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GROUNDWATER AVAILABILITY AND USE IN SUB-SAHARAN AFRICA: A REVIEW OF 15 COUNTRIES

CGIAR RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security

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Table of Contents

FOREWORD

A critical global challenge of our era is to manage the natural resource base in a sustainable manner; striking the right balance between economic growth and optimal resource use. Developing nations are often faced with the added dilemma of trying to do this under a variety of socio-economic and political constraints.

The countries that make up Sub-Saharan Africa are a mix of resource rich and resource poor, but are generally underutilizing their available water resources, including groundwater. Most of the countries in the region have agriculture as their primary source of livelihoods and an entrenched dependence on wells and boreholes for the provision of rural water supplies. This is paralleled by a growing hope that groundwater may also serve to boost the area under informal irrigation. With limited documented information on the groundwater resources and a growing dependence on groundwater extraction taking place for drinking, domestic, irrigation, livestock and industry, there is a pressing need to consolidate existing knowledge.

This book is the culmination of extensive surveys of the literature across 15 Sub-Saharan Africa nations that has resulted in country-level reports that have compiled data, maps and information on the groundwater use, challenges faced, existing policies and future steps needed to promote sustainable use of the resource. The chapters within have drawn from those country reports and aim to provide an overview of the groundwater status within these countries and to bring out the major research gaps that exist.

While the hydrogeological and climatic features of any given region dictate the availability and replenishment of groundwater, the future quantity and quality of groundwater depends to a large extent on the land use and management practices of the communities within an aquifer province. By making use of the hydrogeological knowledge base, appropriate policies and practices can be implemented and the standard of living of the communities improved. Cross learning is also encouraged, by drawing from the examples of policies and practices of the study countries so that it would be beneficial to other nations in the region.

This book serves as a necessary first step towards collating and synthesizing the available information, highlighting the need for a strong database that can contribute towards strengthened groundwater management and policy across the region. Many critical gaps remain and therefore this book represents a small milestone in a much longer journey towards the evolution of sustainable agricultural groundwater development and the Millennium Development Goals.

Colin Chartres

Director General
International Water Management Institute (IWMI)
Sri Lanka

August 2012

PREFACE

The origins of this publication can be traced back over a decade and covers the life of two major research projects lead by the International Water Management Institute (IWMI). The first was the Comprehensive Assessment of Water Management in Agriculture (CA) (www.iwmi.cgiar.org/ assessment/) supported by the government of the Netherlands and the OEPC Fund for International Development that was completed in 2007, and more recently, the three-year Rockefeller Foundation supported project Groundwater in Sub-Saharan Africa: Implications for food security and livelihoods, (www.gw-africa.iwmi.org/).

Both the extensive studies are premised upon the view that across the African continent there are large untapped groundwater reserves that, if used wisely, represents, perhaps the single most important solution to achievement of the Millennium Development Goals, mitigating drought impacts and livelihood improvements of smallholder farmers in Sub-Saharan Africa. However, it has become increasingly clear that access and availability of knowledge on the groundwater systems, and their sustainable groundwater potential is a major universal constraint that needs to be overcome.

Tapping into this latent resource requires a rethink about the different policies and strategies and should be informed by clearer scientific insights into the physical, socio-economic and institutional opportunities and constraints of groundwater availability across a continent that represents a complex mosaic of hydrogeological, climatic and socio-economic conditions.

This book is based upon country reports (CR) from 15 African nations, including virtually all of the focal countries of the Alliance for a Green Revolution in Africa (AGRA). These reports were prepared by recognized experts from IWMI, academia and industry with extensive knowledge on groundwater development and management of their respective country. The CR are a desktop study of the existing geological, hydrogeological, hydrological and socio-economic data and reports from a thorough review of the white and grey literature from various government departments, NGOs, donor reviews and reports, student theses and consultant reports. In most cases, this is the first time such a compilation and analysis has taken place at such a scale.

Special mention and gratitude goes to Dr. Mutsa Masiyandima (formerly at the IWMI Pretoria office) for overseeing the production of several of the CR in southern and eastern Africa as well as writing one of the CR (Zimbabwe) and to Dr. Emmanuel Obuobie (ex-IWMI Accra office and presently with CSIR-WRI Ghana) for contributing to many of the book chapters and to overseeing the other west African CR. We acknowledge the final editing input of Dr. Padmaja Karanam, whose timely contribution helped to enhance the book quality.

We hope that this book and the individual CR will provide a helpful resource document for researchers, practitioners, managers and investors working on groundwater issues throughout Sub- Saharan Africa.

Paul Pavelic, Lao PDR; **Mark Giordano**, Sri Lanka; **Bernard Keraita**, Ghana;
Vidya Ramesh, India; **Tamma Rao**, India

August, 2012

CHAPTER 1

INTRODUCTION

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Introduction

Traditionally, the spread and extent of human settlement beyond the major riparian zones of Sub-Saharan Africa (SSA) and across many other arid regions of the world, has been determined by availability of groundwater supplies, accessed through hand-dug wells and springs. In more recent times, groundwater is the preferred means of supplying water to meet the growing demand of the rural, dispersed communities and the small urban towns across SSA. It is estimated that about 100 million of the rural population throughout SSA are serviced by groundwater for domestic supplies and livestock rearing (Adelana and MacDonald, 2008), with most of the villages and small towns having access to groundwater supplies (Masiyandima and Giordano, 2007). Groundwater development has tended to flourish most in the drier western, eastern and south eastern parts of Africa, where annual precipitation is less than 1,000 mm yr^{-1} (Foster *et al.,* 2006).

There are three main reasons for groundwater's increasing prominence as a water source: 1) the natural storage capacity is high; 2) the water quality is often good; and 3) infrastructure is more affordable to poor communities (Adelana and MacDonald, 2008). The largely ubiquitous presence and perennial nature of groundwater, with a higher resilience to inter-annual variability when compared to surface water, enables it to be used even during times of drought (Calow *et al*., 2010). Strengthened resistance to climate variability is also highly important in SSA where temporal rainfall variability ranks amongst the highest in the world. It is recognized that the chemical quality and in particular, the microbiological quality of groundwater, is usually better than that of surface water, which can help reduce the incidence of water-related diseases, although in some areas, issues stemming from anthropogenic or natural water quality hazards also prevail that may limit use. Groundwater is also a resource that can be developed for localized, small-scale uses and lends itself to incremental development at relatively low cost as compared to surface storages which are more centralized, costlier and subject to evaporation losses.

Not only is access to safe and reliable drinking water critical for a large proportion of the rural communities across SSA, (as they have traditionally accessed water from untreated surface water sources or unprotected hand-dug wells); but adequate access to groundwater for livestock and other agricultural uses represent an important measure of poverty and livelihoods potential (Carter and Bevan, 2008). However, groundwater is increasingly being recognized as an invaluable but often a largely untapped resource for agricultural development in SSA (Giordano, 2006; Masiyandima and Giordano, 2007). The use of groundwater for irrigation has the potential to boost agricultural productivity and thereby alleviate poverty and improve the food security of the local communities involved (Moench, 2003).

Giordano (2006), has established that groundwater supports individual or community irrigation projects on about one million ha in SSA. The most widespread use of groundwater is for village level 'garden-scale' irrigation of vegetables and seedlings, which helps to improve food and nutritional security at a local scale. But there are also important examples of groundwater having considerable potential as a supplementary source of irrigation at small scale (plots of up to 1 to 2 ha) in areas with shallow water tables and intermittent surface water supply are available for irrigation, thus offering security to farmers against the impacts of drought (e.g. in the inland valleys of the Volta basin); and being used for the commercial cultivation of high-value vegetable crops in the vicinity of some cities with developed markets.

The available information suggests that per capita availability of groundwater in SSA is not low, and probably higher than in any European or Asian countries, such as India and China that are some of the highest users of groundwater (Giordano, 2006). Whilst this aggregated view masks the substantial variation that indeed occurs across the region, nevertheless, the level of groundwater based irrigation development in Africa is many folds less than that of Asia. Some authors have claimed that SSA has adequate supplies to support an expansion in groundwater development for irrigation (Allaire, 2009; Giordano, 2006); other have been less optimistic claiming generally poor yields and that patchy aquifers constrain development (Foster *et al.,* 2006). Regardless of the difference in viewpoint, there is consensus that a myriad of factors, most of which are socio-economic and/or institutional also contribute to the extent of groundwater use.

There is wide acceptance that the hydrogeological conditions are the major controller of groundwater availability. Across Africa, there are four major aquifer types: a) the crystalline basement complex, which supports about half of the population of SSA with variable yields; b) consolidated sedimentary rock, supporting a quarter of the population, often with poor yields, c) unconsolidated alluvial sediments supporting 15 percent of the population with generally good yields, and d) volcanic rock for 10 percent of the population, often with good to very good yields (MacDonald *et al.,* 2005). Past and present climate conditions, particularly the rainfall patterns dictate the rates of recharge and hence the long term replenishment and aquifer sustainability.

Whilst groundwater plays a large role in supporting social and economic development in SSA, the resource-base is far from being adequately understood. Adelana and MacDonald, (2008) have argued that there is a lack of systematic data and information on groundwater across SSA, with studies occurring on an ad-hoc basis without strategic oversight or coordination. Groundwater monitoring is limited or absent, and groundwater monitoring systems for gathering, collating and analyzing information have failed in several countries despite the numerous amounts of wells drilled each year presenting a large opportunity (Allaire, 2009; Foster *et al.,* 2006).

The availability and reliability of water resources data has been a problem for many decades across SSA (Robins *et al.,* 2006; Carter and Bevan, 2008). Data still remains scarce and the information which is gathered is being done in an unsystematic manner. The reasons behind this are numerous and complex (Adelana and MacDonald, 2008), including, the lack of clear institutional arrangements and responsibilities, inadequate resourcing, lack of technical expertise and the absence or disconnect with database management and retrieval systems.

There are signs of hope though, with projects such as the Hydrogeological Assessment Project of the Northern Regions of Ghana (HAP) developed in recent years by the Water Resources Commission with financial and technical assistance from the Canadian International Development Agency (CIDA) (1999). The success of the project can be attributed to the extended commitment of the project partners in an environment of stable governance and good technical capability.

The main premise of this book is that data is sparse and the current low state of knowledge creates a barrier to sustainable groundwater development. This publication aims to address some of these gaps and enable the reader to draw synergies across a number of country level case studies. It attempts to consolidate the known information, in a summarized form, about the hydrogeological conditions, groundwater availability and replenishment, groundwater usage patterns, socio-economic factors and institutional arrangements, across 15 African nations. Each of the book chapter covers a particular country which includes: Burkina Faso, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Niger, Nigeria, Somalia, South Africa, Tanzania, Uganda, Zambia and Zimbabwe. As illustrated in Figure 1.1, these countries are clustered within two regions in western and southern/eastern Africa where groundwater development is prevalent. The final chapter provides a synthesis of the previous chapters and addresses the current state of knowledge along with development and management related issues and information gaps.

Figure 1.1 Distribution of the 15 reviewed countries

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CHAPTER 2

BURKINA FASO

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General description of Burkina Faso

Geography

Burkina Faso is a landlocked country - located in the Soudano-Sahelian zone of West Africa. It lies between latitude 9°20' S and 15°5' N and longitude 5°20' W and 2°3' E and covers an area of 274,000 km^2. Burkina Faso shares a border on the north and west with Mali, on the south with Côte d'Ivoire, Ghana, Togo and Benin and on the east with Niger. Administratively, the country is divided into 13 regions: Boucle du Mouhoun, Cascades, Centre, Centre-Est, Centre-Nord, Centre-Ouest, Centre-Sud, Est, Hauts-Bassins, Nord, Plateau-Central, Sahel and Sud-Ouest. These regions are further subdivided into 45 provinces and 301 communes. The capital, Ouagadougou, is situated in the Centre region in the middle of the country.

Physiography and climate

Seventy five percent of the country lies on an old crystalline platform, which gives it an overall flat and monotonous relief with an average altitude of 400 m (Central Plateau). The remaining 25 percent represents mainly flood plains and inland valleys. The vegetation of Burkina Faso is characterized by the extensive development of a continuous or intermittent grassland cover with the predominant vegetation of the steppe, savanna, and woodland. The three main vegetative zones in the country are: (i) Sahelian, located to the north which has a rainfall below 600 mm and with a predominance of steppe vegetation, (ii) the Sudanese, an extensive area that occupies the center, central-north, central-east and east of the country, and (iii) the Sudano-Guinean, which occupies the south and south west of the country and has a greater density of ligneous species than the other two areas. Burkina Faso has not yet established an agro-ecological zoning. It is the phytogeographical zones defined by Moniod (1957) and Guinko (1984) according to floristic and climatic characteristics, which take the place of agro-ecological zones. These zones are North and South Sahelian which are to the north of the country and North and South Sudanian to the middle and south of the country.

The climate of Burkina Faso is characterized by two contrasting seasons with a predominance of either dry air blowing from the north eastern sector, caused by the high Saharan pressures (dry season), or humid air from the south west, caused by high oceanic pressures of the Gulf of Guinea (wet season) (ICRISAT, 1987). Three climatic zones can be distinguished in Burkina Faso: the south Sudanian zone covering the southern part of the latitude 11^{o}30’ N, with isohyets in the range of 900 mm to 1,200 mm; the north Soudanean zone occupying most of the central part of the country between the latitudes 11^{o}30’ N and 14^{o}00’ N, with isohyets from 900 mm to 600 mm; and the Sahelian zone including the region above the latitude 14^{o}00’ N, with isohyets of maximum 600 mm (MEE, 1998). The country is characterized by a tropical climate with a mono-modal rainfall pattern of variable duration and increasing from the north to the south from 3 to 7 months (MEE 2001). The seasonal variation in temperatures is characterized by four periods: two extremely hot periods (highs of up to 41^{o}C in April) and two relatively cool periods (lows of up to 14^{o}C). The extremes are usually recorded in the north of the country.

Drainage

The hydrographic network of Burkina Faso consists of three main river basins: the Mouhoun river basin, the Nakambe river basin, and the Niger river basin (Table 2.1). The Nakambe and Mouhoun rivers drain the central portions of the country and flows into neighbouring Ghana. Other smaller rivers - the Bougouriba, Comoé, Béli, Sirba and

Tapoa - water the country. Burkina Faso is not well watered and many of the rivers dry up in the dry season (October-June), except the Mouhoun and Comoé in the south west that are fed by springs (Bandre *et al*., 1998). Faced with the situation of recurrent droughts in the 1970's and 1980's, the government of Burkina Faso built reservoirs for harvesting runoff during the short rainy season for use in the dry season. A total of 2,000 reservoirs were built to facilitate water availability for domestic supply and livestock (MEE, 2001). The total volume of water stored behind reservoirs was estimated at 2.66 billion m^3 in 2001. Reservoirs contribute to power generation and fresh water supply to the human population and livestock in the country. In the year 2000, it was estimated that about 79 percent of the reservoir volume generated 35 percent of the electricity consumed in the country in addition to supplying 37 million m^3 of water to communities across 36 towns (MEE 2001). Reservoirs have also enabled irrigation of 15 percent of the 165,000 ha total irrigable land in the country (FAO 2005).

Table 2.1 Surface water resources in Burkina Faso

National basin	Basin area (% of country)	Flow volume downstream the basin (km^3)	Volume stored in reservoirs (km^3)	Potential of surface water (km^3)	Potential from modelling (km^3)
Comoé	7	1.55	0.8	1.63	1.41
Mouhoun	30	2.64	0.29	2.75	2.94
Nakambe	36	2.44	2.20	3.32	3.08
Niger	27	0.86	0.1	0.9	1.36
Total	100	7.5	2.66	8.6	8.79

Source: MEE (2001)

Socio-economic context

The population of Burkina Faso stood at 14.0 million according to the 2006 population and household census, with an annual growth rate of 3.1 percent. The country is one of the poorest in the world, with an annual per capita GDP of USD 670, growing at about 8.9 percent. The economy of Burkina Faso is based on agriculture and stock farming. These are the country's principal activities that occupy almost 90 percent of the working population and account for 33 percent of the GDP. Agriculture in the country is mostly subsistence, dominated by small family farmers (3-6 ha for 7-8 workers per farm) who mostly use basic hand tools (almost 70% of farmers use the *daba*) and make marginal use of pesticides and mineral fertilisers (SAFGRAD, 1987).

Groundwater resources

Hydrogeology

The geology of Burkina Faso is dominated by the Precambrian basement crystalline rocks that are associated with the West African Craton and consist of metamorphic and meta-igneous rocks, schists and granites (Figure 2.1) (Ouedraogo et al., 2003; BGS, 2002, MAHRH, 2003). These formations underlay over 80 percent of the country (MEE, 1998; BILAN D'EAU, 1993). The western, northern and southeastern portions of the country are underlain by sedimentary rocks (Gres, calcaire) of Proterozoic to Paleozoic age. These rocks consist of sandstones, schists, conglomerate and dolomite. The northwest and extreme east is underlain by the recent Tertiary sedimentary rocks (continental terminal), which consists mainly of sandstones (Sandwidi, 2007).

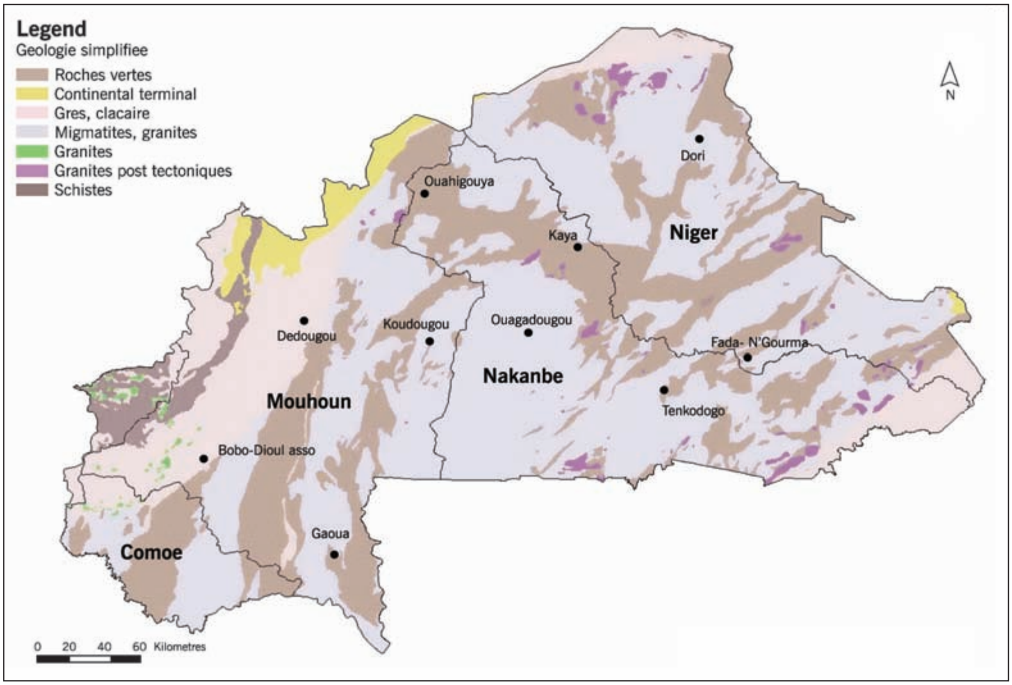

Figure 2.1 Geological map of Burkina Faso (Source: MAHRH, 2003)

Groundwater systems

Burkina Faso has two main types of aquifers categorized by the French system. These are the continuous or generalized aquifer and the discontinuous aquifer. The continuous aquifers are the continental terminal and the weathered zone aquifers. The thickness, hydraulic conductivity and specific yield of these aquifers vary significantly over space but water can be abstracted from them irrespective of the location. They have relatively high well success rate and can easily be developed. The discontinuous aquifers comprise the Precambrian bedrock, the Gourma formation and the Gres premier/intracambrain. These are widespread in the country and are highly localized in nature, with water stored in fractured bedrocks. Borehole or well success rate within this geologic formation is low.

<u>Continuous Aquifers</u>

The continuous aquifers consist of the continental terminal aquifers in the south of the Gondo plains in the north west of the country and the weathered zone aquifers found in Bobo Dioulasso in the south east and Tenkodogou in the south west of the country. The upper layers of the continental aquifer consist of clay, sand, and *gresb* (CIEH, 1976; BILAN D'EAU, 1993). The bedrock comprises of fractured and weathered schists and dolomite. The depth of the water table varies between 10 m and 80 m. Area covered by this aquifer is about 11,000 km^2 with an annual recharge of 430 million m^3 (about 38 mm). The saturated depth of the aquifer decreases from south west to north east, from about 50 m to 5 m. Assuming a drawdown of one-third of the saturated depth, it is estimated that about 1-3 billion m^3 of water can be extracted from this aquifer. Generally, the quality of water from this aquifer is very good. In the northern part of Bobo Dioulasso, this aquifer has a depth of 10-30 m and is mainly used with shallow wells. Not much is known about its recharge in the Bobo Dioulasso area but most recharge occurs through preferential flow. The weathered zone aquifer is found mainly in the Bobo Dioulasso and Tenkodogou regions but also in other areas of Burkina Faso. In general, this aquifer has a depth of 10-50 m. In Bobo Dioulasso, this aquifer has 10-30 m of weathered layer which gives an average yield of 0.5-5 $m^3 hr^{-1}$ with transmissivity between 1.9-5.5x10^{-4} $m^2 s^{-1}$. The piezometric head is between 10 m and above the bedrock. Some 83 percent of the flow in this aquifer is found in up to 50 m depth; 93 percent within 60 m; and 90 percent within 70 m. Optimum depth is between 45 m and 65 m (CIEH, 1976; BILAN D'EAU, 1993).

<u>Discontinuous Aquifers</u>

These aquifers include the Precambrian bedrock, the Gourma formation and the Gres premier and Intracambrain. The Precambrian bedrock aquifer consists of crystalline, volcanic and metamorphic rocks; granite, schist, green rock, etc. Availability of water resources in this aquifer is linked to the fracturing or weathering of these rocks. The weathering of schists produces clay which makes it impervious, thus water can only be found by drilling beyond these layers to the fractured layers. The coverage area of this aquifer is 225,000 km^2 and recharge is estimated at 3-4x10^9 m^3 (equivalent to annual infiltration of 17 mm) (CIEH, 1976; BILAN D'EAN, 1993). The Gourma formation (y doubam group) is characterized by dolomite and calcareous rocks that contain water in fractured zones. Recharge by rainfall is very low. Much is not known about this aquifer and it requires research to understand its characteristics. Finally, the Gres premier and Intracambrain aquifer are not well known but are very important. It has a good yield and is located in areas with many perennial rivers in the Bobo Dioulasso area. It covers an area of 30,000 km^2 and has a discharge of 1.9 billion m^3 (equivalent to annual infiltration of 60 mm). It has a transmissivity of 1.4-4.8 x10^{-3} m^2 s^{-1} and a specific capacity of 1 m^3 hr^{-1} m^{-1}. The thickness of this aquifer in this area is estimated as 100 m. In general the discharge increases with depth. Research is needed to know more about these important aquifers (CIEH, 1976; BILAN D'EAN, 1993).

Aquifer yield, recharge and groundwater potential

Geology, to a very large extent, determines the yield of aquifers. In the crystalline basement rocks, which underlay more than 80 percent of Burkina Faso and has little or no primary porosity; yields obtained in drillings are about 2 m^3 hr^{-1} (MEE, 2001). This yield is hardly sufficient to meet demands for domestic water supply, industry and agriculture. In the sedimentary zones, however, high yields can be obtained, often exceeding 10 m^3 hr^{-1} (MEE, 2001). Figure 2.2 shows the yields of wells drilled across the entire country. Figure 2.3 shows the distribution of piezometric heads of different wells drilled all over Burkina Faso. The water table in the central portions of the country (Plateau Central) is generally at a depth > 40 m. This could be explained by the fact that the Plateau Central is by far the most densely populated and urbanized region of Burkina and for many years, until very recently, domestic water supply of Ouagadougou and several other major towns was mainly from groundwater. Figure 2.3 shows strong variation of piezometric heads in short distances in many locations. This is mainly attributed to the geology of the country. Most of the rocks that constitute the geology are heavily fractured and trap water during the rainy season. Shallow water tables (< 10 m) are found primarily in dried river beds, flood plains and inland valleys.

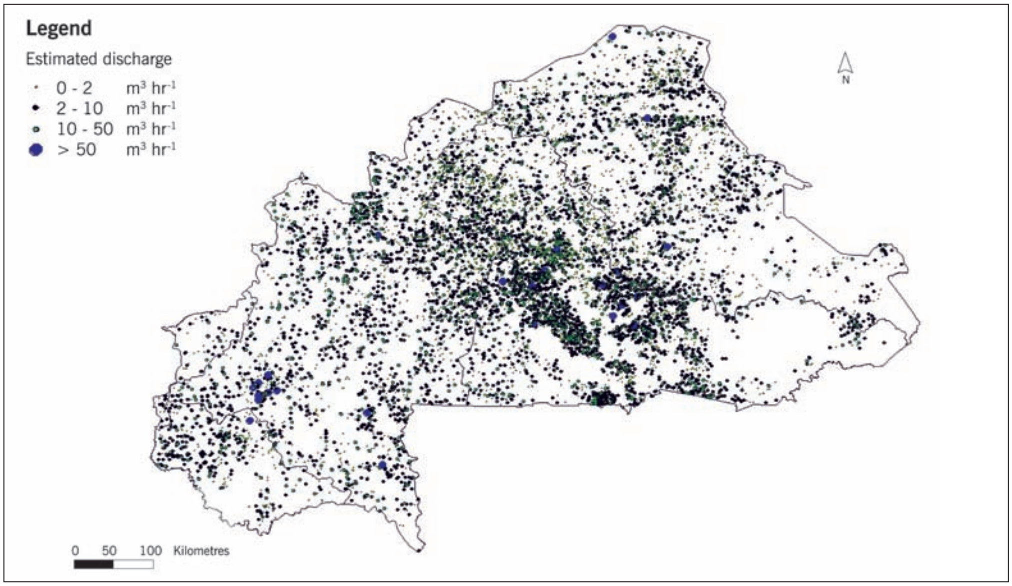

Figure 2.2 Map showing discharge of wells across Burkina Faso (Source: MAHRH 2003)

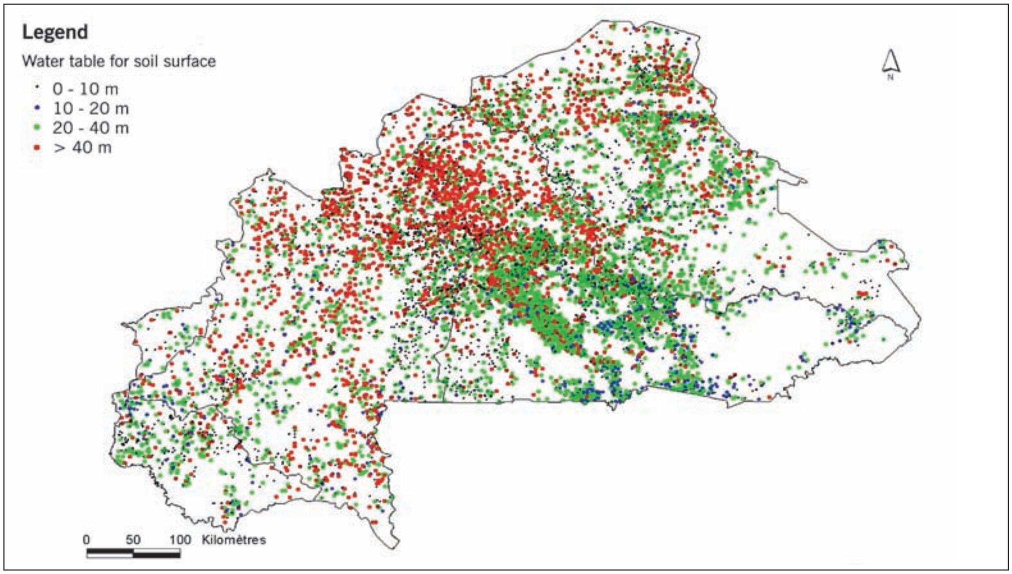

Figure 2.3 Distribution of piezometric heads of different wells in Burkina Faso (Source: MAHRH, 2003)

The main source of recharge to the groundwater aquifers in Burkina Faso, like in many arid and semi-arid areas, is seasonal rainfall. There is no clear indication of the presence of regional groundwater flow except for the areas underlain by sedimentary formation (western, northern and extreme east) and the downstream of the Nakanbe basin (DGH, 2000). Groundwater water level measurements from piezometers indicate that recharge in the northern portions of the country occurs mainly in the lowlands while in the south, recharge occurs practically everywhere (DGH, 2000). Recharge to the aquifers occurs under direct and indirect infiltration processes. While the direct process involves the direct infiltration of rainwater into the ground and subsequently percolating towards the water table, the indirect recharge process involves infiltration of rainwater in the low points (depressions, streams, alluvial valleys) where water concentrates after runoff. The indirect infiltration is more significant in the areas affected by the impoverishment of the soils where the recharge of the water tables occurs primarily around depressions. Generally, recharge rates in Burkina Faso are low, with high temporal and spatial variations. The annual recharge is estimated at 5 mm in the north and 50 mm in the south. For the whole of Burkina Faso, recharge is estimated at 9.5 billion m^3 yr^{-1} (FAO, 1995). Available information on groundwater recharge for specific locations is summarized in Table 2.2.

