DANIDA, (1993), "Rural Drinking Water Supply and Sanitation Project in the Volta Region – Final Report on the Inventory and Assessment of Potential for Hand Dug Wells in the Volta Region, Vol. I – Main Report." WRI, Accra.

Ettouney, H. M., El-Dessouky, H. T. and Alatiqi, I. (1999), Chemical Engineering Progress, 43.

Falkenmark M and Widstand C (1992), Population and Water Resources: A Delicate Balance, Population Bull., 47(3) 1 – 36.

Geological Survey of Ghana (1969), Geological map of Ghana, Compiled by Geological Survey and Published by the Survey of Ghana.

Ghana News Agency Report of January 14, 2006, Cholera Outbreak in KEEA District

Ghana News Agency Report of May 9, 2006, Oguaa Faces another Water Shortage

Ghana Statistical Service, (2000): Population Census.

Ghana Statistical Service, (2002): Population Census.

Ghana's Water Resources Management Challenges and Opportunities, 1998, 16 – 17.

Gill, H. E (1969), A Groundwater Reconnaissance of the Republic of Ghana, with a Description of Geohydrologic Provinces, U.S Geol Survey Water – Supply Pap 1757 – K, Washington, DC.

Gyau-Boakye and Siakwan-Dapaah (1999), Groundwater: Solution to Ghana's Rural Water Supply Industry? Water Resources Research Institute.

Hirdes, W, Davis, D. W., and Esienlohr, B. N. (1992), Reassessment of Proterozoic Granitoid Ages in Ghana on the basis U/Pb Zircon and Monazite dating. Precambrian Research 46, 139–165.

ICOLD, (1998), Compilation of estimates of the number of dams in the main dam building countries suggest there may be as many as 48,000 dams.

Kortatsi, B. K. (1994), "Groundwater Utilization in Ghana", In: Future Groundwater Resources at Risk, Proceedings of the Helsinki Conference, June 1994, IAHS 222, 1994: 149 – 156.

Lavender, S. T and Anderson, J. E. (1984), The Recent African Drought Within the Context of Earlier African Hydrological Experience, Sixth Meeting of the Committee of Cooperation for Development in Africa, Energy Group, Rome.

Leitner, G. F. (1995), Desalination, 102, 199.

Mickley, M. C. (2001), Membrane Concentrate Disposal, U.S Bureau of Reclamation Desalination and Water Purification Research and Development Program Report No. 69

Miller, J. E. (2003), Review of Water Resources and Desalination Technologies, Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California.

Ministry of Works and Housing (1998), Ghana's Water Resources: Management Challenges and Opportunities. Water Resources Management Study.

Nathan Consortium (1970), Framework for River Basin Planning. Ghana Sector Studies. Interim Report for Ministry of Finance and Economic Planning.

Opoku-Ankomah, Y and Amisigo, B. A (1998), Rainfall and Runoff Variability in the Southwestern River System of Ghana.

Opoku-Ankomah, Y and Cordey, I (1994), Atlantic Sea-Surface Temperatures and Rainfall Variability in Ghana, J. Climate 7, 551-558.

Opoku-Ankomah, Y and Forson, M. A (1998), Assessing Surface Water Resources of the South-Western and Coastal Systems of Ghana, Hydrological Sciences Journal, 45, 5, 733 – 740.

Pittner, G. A. (1993), Reverse Osmosis, Z.Amjd, ed., Chapman Hall, New York.

Public Utilities Regulatory Commission (PURC), 2005.

Semiat, R. (2000), Water International, 25, 54.

Steel, E. W and McGhee, T. J, (1979), Water Supply and Sewerage, 5th Edition, New York: McGraw-Hill

Spiegler, K. S. and El-Sayed, Y. M. (1994), A Desalination Primer, Balaban Desalination Publications, Santa Maria Imbaro, Italy.

The CWC Group, Middle East Insight, September 2000, 2-7, www.thecwcgroup.com

United Nations Population Fund, (2002).

United Nations, World Population Projections, 1995.

Vicco Ventures Limited, 2005, Water Tariff Review Proposal

Viessman, W. Jr. and Hammer, M. J. (1993), Water Supply and Pollution Control, 5th Edition, New York: Harper Collins

Wangnick, K. (1998), IDA Worldwide Desalting Plants Inventory Report No. 15, Topsfield, MA.

Water Resources Research Institute (1994), Borehole yields map of Ghana, WRRI, Accra.

Water Supply and Sanitation Sector Assessment Part II, 2000.

WCD Thematic Review III. 2 Financing Trends

World Wide Web Citations:

www.mapsales.com/products/GraphicOgre/Africa/images/200m/GHANAphy.gif

http://en.wikipedia.org/wiki/Cape_Coast.

http://www.ghanaweb.com/GhanaHomePage/NewsArchive/photo.day.php?ID=56580

www.fao.org/ag/agl/aglw/aquastat/countries/ghana/index.stm

http://www.fao.org/ag/agl/swlwpnr/reports/y_sf/z_gh/gh.htm#submenu5

http://maps.grida.no/go/graphic/availability_of_freshwater_in_2000_average_river_flows_and_groundwater_recharge

http://www.fao.org/ag/agl/aglw/aquastat/countries/Ghana/index.stm

http://www.irinnews.org/report.asp?ReportID=45054&SelectRegion=West_Africa

http://www.wateraid.org/ghana

http://www.uneca.org/cfm/2006/docs/ECANewsletter_ENG.pdf

http://resources.ca.gov/ocean/97Agenda/Chap5Desal.html