Table 2.2 Recharge rates for specific locations in Burkina Faso

Study area	Rainfall (mm yr^{-1})	Recharge		Method
		(mm yr^{-1})	(%)	
Central north	515-1000	10 - 250	-	Modelling
Kompienga dam basin (Eastern)	828	43.9	5.3	Chloride mass balance
Central	690	23 - 45	1.8 - 3.4	Modelling
Central north	517	10 - 37	1.9 - 7.2	Soil moisture profiling

Source: Sandwidi (2007) and other sources

Evaluation of the groundwater potential of Burkina Faso by MEE (2001) reveals that the country has a total groundwater storage potential of 402 billion m^3. A breakdown of the estimated total, according to the major river basins, is presented in Table 2.3. The estimates were based on careful assumption of specific yields of the aquifers as specific yields are highly variable in space. Groundwater availability in many locations of the country are limited due to the geology.

Table 2.3 Groundwater resources of Burkina Faso

National river basin	Estimated storage potential (Mm^3)	Annual renewal potential* (Mm^3)
Comoe	88,080	2,530
Mouhoun	175,000	12,400
Nakambe	80,000	8,400
Niger	59,000	9,100
Total	402,080	32,430

* The Annual renewable potential represents the infiltration part of the rainfall in these rivers
Source: MEE (2001)

Groundwater quality

Generally, the quality of groundwater in Burkina Faso can be described as having sufficient quality for direct use although there are quality problems in some localities (Groen *et al*., 1988). According to BGS (2002), groundwater from the basement rocks of the country are dominantly the Ca-Mg-HCO3 water types and are usually fresh. Pollution of groundwater sources, especially shallow groundwater in many places is one of the major problems confronting the use of the resource (Yameogo and Savadogo, 2002). This constitutes a real public health threat since the resource is mostly used for domestic water supply. A joint UNEP-UNESCO initiated groundwater pollution monitoring in the Boulmiougou, Main channel and Kossodo areas showed that water in the shallow aquifers at Boulmiougou had higher nitrate and salinity levels (above the WHO standards) compared to water in the boreholes. The main sources of pollutants were from agricultural chemicals and fertilizers from market gardens, wastewater runoff and industrial effluent.

Salinity values in the range 50-2,700 $\mu S\ cm^{-1}$ have been reported in groundwater samples from north western Burkina Faso (Groen *et al*., 1988). Yameogo and Savadogo (2002) found variable salinity levels in groundwater samples from Ouagadougou and Baskuy. Salinity levels in the range of 100-350 $\mu S\ cm^{-1}$ were obtained from the analysis of water samples from 25 wells in Ouagadogou. In the Baskuy community, the figures obtained were 326-1,595 $\mu S\ cm^{-1}$ in water sampled from 15 wells. Figure 2.4 depicts the spatial distribution of groundwater salinity higher than 1,000 $\mu S\ cm^{-1}$ in Burkina Faso. It can be inferred from Figure 2.4 that the problem of salinity is widespread.

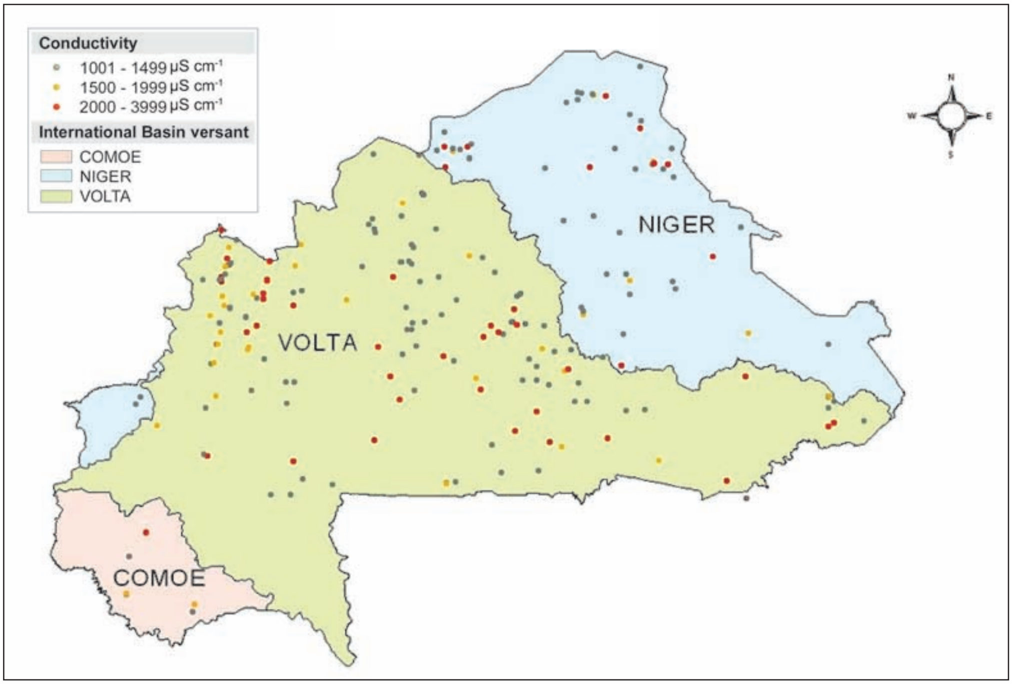

Figure 2.4 Distribution of conductivity > 1000 μS cm^{-1} in Burkina Faso (Source: MAHRH, 2003)

Similar to many developing countries, nitrate levels in groundwater in the country are normally high in populated areas where sanitation is likely to be a problem. Groen *et al*. (1988) reports of nitrate levels higher than the WHO standard (45 mg L^{-1}) in water samples from 15 percent of 168 boreholes drilled in north western Burkina Faso between 1984 and 1986 as part of the Volta Noire rural water supply project. Also, 36 percent of 123 dug wells sampled had nitrate levels above the WHO standard. High nitrate levels were found mostly in villages with high housing densities. Yameogo and Savadogo (2002) found high concentration of nitrate in shallow aquifers in Ouagadougou, particularly between August and early September. This was attributed to high infiltration resulting from rainfall inputs. In the dry season, however, the concentration level go down significantly. Groundwater samples from 5 of 6 wells sampled showed nitrate concertrations below the WHO standard. Sample from the 6th well, located at Kossodou, had higher concerntration (250 mg L^{-1}). Yameogo and Savadogo (2002) observed that high nitrate concentrations are likely to be a feature of shallow groundwaters in many areas of Burkina Faso. Figure 2.5 shows the spatial distribution of boreholes/wells with nitrate concentration above the WHO standard in Burkina Faso.

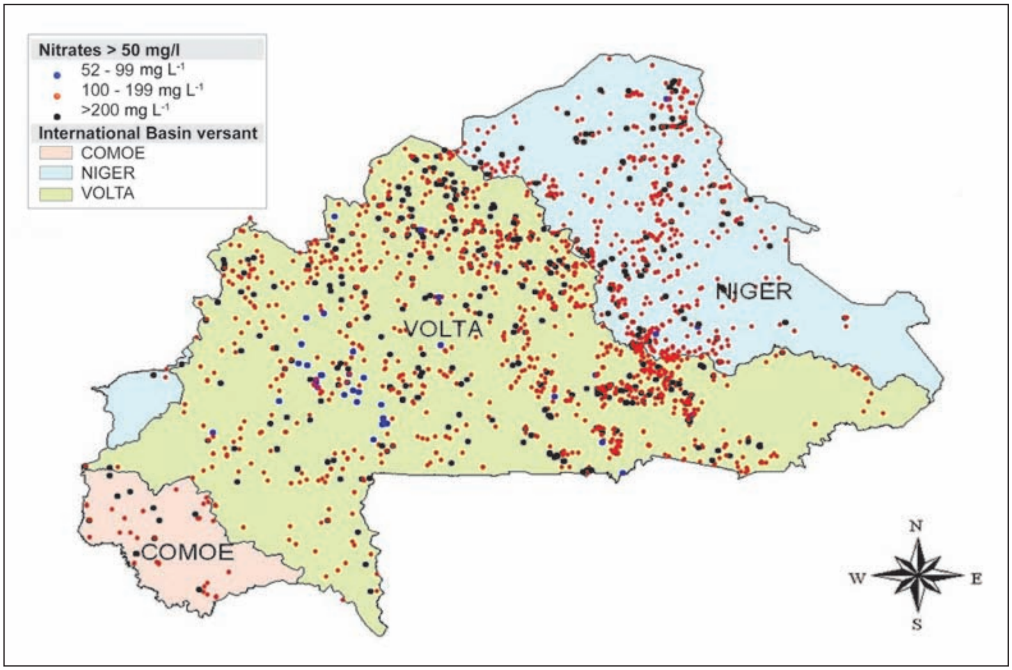

Figure 2.5 Distribution of nitrate concentration in groundwater in Burkina Faso (Source: MAHRH, 2003)

Groundwater development and utilization

Groundwater abstraction

Groundwater abstraction in Burkina Faso is done mainly through boreholes and wells. In 2009, the country had a total of 58,845 boreholes and wells spread across the regions. This number consisted of 38,318 boreholes and 20,527 wells (MEE, 2001). The number of boreholes the country had in 2009 was an increase of more than 50 percent over the 2001 figure of 24,350 (MEE, 2001). Table 2.4 shows the regional distribution of boreholes and wells in Burkina Faso in 2009. About 96 percent of the boreholes were equipped with pumps while only 0.5 percent of the wells were fitted with pumps.

Table 2.4 Inventory of water supply points in Burkina Faso as on September 2009

Regions	Boreholes				Wells				
	Abandoned boreholes	Boreholes with pump	Recent boreholes	Artesian boreholes	Abandoned wells	Drilling well	Wells with pump	Permanent wells	Temporary wells
Boucle du Mouhoun	83	2,889	68	1	105	5	1,372	686	2,168
Cascades	21	1,288	25	1,334	2	162	161	397	1,731
Centre	27	1,636	14	1,677	2	175	208	500	2,177
Centre-Est	70	3,655	43	3,768	1	11	831	1,552	2,930
Centre-Nord	91	4,427	66	4,584	7	841	844	1,917	6,501
Centre-Ouest	20	3,633	56	3,709	5	695	1,072	1,922	5,631
Centre-Sud	38	2,540	8	2,586	5	741	1,145	2,148	4,734
Est	45	3,524	77	1	215	13	565	920	1,713
Hauts Bassins	47	2,186	32	8	52	28	468	356	904
Nord	42	3,284	130	1	224	16	1,067	1,090	2,397
Plateau Central	57	3,201	56	3,314	4	284	380	948	4,262
Sahel	158	2,348	63	2,569	1	1	195	541	1,086
Sud-Ouest	12	2,322	24	1	72	4	810	611	1,497

Cost of groundwater development

Boreholes

The cost of constructing water well is strongly influenced by the underlying geology. Basically, the cost of a well consists of the cost of mobilization, drilling, casing and well development including test pumping. Other costs, according to Danert et al. (2008) include taxes, pump, sitting, supervision, social infrastructure and construction quality. The amount of time spent on drilling also affects the drilling cost. In Burkina, drilling a borehole takes an average of 2 days, compared to the 45 days in Senegal (Antea, 2007). The cost of constructing a borehole in Burkina Faso varies from USD 10,000 to USD 20,000 (Duffau and Ouedraogo, 2009).

A breakdown of the cost is presented in Table 2.5. Based on a study of drilling costs, the average cost of drilling per meter depth in Burkina Faso is reported to be USD 152 (Antea, 2007). This figure consists of the average cost of drilling and installation of casing and screen but excluding the cost of pump.

Table 2.5 Cost of drilled water well in Burkina Faso

Description of work	Costs (USD)
Social component	1,600 - 2,200
Borehole sitting	400 - 1,100
Supervision of works	200 - 700
Drilling	6,700 - 13,300
Hand pump	2,200 - 3,600
Apron	900 - 1,300
Total	10,000 - 20,000

NB: The total costs do not include the cost of failed boreholes. If included, the cost could range from USD 14,400-18,000

Source: Duffau and Ouedraogo (2009)

<u>Shallow wells</u>

Typical boreholes in many locations, especially in areas underlain by basement rock, tap from relatively deeper aquifers at depth of 40-60 m. The cost of construction and abstraction of water from these wells are expensive. Therefore, small scale farmers are not able to afford tapping from the deeper aquifers for irrigation. Much of the groundwater irrigation happening in Burkina Faso and neighbouring countries like Niger, Ghana and Mali are drawing from the shallow aquifers using shallow wells that are constructed with low-cost technologies such as the vibro-bailer method, percussion bailer, small rotary rig, clear water washboring and mud washboring (Sonou, 1997). Factors that determine the cost of a shallow well include capital and depreciation, operation and maintenance of equipment, number of wells constructed per year, and the drilling success rate. In 1995, the cost of constructing a shallow well in Burkina Faso was estimated at USD 200 (Sonou, 1997).

Groundwater utilization

Domestic purposes

The groundwater resource in Burkina Faso is used mainly for domestic water supply, particularly in smaller towns and rural areas. Groundwater based pipe borne systems are used in 48 small towns and in Bobo Diolasso (500,000 inhabitants), where drinking water supply relies entirely on groundwater, and in the capital, Ouagadougou (> 1 million inhabitants), where groundwater provides 15 percent of the drinking water (Bracken and Mang, 2002). The groundwater supplies to Ouagadougou is very important, though it constitutes less than a fifth of the city's water demands, as this represents a reliable source of freshwater in the dry season. While in many of the urban centres the groundwater supply systems are mechanized, those in the rural areas are not mechanized but fitted with hand pumps. On a whole, about 87 percent of the rural inhabitants and 21 percent of urban dwellers have access to water through boreholes and wells (MEE, 2001).

Agriculture: irrigation and livestock

There is hardly any data on the volumes of groundwater being used for agricultural and industrial purposes in Burkina Faso, though it is known that a limited amount from shallow aquifers are used for irrigation particularly in market gardening and also for watering livestock. Most of the existing statistics present a total volume of withdrawal (surface and groundwater) and not a detailed account by source. In the year 2000 for instance, 690 million m^3 (about 6.4 % of the total renewable water) was abstracted from surface and groundwater for irrigation and livestock watering. In the same time, a much lesser amount of 6 million m^3 was supplied to industry.

Though statistics are not available, it is well known that groundwater supports dry season cultivation of vegetables in some areas of the country, particularly in the south where the watertable is low at some period of the year and the recharge is relatively high. Some farmers take advantage of the availability of high residual moisture and shallow groundwater in floodplains, river beds and inland valleys to cultivate. This kind of irrigation is done on small scale with little or no support from government institutions.

Institutional and legal framework

The over sight responsibility of conserving and ensuring sustainable use of water resources, both surface and groundwater, in Burkina Faso rests with the Ministere de L'Environment et de L'Eau (MEE). The MEE is the government ministry in charge of the environment and water. It has 4 permanent departments responsible for handling specific mandates of the ministry, including water. These are (i) General Directorate of Agricultural Hydraulics (DGHA), (ii) General Directorate for Provision of Portable Water (DGAEP), (iii) General Directorate of Inventory of Hydraulic Resources (DGIRH), and (iv) General Directorate for Fishing Resources (DGRH) (MEE, 2001). The DGAEP is responsible for portable water supply to urban and rural areas as well as industries; DGHA is mandated to oversee water use for agriculture, livestock and energy; DGIRH keeps record of all water-related activities and interventions and undertakes research to identify areas in need of intervention; and DGRH is responsible for the development of the fisheries resources of Burkina Faso (Lautze *et al*., 2006).

Presently, there exists a political will and commitment to implement integrated water resources management programs in the entire country. This is for the purpose of satisfying the water needs of all relevant sectors, namely, domestic, agriculture and industry. At the moment, there are seven national regulatory laws that govern surface water and groundwater management in the country. The Burkina National Council for Water is responsible for ensuring the full implementation and enforcement of the laws in all the provinces of the country. There also exist autonomous projects and attached services that play an important role in developing and managing water resources in the country.

The country has a Water Management Policy Act (2001), which provides for state ownership of all water resources (with few limited exceptions) and establishes a permit regime for water abstraction excluding water use for domestic purpose (Lorenzo Cotula, 2006). The legislative provisions also address issues like expropriation and compensation of land rights for the purposes of creating, improving or maintaining the water infrastructure – a key element of the interface between land tenure and water rights.

Conclusions and Recommendations

Groundwater resources in Burkina Faso are less developed compared to many West African countries. Due to the fragile hydrological environment of the country, groundwater plays an important role in meeting the water needs, particularly the domestic water needs of the rural people. Though the groundwater resources in Burkina Faso are used mainly for domestic water supply, they are also used for irrigation, particularly in market gardening and livestock watering. However, there is only little information on the extent of use of the groundwater in agriculture. Considering that Burkina Faso is a landlocked country whose people support a traditional agricultural economy, if well developed, groundwater could play a crucial role in boosting small scale agricultural production to liberate many from poverty.

This study found that the Gres premier and Intracambrain type of aquifers that are located in areas with many perennial rivers in the Bobo Dioulasso area are very productive. They cover an area of 30,000 km^2, have a transmissivity of 1.4 - 4.8 x 10^{-3} m^2 s^{-1} and capacity of 1 m^3 hr^{-1} m^{-1}. But very little is known about these aquifers. A research is needed to explore more about them for the productive and sustainable use of these important aquifers.

Many groundwater studies have been done in several different locations in Burkina Faso, with most of them focussing on the hydrogeology and well drillings. However, these studies were hardly coordinated leaving several gaps (unanswered questions) that need to be filled by way of additional research. A comprehensive groundwater inventory in Burkina Faso is needed. This will help to sufficiently address various important issues including: the extent of groundwater use by the various sectors (domestic, agriculture-irrigation and livestock, and industry), the spatial and social patterns in groundwater use, the background of households using the resource, and comparative cost analysis of using groundwater and surface water for irrigation and livestock watering.

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CHAPTER 3

ETHIOPIA

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General description of Ethiopia

Geography

Ethiopia is a landlocked country in the horn of Africa, bounded to the north by Eritrea, to the west by Sudan, to the south by Kenya and to the east by Somalia and Djibouti; it lies within the tropics between 3°24' N and 14°53' N latitude; and 32°42' E and 48°12' E longitude. It covers about 1,132,000 km^2. Since 1995, Ethiopia has been divided into 10 administrative regions based on ethnic lines. These are Tigray, Afar, Amhara, Oromia, Somali, Benishangul, Southern Peoples' State, Gambella, Harar and Addis Ababa.

Physiography and climate

Ethiopia has extremely varied topography. Much of Ethiopia is highlands, often referred to as the Ethiopian Plateau. The highlands are bisected by the Great Rift valley into the north western highlands and the south eastern highlands, each with associated lowlands. North of Addis Ababa, the surface of the plateau is interspersed with towering mountains and deep chasms that create a variety of physiography, climate, and indigenous vegetation. The plateau also contains mountain ranges such as the Chercher and Aranna. South west of Addis Ababa, the plateau also is rugged, but its elevation is slightly lower than in its northern section. To the south east of Addis Ababa, beyond the Ahmar and Mendebo mountain ranges and the higher elevations of the south eastern highlands, the plateau slopes gently toward the south east. The land here is rocky desert and, consequently, sparsely populated. Running through central Ethiopia is the Great Rift valley stretching from the Denakil depression in the north and to the coastal lowlands (Afar Plain). The western and south western slopes however descend somewhat less abruptly and are broken more often by rivers. Between the plateau and the Sudanese border in the west lies a narrow strip of sparsely populated tropical lowland. These tropical lowlands on the periphery of the plateau, particularly in the far north and along the western frontier, contrast markedly with the upland terrain.

According to the Ministry of Agriculture about 19 soil types are identified throughout the country. The big proportion of the country's landmass is covered by lithosols, nitosols, cambisols and regosols, in order of their importance. Compared to most other African soils, majority of Ethiopian highland soils remain relatively fertile at depth, though they are deficient in important nutrients and require fertilizer to sustain crop yields. In general, vegetation size and density increase with increasing humidity. Desert steppe vegetation of scattered, low shrubs is found in arid regions. With increasing humidity, the desert steppe vegetation passes into open woodland steppe vegetation of short shrubs and scattered, small trees in annual grasses. Savanna vegetation varies, with increasing humidity, from tall grass and shrub savanna to true savanna, dense tall grasses with scattered short trees. As humidity increases, savanna vegetation gives way to deciduous woodland of small trees (5-12 m) with lower strata of high shrubs (2-3 m). Parts of the deciduous woodland region also consist of bamboo forests. Evergreen woodland consists of transitional forests between deciduous woodland and highland forests.

Ethiopia has a tropical monsoon climate with a wide climatic variation induced by varying topography. The climate of Ethiopia ranges from equatorial desert to hot and cool steppe, and from tropical savannah and rain forest to warm temperate highlands. Mean annual temperature varies from over 30°C in the tropical lowlands to less than 10°C in very high altitudes. Rainfall also has spatial and temporal variation as it is strongly controlled by the inter-annual movement of the position of the Inter Tropical Convergence Zone (ITCZ). The south western and western areas of the country are characterized by monomodal rainfall pattern, the central, eastern and north eastern areas of the country experience a nearly bimodal rainfall distribution and the southern and south eastern areas of the country are dominated by a distinctly bimodal rainfall pattern. Annual rainfall varies from less than 100 mm along the borders with Somalia and Djibouti to more than 2,000 mm in the highlands of the south west. The national average rainfall is 744 mm yr^{-1} (FAO, 1995).

Drainage

The Ethiopian highlands form a drainage divide between the Mediterranean and the Indian Ocean. The country has rivers, which drains from the highlands to the lowlands, rift valley and low-lying neighboring countries to the west, south and south east. The major drainage basins are Abay or the Blue Nile, Tekeze-Mereb, Baro-Akobo, Gibe-Omo, Rift valley (lakes), Awash, Genale-Dawa and Wabeshebelle including the Ogaden dry basin. The Rift valley separates the Nile drainage system, Indian Ocean drainage system and other drainage systems, which have no outlet to the sea. The Nile drainage system includes three major tributaries, which emanate from the Ethiopian highlands, the Tekeze-Mereb, Abay and Baro-Akobo. The Indian Ocean drainage system includes the Wabishebelle and the Genale-Dawa, which emanate from the eastern plateau. The other drainage systems, which have no outlet to the sea include drainage basins of the Danakil which drains into the Danakil Depression (also some referred to as Assale basin), the Awash which drains into lake Abhe; the central rift rivers which drains into the numerous lakes expanding from lake Turkana in the south and lake Ziway in the north; and the Omo-Ghibe rivers which drain into lake Turkana or Rudolf. All the large rivers originating in Ethiopia (except Awash) flow into neighboring countries.

Socio-economic context

Ethiopia has a population of close to 91 million growing at 3.2 percent annually (Central Intelligence Agency, CIA, July 2011 estimate). About 83 percent of this population lives in rural areas. Ethiopia's GDP in 2008 was estimated at USD 318.7 per capita, growing at about 7 percent per year, of which agriculture and services contribute 43 percent each and the remaining 14 percent from industries (UN Data). The agricultural sector plays a central role in the socio-economy of Ethiopia. About 80-85 percent of the people are employed in agriculture, especially farming. The sector contributes about 40 percent of the total GDP with livestock and their products accounting for about 20 percent of total GDP. Smallholders, the backbone of the sector, cultivate 95 percent of the cropped area and produce 90-95 percent of cereals, pulses and oilseeds. Subsistence agriculture is almost entirely rainfed and yields are generally low. Irrigation is limited, and though the potential irrigation area is over 4 million ha, only about 6 percent is irrigated, and most of it is under unimproved traditional systems (Tilahun and Paulos, 2004).

Groundwater resources

Hydrogeology

The hydrogeological conditions of the country are linked with the occurrence and distribution of the various hydrostratigraphic units, the topography, the recharge and discharge conditions which, in turn are related to the spatial and temporal variation of rainfall. These hydrostratigraphic units include the Precambrian basement, Palaeozoic rocks and Mesozoic sediments (Tertiary and Quaternary volcanics and the Tertiary and Quaternary sedimentary rocks and sediments).

i. *Precambrian basement*: The Precambrian basement complex rocks upon which all younger rock formations are deposited contain relatively low groundwater reserves. The main water bearing formations of the Precambrian are found within the structural discontinuities of various crystalline rocks of the lower complex (high grade gneiss, migmatites, granulites and metamorphic granitoids), in the upper complex, syn-tectonic and post-tectonic granitoids. Since metamorphic rocks are subjected to several orogenic episodes, they are strongly folded, foliated and fractured. These structures play an important role in the movement and occurrence of groundwater. Some geological structures of hydrogeological importance in the Precambrian rocks include: (i) the intersection of the main regional tectonic structures; (ii) occurrence of post crystalline tensile and shear fractures; and (iii) the structural heterogeneity due to the occurrence of migmatites and granulites in the gneiss, or quartz and pegmatite dikes;

ii. *Generally, Precambrian* intrusive igneous rocks and metamorphic rocks have very low (less than 1%) primary porosity. As a result, permeability is small and in most practical cases serve as an aquiclude. Water-bearing properties of these rocks are believed to be dependent on the extent of weathering and occurrence of fractures. In these rocks, the deeper the weathered zone, the greater is the amount of water. The weathered layers can have porosities of up to 50 percent and therefore act as a major reservoir. The success and failure of well site locations depend very much on the proper understanding of the complex structures of the Precambrian metamorphic and intrusive rocks and the existence of thick permeable weathered zones. Even though crystalline rocks are generally impervious, groundwater occurs mainly in the weathered and creviced zones. Shallow productive unconfined aquifers can be found in the regional fractures and in thick soil overburden (regolith). The metamorphic rocks exposed in western and southern Ethiopia are located within the area of favorable climatic conditions. However, their water holding properties are poor as witnessed by the springs which emerge from the contact between overburden soils and the massive gneisses. In the eastern part of the country, the known aquifers are metamorphic granites and migmatites. Generally the groundwater potential and the current development in the Precambrian basement complex rocks of Ethiopia are very low;

iii. *Palaeozoic rocks:* The Paleozoic and Mesozoic rocks are entirely sedimentary. Both the primary and secondary permeability in these rocks play an important role in the occurrence and movement of groundwater. In the clastic sedimentary rocks, the main water-bearing horizon is constituted by interstitial spaces. The water holding capacity may be conditioned by the degree of assortment, grain size, cementation and jointing. Precipitates arising from percolating water readily close interstices of clastic sediments. Cementation and resulting consolidation provides favourable condition for the development of joints. Carbonate rocks are among the most productive aquifers in the Mesozoic rocks even though their permeability and porosity vary considerably. This variation is related to their mode of origin and environment of deposition. The Paleozoic formations are localized in the Ogaden and Tigray regions. They are essentially constituted of Edagarbi tillites, shales, silts and Enticho sandstones. Since Paleozoic sediments are known to overlie impervious basement rocks, they can store sufficient quantities of water, particularly in the channel fills and within the clastic sediment horizons. Paleozoic sediments contain water mainly in the conglomeratic horizons and in weathered zones. Generally the Paleozoic do not have groundwater reserves comparable to that of the Mesozoic and Cenozoic volcanic rocks;

iv. *Mesozoic sediments:* The Mesozoic sedimentary rocks can make good aquifers when they are found under more favorable climatic conditions. They outcrop in the north western plateau, mainly in Tigray, in the Blue Nile Gorge in south eastern Ethiopia, in Harrghe, Bale and southern Sidamo. The main aquifers in the Mesozoic formations include the arenaceous type formation (Adigrat sandstones), calcareous-dolomitic layers very often fossiliferous (Abay beds and Antalo limestones), Agula shales and Amba Aradam formation (more arenaceous-conglomeratic). Generally Mesozoic sediments (upper sandstone, middle limestone, and lower sandstone) have varied hydrogeological characteristics. In the lower sandstone, groundwater can be saline in zones where it is in hydraulic contact with the overlaying saline aquifers. In the south east of the country, the formation is too deep for economical drilling. Limestones (Hamanlei and Antalo) are generally permeable, fractured and karstified. Antalo limestone is one of the major aquifers in Ethiopia;

v. *Tertiary and Quaternary volcanics*: Tertiary and Quaternary volcanic rocks cover extensive areas. The volcanics of Tertiary, known as the Trap Series, overlie the Mesozoic sedimentary rocks. They usually form the highlands or the plateaux. They are highly weathered and form thick residual soils.The simplified stratigraphy, from the oldest to the youngest of the Cenozoic volcanics are the Ashenge group, Shield group, Makdala group and the Aden volcanic series. Generally important aquifers could be formed in the Ethiopian volcanic province by occurrence of paleosols, interbedded loose pyroclastic materials and reworked agglomerates, buried paleovalleys, structural discontinuities, contraction joints within thick lava flows, thick residual soils, many permeable zones between the contact of the different generation of lava flows and inter-trappean beds;

vi. *Tertiary and Quaternary sedimentary rocks and sediments*: Though not extensive, there are some sandstone outcrops of Cenozoic age in the Afar and eastern Ogaden. These are variegated sandstone (Jessoma Sandstone), biogenic massive limestone (Auradu series), gypsum, dolomite, cherty limestone and clays (Taleh Series), and fossiliferous limestones with marly and clayey intercalations (Karkar series) and the Red bed (Garat formation). In these rocks important aquifers can be located in channels filled by younger sediments, coarse sandstone and conglomeratic layers interbedded with shales, the contact between clastic and chemical sediments, interstratifications of basaltic lava flows with loose sediments and the alluvial sediments on flood plains.

Groundwater systems

In most cases, the groundwater/aquifer systems of Ethiopia are discontinuous and isolated. There are confined, unconfined and semi-confined aquifer systems with local artesian conditions. The temporal and spatial variation of groundwater occurrence is very high. This is owing to differences in structural setting and local lithological variations; the former being the main cause for the drastic variability. The groundwater condition (depths, safe yields, etc.,) of the main aquifer systems of Ethiopia is summarized as follows (Table 3.1).

Table 3.1 Characteristics of the major aquifer systems

Aquifer system	Depth (m)	Yield (L s^{-1})	Location	Aquifer description
Weathered and fractures intrusive and old Precambrian rocks (granite, metamorphic rocks etc.,)	30-60	1-2	Western, south western parts of the country	These types of rocks have very low fracture permeability while the depth of fracturing is shallow and accordingly groundwater in this type of aquifer is also shallow. However, if thick layer of weathered over burden exists, relatively good potential of groundwater occurs.
Sedimentary rocks (Mesozoic sand stone, karstic limestone etc.,)	200-300	2-5	Eastern, south eastern parts of the country	The primary porosity developed is very poor for some of the layers (limestone) while secondary porosity and karstification are very common in the limestone. Good yield of water is extracted from the karstified limestone and the sand stone.
Tertiary volcanics (having primary and secondary porosity)	50-250	2-6	In the central, eastern and western highlands of Ethiopia	These aquifers exist extensively throughout the country especially in the western, central and eastern highlands. The water quality in this type of aquifers is generally good.
Quaternary volcanics	100-250	2-5	Rift valley	These are young volcanics of the rift floor where high tectonic activity is occurring which has resulted in highly fractured rocks and as a result a favourable situation for groundwater recharge and occurrence exist.
Unconsolidated sediments (alluvial, colluvial, lacustrine sediments)	20-100	1-5	Mostly in the rift valley, western low lands, river valleys, isolated depressions throughout the country	Very important hydrogeologic formations that are used to be very good sources of groundwater in Ethiopia.
In situ developed soils	5-20	0.1-1	Throughout the country (especially in the high lands and mid lands of the country)	These are soils developed within micro catchments where the rainfall directly infiltrates and stores in the saturated zone. These types of soils are found to be useful sources of water especially in the highlands of Ethiopia where traditional and improved hand dug wells are the major sources of water supply. Seepage springs are also common whenever there is a break in slope and/or a lower contact of the soil is exposed to the surface.

From a groundwater potential point of view, three broad aquifer classes can be identified:

- Aquifers with intergranular permeability (unconsolidated sediments: alluvium, eluvium, colluvium, lacustrine sediments and poorly consolidated sandstone);
- Aquifers with fracture and/or karstic permeability (consolidated sediments and metamorphosed carbonates (limestone, sandstone, shale, marl, evaporite, marbles);
- Aquifers with fracture permeability (basalts, rhyolites, trachytes, ignimbrites).

Each of the above three broad categories are in turn divided into high, moderate and low productivity (Table 3.2). As a fourth category localized aquifers with fracture and intergranular permeability, particularly in the basement rocks (non carbonate metamorphic rocks, garnitic, intrusives and dolerites) are also included.

Table 3.2 Aquifer classifications and yield based on qualitative field observations and aquifer test

Aquifer productivity	Mean permeability (m d^{-1})	Number of boreholes	Specific capacity (L s^{-1} m^{-1})			Estimated optimum yield (L s^{-1})	
			Range	Mean	Median	Mean	Median
High	14.5	106	0.03-40.5	3.3	2	29.7	18
Medium	2.1	116	0.02-13.5	0.53	0.13	4.8	1.2
Low	0.25	15	0.001-3.4	0.1	0.04	0.9	0.4

Source: Tadesse (2004)

Groundwater recharge

The main source of recharge in the country is rainfall, supplemented by channel losses from large rivers draining in permeable and fractured hydrostratigraphic units. Recharge is highest in the north eastern and south western plateau where annual rainfall is high. Rapid infiltration occurs in areas covered by fractured volcanics and to a lesser extent in sedimentary rocks and thick permeable soils. The Ethiopian rift acts as a discharge zone, which contains numerous perennial rivers, fresh, alkaline and brackish lakes, cold and thermal springs. In Ethiopia, the estimated annual recharge is about 28,000 million m^3 and annual production is in the order of 18 million m^3 (Tadesse, 2004). It is understood that this figure may change as more and more data is collected in different parts of the country. With the exception of much of the Afar depression, where the annual recharge is close to zero, the recharge for the different river basins is summarized below (Table 3.3).

Table 3.3 Annual surface water runoff and groundwater recharge for major river basins

Major basins	Area (km^2)	Average runoff (m^3 s^{-1})		Total annual runoff (Mm^3)	Average recharge (mm yr^{-1})
		Median	Mean		
Abay	198,510	500	1,680	53,000	100
Baro-Akobo	75,720	220	415	13,100	120
Tekeze (Atbara)	87,770	30			50
Mereb	23,480			11600	10
Barka	41,370				10
Red sea	43,960				10
Gulf of Aden	2,000				10
Ogaden	71,890				10
Wabishebelle	205,410	40	80	2,500	30
Genale-Dawa	168,140	40	125	4,000	30
Omo	77,210	300	520	16,400	100
Rift valley	54,900			1,100	50
Awash	113,320	60	80	2,500	30
Danakil	69,520				10

Source: Chernet (1993)

Groundwater quality

Water quality of groundwater in Ethiopia varies widely. It is primarily influenced by geology, physico-chemical factors, biological factors, anthropogenic influences such as pollution from industrial, municipal and agricultural sources, geomorphological and geographical setting as well as climatic condition. A generalized summary of the range of values measured for major water quality parameters is presented in Table 3.4.

Table 3.4 Groundwater quality in Ethiopia

Parameter	Level	Location
Total Dissolved Solids	High 1,500-3,000; Lowest < 500	Highest in Afar, Ogaden and Wabe Shabele; lowest in crystalline basement rocks in north–central and south west highlands and south of the Rift.
Fluoride	Usually about 10; but as high as 200-300 also recorded.	Highest in the Rift, moderately high in volcanic rocks in the highlands and low in ancient basement rocks.
Nitrate-N	Generally < 10; but as high as 728 has been reported	Generally low, but higher in urban areas due to poor sanitation. Highest level reported in a spring in Addis Ababa.
Iodine (μg L^{-1})	8-24	While these levels are not low, iodine deficiency has been reported in Shoa, Jimma, Arsi and Gomo-Gofa region with some villages having giotre prevalence in excess of 90 percent.
pH (-)	4.1-12	Highest in the Rift lakes
Sodium	Highest 6,900-9,131	Rift, Dire Dawa, Oromiya, Tigray and SNNP
Copper	Highest: 27.6	SNNO
Zinc	1-40	High in Afar, Oromiya, SNNP and Tigray states
Chloride	Highest: 17,500	Reported in shallow wells in Omo zone
Sulphate	Highest: 3,780	Highest in Afar, but generally elevated in all states except Addis Ababa, Benshangul-Gumze and Gambella
Microbiota *(E. Coli)*	3-4 log units	High in urban areas resulting from poor sanitation

*All units in mg L^{-1} unless indicated

Source: MacDonald *et al*. (2001) and authors' data

Groundwater development and utilization

Groundwater abstraction

Groundwater is drawn from hand-dug wells, drilled boreholes and springs. Drilled wells within a relatively shallow depth and installed with hand pumps are also used commonly in many places. Many urban centres and rural villages in arid and semi-arid regions are supplied by deep boreholes fitted with submersible pumps. Other main groundwater tapping systems are springs, widespread in the escarpment and the highlands, which supplies the great majority of the rural community, particularly in the rugged mountainous regions. The reliability of the resource in sufficient quality and better-quality are the two factors that normally determine the choice of raw water. For example, spring sources though having better quality water, are not always reliable sources as their flow fluctuates and even ceases to flow during the dry seasons.

In the rural settings, each spring is tapped to serve 200-500 people. For example, in Amhara region, over 1,000 springs have been tapped in the last 5 years. Among the big towns that have springs as source and whose construction works are executed at the federal level, are Arbaminch, constructed in 1991, and Bahirdar; with both having more than 30,000 population (DHV, 2001). In the Abay river basin, 10 percent of the rural water supply needs are met by spring development. The Oromiya Water Resources Baseline Survey indicates that springs meet 6.4 percent of the rural communities' water supply. Generally, there are more springs in the highlands, than in lowlands, but lowland springs tend to have larger amounts of discharge.

Abstraction from springs nowadays is through two spring boxes: the protection box - to protect the water against surface contamination and the collection box - to provide storage and ensure that the all the water from the spring is collected. Loose stones are piled up at the back of the spring box to serve as a wall and to prevent the washing away of soil. The spring boxes are often fitted with an overflow pipe and a drain pipe. From the collection chamber water is conveyed either straight to the consumers or to the service reservoir. Most of the spring capping works done in Ethiopia are for small rural towns and villages and are executed at the regional level and often by NGOs working in the area.

In Ethiopia, wells with depth up to 60 m are normally considered as shallow. Shallow depth wells are either hand dug or augers are employed to drill or are bored using rigs. Most hand-dug wells are lined using either stone masonry or pre-cast concrete rings and when used communally it is normally covered and equipped with hand pumps. The Abay river basin master plan estimates that 70 percent of the rural community of the basin gets their water from hand-dug wells fitted with hand pumps and 20 percent from boreholes with submersible pumps.

In rural areas where traditional dug wells are used the main water lifting equipment is the "rope and bucket" system. These types of wells are not well covered and mostly exposed to pollution. In wells constructed by the government and NGOs, the hand-dug wells are properly covered and fitted with hand pumps. The walls of the wells are cased with concrete rings or masonry. For shallower wells (up to a depth of 45m), mostly Afridev hand pumps are fitted. For depths up to 80 m, Indian Mark II pumps are installed. These hand pumps are selected because of their simplicity during operation and maintenance. They are usually termed as "Village Level Maintained and Operated" (VLMO) pumps. In most places where the groundwater table is at an average depth of 10 m, privately owned hand dug wells are found. These wells are normally open and are rarely lined and may serve as a sole source of water or a supplementary source to the household.

Cost of groundwater development

The cost of drilling in Ethiopia is very high, owing to limited drilling companies and the high price of machinery and accessories for drilling. Hence development of groundwater sector requires a huge financial investment towards appropriate machinery and building capacities to handle them. In some governmental organizations like the Amhara Water Works Construction Enterprise (AWWCE), the cost of drilling is higher, mainly due to the greater staff numbers and the aged machineries with high maintenance cost. Cost analysis of wells shows that the percentage share of cost based on itemized costs varies from place to place and significantly from country to country. In Ethiopia all drilling equipment, including vehicles, casings, fuel, oil, lubricant spare parts, etc., are imported, with the depreciation costs accounting for 33 to 42 percent, and the material costs including fuel, oil, grease accounting for 22 to 25 percent and the labour, overhead, profit margin, and VAT accounts for 33 to 45 percent (AWWCE, 2004).Typical costs of groundwater development are shown in Table 3.5.

Table 3.5 Drilling rate for various scenarios by Amahara Water Works Construction Enterprise

Site	Geology	Well nature		Drilling Methods (rotary)	Well drilling cost per meter (USD)
		Depth (m)	Diameter (m)		
West Gojjam	Basalt	100 60	0.25 0.15	DTH DTH	163.58 135.71
Awi	Basalt	150	0.25	DTH	178.08
South Gondar	Lacustrine Deposit Basalt	100	0.25 0.15	Mud DTH	201.19 151.66
North Wollo	Alluvial Deposit Basalt	100 60	0.25 0.15	Mud DTH	238.01 194.86
North Gondar	Basalt	100 100 60	0.25 0.25 0.15	DTH Mud DTH	220.71 258.32 228.70

Source: AWWCE (2004)

Groundwater utilization

Domestic purpose

Groundwater is the main source of domestic water supply in Ethiopia (85%). Groundwater sources have natural protection from pollution and mostly require no treatment before supplied to the users. These help the schemes to be less expensive, more sustainable and are good alternatives of piped water supply. A well-constructed deep well can serve communities for more than 20 years. Hand-dug wells and springs often do not withstand long droughts, which characterize most parts of Ethiopia. This emphasizes the importance of drilling shallow and deep wells, even if there are possibilities of developing springs and hand dug wells in order to acquire water security for drought mitigation and preparedness. Furthermore, many organizations involved in rural water supply development (NGOs and GOs) are promoting springs and hand dug wells that require simple equipments and are cost effective. In some *woredas*, the available springs are all developed for domestic water supply and other purposes, while parts of the *woredas* where springs are not available and/or hand dug wells are not feasible; the water availability and supply are very low. Therefore to provide more people with improved water supply, more shallow and deep wells need to be developed resulting in a rising number of drilled wells. Many people living in urban areas do not have access to basic and reliable sanitation facilities. Besides, majority of the households do not have sufficient understanding of hygienic practices with regards to food, water and personal hygiene. A study has projected that 41,789 shallow wells and 18,835 deep wells are required for domestic and sanitation purposes in rurals area in Ethoipia (MoWR, 2002a).

Irrigation

In Ethiopia, despite the high groundwater potential and opportunity to overcome dry spells and drought through supplementary irrigation leading to possibility to increased production and productivity in high potential areas, no significant attention has been given to using the groundwater resource for agriculture. A few places in Ethiopia though, have demonstrated the comparative advantages of groundwater irrigation over rainfed agriculture and surface water irrigation. In Amhara and Tigray for instance, groundwater from shallow aquifers is found to be more productive than ponds. In high technology groundwater irrigation farms around Addis Ababa (flower farms) and Debrezeit (eg. Gneiss farm), phenomenal success has been noted. Aiytenfsu and Zemeagegnehu, (2003) estimated that there could be less than 200 ha of land irrigated with groundwater for horticulture and flower farms, more so in Oromia region.

Projections however show that some valleys like Raya and Kobo, have a recharge potential of 85 and 71 million m^3 yr^{-1}, groundwater reserve of 7,150 and 4,340 million m^3 and estimated exploitable groundwater resources of about 160 and 109 million m^3 yr^{-1} respectively (REST, 1998; KGVDP, 1989). These groundwater potential can irrigate about 35,000 ha, which is 20 percent of the total area of the valley plains. If conjunctive use approach is considered to supplement shortage of rainfall, assuming half or quarter of the crop water requirement from groundwater, the possibility of sustainable agriculture in the valleys could increase to 40-80 percent of the total area of the valleys. This shows that there is a high prospect for developing groundwater resources in the valleys. In the Raya Valley about 3,888 ha of land is being irrigated by the local community under the supervision of the Relief Society of Tigray (REST, 1998).

Livestock watering

Ethiopia had an estimated livestock population of 75 million in 1993 of which about 29 million were cattle, 24 million sheep, and 18 million goats. The total population of camels were 1 million while those of horses, donkeys and mules, 3.5 million (EMA, 1988). Livestock live both in the highlands and the lowlands. The utilization of water resources for livestock development can be seen from two aspects. One is the watering of the cattle especially in the arid areas, while the other aspect is the growing of forage by means of irrigation/ water spreading/ or terracing. The use of constructed watering points for livestock is rather limited because most of the livestock use the naturally available water sources such as streams and lakes. Similarly, the use of irrigation to grow forage is also limited to few places such as the Awash basin though the importance is high.

Industrial purpose

Most industries in the country have their own boreholes fitted with pumps. They use groundwater to supplement the supply from the mains and when there is any breakdown on the mains. Groundwater is mostly used in the mining, beverages, food processing, textile, and cement corporations. In the mining industry, water is used for washing. In fact it is taken to be a mineral as in the case of mineral and thermal waters. Minerals can also be extracted from water as in the case of soda ash development from the lakes Abiyata, Shalla and Chitu in the central main Ethiopian rift.

Institutional and legal framework

The lead institution in the management of water resources in Ethiopia is the Ministry of Water Resources (MoWR). However, there are other key players in the sector as shown in Table 3.6.

Table 3.6 Key institutions involved in water management in Ethiopia

Project Cycle	Urban Water	Rural Water
Planning	MoWR (policy and strategy) Regional Water Bureaux (RWB) Towns (town administration)	MoWR Water Bureaux (RWB)
Decision Making	Council of Ministers (for major projects) Regional Council	Regional Council Zonal Offices of Water Community Organisations Households (wells)
Implementation	MoWR (large projects) RWB with zonal departments Contracts Consultants	RWB with zonal offices NGOs Contractors ESRDF Community Organization
Operation and Maintenance	RWB and line departments Towns water services (water board) MoWR for large rehabilitation works Contracting services to private sectors	Zonal offices for back-up support Community Organization
Monitoring and Evaluation	Bureau of water and line departments ESRDF Planning and Economic Department Research organizations Funding Agencies NGOs	

Source: MoWR (2001)

The principal water policy document in Ethiopia is the Comprehensive and Integrated Water Resources Management Policy issued by the MoWR in July 2000 (MoWR, 2002b). This document sets out management policy on water resources in general and those that relate to water supply and sewerage, irrigation and hydropower. It also describes policies on various cross cutting issues, such as those dealing with groundwater resources, watershed management, water rights allocation, trans-boundary concerns and technology. As far as groundwater is concerned the policy emphasizes to identify the spatial and temporal occurrence and distribution of the country's groundwater resources and ensure its utilization for different water uses. It also stressed to exploit the groundwater not more than its sustainable yield. Moreover, the policy highlights the establishment of norms, standards and general guidelines for sustainable and rechargeable management of groundwater. In the technological and engineering aspect special focus is given to wells and drilling like standards and guidelines for the manufacture and import of drilling rigs, need to develop shallow wells at local levels, and promotion of indigenous technologies in groundwater development and utilization. Proclamation No. 197/2000 in the policy declares that *"All water resource of the country are the common property of the Ethiopian people and the State*". It gives the Ministry of Water Resources the authority to allocate and apportion water to all regions regardless of the origin and location of the resource. The proclamation lists a wide range of regulatory tasks among the powers and duties of the same Ministry.

Conclusions and Recommendations

Groundwater is the most important source of water supply for the great majority of the population and in some arid and semi-arid regions; it is the only source of water in Ethiopia. Despite its immense importance, the government has given less attention to the groundwater sector. As a result, the hydrogeology of the country is poorly understood as compared to surface water systems. The only source of hydrogeological information at the national level is the hydrogeological map of Ethiopia at 1:2,000,000 scale and very few areas are mapped in detail. The available studies of the groundwater resources are very limited. Therefore, studies of the groundwater resources of the country in terms of quantity, quality, management, aquifer characterstics and water balance are of great importance.

The main source of groundwater in the country are springs and shallow wells. For the last few decades, deep boreholes in peripheral regions the rift, and in some urban areas provide water for many small towns and rural villages. Recurring droughts have affected the livelihoods of the very poor members of the rural population and created large water supply problems. Many parts of the country, with high food insecurity and having good groundwater access, have started to exploit the resource through dug wells, shallow wells and in some cases deep wells to provide supplementary and full irrigation. Groundwater is also an important source of livestock water in parts of the country, particularly the eastern parts. This is resulting in declining water tables and unless this situation is addressed through proper management of the resources, there will be a severe problem in the very near future due to lack of water. Moreover groundwater resource development activities are facing numerous problems right from the planning to the implementation stages.

Drilling of wells, which is now a common practice to supply the urban and the rural communities with safe and potable water has been observed to having inherent problems in many parts of Ethiopia. Some of these problems are related to the actual drilling activities, mainly related to a lack of understanding of the hydrogeological conditions before drilling and paucity of proper manpower and equipment. The cost of drilling in Ethiopia is very high, owing to limited drilling companies and the high price of the machinery and accessories for drilling. Hence, the development of groundwater requires a lot of investment and capacity building.

The institutions involved in the water sector in Ethiopia have undergone significant change. Previously, the instability of institutions had negative repercussions on water resources development. However after the establishment of the Ministry of Water Resources and the preparation of the basic water policy document, which is a Comprehensive and Integrated Water Resources Management Policy in July 2000, there have been positive signs. More recently, several water related proclamations have been issued. It appears that the water sector development is finally getting due attention, although a lot is yet to be done to attain the Millennium Development Goals. Given the low level of activities, in relation to water supply, an enormous amount of effort is required in the coming years to meet the growing populations need for quality water. Future, groundwater development and proper utilization practices should concentrate on issues that would produce relevant practical results and make significant contribution to the economic development of the country.

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CHAPTER 4

GHANA

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General Description of Ghana

Geography

Ghana is situated on the west coast of Africa between latitude 4°44' N and 11°15' N and longitude 1°12' E and 3°15' W, and occupies a land area of about 239,460 km^2. It shares boundaries with Cote d'Ivoire in the west, the Republic of Togo in the east, Burkina Faso in the north and the Atlantic Ocean (gulf of Guinea) in the south. The country is divided into ten administrative regions: three to the north (Northern, Upper East, and Upper West), three in the middle zone (Brong Ahafo, Eastern and Ashanti) and four to the south along the coast (Western, Central, Greater Accra and Volta). The regions are further divided into 170 districts. The Volta Basin occupies the northern and central parts of Ghana and drains an area of about 45 percent of the country.

Physiography and climate

Ghana's topography consists mainly of rolling plains, escarpments and low hill ranges. Most of the land lies at an elevation below 500 m, and over half at less than 150 m (WARM, 1998). The terrain is predominately flat and gently undulating with slopes less than 5 percent and in many places less than one percent (Quansah, 2000). The country is characterized by 6 distinct agro-ecological zones (guinea savannah, sudan savannah, transition zone, rain forest, deciduous forest, and coastal savannah) defined on the basis of climate, reflected by the natural vegetation and influenced by the soils. The soils of Ghana have been formed from weathered parent materials of the mid palaeozoic age or older and have been leached over a long period (Benneh *et al*., 1990; Andah *et al*., 2003). A sectional view of the soil profile reveals that many of the soils in the country have light textured surface horizons in which sandy loams and loams are common.

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

Drainage and hydrology

Ghana is well-watered with high annual rainfall varying from 800 to 2,200 mm. It has a dense system of rivers and streams. The country's surface water resources are concentrated in three main river systems. These are the Volta river system, which consists of the Black, White, Lower Volta, Oti and Daka rivers and other tributaries; the South western river system, which comprises - the Bia, Tano, Ankobra, and Pra rivers; and the Coastal river system, which consists of the Tordzie/Aka, Densu, Ayensu, Kakum, Butre, Ochi-Amissa, and Ochi-Nakwa rivers. The Volta, South western and Coastal river systems drain about 70, 22 and 8 percent, respectively, of the total land area of Ghana. The Volta river system contributes 64.7 percent of the total runoff generated within Ghana (WARM, 1998). The South western and Coastal river systems contribute 29 and 6 percent respectively. The Volta River is shared by Ghana, Cote D'Ivoire, Burkina Faso, Mali, Togo and Benin. The Bia river is shared with Cote D'Ivoire, while the lower reaches of the Tano river forms the boundary with Cote D'Ivoire.

Though well-endowed with surface water resources, the major concern is the seasonal, spatial and temporal unevenness in water availability in Ghana. For example, the northern parts and some coastal parts of the country experience prolonged dry seasons of about 7 months with very high evaporation losses, which lead to drying up of many surface water bodies. This makes surface water supplies unreliable and insufficient to meet the water demands for socio-economic development. In addition, there are location-specific health challenges that restrict surface water use such as pollution and some water-borne diseases such as guinea worm (WARM, 1998). Supplies from groundwater sources are increasingly being used in Ghana to supplement supplies from surface water. In particular, groundwater sources are preferred means for domestic water supplies in rural communities and small towns in Ghana (Dapaah-Siakwan and Gyau-Boakye, 2000).

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

Generally, rainfall decreases from south west towards south east and the north. Annual rainfall values range from about 800 mm in the south east along the coast in Accra, to about 2,200 mm in the extreme south west along the coast in Axim. The mean annual temperature is about 30^{o}C. For most parts of the country, temperatures are highest in March and lowest in August. The northern parts of the country experience hot days and cool nights between December and March (dry season) due to the movement of the Tropical Continental Air Mass

(Harmattan). In the south, effects of the Harmattan are felt in January. Humidity is high in the south, particularly at the coast where relative humidity could be 95-100 percent in the morning and about 75 percent in the afternoon (Andah *et al.,* 2003). The north experiences low humidity with relative humidity values of 20-30 percent during the Harmattan period and 70-80 percent in the rainfall season. Annual potential open water evaporation has been estimated as ranging from about 1,500 mm in the south to more than 2,500 mm in the north (WB/UNDP/ADB, 1992).

Socio-economic context

The population of Ghana was estimated to be 22.9 million in 2008, based on the 2000 population census figure and a growth rate of 2.7 percent, (UN-World Food Programme, 2009). The average rural population constitutes 56 percent of the total population, with highest rural population in the Upper East Region, followed by the Upper West and the Northern region. Highest population densities are found in the Greater Accra Region and in the Cocoa producing areas in the south of Ghana. Assuming an annual growth rate of 2.5 percent (average of all inter-censual growth rates), Ghana's population is projected to be about 30.2 million by the year 2020 (Agodzo *et al.,* 2003).

Ghana is one of the more economically sound countries in Africa even though it depends on international financial and technical assistance and remittances from the large Ghanaian community in the Diaspora. The Gross Domestic Product (GDP) per capita exceeded USD 2,000 in 2006 and 2007 but declined to 1,400 in 2008 due to huge expenditure made by the then Government on developmental projects and election activities. The economy is largely informal with about 91 percent of all economically active people (age: 15-64 years) employed in the informal sector (UN-World Food Programme, 2009). Agriculture, particularly private-owned and small-scale, is the backbone of the economy accounting for 38 percent of the GDP in 2008 and employed 56 percent of the labour force in 2005 (CIA, 2010). The main agricultural export crop is cocoa, which generates about 30-40 percent of foreign exchange earnings. Other important agricultural export crops are timber, horticultural products, fish/sea foods, game and wildlife. Over 90 percent of Ghana's agricultural production is done by peasant smallholders on plots less than 2 ha who produce most of Ghana's cocoa (UN-World Food Programme, 2009). About 20 percent of Ghana's estimated 136,000 km^2 agricultural land is under cultivation (Seini, 2002). Agriculture is mostly rainfed, heavily dependent on the weather and thereby makes agriculture's performance highly unpredictable.

The service sector is the second most important contributor to GDP and a key driving force to economic activities. It accounted for about 34 percent of GDP in 2008. Recent efforts to develop the tourism sector have led to a rapid growth in international tourism and there is still a considerable untapped potential in this sector. Retail services, although still limited, are strong in the urban areas. The industrial sector contributed some 28 percent to GDP in 2008. This is a slight increase over previous contributions in 2006 and 2007. The industrial sector is broad and diverse and includes mining, timber and agricultural processing plants, brewing, cement manufacture, oil refining, textiles, electrical, pharmaceuticals, and others. Gold and timber exports are the two most important foreign exchange sources after cocoa. Other sources of foreign exchange earnings include the export of diamond, bauxite and manganese. The diamond industry is saddled with a history of smuggling and poor management, as there is extensive illegal mining and a thriving parallel market.

Groundwater resources

Hydrogeology

The main geological formations in Ghana are the basement crystalline rocks, the Palaeozoic consolidated sedimentary formation, and the Cenozoic, Mesozoic and Palaeozoic sedimentary strata (Figure 4.1). These formations are overlain by the regolith, which is a weathered layer of varying lithology, found in the uppermost metres or tens of metres of the profile (Martin, 2006; HAPS, 2006). The thickness of the regolith is influenced by lithology, structural characteristics, topography, vegetation cover, erosion, aquifer characteristics and climate.

The basement crystalline rocks are Precambrian age rocks which consist of granite-gneiss-greenstone rocks, phyllite, schist, quartzite, strongly deformed metamorphic rocks and anorogenic intrusions (Key, 1992). They cover 54 percent of the country. The structural trend in these basement rocks is influenced by the principal tectonic stress orientation and therefore follows a north east-south west (WNW-ESE) axis (Apambire, 1996). The formation is subdivided into the Birimian, Granite, Tarkwan, Dahomeyan, Togo and the Buem formations. The Birimian group dominates the basement crystalline formation and covers densely populated areas including most of western, south central, north east and north west of the country. The thickness of regolith generally ranges from 2.7-40 m but can go up to 140 m in the extreme north west of the country (Apambire *et al*., 1997; Apambire, 1996; Smedley, 1996).

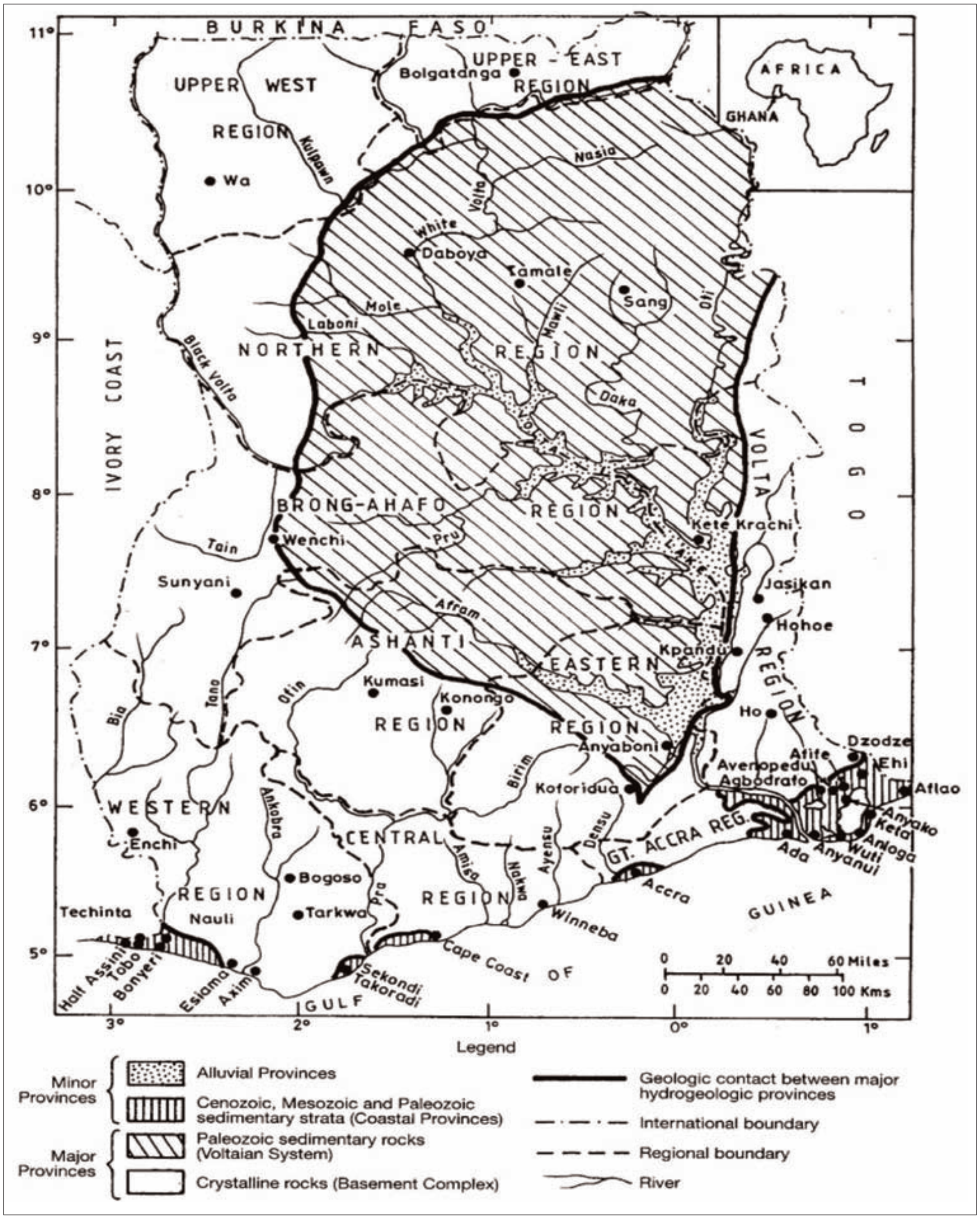

Figure 4.1 Geological groups and river systems of Ghana (Source: Geological Survey of Ghana 1969)

The Paleozoic consolidated sedimentary formations, locally referred to as the Voltaian formation; mainly consist of sandstone, shale, arkose, mudstone, sandy and pebbly beds, and limestone (WARM, 1998). It covers 45 percent of the country. Based on lithology and field relationships, the Voltaian formation can be sub-grouped into the upper, middle and lower Voltaian. The upper Voltaian consists of massive and thin-bedded quartzite sandstones, which are interbedded with shale and mudstone in some areas. The middle Voltaian (Obusum and Oti Beds) mostly comprise of shale, sandstone, arkose, mudstone and siltstone. The lower Voltaian consists of massive quartzite sandstone and grit. They cover most of the eastern parts of the country. The regolith in the Voltaian formation is not as thick as compared to the Precambrian formation and ranges from 4 to 20 m in the southern part (Acheampong, 1996).

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

Groundwater systems

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

Figure 4.2 is a geological cross section of an unconfined aquifer in the Precambrian basement rocks in the Atankwidi sub-catchment of the Volta basin in Ghana, which is indicative of the occurrence of groundwater in a larger part of the Precambrian formation in the country (Martin, 2006; HAPS, 2006). The most productive groundwater zone, according to the model, is the area around the lower parts of the regolith and the upper parts of the fractured bedrock. The depth of the productive zone varies greatly depending on location but generally ranges between 10 and 60 m (WARM, 1998). Most boreholes in northern Ghana have depths less than 80 m (Agyekum, 2004) and are believed to be tapping water from the productive zone. Groundwater in the regolith aquifer occurs mostly under semi-confined or leaky conditions. The upper part of the regolith is sandy clay in nature and in some areas can allow for the development of discontinuous shallow perched aquifers (Martin, 2006). Groundwater also occurs along lithologic contacts and fault zones in some areas of the Precambrian formations.

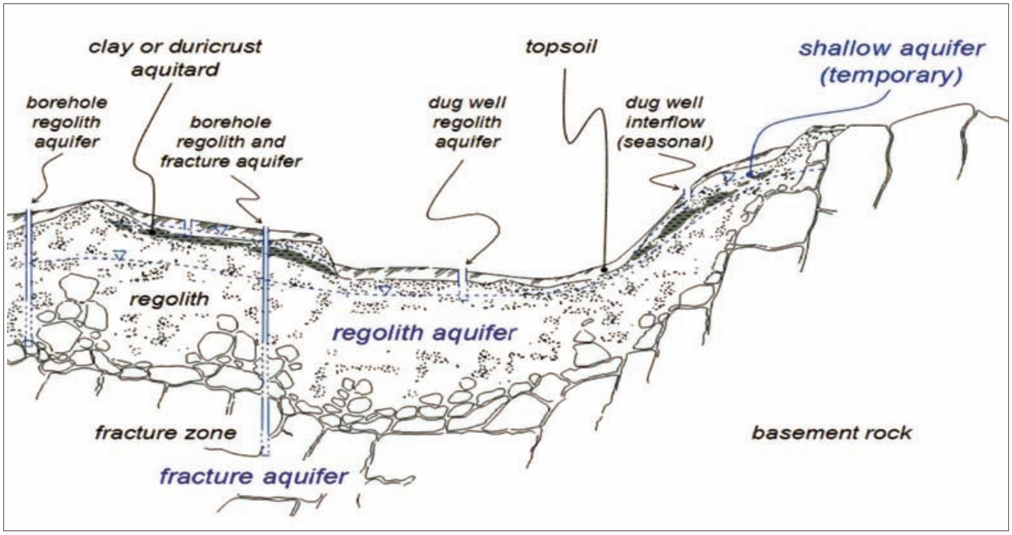

Figure 4.2 Groundwater occurrence in basement rock in Ghana (Source: HAPS 2006; Martin 2006)

The Voltaian formation has lost much of its primary porosity as a result of consolidation and cementation. Groundwater in this formation occurs mainly in fracture zones in the bedrock and in some locations, also along bedding planes. According to Acheampong (1996), the fracture zones are mainly sub vertical and are generally developed in bedrock at depths greater than 20 m below ground surface (HAPS, 2006). The bedrock is characterized by high permeability and low primary porosity. The thickness of the fracture zone largely depends on depth, weathering intensity, lithology and structural history. The regolith layer in the Voltaian formation is thin and unsaturated in many areas and therefore provides only limited amounts of groundwater. Hydrogeologically, the Voltaian terrain is the most complex and least understood of all the formations in Ghana.

Three aquifers occur in the Cenozoic and Mesozoic formations, located in the extreme south eastern and western areas of Ghana. The first aquifer is unconfined and occurs in the recent sand, very close to the coast. It has a depth ranging between 2 m and 4 m and contains fresh meteoric water. The intermediate aquifer is either semi-confined or confined and occurs mainly in the red continental deposits of sandy clays and gravels. The depth of this aquifer varies from 6 to 120 m, and contains mostly saline water. The third aquifer is composed of limestone, which varies in depth between 120 m and 300 m and has an average yield of 148 m^3 hr^{-1} (WARM, 1998; Dapaah-Siakwan and Gyau-Boakye, 2000). Groundwater in this aquifer is fresh and occurs under artesian conditions.

Table 4.1 gives a summary of the basic characteristics of the major aquifer systems in Ghana, based on available data. Most boreholes are drilled in the Birimian sub-province of the Precambrian basement formation. Borehole success rates are generally low with borehole yields less than 10 m^3 hr^{-1}.

Table 4.1 Characteristics of major aquifer systems in Ghana

Study area	Precambrian basement	Voltaian	Cenozoic-Mesozoic-Paleozoic
Estimated number of boreholes drilled by 2001	13,500; 90% of them in Birimian	512	480; only in coastal-plain sub-province
Borehole success rate (yield > 0.78 m^3 hr^{-1})	Lowest in Dahomeyan; 36%; highest in Buem-Togo series: 85-90% (87.9)	22-56%	36% in Coastal block-fault; 78% in Coastal-plain
Depth of boreholes	30-62 m	45-75 m (55 m)	3-100 m in sand; 100-600 m in limestone
Yields of boreholes (m^3 hr^{-1})	Highest: 0.48-36 (7.6) in Birimian and Tarkwaian formations ; Average for Buem/Togo: 5.6 ; and 4.0 for Granitoids	Normal range: 0.41-9.0; could be up to 73	Coastal-plain averages: 16.6; Coastal block-fault: 3.9
Transmissivity (m^2 d^{-1})	Birimian, Tarkwaian and Granitoids: 0.2-119; Buem/Togo: 0.9-40; Dahomeyan: 0.3-42	0.3-267 (11.9)	22.3-25.1

(Numbers in brackets are average values)

Source: Agyekum (2004); Dapaah-Siakwan and Gyau-Boakye (2000); Darko and Krasny (2003); HAPS (2006)

Groundwater recharge

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

Available data on groundwater recharge for specific locations in the country are summarised in Table 4.2. The recharge values presented have been estimated using various methods including water balance, chloride mass balance, water table fluctuation and hydrological modelling. Based on this data, the recharge for the country generally varies from 1.5-19 percent of the annual rainfall.

Table 4.2 Groundwater recharge for specific locations in Ghana

Study area	Region	Rainfall (mm)	Recharge (% rainfall)
Atankwidi River Basin	Upper East	910-1,138	4-13
Southern Voltaian Sedimentary Basin	Eastern	1,400	12
Pra River Basin	Ashanti, Eastern, Central	1,170-1,490	3.9*
Volta River Basin	Mostly all the Central and Northern	1,002	5*
North eastern Ghana	Upper East	990	3-16
White Volta Basin	Upper East, Upper West Northern	824-1,294	2.5-19
White Volta Basin	Upper East	1,233	8
Tamale, Yendi, Bole	Northern	1,069-1,192	2.5-11.2
Wa	Upper West	1,007	1.5
Navrongo	Upper East	987	6.6

* Net recharge inside the basin was considered equal to discharge of groundwater across basin boundary Source: Modified from HAPS (2006)

Groundwater quality

Table 4.3 shows the quality of groundwater abstracted from boreholes in Ghana. While the quality is generally good for domestic and agricultural use, there are some specific quality problems in certain localities (Andah, 1993; Kortatsi, 1994a; WARM, 1998; Darko *et al.*, 2003). The problems include low pH (3.5-6.0) found mostly in the forest zones of southern Ghana, high concentrations of iron in many places throughout the country, high concentration of manganese and fluoride mostly in the north of Ghana as well as high mineralization with total dissolved solids (TDS) in the range of 2,000-14,584 mg L^{-1} in some coastal aquifers (Kortatsi, 1994a). Most of these water quality issues can be attributed to geochemical processes taking place in the bedrock of aquifers, anthropogenic activities or sea water intrusion in the case of high concentration of sodium chloride in coastal aquifers.

Table 4.3 Summary of water quality in geological formations of Ghana

Parameter*	Gneiss	Granite	Phyllites	Sandstone	Mudstone and shale	Sand and gravel	Limestone	Quartzite
pH	7.5	6.99	6.83	6.95	7.64	7.53	7.7	6.36
TDS	4,888	387	211	534	425	632	932	398
Calcium	595	49.38	32.09	25.08	26.1	68.72	58.08	42.05
Magnesium	207	19.06	15.67	7.57	9.12	33.5	36.14	23.37
Sodium	720	47.99	11.67	262.6	125.4	134.5	296.8	24.53
Chloride	1,790	73.48	9.9	70.42	42.04	173.6	196.9	103.6
Sulphate	1,800	10.6	7.16	65.17	11.18	101.2	77.25	60.06
Bicarbonate	34	81.17	104.1	97.5	189.3	154.6	149.7	67.05
Total iron	0.1	1.01	2.15	1.95	0.65	1.84	0.47	2.87
Manganese	0.05	0.44	0.39	0.17	0.1	0.22	0.16	0.45
Fluoride	0.25	0.35	0.32	0.78	0.57	0.6	1.76	0.23
Nitrate-N	0.5	1.61	0.59	0.75	0.14	2.22	1.79	2.32
Total Hardness	2340	172.3	123.7	70.8	222.8	230.4	229.9	179.6

*all values except pH are in mg L^{-1}
Source: Kortatsi (1994a)

Groundwater development and utilization

Groundwater abstraction

Groundwater is abstracted from all the hydrogeologic provinces in the country. The main structures for accessing groundwater in Ghana are boreholes, hand-dug wells and dugouts. The numbers of groundwater abstraction structures have been steadily increasing over the years (see Table 4.4). The trend shows increasing reliance on groundwater as a source of water in Ghana.

Table 4.4 Changes in number of abstraction structures in Ghana over years

	1994	2000	2008
Boreholes	10,500	11,500	15,000
Dug wells	45,000	60,000	95,200*

*Estimate based on linear projection

Sources: Kortatsi, (1994a); Dapaah-Siakwan and Gyau-Boakye (2000); Gyau-Boakye et al. (2008)

Boreholes abstract water from deep aquifers and are relied upon in several regions in Ghana. They are mostly used for abstracting groundwater from deep aquifers for the purpose of domestic use. Boreholes are normally fitted with hand pump or motorized pump, in cases where water is lifted into overhead water storage tanks and supplied to homes for domestic uses. The types of hand pump commonly found in the country include Afridev, Ghana-modified India Mark II and Nira. Most boreholes have been drilled for community use but few private organizations and very few individuals have drilled their own boreholes. Hand-dug wells are cost effective structures for extracting shallow groundwater. They are used extensively as traditional water supply systems in many rural and urban communities throughout the country. There is limited data on the yields of hand-dug wells in the country, except for the Volta region (extreme east of Ghana) where an inventory of hand-dug wells has been documented (Kortatsi, 1994a).

Cost of groundwater development

The cost of developing a typical borehole and wells in Ghana includes the cost of geophysical exploration, drilling of the water well, pumping test, water quality test and installation of pump. The breakdown of each of the major cost components and typical figures are given in Table 4.5.

Table 4.5 Cost for developing groundwater resources in Ghana

Cost item	Activity	Costs*
Geophysical exploration	• Locating suitable aquifers and best points for boreholes and wells. • Involves resistivity and electromagnetic (EM) profiling, and Vertical Electrical Sounding (VES)	7 USD/m for resistivity and EM profiling; 143 USD per point for VES
Drilling	• Cost elements are drilling, construction, pump tests and development	USD 3,500 for typical borehole 60 m deep and 0.14 m diameter. Tubewells cost about USD 400. Hand-dug well costs varies widely from USD 40-1,300
Pump and installation	• Submersible pumps are commonly used include Italian models like Pedrollo, Indian Mark II, and recently cheaper Chinese made pumps	Cost varies with make but typically USD 1,285-3,200. Installation costs about USD 100
Water quality analysis	• Analysis of key physico-chemical and microbiological parameters depending on use	USD 200 per sample

Source: * Provided by FBB Drilling Construction, Ghana

Groundwater utilization

<u>Domestic purpose</u>

Estimates show that over 95 percent of groundwater use in Ghana is for domestic purposes (Gyau-Boakye *et al*., 2008). Groundwater abstracted from boreholes in all regions in Ghana, except in Greater Accra, is exclusively used for domestic purposes. Data from the population census in 2000 showed that groundwater sources (mainly boreholes and hand-dug wells) constitute 33 percent of the main sources of drinking water supply in Ghana (GSS, 2002). Table 4.6 provides information on the dependency ratios of groundwater for domestic use, by administrative regions in 1994. Rural areas and small towns are the major users of groundwater. As of 2004, portable water supply coverage in rural communities and small towns from groundwater sources was estimated to be 41 percent. Martin and van de Giesen (2005) have reported that 11 of the 20 towns on the Ghana side of the Volta Basin, each with population of over 10,000 inhabitants, depend exclusively on groundwater for domestic water supply. About 50 percent of the total number of hand-dug wells in the country is used solely for drinking water supply and about 66 percent is used for both drinking and other domestic purposes (Kortatsi, 1994b). The remaining 34 percent is used for irrigation and watering of livestock. In many communities, hand-dug wells are unprotected and easily get polluted.

Table 4.6 Population dependency on groundwater supply for domestic use

	Borehole (%)	Well (%)	Dug-out (%)	Total (%)
Western	17	11.6	1.5	30.1
Central	12.9	11.3	2.7	26.9
Greater Accra	0.6	4.5	1.5	6.7
Eastern	14.8	13.4	4.8	32.9
Volta	10.8	19.1	3	32.9
Ashanti	18.2	6.5	1.5	26.2
Brong Ahafo	8.6	12.1	4.7	25.5
Northern	2	17.8	8.6	28.4
Upper West	68.1	1.7	4.6	74.5
Upper East	63.6	11.3	2	76.8

Source: Adapted from Gyau-Boakye and Dapaah-Siakwan (1999); Authors' own estimates

Irrigation

Less than 5 percent of the annual groundwater usage in Ghana is attributed to irrigation and watering of livestock. In Southern Ghana, the Keta basin is most renowned for groundwater irrigation. More than 60 percent of the shallow hand dug wells drilled are used solely for irrigation. These wells have depths ranging from 1 - 5 m and are spaced less than 100 m apart. The abstraction rate of wells in this area varies from 1.0-22.6 $m^3 d^{-1}$ with an average rate of about 2.7 $m^3 d^{-1}$ (WRRI/DANIDA, 1993). Water lifting devices include manual rope-bucket systems and small irrigation pumps. The most commonly irrigated crop is shallots, although other vegetables are also grown. Typical farm size in the area is about 0.08-1.5 ha and farming is done all-year-round (Agodzo *et al*., 2003).

Elsewhere in southern Ghana, shallow groundwater is used for growing leafy vegetables in urban and peri-urban areas of Accra, Kumasi, Tamale and Takoradi. Cornish and Aidoo (2000) reported in a study on agriculture in the peri-urban areas of Kumasi that 50 percent of 410 vegetable farmers irrigate their crops with shallow groundwater abstracted *via* dugouts. The dugouts are shallow excavations of 1 to 2 m deep and about 1.5 m in diameter. The groundwater irrigators cultivate an average farm size of 0.9 ha. In the Accra plains, about 70 percent of the boreholes were drilled for agricultural purposes while 33 percent of these are actually being used for irrigation (Kankam-Yeboah, 1987). Groundwater irrigators are mostly small-scale farmers who produce vegetables such as cabbage, spring onions, carrots, tomatoes, green pepper, okra and shallots on small plots and sold in readily available markets in nearby cities and towns. Irrigation is limited to watering salt tolerant vegetables such as cabbage, onions, tomatoes and carrots. A pilot groundwater irrigation project carried out in the Accra plains realised crop yields of 5 ton ha^{-1} and 3 ton ha^{-1} for cabbage and onion respectively. This compares well with the 5-8 ton ha^{-1} and 2-5 ton ha^{-1} for cabbage and onion grown in Ghana under similar agronomic practices but under more favourable climatic conditions and irrigated by river water (Andah, 1993).

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

<u>Livestock watering</u>

Watering of livestock with groundwater takes place mainly in the Upper East, Upper West, Northern and Greater Accra regions. In the Northern, Upper East and Upper West regions, animals are not restricted but are allowed to move around in search of food and water. Watering troughs are constructed within 10 m of boreholes. Spillways are constructed from the drainage aprons of the borehole to the watering troughs. Spilled water from the boreholes collect in these troughs is for use by livestock, mainly goat, sheep, cattle and pigs. About 70 percent of Ghana's 1.34 million head (mh) of cattle (2003 estimate) and 40 percent of other livestock and poultry (sheep-3.02 mh; goats-3.56 mh; pigs-3.03 mh; and poultry-2.64 mh) are produced in these 3 regions and are watered exclusively using groundwater (Kortatsi, 1994a).

Industrial purpose

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

Institutional and legal framework

Institutions and policies

The Government ministry responsible for the water sector in Ghana is the Ministry of Water Resources, Works and Housing (MWRWH). This ministry discharges its responsibility in the water sector through one of its departments known as the Water Directorate. Activities of the Water Directorate are focused on overall water resources management and drinking water supply. It also oversees the activities of three key agencies within the water sector, namely the Water Resources Commission (WRC), Ghana Water Company Limited (GWCL), and Community Water and Sanitation Agency (CWSA). The WRC was established in 1996 to regulate and manage the country's water resources and co-ordinate government policies in relation to them. The GWCL was established in 1999 with the responsibility to supply water in urban areas of Ghana, while the CWSA was created in 1998 to facilitate the provision of safe drinking water and related sanitation services to rural communities and small towns in Ghana. Since water resources have strong link with the environment, MWRWH has strong collaboration with the Ministry of Environment, Science and Technology (MEST). Two important institutions under MEST that play important roles in the water sector are the Environmental Protection Agency (EPA) and the Water Research Institute of the Council for Scientific and Industrial Research.

Before the formation of the WRC, the institutional and legal frameworks for planning and managing water resources were inadequate and lacked integration. Thus, various aspects of freshwater management were undertaken by different water agencies within the context of their institutional or established mandates to serve individual sectors of the economy. Most of the water agencies were unable to work efficiently and effectively due to inappropriate policies for water resources management, unclear definition of institutional mandates, inadequate or total lack of resources, lack of enabling environment, lack of institutional mechanism for monitoring, enforcing and prosecuting offenders, inadequate education and training facilities, and lack of community participation and commitment among others. Prompted by the challenge of lack of a comprehensive water policy, a national water policy document was prepared in 2007, which is strongly based on the principles enunciated in the Ghana Poverty Reduction Strategy, the Millennium Development Goals and the "Africa Water Vision" of the New Partnership for Africa's Development (NEPAD) and contains sections on integrated water resource management (including water for energy, food security and transportation), urban and community/small town water delivery. The policy also highlights the international legal framework for the domestic and trans-boundary utilization of water resources (MWRWH, 2007).

Regulations and water rights

Water resources in Ghana are mainly regulated and managed by the WRC Act, (No. 522 of 1996) and the Water Use Regulations, Legislative Instrument (LI 1692 of 2001). Before these Acts came into being, organisations and agencies wishing to abstract water for any use were not required to follow any procedure or seek any permission to do so. The granting of water use permit is considered a tool to regulate water abstraction and control pollution of water bodies in Ghana. Previous laws concentrated on surface water only. The WRC Act, which addresses water resources in its entirety has filled the gap in the regulation of groundwater use. Section 12 of Act 522 stipulates "*the property in and control of all water resources is vested in the President on behalf of, and in trust of the people of Ghana*". This implies that there is no private ownership of water in Ghana, but the president, or anyone so authorised, may grant right for water use (WRC, 2010). The WRC is mandated under the Act to regulate and control the use of water resources, through granting of water rights and water use permits. Permits can be given to individuals and agencies for surface water and groundwater abstraction for domestic, commercial, industrial and agricultural use; hydraulic works construction such as diversion and damming; engaging in the business of drilling for water; hydro-power generation; water transportation, fisheries (aquaculture); recreational use; and underwater wood harvesting.

Water rights granted by the commission are not transferable except with a written approval of WRC. Water rights may also be suspended, varied or terminated in the public interest, in which event compensation is payable to the holder of the right. Categories of water use that are exempted from the requirement of permit include: preventive use of water for the purpose of fighting fire and any water abstraction by manual means. Water abstraction by mechanical means, where abstraction level does not exceed 5 L s^{-1} and subsistence agriculture water use for land not exceeding 1 ha, do not require a permit but should be registered. The LI 1827 of 2006 was enacted to regulate and ensure safe development of groundwater resources in the country through licensing of water drilling companies, by stipulating the process of obtaining a drilling licence and details on how to notify WRC on the intention to drill. This LI, grants exemption to communities and individuals who construct hand dug wells for domestic water supply.

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

Conclusions and Recommendations

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

Groundwater is abstracted from all the geological formations in the country. Currently, there are over 75,000 abstracting systems all over the country. These are made up of > 15,000 boreholes, and > 60,000 hand-dug wells and some dugout. About 95 percent of all groundwater uses in the country is for domestic purpose including drinking. About 50 percent of the total number of hand-dug wells is used for drinking purpose while about 66 percent are used for both drinking and other domestic purposes. About 5 percent of groundwater uses in the country is used for irrigation and livestock watering mostly in the Volta Region, Upper East, Upper West, and Greater Accra Regions. The quality of groundwater in Ghana is generally good for multi-purpose use except for the presence of low pH (3.5-6.0), high iron concentration (ranging 1-64 mg L^{-1}), manganese and fluoride in certain localities as well as high mineralization with total dissolved solids in the range of 2,000-14,584 mg L^{-1} in some coastal aquifers particularly in the Accra plains. About 30 percent of all boreholes in the country have iron problems.

Economically, the cost of borehole exploration and construction was estimated to be over 9,000 USD for a maximum depth of 60 m. Hand-dug well and shallow tube well cost about 313 USD and 40-1,300 USD, respectively. Compared to India and China, the cost of groundwater development in Ghana is very high. However, compared to the cost of water supplies from surface water sources, groundwater is less expensive and has other additional advantages. Ghana now has a national water policy, which is underpinned by the principles in the Ghana Poverty Reduction Strategy, the Millennium Development Goals and the "Africa Water Vision" of the New Partnership for Africa's Development (NEPAD). The policy gives direction for sustainable development, management and use of water resources in the country. The Water Resources Commission, under the Water Directorate of the Ministry of Water Resources, Works and Housing, has the overall responsibility of the water sector of Ghana. The regulation and management of Ghana's water resources including groundwater is guided by the Water Resources Commission (WRC) Act, (No. 522 of 1996) and the Water Use Regulations Legislative Instrument (LI 1692 of 2001). The granting of water use permit is considered a tool to regulate water abstraction and control pollution of water bodies in Ghana.

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CHAPTER 5

KENYA

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General description of Kenya

Geography

The Republic of Kenya lies on the eastern side of the African Continent where it is bound by the Indian Ocean, which serves as an important drainage outlet for the entire East and Central Africa and a means of international maritime contact. Kenya shares international boundaries with the Republic of Uganda in the west, United Republic of Tanzania in the south, Sudan and Ethiopia in the north, and Somalia in the east. Kenya covers an area of about 592,000 km^2 and is bound by latitudes 5°20' E and 4°40' S, and longitudes 33°50' E and 41°45' E. Of the territorial areas of 592,000 km^2, lakes occupy about 11,200 km^2 (2%) while arid and semi-arid lands occupy about 490,000 km^2 (83%). Only 15 percent of the country's surface area constitutes the high potential land. Kenya is more or less bisected by the Equator and by the latitude 38° E. Kenya is divided into eight administrative provinces and further subdivided into 47 countries.

Physiography and climate

Kenya's topography is characterised by two distinct physical regions, the lowlands and the uplands. The lowlands by and large constitute low potential areas, while the uplands are high potential areas and in terms of agricultural production, is the strength of the country's economy. The physical environments of Kenya are extremely diverse, wherein the equatorial, tropical, savannah, aeolian, glacial, volcanic and tectonic zones are all present. Kenya's structural geology is a major contributor to the varied physiographic environments. The geology is dominated by a gentle dome-shaped asymmetrical shield. The land rises very gently westwards from sea level on the east to about 920 m above mean sea level (AMSL). The rise beyond this height becomes significantly steeper. The entire terrain is dominated by well-preserved plateaus whose height and similarity in form can be used as a reasonable basis for dividing the country into eight physiographic units. These are the coastal belt and plains, the Duruma-Wajir low belt, the low foreland plateau, the Kenya highlands (western and eastern), the Kenya Rift Valley, the Nyanza low plateau, the Nyanza lowlands and the northern plain land.

The Kenyan climate is controlled mainly by latitude, altitude, topography and the distance from large bodies of water. The characteristics of prevailing winds moderate the climate. The location of Kenya along the equator and the greatly varied surface configuration ranging from sea level to heights of over 5,500 m above sea level combine to create a physical and climatic environment varying from almost equatorial characteristics to polarial ones in highlands. The country has five distinct ecological zones: (i) Alpine moor lands and grassland zone at high altitudes above the forest line, (ii) the humid to dry sub-humid belts which are suitable for intensive agriculture and forests, (iii) the humid to dry sub-humid belts which are suitable for agriculture in areas where the soils and topography permit, (iv) the semi-arid zones with marginal agricultural potential, and (v) the arid zones with low agricultural potential. The condition of soil in Kenya has been studied and is presented in the Kenya soil map (Sombroek *et al*., 1982). The soil map classifies Kenya's soil into 22 units out of the 26 units outlined in the FAO legend of 1974. The major soil types are the Solonetz (15%), Luvisols (12%) and Cambisols (10%).

Drainage

The present drainage pattern is influenced almost entirely by Kenya's central highlands. The main rivers drain either radially from the central highlands or from the southern foothills of the Ethiopian highlands. Generally, the main rivers drain eastwards towards the Indian Ocean, while the rest flow into lake Victoria. For the administration of water resources, the country is divided into five catchments/ regions, namely the lake Victoria Basin, Rift Valley Basin, Athi river Basin, Tana river Basin and Ewaso Ngiro river basin. Lake Victoria basin contributes nearly 50 percent of the available water resources from 8.4 percent of the total area of the country. The Kenyan lakes, for example, hold 315 million m^3 of water that is currently underused and in some cases, the riparian areas in terms of agriculture, are the least developed.

The three main river systems east of the Rift Valley have some similar characteristics. Their headwaters occur in high rainfall areas of volcanic rocks, in which are the groundwater reservoirs, which provide their dry weather flow. On leaving the volcanic system all the three rivers flow through the country bedrocks, the area being mostly semi-arid and subject to long drought periods. The dry periods are sometimes followed by heavy storms resulting in high and rapid runoff carrying a heavy load of silt from erosion of the topsoil cover of their catchment areas. The tributaries therefore contribute largely to flood and silt conditions in the downstream reach of the rivers traversing sedimentary formations, in which they meander, overflow their banks, and occasionally change their course. This is typical of Tana river. These sedimentary formations are generally permeable and the rivers lose water gradually by percolation from their beds as well as by evaporation.

Socio-economic context

Kenya is one of the economically fast growing countries in Africa even though it depends on a market based economy along with a few state-owned infrastructure enterprises, and maintains a liberalized external trade system. The total population is 32.4 million (2004), of which 59 percent live in rural areas. The average population density is 56 inhabitants km^{-2}, but its distribution is highly influenced by the climate and the agro-ecological zone. Improved water sources are accessible for 62 percent of the population, ranging from 89 percent in urban areas to 46 percent in rural areas. Improved sanitation facilities are used by 56 percent of the population in urban areas and by 43 percent in rural areas, while the average for the whole country is 48 percent.

In 2006, Kenya's GDP was about USD 17.39 billion and the per capita GDP averaged slightly more than USD 450 annually. Adjusted in purchasing power parity (PPP) terms, per capita GDP in 2006 was about USD 1,200. The country's real GDP growth picked up to 2.3 percent in early 2004 and to nearly 6 percent in 2005 and 2006, compared with a sluggish 1.4 percent in 2003. In 2010, Kenya has seen the return of higher growth, projected at 4.9 percent, and may now be at a tipping point for a robust growth. The agriculture sector had a rebound in 2010 and is expected to grow by 5 percent. This is an important development after two consecutive years of decline, when the sector contracted by a combined 6.7 percent. Favourable weather conditions and specific policy interventions under the Government's Economic Stimulus Program helped turn the sector around. The performance of Kenya's main agriculture exports in 2010 was strongest for tea which recovered rapidly from 2009 weather conditions.

Agriculture is the leading sector of Kenya's economy and its performance greatly influences the overall economical performance of the country. Agriculture employs about 80 percent of the population and accounting for 26 percent of Kenya's GDP. However, Kenya has not yet put its available land resources to full use. Out of 9.4 million ha of potentially cultivable land, only 2.8 million ha is devoted to agriculture, which heavily relies on rainfed production with very little irrigation. The irrigation potential for the country is estimated at approximately 550,000 ha, but only about 109,000 ha has been put to irrigation use. The country has a food deficit and insecure food supply as a result of periodic droughts and low access to production resources. In the arid and semi-arid areas, about 2 million people are permanently on famine relief and the number sometimes rises to 5 million during droughts. Although Kenya is the most industrially developed country in East Africa, manufacturing still accounts for only 14 percent of the GDP, which is only a marginal increase since independence. While the expansion of the sector post independence was initially rapid, it has stagnated since the 1980s, hampered by shortages in hydroelectric power, high energy costs, dilapidated transport infrastructure, and the dumping of cheap imports. However, with urbanization, the industry and manufacturing sectors have become increasingly important to the Kenyan economy, and this has been reflected by an increasing per capita GDP.

Groundwater resources

Hydrogeology

Water availability and water quality depend on all the four major geological areas that are represented in the complex geology of Kenya. The Rift Valley system is represented by volcanic as well as igneous and Precambrian metamorphic complexes divided into four major systems. The Palaeozoic is well-developed and mostly important in terms of surface coverage and is represented by Quaternary sedimentary and Tertiary volcanic rocks. These are igneous, metamorphic and sedimentary rocks and occupy 26 percent, 17 percent and 55 percent of the land surface respectively. The structural geology is dominated by a gentle dome-shaped asymmetrical shield. The earliest fault probably appeared during the late Miocene and another phase of major faulting is known to have occurred in Pliocene and Quaternary times.

Water storage and transmission capacities of rocks are attributed mainly to hydrogeological properties. These capacities of rocks are a function of the lithologies. The variation in the age of rocks becomes important, especially in very old rocks where post depositional alterations have affected the primary porosities of rocks. The hydrogeology of Kenya can be regarded as having three major geological units as discussed below.

Volcanic rocks

The volcanic rocks cover about 26 percent of the country. The petrology/lithology of these rocks includes phonolites, trachytes, tuffs and basalts. The thickness of these rocks varies from a few meters to several hundred metres and thereby implies that groundwater may occur at great depths. The successive lava flows are reflective of the old land surfaces. This means that in a borehole, more than five aquifer layers may be struck. Aquifers in these formations are often confined. The yields, depth to aquifers and static water level are also expected to vary significantly. Water in these rocks is of low total dissolved solids and high bicarbonate.

Precambrian metamorphic basement and intrusive

These rocks are distributed widely in the Central, Western and North western regions of Kenya covering about 17 percent of the country. Granites, gneisses and schists dominate the petrology of these formations. In most cases, the rocks are deeply weathered to varying degrees. Groundwater occurs where these rocks are fractured and faulted. The aquifers in these formations are generally confined. The yields, depth to aquifers and static water level are also expected to vary significantly. The confined groundwater is generally hard at moderate electrical conductivity. Unconfined groundwater occurs in cases where there is weathering in the upper parts of the basement system. In these cases, the water level has considerable temporal fluctuation and in a few cases, boreholes in this type of aquifers dry up during dry spells.

Sedimentary rocks

These cover about 55 percent of Kenya and predominate the eastern, north western and around lake Victoria in the west. The lithology varies from sand, clay, sandstone, shale and limestone.

Groundwater systems

Rock types influence groundwater occurrence. The three types of rocks - metamorphic, sedimentary and volcanic occur in Kenya and have sufficient number of boreholes drilled in them to draw inferences on their aquifer characteristics. From Table 5.1, it is clear that boreholes in volcanic areas have the highest elevations (1,763 m AMSL), while those in sedimentary formations have the lowest (439 m AMSL). This is because the mountainous areas of Kenya are within the volcanic mountain ranges while the coastal stripe and the north eastern province are dominated by sedimentary formations. The deepest boreholes of 125 m are encountered in the volcanic areas. In areas such as Marsabit and Nairobi, drilling depths of about 320 m are common. Boreholes in the basement and sedimentary formations are shallower. The static water level and struck water level in the volcanic regions are also deeper and have the highest piezometric pressure and yields. The specific capacities of basement rocks are low due to the localized nature of their aquifers. The regional nature of the aquifers in the volcanic and sedimentary areas results in higher specific capacities for aquifers drilled within them.

Table 5.1 Aquifer characteristics

Rock Type	Number of Boreholes	Elevation (m AMSL)	Total Depths (m)	Main Water Struck Levels (m)	Water Rest Levels (m)	Tested Yield ($m^3 hr^{-1}$)	Draw down (m)	Specific Capacity ($m^3 hr^{-1} m^{-1}$)
Volcanic	5,844	1,763	125	94	49	7.5	37.1	0.2
Basement	2,396	1,267	80	55	26	4.5	31.1	0.15
Sedimentary	1,321	440	81	54	35	5.6	17.4	0.32
Volcanic over Basement	243	1,080	83	54	29	7.4	25.9	0.29
Sediments over Basement	100	1,074	91	51	26	5.7	32.3	0.18
Sediments over Volcanic	10	1,265	90	63	29	7.6	24.1	0.32
Volcanic over Sediments	78	1,332	107	79	27	10.8	41.2	0.26
Others	30	1,054	104	63	39	4.9	19.4	0.24
Unknown	338	1392	79	56	26	4.9	24.4	0.2

Source: National Water Master Plan (1992)

Borehole aquifer characteristics by province (see Table 5.2) shows that elevations, total depths, water struck levels, artesian pressure of boreholes in Central (Nyandarua district), Rift Valley (Nakuru, Narok and Kericho districts), and Nairobi provinces are the highest, and depths of boreholes drilled within the older sedimentary formations in north eastern province area also have high total depths.

Table 5.2 Borehole aquifer characteristics by province

Province	Elevation (m AMSL)	Average depth (m)	Maximum depth (m)	Struck levels (m)	Rest levels (m)	Average yields (m^3hr^{-1})	Yield range (m^3hr^{-1})
Nairobi	1,720	153	471	113	765	7.7	1- 56*
Central	1,835	130	270	97	46	7.8	1-45.5*
Coast	241	68	136	42	24	5.8	0.3- 56.8*
Eastern	1,258	93	252	65	35	5.4	0.3 - 46*
North Eastern	377	123	350	99	80	4.8	0.3 - 48*
Nyanza	1,320	76	201	55	19	6.4	0.3 -47*
Rift Valley	1,728	113	260	83	47	6.7	0.3 - 41*
Western	1,348	53	116	35	12	3.7	0.3 - 18

* Dry boreholes or boreholes with unsaturated conditions not included
Source: National Water Master Plan (1992)

The groundwater potential is estimated to be 619 million m^3 (Chilton *et al.,* 1995 and Swarzenski, 1977); deep aquifers are exploited through boreholes and shallow aquifers through shallow wells. The present groundwater abstraction rates by drainage basin are estimated using the above ratio. The results are shown in Table 5.3. The total present groundwater abstraction rate in Kenya is estimated at 57.21 million $m^3 yr^{-1}$. Total safe abstraction rate in Kenya is estimated to be 193 million $m^3 yr^{-1}$ (NWMP, 1992).

Table 5.3 Groundwater abstraction rates

Drainage basin	Basin area (km^2)	Annual rainfall (mm yr^{-1})	Rainfall (million $m^3 yr^{-1}$)	Abstraction (million $m^3 yr^{-1}$)
Lake Victoria	46,229	1,368	63,241	9.34
Rift Valley	130,452	562	73,314	11.67
Athi river	66,837	739	49,393	27.76
Tana river	126,026	697	87,840	4.79
Ewaso Nyiro	210,226	411	86,403	3.65
Total	579,770		360,191	57.21

Source: National Water Master Plan (1992)

The main source of groundwater recharge in Kenya is precipitation. Rainwater infiltrates into the ground through the top soil, sand formations, fissured and fractured rocks or other unconsolidated rock formations and is stored in aquifers/zones at varying depths. The economical depths at which boreholes draw water for domestic supplies in Kenya are found to be about 200 to 300 m. Only a small fraction of the rainwater gets stored as groundwater in a given period. In the arid and semi-arid climatic zones, the groundwater recharge is generally in the order of 3 percent of the annual rainfall while in the humid/sub-humid zones, the recharge is about 10 percent. However, in the sandy aquifers or those in unconsolidated basaltic rocks, recharge is much higher, in the order of 30 percent of the annual rainfall.

Groundwater quality

In Kenya, only about 15 percent of the available borehole completion records have water quality data available. This percentage is rather low to assess the water quality distribution by regions. However, an overview of this distribution can be inferred from the minimal data available. The National Water Master Plan (NWMP) study of 1991 attempted to draw up groundwater quality distribution by province and the results are summarized in Table 5.4.

Table 5.4 Groundwater quality by Provinces

Parameter*	Nairobi	Central	Coast	Eastern	North Eastern	Nyanza	Rift Valley	Western
pH	7.9	7.5	7.5	7.4	7.9	7.8	7.9	6.7
Turbidity (NTU)	28.9	42.9	36.5	26.2	32.8	39.3	25.6	27.6
Dissolved Oxygen	3.05	2.66	1.12	1.86	0.64	4.83	11.3	0.16
Conductivity ($\mu S\ cm^{-1}$)	859	494	3,291	1,109	2,315	719	1,074	354
Iron	1.48	2	1.26	2.3	0.99	1.25	1.57	0.89
Manganese	0.70	0.42	27.9	2.9	29.2	2.90	0.79	1.52
Calcium	43.3	17.3	135.1	63.4	151.9	57.6	52.2	18.6
Magnesium	8.16	7.13	117.3	41.3	123.7	34.6	31.9	13.5
Sodium	164	77.2	746.7	143.3	375.6	106	209	13.7
Potassium	19.3	12.3	16.5	23.8	17	15.1	15.4	4
Hardness	48.4	68.4	369.8	348.7	239.8	238.7	161.9	78.4
Chloride	72.4	35.4	1063	142.5	793.6	117.8	153.8	15.6
Fluoride	6.59	1.78	1.16	1.9	5.69	2.38	3.33	2.04
Sulphate	32.3	11.1	160.2	151	259.9	107.2	102	20.6
Total Dissolved Solids	521	314	2,122	750	2,101	585	916	181

* All units in mg L-1 except for pH or unless indicated otherwise
Source: National Water Master Plan (1992)

Groundwater in western, central, Nyanza and Nairobi provinces contains little dissolved solids and consequently has low electrical conductivity. It is therefore generally satisfactory for all domestic purposes from the chemical content point of view. Along the coast, the electric conductivity is high due to salt-water intrusion inland. In the coast, eastern and north eastern provinces, the water quality is observed to be poor; this can be attributed to marine transgression. Further, most of the shallow wells in these areas are unprotected and may therefore have significant bacteriological contamination. Whether or not groundwater of a given quality is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that use. While good quality groundwater has the potential to accelerate economic returns, poor water quality can cause soil and cropping problems, resulting in reduced crop yields. In Kenya, while certain water types have been declared unsuitable under some criteria, the same water types are usable under certain other conditions. This is due to water scarcity factor in some regions, where in poor quality water is often better than no water at all.

Groundwater development and utilization

Groundwater abstraction

<u>Boreholes</u>

As of August 2004, about 14,260 boreholes had been drilled; an increase of 51 percent from 9,452 boreholes recorded in 1991. Of these boreholes, over 23 percent were drilled for domestic water supplies, over 18 percent for either agricultural, livestock, industrial or commercial purposes and less than 6 percent for domestic purposes only. The other boreholes are used for observation and exploration purposes. Many boreholes are either not in use or abandoned due to poor quality water, low yields or high maintenance costs, especially in areas where alternative sources of water are readily available. Over 61 percent of all boreholes drilled in Kenya are within the volcanic rocks, 25 percent within the basement rocks and about 14 percent within the sedimentary rocks.

<u>Shallow wells</u>

Unconfined groundwater occurs in the Quaternary sediments consisting of river sand, in the fractured parts of faults and in syncline parts of folds, in the weathered parts of rocks, and in granite rocks. Unconfined groundwater is used in the form of water holes, hand dug wells, hand-drilled and machine drilled shallow wells at a few metres to about 50 m in elevated areas. The ease with which the construction of shallow wells can be undertaken implies that there is an unsystematic construction of the same especially by individuals. There exist many shallow wells whose details are not available in government departments. However, previous studies on the extent and structure of shallow aquifers in Kenya have been undertaken in the western province, Kwale district and Wajir district areas.

Modes of groundwater abstraction

In Kenya, various modes are used to abstract groundwater from boreholes and wells. The most common are characterised in Table 5.5. They are also reflected in the Master Water Plans for the country.

Table 5.5 Characteristics of various kinds of pumps used for groundwater abstraction in Kenya

Pumps	Features	Pumping Head (m)	Yield (m^3 hr^{-1})	Types/Brands mostly used
Hand operated	Cheap and easy to install; need regular maintenance	60	0.5-3	N1RA, SWN, Afridev, India Mark II
By wind	Expensive to install; cheap to operate	60-100	50	n.a
Diesel and electric	Diesel pumps–relatively expensive; require more maintenance	100-300	3-8	Grudfos, Lowara, Brisan, Caprari

n.a: not available

Source: Compiled from various sources and personal communication

Cost of groundwater development

Borehole development costs depend mainly on the depth of the boreholes. The average cost of sinking and casing a borehole is USD 70 m^{-1}. The average cost of digging an open well is USD 1 m^{-1} for unlined wells and between USD 10 and 100 m^{-1} for masonry and concrete lined wells. Due to high cost of lined wells, many of the wells developed by individuals are not lined as they lack sufficient financial resources. The pumping costs depend on whether electric power or diesel engines are used to power the pumps. Generally, use of diesel engines to pump water is three times costlier to the use electric motors for groundwater extraction. This is however changing fast, due to rapid increase in the electricity rates in comparison to the diesel costs. The pumping cost of a 2 kW pump powered by diesel engine is about 0.2 USD hr^{-1}, while the cost of a 2 kW electricity driven unit is 0.1 USD hr^{-1}. As the power requirement increases, the cost goes up to 2.5 USD hr^{-1} for a 20 kW diesel engine driven unit and 1 USD hr^{-1} for a 20 kW electric power driven unit. Over three months, the cost goes up to 1,600 USD for diesel units and 700 USD for electric power units in the 20 kW category, considering

10 hours of pumping per day and 6 days of pumping per week. Specific costs of common pumps used in Kenya are shown in Table 5.6.

Table 5.6 Cost of commonly used pumps in Kenya for groundwater abstraction

Water lifting device	Average cost (USD)
Hand pumps	200-450
Wind pumps	2,000-4,000
Diesel and electric pumps	3,000-7,000
Solar pumps	600-7,000

Source: Compiled from various sources and personal communication

Groundwater utilization

Groundwater in Kenya is used for many different purposes including human consumption, crop production and for livestock and wildlife watering. The specific uses depend on the location of the water resource (either the borehole or the well). In semi-arid areas, which form 80 percent of the country's area, land is used mainly for livestock, wildlife and subsistence farming. In these cases, groundwater is mainly used for livestock and wildlife watering. In some districts though, and in particular Kwale, Kilifi, Mombasa and Wajir, the groundwater is extracted using shallow and medium depth open wells, and is also used partly for crop production farming. In Mombasa, Kwale and Kilifi, water is used for growing both food crops and cash crops, the most common being tomatoes and amaranths. Cash crops are rarely planted as pure stands and are mostly intercropped with food crops, mainly maize, which also then benefits indirectly from the water supply. In many cases, the water is extracted manually and only small portions (less than 200 m^2) of land are irrigated. In few cases where the water is extracted using electric motor driven pumps, large areas (up to 1 ha) are cropped. In this case, farming is done on commercial basis.

Domestic purpose

In Kenya, the situation of rural water supply is worse than the urban water supply. Most of the rural domestic water supply is directly from untreated sources such as rivers, lakes, unprotected springs, pools and ponds, shallow hand dug wells, wetlands and sand beds, hence is not safe for potable purposes. In the case of Small Scale Rural Water Supply (SSRWS), the water supplies are mainly water points with some pipe works, for domestic use and livestock watering. Large Scale Rural Water Supply (LSRWS) may have pipe reticulation consisting of the trunk, secondary and tertiary mains for distribution and transmission. Individual connections are the major type of service connection. At the periphery supply areas, schemes may have water points to serve the surrounding rural population.

Irrigation

Along the shores of lake Naivasha and in many parts of Kiambu district near Nairobi city, groundwater is extracted for the purpose of commercial farming where vegetable crops, fruits and other horticultural crops are grown. Closer to lake Naivasha, groundwater is extracted for production of flowers, horticultural crops mainly for export, and for fodder crops. Recently however, production of cabbage for the local Nairobi consumption has come up. The development is by private firms as well as the government for the International Livestock Research Institute (ILRI). Across Kiambu district, the groundwater is used for producing vegetables, and due to its proximity to the largely populated Nairobi city (capital of Kenya), has a huge ready local market to sell their produce.

Both boreholes and shallow wells are common in Kiambu and it is estimated that over 5,000 small-scale farmers have shallow wells, which are also used for livestock watering, mainly dairy cows, as the farmers keep on an average two animals and two chicken. It is noteworthy that Kiambu contributes over 50 percent of the egg production in Kenya and over 75 percent of chicken meat. It can be safely assumed that groundwater, where it is used in agriculture production, is mainly for commercial purposes regardless of the scale of production. Overall though, the contribution of groundwater to irrigation is minimal, as most of Kenya's irrigation is reliant upon surface water.

Institutional and legal framework

In 1993, through the Water Resources Assessment and Planning Project (WRAP), funded jointly by the governments of Kenya and the Netherlands, efforts were initiated to prepare the National Water Policy Discussion paper. This discussion paper brought out all the key issues in the water sector, and was discussed at a ministerial workshop. SIDA, as one of the most consistent development partners in the region, took over the support of the process and constituted under its program, a National Water Policy Project. The WRAP is now responsible for the planning, development and management of all water resources in the country.

It then funded study tours to various countries including South Africa and Israel, with a view of borrowing positive experiences that would assist Kenya in developing a policy that is responsive to the water sector needs. Further consultations were held with key actors outside the government, that included NGOs and development partners and their inputs incorporated in the final draft of the National Water Policy, which reflected the views of a range of water sector actors. The final draft was submitted to the Cabinet for approval and guidance as appropriate. The Cabinet then directed that the National Water Policy be tabled in Parliament as a Sessional Paper. This process culminated in the enactment of the Sessional Paper No.1 of 1999 on National Policy on Water Resources Management and Development on 29th April, 1999. SIDA also continued to support the implementation of the policy focusing on handing over of water supplies to communities and the review of the Water Act Cap 372 that culminated in the enactment of the Water Act 2002.

The policy directions included in the institutional framework:

- The need to redefine the role of government in the water sector, focusing more on regulatory and enabling functions;
- It recommends that government should fully support private sector participation and community management of water services;
- It recommends that the roles of actors in the water sector should be clearly defined and role performance indicators should be used to determine and facilitate monitoring of the activities of water sector actors;
- It recommends the review of the Water Act to address all legislative issues. This is meant to make the Water Act the principle act to guide the water sector activities;
- Handing over of the management of the currently government managed water utilities to beneficiary communities.

Policy direction on financing of the water sector:

- Recognizing the central role water development plays in promoting economic growth, the policy calls for the government to make the necessary efforts to mobilize local financial resources for water resources management and development;
- It recommends broadening of the revenue base based on the following three basic principles - water as an economic good, the user pays principle and the polluter pays principle;
- Introduction of appropriate tariffs and licensing procedures for water vending operations;
- The call for proper channelling of donor and non-governmental organizations funds to ensure that they are directed to the needy areas. The aim of this is to promote the maximization of the available resources.

Groundwater development challenges

Water resources in Kenya are marked by both gross spatial and temporal variability. Both surface water sources and groundwater are replenished by rainfall through the hydrological cycle. Groundwater is unevenly distributed in drier areas; the water quality is poor and yields are low, usually less than 80 L min^{-1}. In high rainfall areas, due to high recharge, the water yields are high (up to 117 L min^{-1}) and water quality is good. Some areas are devoid of extractable quantities of groundwater while others have water of unsuitable quality. Assuming the limit for chronic water scarcity is 1,000 m^3 per capita yr^{-1}, Kenya is already experiencing acute water scarcity as its population in 1998 itself had reached 26 million. Eight urban centres including Nairobi, Mombassa, Nakuru, Kisumu and Eldoret are currently experiencing chronic water shortages. The situation has been aggravated by the persistent and continuing droughts in East Africa. Whether water scarcity is examined in terms of river basins, provinces or districts, the future role of water resources in the social and economic development of the country will be crucial.

The groundwater in Kenya is extremely variable in its chemical composition. The variation occurs both spatially and seasonally. The quality is essentially controlled by the geological formation in which the aquifer occurs. In central and western Kenya, the water is generally soft with moderate alkalinity. Chemically, this water is satisfactory for domestic purposes. In most parts of the coast, eastern and north eastern regions, the water is however saline and of poor quality. In general, the major problem with groundwater exploitation is salinity and fluoride levels. In the case of fluoride, its concentration generally exceeds the W.H.O. drinking water guidelines of 1.5 mg L^{-1} in many areas. This represents one of the major factors limiting groundwater use in Kenya for drinking purposes.

Conclusions and Recommendations

To properly manage any resource, including groundwater, it is imperative that the quantity and quality of the said resource are well known. Unfortunately, in contrast to other water resources, knowledge on groundwater as a resource in Kenya is very limited. Technologies and techniques for exploration and assessment of groundwater resources are both relatively expensive and complicated. Consequently, field data is rarely sufficient to produce satisfactory projections and understanding of groundwater systems. This difficulty is further aggravated by the heterogeneous nature of the subsurface. The country also faces institutional and resource challenges in regards to groundwater management. Though there is a government institution responsible for this, data collected is fragmented and therefore difficult to integrate for any meaningful comprehensive assessment of the groundwater resources in Kenya.

Groundwater in Kenya being used in various sectors such as domestic, agriculture (irrigation, livestock, fisheries), industrial and wildlife and nature preservation, with increasing demand for groundwater in the country, better management approaches will be required to manage competition for the resource among these sectors. But management must go beyond quantity related issues to address the groundwater quality challenges. Kenya's aquifers are increasingly exposed to anthropogenic pollution, saline water intrusion and hydro-geochemical evolution, deteriorating the groundwater resource. The sources of pollution include agricultural, industrial and domestic effluents, emissions and residues. The location and development of urban and agricultural settlements in the past occurred in areas where there was reliable water sources and therefore, most urban and agricultural settlements in Kenya are located either in recharge areas or where the groundwater is easily accessible. In future it would be prudent to locate industries and settlements in areas where any effluent would be least likely to impact upon the underlying aquifers.

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CHAPTER 6

MALAWI

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General Description of Malawi

Geography

Malawi is a small landlocked country located between latitudes 9°22' S and 17°03' S and longitudes 33°40' E and 35°55' E in Sub-Saharan Africa. It is bordered by Tanzania to the north and northeast, Mozambique to the east, south and southwest and Zambia to the west and northwest. The country's total surface area is approximately 118,484 km^2, of which 28,000 km^2 is taken up by lake Malawi (Kululanga and Chavula, 1993). Administratively, Malawi is divided into three regions (Northern, Central and Southern) and has a total of 28 districts.

Physiography and climate

Malawi is divided into four major physiographic zones, namely: high land areas (comprising mountains and hills), plateau areas, rift valley escarpment, and rift valley floor and lake Chilwa plains (Water Department/UNDP, 1986). The plateau areas occupy approximately 75 percent of the land surface and ranges from 750-1,300 m in altitude while the rift valley floor comprises the flat land along lake Malawi and lake Chilwa and ranges from 450-600 m in altitude. These are ancient erosion surfaces of late Cretaceous to Miocene age, which slope away from the escarpment zones as a result of uplift along the rift valley system, but the drainage systems have kept pace with these earth movements and largely drain towards the rift valley floor. As a consequence, the valleys become more incised towards the escarpment (Water Department/UNDP, 1986). The plateau areas are drained largely by *dambo*s, i.e., broad, grass-covered swampy valleys that are liable to flooding and commonly have no well-defined channels. The plateau areas are mostly covered by a thick mantle of saprolite derived by *in-situ* weathering of the underlying strata. The predominant soils covering the plateau and lakeshore areas are deep, calcimorphic alluvials and colluvials, with hydromorphic soil deposits found in isolated depressions. The Lower Shire valley is a wide rift valley system in the extreme southern part of Malawi, lying at altitude 35 to 105 m above sea level, and is mainly covered by calcimorphic alluvials, with extensive areas dominated by hydromorphic soils and vertisols.

Malawi experiences a tropical-continental climate with two distinct seasons, namely: a wet season from November to April and a dry season from May to October. The dry season is characterized by strong southeasterly trade winds (locally known as the *Mwera*), while during the wet season the winds are generally northeasterly (the *Mpoto*) and weaker.

A cool dry winter season prevails from May to August with mean temperatures varying between 17 and 27°C while a hot dry season lasts from September to October with average temperatures varying between 25 and 37°C. There is evidence suggesting the existence of variability in temperature and an increased intensity of floods and droughts (EAD, 2008). Three major synoptic systems bring rainfall to Malawi: the Inter Tropical Convergence Zone (ITCZ), the Zaire Air Boundary (ZAB), and tropical cyclones (Kululanga and Chavula, 1993). In addition, Malawi is vulnerable to the less predictable El Nino and Southern Oscillation (ENSO) phenomena.

Drainage

Malawi is generally rich in both surface and groundwater resources. Surface water resources comprise a network of rivers (e.g., Shire, Ruo, Linthipe, Bua, Dwangwa, Rukuru, Songwe, Ruhuhu, Kiwira, etc.) and lakes (lake Malawi, lake Chilwa, lake Chiuta). The country's drainage system has been divided into 17 Water Resources Areas (WRAs), two of which drain outside the lake Malawi/Shire system, i.e., they drain into lake Chilwa and lake Chiuta. The

WRAs are further subdivided into 78 Water Resources Units (WRUs), as shown in Figure 6.1 (Kululanga and Chavula, 1993).

Lake Malawi, with a surface area of about 28,760 km^2, has a great influence on the water balance in the region. The mean annual rainfall over the lake is estimated to be 1,549 mm. The total inflow into the lake is 927 $m^3 s^{-1}$, out of which 400 $m^3 s^{-1}$ is from Malawi, 486 $m^3 s^{-1}$ from Tanzania and 41 $m^3 s^{-1}$ from Mozambique. The average outflow is 395 $m^3 s^{-1}$. The mean lake level is 474 m. The only outlet of the lake is the Shire river (Kululanga and Chavula, 1993). The catchments area of lake Chilwa is estimated to be 5,000 km^2. Most of the rivers that drain their water into lake Chilwa arise from the northern mountain slopes of Zomba and Mulanje Massif. All the rivers are perennial in their upper reaches but they gradually lose their flow and recharge aquifer systems in the Chilwa - Phalombe plains due to the porous nature of the area (Kululanga and Chavula 1993).

Socio-economic context

Malawi's population is estimated at 13.1 million, with a population density of 107 people km^{-2} (EAD, 2008). Nearly 90 percent of the people live in rural areas. The main economic base of the country is the agriculture sector, with subsistence and smallholder farming being the main activities for the rural population. Agricultural production contributes over 90 percent of foreign exchange earnings. Maize is the main staple food, taking up nearly 80 percent of the cultivated land. The main export crops include tobacco, tea and sugar. The performance of the tobacco sector is instrumental to swift short term growth, as tobacco accounts for over 50 percent of the country's exports (EAD, 2008).

Malawi's per capita GDP was about USD 133 in 2002 that was lower than the estimated USD 139 for the year 2003 (EAD, 2008). However, revised real GDP in 2002 rose by 1.8 percent, from a low of about 0.4 percent in the year 2001. In 2004, the estimated contribution of the agricultural sector to the GDP was estimated at 54.8 percent, while industry was at 19.2 percent, and services at 26 percent. Until 1980, Malawi has achieved economic growth well above most Sub-Saharan African (SSA) countries, at an average GDP growth rate of 7 percent. A greater proportion of this growth came from the smallholder sector. However, economic growth was significantly down thereafter and even ran into negative growth during1981-1991 and saw a corresponding decline in the smallholder sector contribution to GDP and this situation deteriorated in 1992 due to serious drought situation. Over the same period, the contribution of the estate sector steadily increased while the manufacturing sector showed insignificant change.

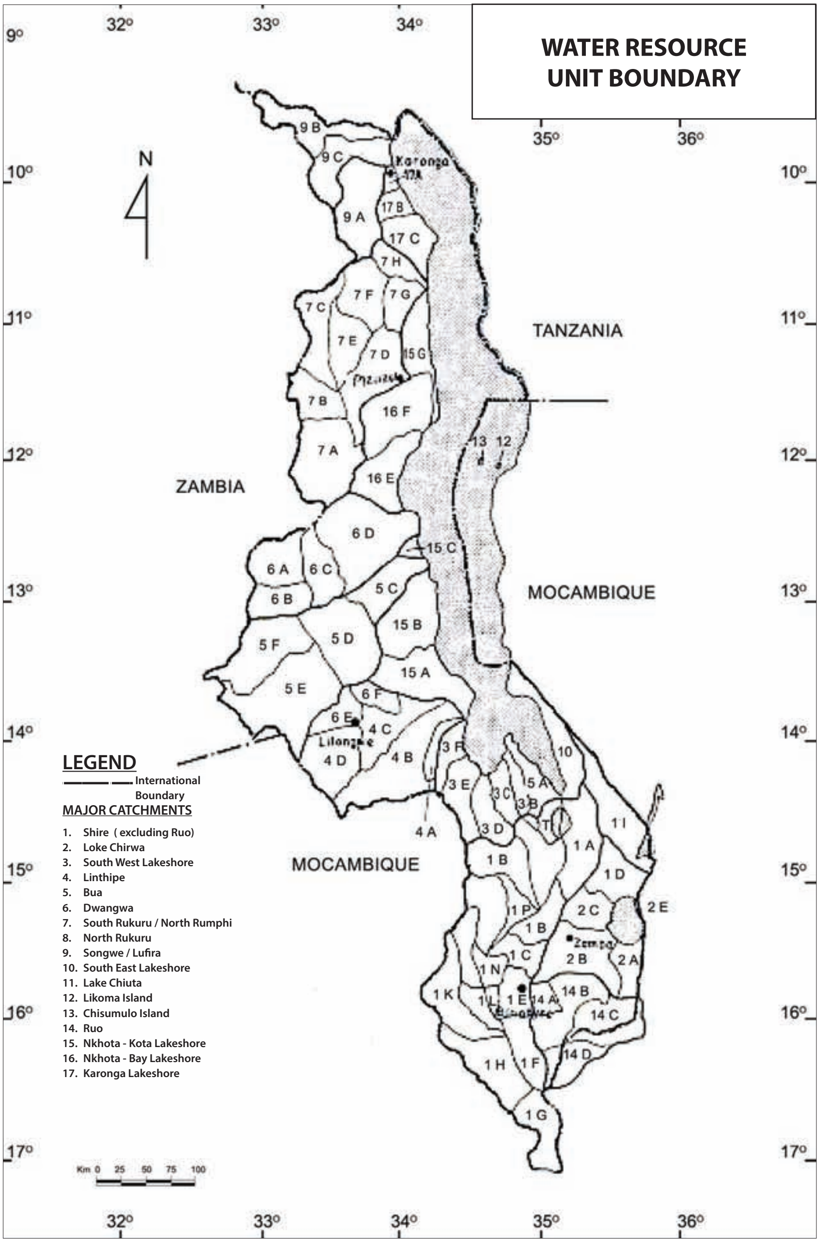

Figure 6.1 Water resources units of Malawi (Source: Water Department/UNDP 1986)

Groundwater resources

Hydrogeology and groundwater systems

Malawi has three major aquifer systems, namely: the extensive but low yielding weathered Precambrian basement complex aquifer of the plateau area, the high yielding alluvial aquifer of the lake shore plains and the lower Shire valley and the lake Chilwa - Mphalombe plain, and the medium yielding aquifer of the fracture zone in the rift valley escarpment. Characteristics of the weathered Precambrian basement complex and alluvial aquifers are shown in Table 6.1. The prolonged *in-situ* weathering of the crystalline basement rocks has produced a layer of unconsolidated saprolite material that forms an important source of water supply for domestic requirements. The weathered zone is best developed over plateau areas where it is commonly 15-30 m thick and locally even thicker (Water Department/ UNDP, 1986). Towards the crest of the escarpment, the uplift associated with the development of the rift valley has resulted in the rejuvenation of rivers and increased erosion, and thus the thickness of the aquifer tends to be reduced in these areas. It also thins towards bedrock outcrops. The saprolite thickness tends to be greatest along fracture zones. Alluvial aquifers are fluvial and lacustrine sediments that are highly variable in characteristics in both vertical sequence and lateral extent. They occur in several basins which, apart from lake Chilwa, are all located along the rift valley floor: Karonga lakeshore, Salima-Nkhotakota lakeshore, upper Shire valley, and lower Shire valley.

Table 6.1 Characteristics of major aquifer systems in Malawi

	Weathered basement complex	Alluvial
Borehole yield (L s^{-1})	1-2	15
Hydraulic conductivity (m d^{-1})	0.5-1.5	1-10
Depth of boreholes (m)	45-50	60
Depth of water table (m)	15-25	5-10
Transmissivity (m^2 d^{-1})	5-35	50-300
Storage coefficient	5 $x10^{-3}$-$1x10^{-2}$	$1x10^{-2}$-$5x10^{-2}$

Source: Ministry of Irrigation and Water Development (2006)

Most lithological records from boreholes provide very little information about the successions. The overall impression is that clays usually dominate the sequence although in many localities there are significantly thick layers of poorly sorted sands. The sedimentary environment likely to produce the highest groundwater yields are buried river channels and littoral (beach and dune) zones of the lakeshore, where deposits are usually coarse grained and well sorted. The lake Chilwa basin is different from the other alluvial areas in that it is not in the bottom of the rift valley floor, but perched on the eastern side of it. The lithological logs suggest that much of the succession is clayey.

Estimates of recharge have been made from the analysis of flow hydrographs, groundwater level fluctuations, flow nets and catchment balances. Although the results vary considerably, annual groundwater recharge ranges from 15-80 mm (Water Department/UNDP, 1986). However, studies done by Chavula (1989) established that the annual recharge for the eastern side of the lower Shire Valley alluvial aquifer is greater than 200 mm yr^{-1}. It is worth noting that the Malawi Government has not yet developed a hydrogeological map showing the distribution of groundwater recharge in the country. Suffice to say that areas which receive high rainfall exhibit high groundwater recharge rates and vice versa. The rate of groundwater abstraction still remains very low and estimates put the figure at less than 1 mm yr^{-1} (Water Department/UNDP, 1986; Chavula, 1989).

Groundwater quality

Bath (1980) and the Ministry of Irrigation and Water Development (Water Department/UNDP, 1986) conducted detailed water quality studies in Malawi in 1980 and 1986, respectively. On a national scale, groundwater quality is generally acceptable for human consumption. In the basement complex aquifer, groundwater resources are characterized by the dominance of alkaline earths in the action group and by the carbonates in the anion group (Water Department/UNDP, 1986). Total dissolved solids values are generally less than 1,000 mg L^{-1} and typically around 350 mg L^{-1}. Groundwater in the alluvial aquifers is more mineralized than in the basement aquifers. A number of boreholes have been abandoned due to high salinities, notably in the lower Shire valley and the eastern part of Bwanje valley.

Chemical parameters of concern include fluoride, sulphate, iron, chloride and nitrate. Groundwater with fluoride content in excess of 1.5 mg L^{-1} is common in the Salima/Nkhotakota and Karonga lakeshore areas. In these areas, high fluoride content is associated with fault zones and hydrothermal activity in the rift valley. High sulphate in groundwater is common in the western part of Dowa district and is thought to be a direct result of progressive oxidation of sulphide-rich parent material, probably pyrite and pyrrhotite in veins producing sulphuric acid and the subsequent reaction with minerals containing magnesium and calcium. Chloride rich groundwater resources are common in the lower Shire valley and are associated with the dissolution of evaporite minerals and chemical filtration as described by Bath (1980) and Chavula (1989).

Generally boreholes supply water of superior microbiological quality to other sources such as dug wells. Reasons for inferior quality of water drawn from hand-dug wells may be explained as follows (Water Department/UNDP, 1986; Kululanga and Chavula, 1993):

- Shallow groundwater table (less than 2 m depth) with seasonal fluctuation bring the water close to the ground surface, where water can easily get polluted;
- Faecal contamination is a high probability since dambos (complex shallow wetlands) are extensively used for grazing and watering livestock all year round; and
- Poor siting of water points since dug wells are sometimes placed very close to traditional water sources which are always open and invariably grossly polluted.

Groundwater development and utilization

Groundwater abstraction

By 1994, there were about 9,600 boreholes and 5,600 protected shallow wells, the majority of which were constructed by the Malawi Government. However, since then, there has been a dramatic increase in boreholes drilled by the government, non-governmental organizations and the private sector; and according to the Ministry of Water Development, about 19,000 boreholes were drilled by 2001. This trend continues and the number of boreholes is increasing as a result of the proliferation of drilling contractors across the country. Furthermore, due to the recent increased occurrence of drought, the number of hand-dug shallow wells has reduced considerably because they are highly vulnerable and prone to drying up. People have therefore opted for boreholes instead of shallow wells. Since about 1998, the Department of Irrigation (DoI) has introduced several irrigation technologies targeting smallholder farmers, including motorized pumps, river diversions, and manual pumps (treadle pumps). The demand for the latter is reportedly high as data shows that by 2001, Malawi had imported 10,000 treadle pumps. The Ministry of Agriculture in 2001 introduced loan schemes to farmers for purchase of motorized and treadle pumps. The use of motorized pumps is widely common, especially by the estates and private commercial farmers. In 2001, the Malawi Project Inc., with support from Healing Hands International, purchased 3,000 drip irrigation systems and conducted training of Malawians as drip system instructors.

Currently there are about 30,000 boreholes and 8,000 protected hand-dug wells in Malawi. The Ministry of Irrigation and Water Development is in the final stages of developing a map showing the distribution of boreholes in the country. A database is being set up to support the management efforts.

Cost for groundwater development

Information obtained from the Ministry of Irrigation and Water Development and from borehole contractors (personal communication with McPherson Nkhata and Lucky Penumulungu, respectively, 2010) show that generally groundwater development in Malawi is very expensive. Costs associated with groundwater development comprise site exploration, drilling, and pump installation. Cost of groundwater development in Malawi presented in Table 6.2.

Table 6.2 Cost for groundwater development in Malawi

Average cost	Cost (USD)
Bore hole survey	39,762
Drilling (cost range)	3,380-3,579
Description of the work in Malawi	
Drilling	4,771
Rural water supply BH	240
Cost of BH development is pegged per hour for a 113 mm diameter hole	8
Drilling cost per 0-45 m depth	16
Cost after 45 m depth per meter	18
Submergible pump cost (range)	1,511-1,790
Cable cost for submergible pump	240
Pumping test per hour	16

Source: Ministry of Irrigation and Water Development (2006)

Groundwater utilization

Domestic purpose

Boreholes fitted with Afridev hand pumps are extensively used for rural groundwater supply. Each borehole is designed to serve a total of 250 people at a per capita consumption of 36 L d^{-1} within a walking distance of 500 m radius whereas a hand-dug well caters to 125 people. Current estimates show that 65 percent of the human population in Malawi depends on groundwater for domestic water supply (Ministry of Irrigation and Water Development, 2006): about 82.3 percent of the rural population depends on groundwater whereas the figure for the urban population is 19.8 percent. There are a number of urban centres in Malawi that get their water supply from groundwater, e.g., Madisi (Dowa district), Salima (Salima district), Karonga (Karonga district), Nkhotakota (Nkhotakota district) and Ngabu (Chikwawa district). It is envisaged that more rural areas and towns in Malawi will get their water supplies from groundwater resources in future because of the unreliable rainfall and irregularity of river flows, currently abstracted to sustain gravity fed rural piped water schemes and urban water supply. Climate change will only expedite the process of groundwater development in Malawi.

Irrigation

Groundwater use for irrigated agriculture is at present mostly confined to growing vegetables and maize in *dambo* areas during the dry season. In most cases, water is drawn from hand-dug wells and applied to crops using watering cans. But the advent of treadle pumps has seen the proliferation of these devices for irrigated agriculture in *dambo* areas. However, Ngolowindo Irrigation Scheme in Salima district remains the major scheme in Malawi that uses groundwater as a source of water supply. The scheme was established in 1985 through funding from the European Community and had an initial membership of 60 farmers that has now grown to 163. Out of these, 23 are involved in agro processing while the rest are engaged in irrigation farming, growing horticultural crops. Under the scheme, local farmers grow vegetables and maize using furrow irrigation. Groundwater is abstracted from the alluvial aquifer using two electrical pumps fitted on boreholes yielding 6.2 and 10.5 L s^{-1} respectively. The water is then stored in an overhead tank with a capacity of 927 m^3 from where the water is conveyed to the field using siphons. Excess water is drained through a 1.5 km drain. In order to cope with the high water demand, farmers plant crops in a staggering fashion. Operational costs of running the pump constitute the major cost to farmers at Ngolowindo Scheme. On average, farmers pay USD 543 per month for electricity use (Khosa, 2008).

Detailed studies on groundwater potential for irrigated agriculture were carried out in 1980 by Hunting's Technical Services Limited of UK (Ministry of Agriculture and Natural Resources, 1980). The studies showed that alluvial aquifers along the shores of lake Malawi and in the lower Shire valley have great potential for irrigation use. But so far, only Ngolowindo irrigation scheme uses groundwater as an irrigation source. Thus, groundwater potential has not been fully exploited for irrigated agriculture in the country. With the Malawi Government's adoption of the Greenbelt Initiative (GBI), to ensure food security at household level by intending to irrigate more than one million ha of land, the number of irrigation schemes in the country is expected to increase rapidly and most of these will depend on groundwater. According to the Malawi Integrated Water Resources Management and Water Efficiency Plan (Ministry of Irrigation and Water Development, 2006), the country's irrigation potential is far in excess of 400,000 ha. At present land under irrigation is limited to 70,000 ha of which 48,000 ha is for estates and 14,000 ha is smallholder sub-sector mainly producing crops such as rice, sugarcane and horticultural crops (Ministry of Irrigation and Water Development, 2006).

Livestock watering

A number of farmers use groundwater for livestock production, mainly as a source of drinking water supply for the animals and not for the production of pasture. The government has also drilled a number of boreholes in national parks and fitted them with windmills in order to supply water to the wildlife.

Institutional and legal framework

The onus to manage groundwater resources in Malawi lies with the Ministry of Irrigation and Water Development. Both the Departments of Water Resources (Groundwater Division) and Water Supply are responsible for policy formulation on groundwater development in the country. For example, the Groundwater division is responsible for groundwater research, storage of borehole data, issuance of groundwater abstraction rights through the Water Resources Board, etc., whereas the responsibility to operate and maintain boreholes rests with the Water Supply Department.

Development of groundwater resources is normally the responsibility of the NGOs (WaterAid, Red Cross Society of Malawi, Concern Universal, Water for People, etc.), the donor community (UNICEF, World Bank, the African Development Bank, JICA, etc.), and the private sector. These organizations do not work in isolation, but rather, collaborate with the Ministry of Irrigation and Water Development.

Under the Water Resources Act of 1969 all water abstractions must be licensed (except for general household municipal use). This also applies to all industrial effluent discharges into public water bodies, including human sewage. Section 5 of the Water Resources Act, stipulates that all individuals have the right to use public water, without a need of water rights, for domestic purposes only. Annual permits are required for abstractions greater than 1,000 L d^{-1}, except for municipal use. The charging system is based on the water source and type of usage; however, the collection of revenue is severely limited by lack of appropriate collection system and staff. Efforts to revise and amend the Water Resources Act of 1969 were started in the mid 1980s but the process has been very slow and has not materialized due to a number of factors. However, following recent revision of the policy, efforts are underway to finally amend the Act. The existing Act makes provision for the control, apportionment and use of the country's water resources. The Irrigation Act 2001 and the Water Resources Act 1969 provide for the formation of water user associations (WUAs) or irrigation management authorities to promote local community or farmers' participation in the development and management of irrigation and drainage, and proper utilization of the available water resources.

Groundwater development challenges

There are many constraints that hamper the development of groundwater resources in Malawi. These include inadequacies in existing capacity, knowledge about the resource, and available financial resources. Before 1994, hydrogeologists on site or very qualified personnel supervised all borehole surveying and drilling works in Malawi. As a result of this strict supervision, water points were constructed in accordance with the recommended standards. But with the advent of multiparty democracy in the country since 1994, unskilled personnel are sometimes engaged in borehole construction, resulting in an increase in low yielding boreholes and poor services. This is a problem that needs to be addressed immediately if the country is to continue sustainable exploitation of groundwater resources and further their socio-economic growth. Hence there is a clear need to train more hydrogeologists in Malawi.

Apart from studies carried out in 1986 during the preparation of the National Water Resources Master Plan, there have been no follow up studies undertaken to assess the quantity and quality of groundwater resources countrywide. Unless such studies are formulated, it will be difficult to know how groundwater resources have changed over time. In the light of the above, there is need to encourage and promote research in groundwater resources and related fields.

Availability of financial resources is critical in the development of groundwater resources in Malawi. But being a developing and donor-dependent country, the country does not have adequate financial resources to independently develop its groundwater resources. It is therefore not surprising that Malawi still has a large proportion of its human population collecting water for domestic consumption from unprotected well and polluted rivers. Therefore, there is need to seek more donor assistance with a view to develop groundwater resources within the country.

Conclusions and Recommendations

Malawi is generally rich in water resources which are stocked in its lakes, rivers and aquifers. The prolonged *in-situ* weathering of the crystalline basement rocks has produced a layer of unconsolidated saprolite material that forms an important source of water supply for domestic requirements. Malawi has three major aquifer systems, namely: the extensive but low yielding weathered Precambrian basement complex aquifer of the plateau area, the high yielding alluvial aquifer of the lake shore plains and the lower Shire valley and the lake Chilwa - Mphalombe plain and the medium yielding aquifer of the fracture zone in the rift valley escarpment.

While commendable progress has been made in the development of water resources in Malawi, there are environmental issues that the country should address as a matter of urgency in order to conserve resources from further depletion and degradation. Factors that contribute greatly to the depletion and degradation of water resources in Malawi include poor management of catchment areas, environmentally unfriendly agricultural practices, rapid population growth, inappropriate discharge of industrial wastes and the weak institutional structures for enforcing the Water Resources Act. There is considerable scope for expanding rice production in Malawi under irrigation, but there is also a high potential for the production of high value crops, other than rice, for the export and municipal markets under irrigated agriculture. To attain this economic goal, it is imperative that institutions with the mandate to manage water resources in Malawi are given all the necessary support from the government, especially in the areas of law and finance to support the implementation of projects related to water resources development.

Groundwater studies have not been conducted across the country after the 1986 studies, which were carried out to contribute to the preparation of the National Water Resources Master Plan. Unless countrywide studies are undertaken, to assess the current quantity and quality of groundwater, it will be difficult to understand how the resource has changed over time. Thus there is a pressing need to encourage and promote research in the area of groundwater resources. Availability of financial resources is critical in the development of this resource but as Malawi does not have adequate financial resources, the country still has a large proportion of its the human population using water from unprotected well and polluted rivers for domestic consumption. Therefore there is need to seek more donor assistance with a view to developing groundwater resources in the country.

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CHAPTER 7

MALI

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General Description of Mali

Geography

Mali is a Sahelian country in West Africa. It is located between latitudes 10° and 25° N, and longitudes 13° W and 5° E. Mali is bordered by Algeria to the south west and by Burkina Faso and Niger to the north. It has a large area of about 1.24 million km^2 with its terrain dominated by flat or rolling sand-capped plains in the north and savannah in the south, although rugged hills occur in the north east. Elevation varies from the highest point of 1,155 m at Hombori Tondo to the lowest of 23 m on floodplain of the Senegal river. Administratively, Mali has eight regions: Sikasso and Bamako are situated in the extreme south, in the Guinean savannah; Timbuctu, Gao and Kidal constitute the northern desert part of the country; Kayes, Kulikoro, Segou and Mopti occupy the Sahelian zone. The capital city is Bamako.

Physiography and climate

The country has five distinctive agro-ecological zones. The Saharan zone to the north is a part of the Sahara desert that covers about 53 percent of the total land area. The zone receives about 150 mm of rainfall annually and the potential evapotranspiration exceeds 2000 mm yr^{-1}. The Sahelian zone at the middle of the country covers 281,000 km^2 and can be sub-divided into a northern part (with 200-350 mm annual rainfall) and a southern part called the Sahelo-Sudanian zone (350-600 mm). The Internal Delta, which includes both the Central delta of the Niger river and the lacustrine area, falls within the Sahel zone, but is distinct because of its high agricultural potential. Further south are the Sudanian and the North Guinean or Sudano-Guinean zones, which receive the highest rainfall of 800-1300 mm. Mali's terrain is primarily savanna in the south and flat to rolling plains or high plateau (200–500 m in elevation) in the north. There are rugged hills in the north east, with elevations of up to 1,000 m. Desert or semi-desert covers about 65 percent of the country's area. The Niger river creates a large and fertile inland delta as it arcs north east through Mali from Guinea before turning south and eventually emptying into the Gulf of Guinea.

Mali's climate ranges from subtropical in the south to arid in the north. The country is mostly dry, interspersed by a 4-5 month long rainy season. In Bamako, at an elevation of 340 m above sea level, temperatures generally range from 16^oC to 39^oC. January is the coldest month, with temperatures ranging from 16^oC to 33^oC, and April is the hottest month, with temperatures averaging 34^oC to 39^oC. Annual precipitation in Bamako averages 1,120 mm. The driest months are December and January with zero rainfall and the wettest month is August, which averages 220 mm of rainfall. Most of the country receives negligible rainfall, and droughts are a recurring problem. During dry seasons, a hot, dust-laden harmattan haze (West African trade wind) is also common. Flooding of the Niger river occurs regularly in the rainy season (approximately June/July–November/December).

Drainage

According to FAO-AQUASTAT (2005), about 47 percent of the total land of Mali is located in the Niger river basin, 11 percent in the Senegal river basin; 41 percent in the Sahara desert and only one percent in the Volta river basin. The Niger and Senegal rivers and their respective tributaries provide most of the perennial surface water in Mali, with an average annual flow of 50 km^3 yr^{-1}. The Niger river has 1,700 km of its total length of 4,200 km in Mali, and provides the country with a total runoff volume of about 35 km^3 yr^{-1}. Unfortunately, a third of this volume is lost by evaporation in the Delta Central and in the wetlands. Groundwater contribution to the internal renewable water resource is estimated at 20 km^3 yr^{-1}. About

40 km^3 yr^{-1} of surface water enter the country mainly from Guinea and Cote d'Ivoire. This puts the total volume of annual renewable water in Mali to be about 100 km^3. This figure includes 10 km^3 yr^{-1} overlap between surface and groundwater.

The perennial rivers in Mali are concentrated exclusively in the southern and the central part of the country, whereas the northern part is characterized by the presence of fossil water reserves. Groundwater abstraction is currently estimated at 0.11 km^3 yr^{-1} which is 0.5 percent of the surface water resources available (FAO-AQUASTAT, 2005). The volume of groundwater used for irrigation is extremely low compared to surface water use. Groundwater is primarily used for domestic water supply (N'Djim and Doumbia, 1998). In 1987, the total annual water withdrawal in Mali was 1.4 km^3, of which agriculture took a giant share of 97 percent, followed by domestic supply (2%). The remaining one percent went to industry (FAO, 2003).

Mali's total annual renewable water resources amount to 100 km^3. Access to improved drinking water is higher in urban areas (78%) than in rural areas (36%). Household connections to improved drinking water are lower in both, at 11 percent of urban households and 2 percent of rural households. Only 59 percent of urban households and 39 percent of rural households have improved sanitation coverage (GOM 2006). Approximately 90 percent of the country's water consumption is for agricultural purposes (GOM 2006; USAID 2010).

Socio-economic context

The population of Mali is estimated to be about 14.16 million (July 2011), with a growth rate of 2.61 percent (CIA, 2011). About 47.3 percent of the population is under 15 years; 49.7 percent between 15 and 64 years and 3 percent are 65 years or older. About 56 percent of the total population have access to improved water source (81% and 44% in urban and rural areas, respectively). 68 percent of the Malian population live under the poverty line and 21 percent face extreme poverty especially in rural areas (UNDP, 2004). Life expectancy is estimated at 52.6 years in 2011. Most of the population (66%) live in rural areas and the schooling rate in those areas is very low (CIA, 2011).

The economy of Mali is heavily dependent on gold mining and agricultural exports (CIA, 2011). Agriculture makes a contribution of 38.9 percent to the GDP (2010 est.), employing 80 percent of the working population. In 2001, agriculture provided approximately 75 percent of the export earnings, with cotton alone making up about 50 percent of the exports (Margat, 2001). Small-scale traditional farming dominates the agricultural sector and subsistence farming occurs on about 90 percent of the land under cultivation (U.S. Department of State, 2000). Industry and services contribute 21.5 and 39.6 percent, respectively, to the GDP (CIA, 2010 estimates). In 2005, it was estimated that about 36 percent of Malians live below the poverty line. The gross domestic product (GDP) per capita (purchasing power parity) estimated in 2010 is USD 1,200 (CIA, 2011). The cultivable area in the country is about 43.7 million ha, which is 35 percent of the total surface area of the country. In 2008, only 4.98 million ha was under cultivation, equal to about 4 percent of the total land area. Total area equipped for irrigation was estimated at 235,800 ha in 2002 (FAO-AQUASTAT, 2005) representing 4.9 percent of the cultivated land. Land is technically owned by the government, and farmers are designated as land users.

Mali faces several environmental challenges including desertification, deforestation, soil erosion, drought and inadequate supplies of potable water. Deforestation is a particularly serious and growing problem and according to the Ministry of the Environment, Mali's population consumes 6 million tons of wood per year for timber and fuel. To meet this demand, 400,000 ha of tree cover are lost annually, virtually ensuring destruction of the country's savannah woodlands. About 90 percent of the 1.4 million ha under cultivation are devoted to subsistence farming, primarily for growing cereals such as corn, millet, and sorghum, which contribute to the main agricultural products which also include cotton, peanuts, rice, sugarcane and vegetables, as well as livestock (cattle, goats, and sheep). Cotton and livestock are the primary agricultural exports. Mali, Sub Saharan Africa's leading producer of cotton, produced an estimated 419,000 tons of raw cotton in 2002 and a record harvest of 612,000 tons in 2003, but in 2004 the country's agricultural sector was threatened by locust plague. Mali's primary sector also includes forestry and fishing activity. Most of Mali's forest products are used for fuel wood, on which the populace is heavily dependent for its energy needs. Artisanal fishing, mostly on the Niger river, also is an important economic activity, but it is vulnerable to drought, pollution, and changes resulting from the construction of dams and has been on a decline since the early 1980s.

Groundwater resources

Hydrogeology

Mali is underlain by geological units associated with two main geological structures, the West African Craton in the west and the Tuareg Shield in the southeast. Main geological units include the Birimian (Precambrian) crystalline basement, lower Cambrian to Palaeozoic indurated sandstones and metamorphosed clays, Permian dolorite intrusions, mixed continental sediments of the Continental Intercalaire' formation, upper Cretaceous to Eocene marine sediments, the Pliocene 'Continental Terminal' sedimentary formation and superficial deposits of Quaternary age (British Geological Survey, 2002; UN, 1988). Figure 7.1 depicts a simplified geological map of Mali.

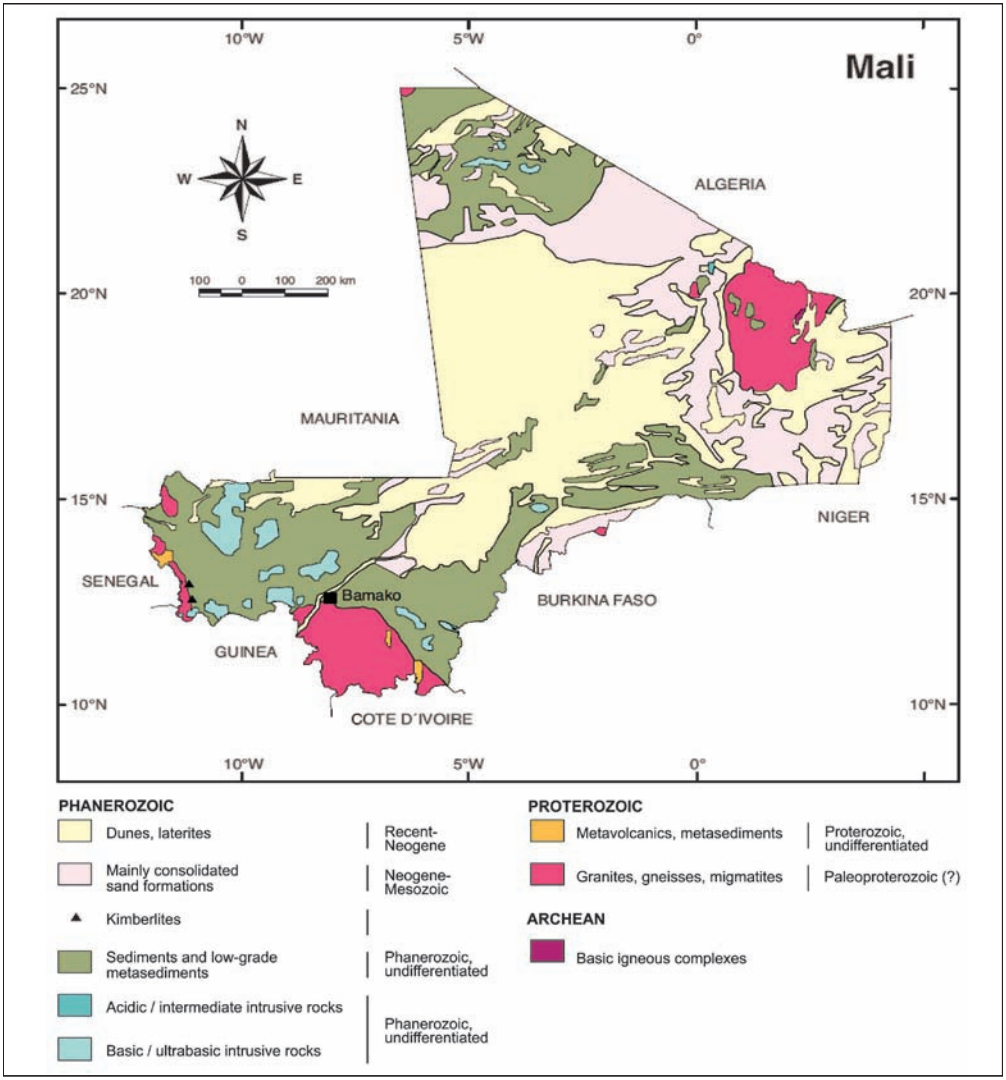

Figure 7.1 Geological map of Mali (Source: http://petroma-mali.com/pdf2/malicraton.pdf)

According to BGS (2002), the crystalline basement is found mostly in southern Mali, also in the Kayes region and the middle of the Adrar des Iforas and consists mainly of metasedimentary and metaigneous units. More than two thirds of Mali is underlain by the lower Cambrian and Palaeozoic sediments. Palaeozoic sandstones, schists and limestones crop out in the northern part of the Taoudenit basin. The Continental Intercalaire' Formation occurs in the middle portions of the Taoudenit basin in central Mali, in eastern Mali on the east edge of the Adrar des Iforas plateau and in the south east in the Tullemeden basin. It consists of clays, fine to coarse unconsolidated sandstones and basal conglomerates. Also in the south east of Mali is the 'Continental Terminal' Formation (CT), which crops out in the central Taoudenit basin. The CT is also found around the southern borders of Mali, in the Gondo basin (UN, 1988).

Groundwater systems

The groundwater aquifers in Mali can be categorized into 3 major groups, namely, continuous/generalized, fractured semi-continuous, and fractured discontinuous (Figure 7.2). The continuous/generalised aquifer is associated with geological formations which are slightly or not consolidated. These aquifers are made up of secondary Quaternary sediment deposits and they form the Continental Terminal/Continental Quaternary. They are generally 20 to 50 m thick and could reach 100 m in some locations. The fractured semi-continuous aquifer is made of limestone, dolomite and grey rocks overlaying the Continental Terminal. The fractured discontinuous aquifer is essentially made of schist. These three major aquifer groups are subdivided into 9 aquifer systems and further subdivided into 29 hydrogeological units comprising of 61 hydrogeological sectors. Hydrogeological units and sectors represent locations characterized with similar geology, geomorphology and climate conditions. Each of these locations is characterized by specific piezometric conditions.

Monitoring of the groundwater systems in Mali was started in 1981. As of 1990, a total of 210 piezometers in 103 sites around the country were regularly monitored for water quality and piezometric levels. Piezometric heads recorded in Mali fluctuate between levels < 200 m AMSL to > 350 m AMSL. On an average, most of the country is located between levels 200 and 300 m AMSL.

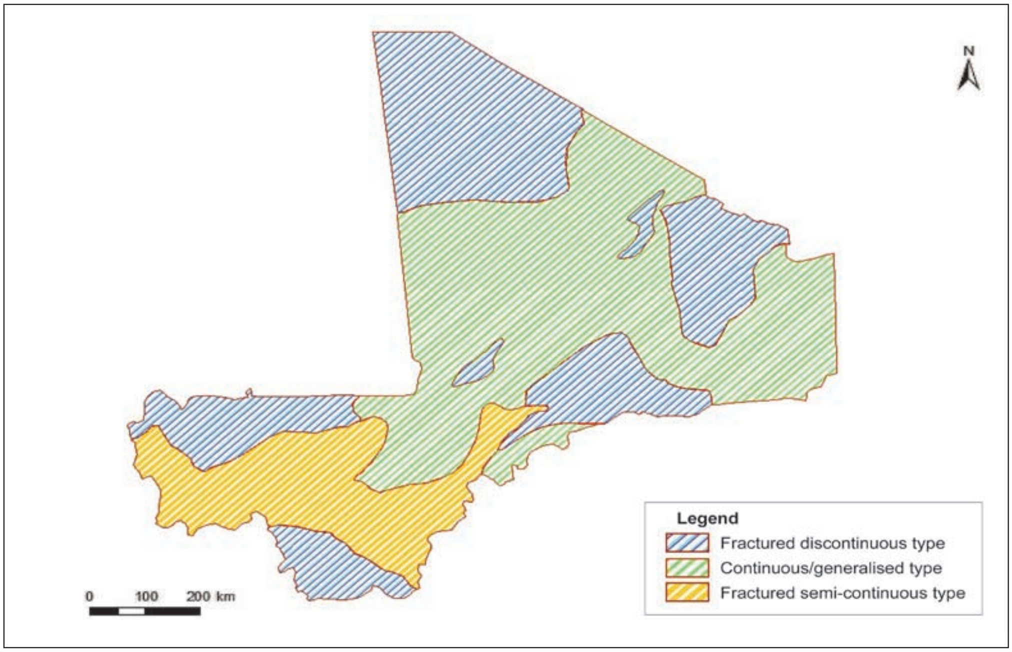

Figure 7.2 Groundwater aquifers in Mali (Source: MMEE 2006)

The most productive aquifers in Mali are those associated with the sedimentary formations, particularly the Continental Intercalaire and the Continental Terminal. Groundwater occurs in abundance in these formations. Unfortunately, these aquifers are located in less populated areas and therefore are seriously under exploited. The Continental Intercalaire, for instance, is only largely exploited in the west and on the southern edge of the Adrar des Iforas even though it is the most productive formation. Groundwater wells in this aquifer could be deeper than 150 m below the ground and water levels could be as deep as 100 m (UN, 1988). The Continental Terminal aquifers have been developed in areas like the inner delta and in places where the water table is shallow, good yield can be obtained. Well depths are normally in the range of 20-60 m below ground level (British Geological Survey, 2002).

Aquifers of the crystalline basement formation have little or no primary porosity. Generally groundwater occurs in fractures in the bedrock and sometimes in abundance in the regolith mantle (weathered layer) depending on the thickness. According to UN (1988), permeability of aquifers in the crystalline basement of Mali is mostly low and irregularly distributed. Water level variations in these aquifers are large and the average depth of well is 60 m. According to UN (1988), groundwater availability in the lower Cambrian and Palaeozoic formations depends on local lithology and degree of fracturing. Groundwater is found mostly in the top 20-60 m and water levels are normally 10-20 m below the ground.

The highest reserves of groundwater in Mali (more than 5 million $m^3 km^{-2}$) are located in the north and central parts of the country, particularly in the Tamesna, Southern Azaoud and North-western Gourma hydrogeological units. Recharge to the groundwater takes place mostly in the south and east of the country where annual rainfall is higher than 700 mm. It is estimated that annual recharge in these two regions is higher than 150,000 $m^3 km^{-2}$. By contrast, in the Volta basin portion of Mali, groundwater recharge is less than 50,000 $m^3 km^{-2}$ (UN, 1988).

Groundwater is abstracted from nearly all the administrative regions in Mali. Pumping tests done so far show transmissivity in the continuous/generalized aquifers to be on average about $1.3 \times 10^{-3} m^2 s^{-1}$ and varies between $1.4 \times 10^{-7} m^2 s^{-1}$ and $5 \times 10^{-2} m^2 s^{-1}$. In the fractured aquifers, average transmissivity is estimated at $2 \times 10^{-4} m^2 s^{-1}$, ranging between 1.4×10^{-7} and $2 \times 10^{-2} m^2 s^{-1}$ (MMEE, 2006). Table 7.1 shows selected characteristics of boreholes in one district in Mali. Potential availability is believed to be broadly sufficient, considering the theoretical annual water needs of 6.12 billion m^3 (N'Djim and Doumbia, 1998). Aquifers recharge for the entire country is estimated at 20 $km^3 yr^{-1}$ (FAO, 1995).

Table 7.1 Technical characteristics of boreholes in Koro district of Mali

Townships	Depth (m)	Static level (m)	Discharge ($m^3 h^{-1}$)	Conductivity ($\mu S cm^{-1}$)
Koro	84	38	6.68	911
Barapiéli	69	45	9.3	800
Bondo	104	54	2.5	1,069
Dougoutène 2	70	36	4.9	474
Koporopen	66	33	9.5	436
Koporokendié na	71	39	5.7	220
Madougou	81	48	3	1,105
Pel Maoudè	61	34	6.9	502
Yoro	58	26	3.45	871
Youdiou	81	39	6	566
Dioungani	95	59	4.4	1,472
Dinangourou	86	65	2.27	718
Dougouène 1 (Toroly)	95	59	4.4	1,472

Source: MMEE (2006)

Groundwater quality

Groundwater in most places in Mali is fresh and of good quality even though salinity and high nitrate contents have been report as problems in some areas (British Geological Survey, 2002). Salinity problems have been largely attributed to recent irrigation practices while nitrate problems have been linked to poor sanitation in urban areas.

In many of the rural areas, nitrate concentrations in groundwater are below the WHO guidelines value for drinking water (11.3 mg L^{-1}). Quality analyses of groundwater samples from the Continental Intercalaire aquifer in the Taoudenit Basin reported by Fontes *et al*. (1991) indicate that nitrate may not be a problem for this aquifer as low concentrations of nitrate (ranged from < 0.1 mg L^{-1} to 7.3 mg L^{-1}) were found in the groundwater. Groundwater from the aquifers of the lower Cambrian and Palaeozoic formations, generally, do not have salinity problems. The Continental Intercalaire and the Cambrian schists have highly variable salinity levels with very high salt contents in some localities. Fontes *et al*. (1991) have reported electrical conductivities in the range of 50-13,100 μS cm^{-1} for groundwater in the Continental Intercalaire in the Central areas of the country. Dissolved salt content of up to 17,000 mg L^{-1} has been measured in groundwater in the Cambrian schists (UN, 1988). Valenza *et al*. (2000) reported electrical conductivity of 300-500 μS cm^{-1} and 300 μS cm^{-1} for the groundwater in the west and east respectively, of the Niger river in Mali.

Fluoride contents in groundwater are generally, below the WHO guidelines value (1.5 mg L^{-1}). Fluoride concentrations in the range of < 0.2–1.7 mg L^{-1} (0.3–0.7 mg L^{-1} for most samples) have been recorded for groundwater from the Continental Intercalaire of the Taoudenit Basin (Fontes *et al.,* 1991). Concentrations of iodine, iron and manganese were found by Fontes *et al*. (1991) to be in the range 1-440 μg L^{-1} (average 69 μg L^{-1}), < 0.01–3.5 mg L^{-1}, and < 0.002–3.8 mg L^{-1} respectively, in the Continental Intercalaire of the Taoudenit Basin. The levels for other parameters are shown in Table 7.2.

According to Diarra (1997), the main problem associated with groundwater use in Mali is pollution of the resource from improper discharge of industrial wastes and domestic sewage. Industrial wastes from tanneries, gold mines and sometimes the agro-food industries contain high toxic material, which easily infiltrate through the soil to contaminate the shallow aquifers. In Bamako, for instance, most of the wells that supply water to the estimated 55 percent of the population are often poorly constructed and are situated close to sanitation facilities (e.g., latrines and sewers). In locations where the soils are highly permeable, the waste could easily infiltrate and pollute the groundwater. Laboratory analysis of groundwater samples carried out by the National Water and Energy Department in Bamako have shown that groundwater in Bamako is also highly polluted with pesticides, metals (mercury and lead dominate) and other chemical substances (Diarra, 1997).

Table 7.2 Typical groundwater quality in Mali

Parameter*	Concentration
Nitrate	< 0.1–7.3
Fluoride	< 0.2-1.7
Iron	0.01-3.5
Manganese	0.002-3.8
Iodine (μg L^{-1})	1-440
Uranium (μg L^{-1})	0.05-106

*All units in mg L^{-1} unless indicated
Source: Fontes *et al*. (1991)

Groundwater development and utilization

Groundwater abstraction

Groundwater abstraction in Mali is mainly done using boreholes and wells. A survey on access to domestic water conducted in the 10 administrative regions of Mali in 2003 listed a total of 15,154 boreholes out of which 14,182 were equipped with pumps; 29,674 improved wells; 161,776 traditional wells and 3,213 dugouts (MMEE, 2006). In addition to the above-mentioned structures that provide potable water, there are hundreds of traditional wells used in rural Mali to abstract water from both surface and groundwater sources for agriculture.

Pumps used in Mali for drawing water from aquifers for irrigation, domestic supply or livestock watering include PVC hand pumps (handle-held pumps), motor driven pumps, hand and foot pumps, wind powered pumps, and solar powered pumps (hand-activated pump). PVC hand pumps have exterior characteristics similar to other pumps but the interior parts (valves, pistons, etc.) are made of PVC, which is half the price of traditional pumps and do not corrode easily. Motor driven pumps have two pumps (vertical turbine pump and submersible pump) and can deliver about 10 m^3 hr^{-1} with a vertical head of up to 50 m. In the 1950's, windmills were installed in some parts of eastern Mali (south of Gao) but due to poor maintenance they are not operational. Lastly, there are the hand and foot pumps; the main brands currently widely in use are Vergnet Types I & II (50%), which is a locally made pump, India (40%), and Kardia (10%).

Groundwater is abstracted from nearly all the administrative regions in Mali with varying rates of success. In general, the success rate of drilling a well ranges from an average of about 57 percent in the Kayes region to about 79 percent in the Segou region (N'Djim and Doumbia, 1998). The overall average for the entire country is about 71 percent (see Table 7.3).

Table 7.3 Average rate of well-sinking success and discharge by region in Mali

Region	Success Rate (%)	Average Discharge ($m^3 h^{-1}$)
Kayes	56.9	6.9
Koulikoro	63.9	4.9
Sikasso	76.1	6.4
Segu	78.5	6.8
Mopti	68.6	9.0
Timbuctu	66.5	15.5
Gao	69.2	9.0
Bamako	89.2	8.2
Average	71.1	8.3

Source: National Office of Planning (1991) *cited* in N'Djim and Doumbia (1998)

Cost of groundwater development

The unit cost of digging and lining large diameter wells depends on the depth of the wells, the hardness of the formation, the difficulty of access and the distance from the capital. Moreover, in discontinuous aquifers, it is always necessary to drill a reconnaissance borehole to ascertain the presence of water before digging a well, and the cost of the drilling should obviously be added to the construction cost of the dug well. This type is the most appreciated in the rural areas because of low cost maintenance, permanent water accessibility and short waiting time to water access. The World Bank Report (2006) estimates the unit cost per meter to be USD 900-1,400 and rehabilitation (simple repairs of the water lifting system and casing to replacement of the whole well) at USD 2,500-5,200. Other estimates from a groundwater project in the Mopti Region was USD 715 m^{-1} for the cost of well digging in very hard rocks (FAO, 1986). Estimates from more than 200 boreholes installed in western Mali between 1980 and 1982 are shown in Table 7.4. The cost of unsuccessful boreholes averaged was approximately USD 103 m^{-1} (FAO, 1986). The cost of well cistern was estimated at about USD 770 (FAO, 1986).

Table 7.4 Cost of production drilled wells by geologic formation in western Mali

Nature of formation	Success rate (%)	Average depth of productive well (m)	Average cost per production well (USD)	Average cost of one meter of production well (USD)
Granite	25	38	24,360	641
Schist	39	37	16,020	433
Kayes sandstone	55	46	15,540	337
Nara sandstone	33	40	16,720	418
Claystone	25	58	36,800	634
Tillite	55	47	15,940	339
Pelite (Kayes)	42	35	14,500	414
Pelite (Nara)	47	47	15,060	320
Dolerite	36	30	14,260	475

Source: Burgeap (1982a) cited in FAO (1986); a well is considered as productive if it can deliver a minimum discharge of 1 $m^3 h^{-1}$ under a stable drawdown

Groundwater utilization

Groundwater in most regions of Mali is put to multipurpose use including domestic water supply, irrigation and watering of livestock. The distribution of water among the types of use varies from one region to another, though most groundwater is used for domestic purpose. The theoretical annual water needs in Mali is estimated at some 6.12 billion m^3, shared as 62 million m^3 for domestic supply, 60 million m^3 for livestock and 6 billion m^3 for irrigation (N'Djim and Doumbia, 1998). FAO data indicates that groundwater services around 20 percent of this demand (FAO 2005).

Domestic purpose

About 55 percent of the population residing in the capital city of Bamako use water drawn from groundwater aquifers. In the rural areas, groundwater is either the only source or the main source of potable water supply for the people. The source is either in the form of traditional wells (village sump wells, usually shallow with depth between 2 and 10 m), numbering an estimated 800,000 and not necessarily meeting the quality standards (e.g. sumps, pools and other water-holes) or modern water sources (e.g. drilled wells with pumps, cistern wells, or other modern wells), estimated at 3,000 modern wells and nearly 9,000 pumps. A 1992 survey of 384 rural centres showed that three centres have a reticulated water supply; 211 are served by modern wells and sumps; 24 are equipped with solar pumps with mini networks; and 146 (36 %) are without modern wells. According to a WaterAid country report for Mali, the satisfaction rate for rural area "potable water" is about 49 percent and access to potable water for most of the Malian population, especially in rural areas in the desert and sub-desert regions (Mopti, Timbuctu, and Gao) of the country will require a greater use of groundwater. Telmo (2002) estimated that 48 percent of the households in Gouansolo had access to improved water supplies from groundwater aquifers (i.e., borehole pumps). According to CIA (2004), groundwater withdrawn for industrial uses in Mali is just one percent of the overall abstracted groundwater in the country and the per capita volume of water used in industrial production is estimated to be one m^3 per person per year.

Irrigation

Agricultural and economic activities in Mali are mainly confined to the southern region of the country where the Niger river serves as the source for irrigation. The potential land suitable for irrigated agriculture is 2.2 million ha, of which about 566,000 ha is irrigated from surface water sources. Of this total surface water irrigated area, 295,791 ha currently receives controlled water supply, while 60,000 ha is more or less abandoned because of the lower river floods (case of partial control facilities), technique related problems (for example poor maintenance of facilities) and institutional constraints (lack of agricultural credit, land issues, lack of beneficiaries ownership, involvement in management of irrigation infrastructures). Of the three major types of irrigation (surface irrigation, sprinkler and drip irrigation), only surface irrigation is actually practiced in Mali. Subsistence cereals dominate the Malian diet, and the main subsistence crops grown are rainfed millet and sorghum, with commercial agriculture devoted to cotton and rice, the latter of which is irrigated from surface water sources.

There is hardly any documented case of groundwater use for irrigation in Mali. An attempt was made at estimating the size of plot that could be irrigated with the amount of groundwater abstracted in the various regions of the country as at 1989. Considering that millet is a common crop that small scale farmers in Mali often cultivate, it can be estimated that groundwater irrigable land in Mali, as of 1989 was about 5,000 ha maximum (Table 7.5). The estimate is based on the assumption that all the abstracted groundwater in each region was used for irrigation.

Table 7.5 Estimates of potential groundwater irrigated area coverage in Mali

Region	Volume* (million m^3)	Potential cultivated area (ha)
Kayes	3.689	858
Koulikoro	3.586	834
Sikasso	4.277	995
Segu	3.370	784
Mopti	3.260	758
Timbuctu	1.879	437
Gao	1.361	317
Total		4,983

Source: *1989 estimated volume of groundwater exploited for irrigation in each region (N'Djim and Doumbia, 1998)
[Average water requirement for 90-day millet under Sahelian climate is 430 mm (IDRC, 2003)]

Legal and institutional framework

In Mali, the state owns all groundwater resources in the country. The country has a Water Code (No. 02-006:2002) enacted in the year 2000, which regulates the use, conservation, protection and management of water resources. The code provides the ground for a new regulation for the water sector and legitimizes the structures in charge of water resource management. It stresses the principle of public water dominance and provides details of the modalities of resource management and protection, through determining the rights and obligations of the State, territorial collectivities and users. As per the code, water users require permits to extract water for all purposes, except for domestic use and in amounts below specific volumes. The Water Code prohibits discharge of substances that may negatively affect water resources. Under the Water Code, local governments are responsible for water supply (GOM, 2000; Cotula, 2006; USAID, 2008). In addition, the Water Code recommends the initiation of a development fund for public water services and creates a national council of regional and local councils, basin committees in charge of making consultations and propositions on resource management and planning projects (Direction Nationale De L'hydraulique, 2000).

While various government ministries, departments and agencies have responsibility over different aspects of water resources in Mali, the Ministry of Mines, Energy and Water (MMEE) has the overall responsibility over the resource and particularly with formulating the overall policy for the water sector. MMEE discharges its responsibilities through one of its directorates, the National Directorate for Water Supply (DNH); the DNH functions primarily through its regional and sub-regional offices. There exists a commission for regulation of water and electricity, an independent entity, which works with the MMEE to develop water regulations and ensures that water users, particularly mining operators, respect the regulations. The commission has the authority to impose sanctions on any department, contracting authority, user and legally recognized operator who do not abide by the existing regulations. As in most African countries, Mali does not have a separate institution responsible for groundwater. The water institutions at the various administrative levels take care of both surface and groundwater.

Groundwater development challenges

The main problem associated with groundwater in Mali is it's pollution from improper discharge of industrial wastes and domestic sewage. Industrial wastes from tanneries, gold mines and sometimes the agro-food industries contain high toxic material, which easily infiltrate through the soil to contaminate the shallow aquifers. In Bamako, for instance, most of the wells that supply water to the estimated 55 percent of the population are often poorly constructed and situated close to latrines and sewers. The high level of permeability of the soil allows wastes to infiltrate and pollute the groundwater. According to Diarra (1997), laboratory tests carried out by the National Water and Energy Department of Mali have shown that groundwater in Bamako is also highly polluted with pesticides, metals (mercury and lead dominate) and other chemical substances.

Conclusions and Recommendations

Mali has extensive untapped groundwater resources which are used for domestic water supply but with limited use for irrigation and livestock watering. With about 90 percent of the cultivated land under small scale traditional farming and considering the significant contribution of the agricultural sector to the country's GDP, well developed groundwater resources for irrigation and livestock watering can have an important impact on the Malian economy and the living standards of a majority of the labour force who are engaged in farming. Groundwater can be abstracted from all the regions in Mali with a good (71%) average success rate of drilling. Generally in most part of Mali, the quality of groundwater is good for multipurpose use though improper discharge of industrial wastes and domestic sewage in some places pose a major threat to the use of the resource.

A comprehensive groundwater inventory is needed in Mali. This is particularly important to deal with some unaddressed issues in this study and to update some of the available information such as costs of the groundwater structures and lifting devices and the extent of groundwater use by the various sectors. The inventory should also include the social patterns in groundwater use, especially for irrigation and livestock. It should as well cover some socio-economic issues like the background of households using the resource, comparative cost analysis of using groundwater and surface water for irrigation and livestock watering, differences in abstraction systems used by small and commercial farmers and some gender dimensions. For sustainable use of groundwater resources in the country, it is important to establish a relationship between discharge and recharge of the groundwater. This should be done for the various hydrogeological units. By this, it would be possible to identify areas that abound in the resource for tapping and also to predict areas that are likely to experience problems of over exploitation in the near future and to curb this through appropriate policy decision.

Very limited information is available on the institutional aspects of groundwater use in Mali. This also requires further studies and could be included in the inventory studies. Issues to be addressed in this area include: the institutional framework for groundwater extraction, appropriation and use; the existence of any traditional institutions and laws governing groundwater; how “modern” codes mesh with “traditional” institutions and any differences between “informal” and “formal” systems regulating the use of the resource.

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CHAPTER 8

MOZAMBIQUE

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General description of Mozambique

Geography

Mozambique is situated on the east coast of Southern Africa facing Madagascar, between 10°27' S and 26°52' S latitude and 30°12' E and 40°51' E longitude. It covers an area of about 800,000 km^2, and has around 2,800 km of coastline. In the south, up to Beira, the country consists of a vast plain lying between 200 and 500 m above sea level and dominated in the west by the high plateaus of Natal, Swaziland, Transvaal and Zimbabwe. In the centre along the Zambezi river, wedged between Zimbabwe and Zambia, is the high plateau. East of lake Malawi, the country slopes gently down towards the Indian Ocean. The country is divided into 11 provinces and 148 districts. The capital Maputo is located in the most southern part of the country.

Physiography and climate

The climate of Mozambique can be described as being mainly warm, tropical climate (Savannah climate) in the area north of the Zambezi river and the coastal regions. South of the Zambezi river the climate is classified as tropical dry savannah and some upland areas around Chimoio, Lichinga and the area north of Tete, have a humid temperate climate. The average annual rainfall in Mozambique is around 1,000 mm, but the distribution shows great variations between the north and the south and the coastal and inland areas. Rainfall is mainly restricted to the warm season between November and April. Temperatures vary from an annual average of 18°C in the uplands of Lichinga, to an annual average of 26°C along the northern coast and near Tete. The average annual potential evaporation varies from 1,200 mm in the upland areas, to over 1,800 mm in the low areas in the north (DNA, 1987).

Natural vegetation covers about 78 percent of the total area of Mozambique, which is about 62 million ha. Although 36 million ha (45% of the total land area) is estimated to be suitable for agriculture, only 4.4 million ha was in use as such in 2002 (FAO, 2005). Soil, especially along the coastal areas, is generally sandy, having low fertility. Fertile soil is found at deltas (mouths) and along the rivers such as the Zambezi, Limpopo, Incomati, and the Umbeluzi. These locations have high agricultural potential and are most suitable for irrigation. Mozambique, being a generally low-lying country has a large number of river basins which drain across the central African highland plateau into the Indian Ocean. Most of these rivers are small and are highly seasonal, with torrential flow characteristics. Lake Niassa, Lake Chirua and the Cahora Bassa reservoir, covering about 7,000 km^2 in Mozambique (the remainder fall in the neighbouring countries), form the most important fresh water resources. Furthermore there are 1,300 small lakes, 20 of which have an area of between 10 and 100 km^2. As Mozambique is located at the downstream end of these transboundary river basins, it is in a very vulnerable position by being extremely dependent on the imported flows in terms of their quantity and quality (FAO, 2005; DNA, 1987).

Socio-economic context

The Mozambican population is currently estimated at a little more than 20 million and growing at 2.5 percent annually. Though ranked as one of the poorest countries in the world with GDP of USD 428, (2010 estimates), the economy is growing at a very fast rate (6-9%). About 70 percent of the population lives in rural areas and engages in agriculture, forestry and fisheries. Agriculture is the most important sector in Mozambique's economy as it employs more than 80 percent of the labour force and provides livelihoods to the vast majority of the population. It is also an important source of foreign exchange earnings, contributing to an estimated 25 percent of the country's export value. Agricultural is predominantly rainfed, so both temporal and spatial distribution of rainfall is critical. Other than agriculture, the country mines coal, natural gas and petroleum (energetic minerals), gold, iron and copper (metallic minerals), and marble and precious stones (non-metallic minerals). Though currently the mining sector is not yet as significant as agriculture, recent years (2010-2012) have seen a massive increase in proven reserves in coal (Tete) and gas (Cabo Delgado) and expansions in hydropower are planned, which would make Mozambique a major electricity producer and an exporter of coal. There are also some limited activities in the industrial and manufacturing sector like in food processing, cement production and petroleum refinery mostly in the cities of Maputo and Beira, which are the two major cities of Mozambique. Equally important are the Mozambican harbours which handle a lot of cargo and also serve some of the neighbouring countries (Hogaune, 2000).

Groundwater resources

Hydrogeology

Mozambique can be divided into three major hydrogeological provinces (DNA 1987). These are: basement complex, volcanic terrains and the Mozambique sedimentary basin. Other similar, albeit smaller sedimentary basins are: Middle Zambezi sedimentary basin, Maniamba sedimentary basin, Rovuma sedimentary basin and the Mozambique sedimentary basin, north of the Save river.

The basement complex covers 57 percent of the country, occupying the western part of the central region and almost the entire region north of the Zambezi. Geologically, the basement complex is divided into the Early Precambrian formations of the Zimbabwe Craton, which mainly consists of green schists, and the Later Precambrian formations of the Mozambique metamorphic belt, which is dominated by the Gneiss Granite Migmatite complex, alternated with metasediments (e.g. marble) and charnocktites. The volcanic terrain is developed along the edges of the sedimentary basin and the basement complex. It mainly consists of basalts, rhyolites and alkaline rocks. Primary and secondary fractures are the most important water bearing features. The weathering mantle is usually not very developed, except in the basaltic terrains, but here the material is very clayey and almost impermeable.

The Mozambique sedimentary basin, south of the Save, covers an area of about 21 percent of the country. Inland, its morphology is characterized by extensive erosion plains, gently dipping coastward. This part of the basin is dominated by continental formations, consisting of textured arkosic sandstones. The coastal belt is characterized by a dune area with an average width of 30 km, dominated by marine and transitional formations. The Incomati and Limpopo have built an extensive alluvial fan, inland from the dune belt. These porous aeolian sands form a regional phreatic aquifer with fresh groundwater. Permeability of the sediments decreases with distance inland from the coast as the clay content increases (Figure 8.1).

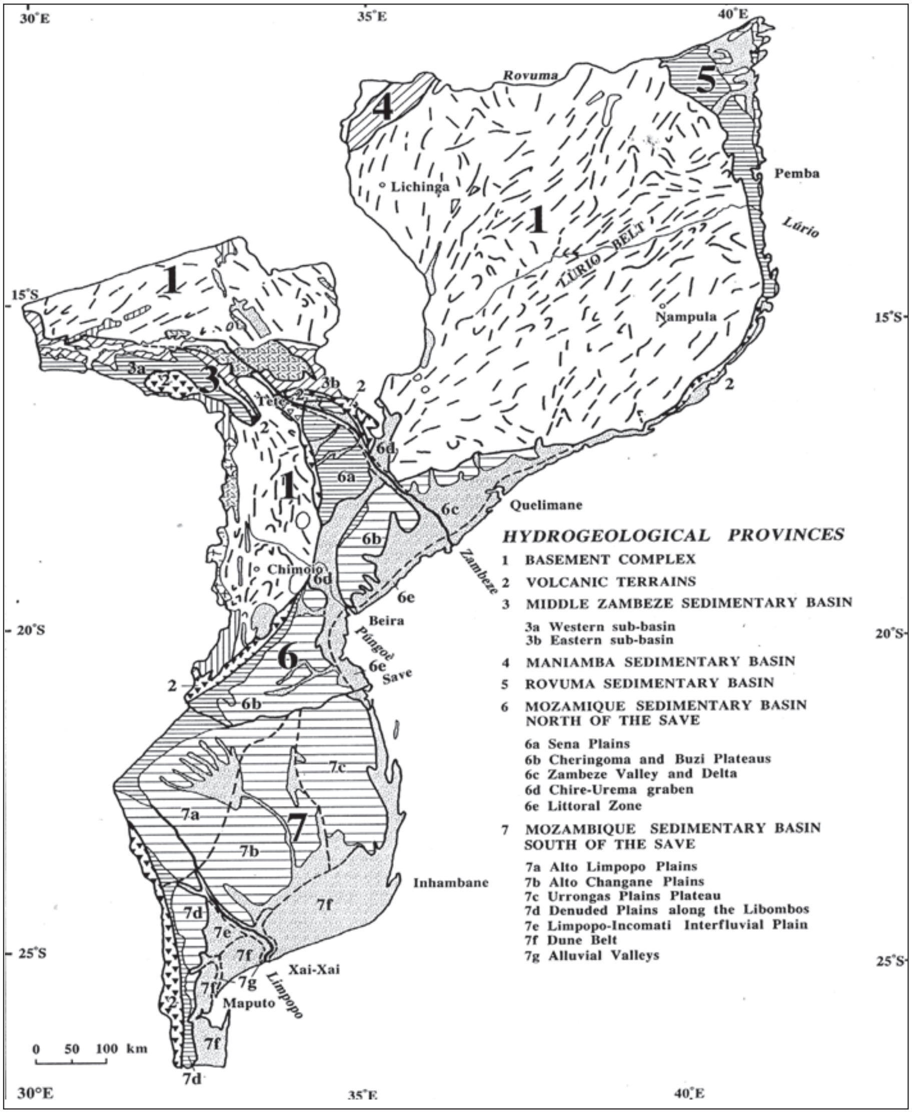

Figure 8.1 Hydrogeological provinces of Mozambique (Source: DNA, 1987)

Groundwater systems

The sedimentary basins form by far, the most productive aquifers in Mozambique. In the south, these form an extensive unconfined aquifer which is well replenished as a result of high rainfall and is easily exploited. Miocene carbonates also form good aquifers where they are karstic. These cover around 25,000 km^2 south of the Save river. The water table in this aquifer occurs at around 50 m depth. Yields can reach up to 20 $m^3 hr^{-1}$ (in the alluvial valleys of the Limpopo and Incomati), but are more often around 5 m^3 hr^{-1} (DNA, 1987).

Quaternary alluvium has in places been exploited for urban domestic supplies in the coastal areas. Much lower yields are found in the crystalline basement rocks, volcanic formations and consolidated sediments, except where weathered overlying layers are well-developed. Groundwater yields in the crystalline basement rarely exceed 7 m^3 hr^{-1} and groundwater storage is restricted to fractures.

The poor yield from boreholes have resulted in drilling to deeper depths with several number of boreholes exceeded depths of more than 100 m in Cretaceous and Cenozoic formations across the Cabo Delgado Province (BGS, 2002; DNA, 1987). Borehole yields in the volcanic terrain are very low, with averages below 3 m^3 hr^{-1} (DNA, 1987).

Reliable information on natural aquifer recharge in Mozambique is very scarce as only a few studies have been conducted on this subject in a few small areas. The recharge in the sandy soils around Maputo has been studied by IWACO in 1985 and was found to be somewhere between 140 and 185 mm yr^{-1}, which is around 20 percent of the total precipitation. In other areas with sandy soil and more precipitation, recharge was found to be higher, for example, 210 and 350 mm yr^{-1}, or around 30 percent of annual rainfall, near Pemba. In drier areas with less permeable soils, such as the semi-arid Chitima region near Tete, recharge values of less than 10 mm yr^{-1} were estimated (IWACO, 1985; DNA, 1987).

Groundwater quality

Little information is available on the quality of groundwater in the aquifers of Mozambique, but, the available information suggests that the groundwater for the larger part is fresh, especially in the aquifers of the basement complex and the volcanic terrains. Significant salinity problems are experienced in some parts of the Tertiary aquifers in the south as a result of natural seawater intrusion and marine deposits, forming areas with brackish groundwater. In large parts of Gaza, Maputo and Inhambane provinces, the groundwater (main aquifer 20-80 m depth) has electrical conductivity values well above the WHO standards of 1,500 μS cm^{-1} for drinking purpose. These values also make the water unsuitable for many crops and for livestock watering. In some particular instances (Chokwe, Chibugo), deep boreholes (100-150 m) have been drilled to reach the fresh water aquifers for irrigation. These boreholes are however too expensive (proper sealing of the upper saline aquifer needs to be achieved) to be considered for irrigation.

In most areas, groundwater of the phreatic aquifers is of acceptable quality, though in limited quantity. Pollution possibilities exist in the vicinity of industrial and urban developments (including that from sewage effluent and from centres of petroleum and chemicals manufacture and ports) as well as from agricultural activity. Pollution incidence is likely to be greatest in the coastal lowlands (DNA, 1987; BGS, 2002). Localized groundwater salinization is occurring in the Chokwe (Gaza Province) area, where since the 1930's extensive irrigation is in practice (using surface water). This has raised the local groundwater table and in addition has led to increased levels of salinity. An estimated 2,000 ha (out of 30,000 ha) has already been lost for normal crop production. Pollution by heavy metals is hardly measured or recorded.

Groundwater development and utilization

Groundwater abstraction

The distribution of boreholes in the country according to the national database is shown in Figure 8.2. Considering the higher yields in the alluvial formations, there seems to be potential for exploitation of groundwater in these formations found near the various rivers. Well yields here are such that large scale groundwater development (for agricultural purposes) is possible in some areas i.e., in the Zambezi and Incomati river basins with safe well yields of up to 100 $m^3 h^{-1}$. As of now, larger scale exploitation is limited to a number of towns that rely either completely or partly on groundwater extraction for their drinking water supply (AfDB, 2005). Groundwater is currently used only in the five main towns of Chokwe, Pemba, Tete and Xai Xai (World Bank, 2007).

A special case is the Maputo peri-urban area, where an estimated 50,000 households are served by over 400 private operators using water from boreholes. Currently efforts are on, to register and regulate this informal service provision. During a meeting in December 2009, of the water regulating body of Maputo areas, [ARA-Sul (Southern Water Regulating Body)], it was mentioned that around the Maputo area (Incomati basin in particular), groundwater licenses for irrigation should be avoided, considering the strategic importance of groundwater in the water supply of Maputo.

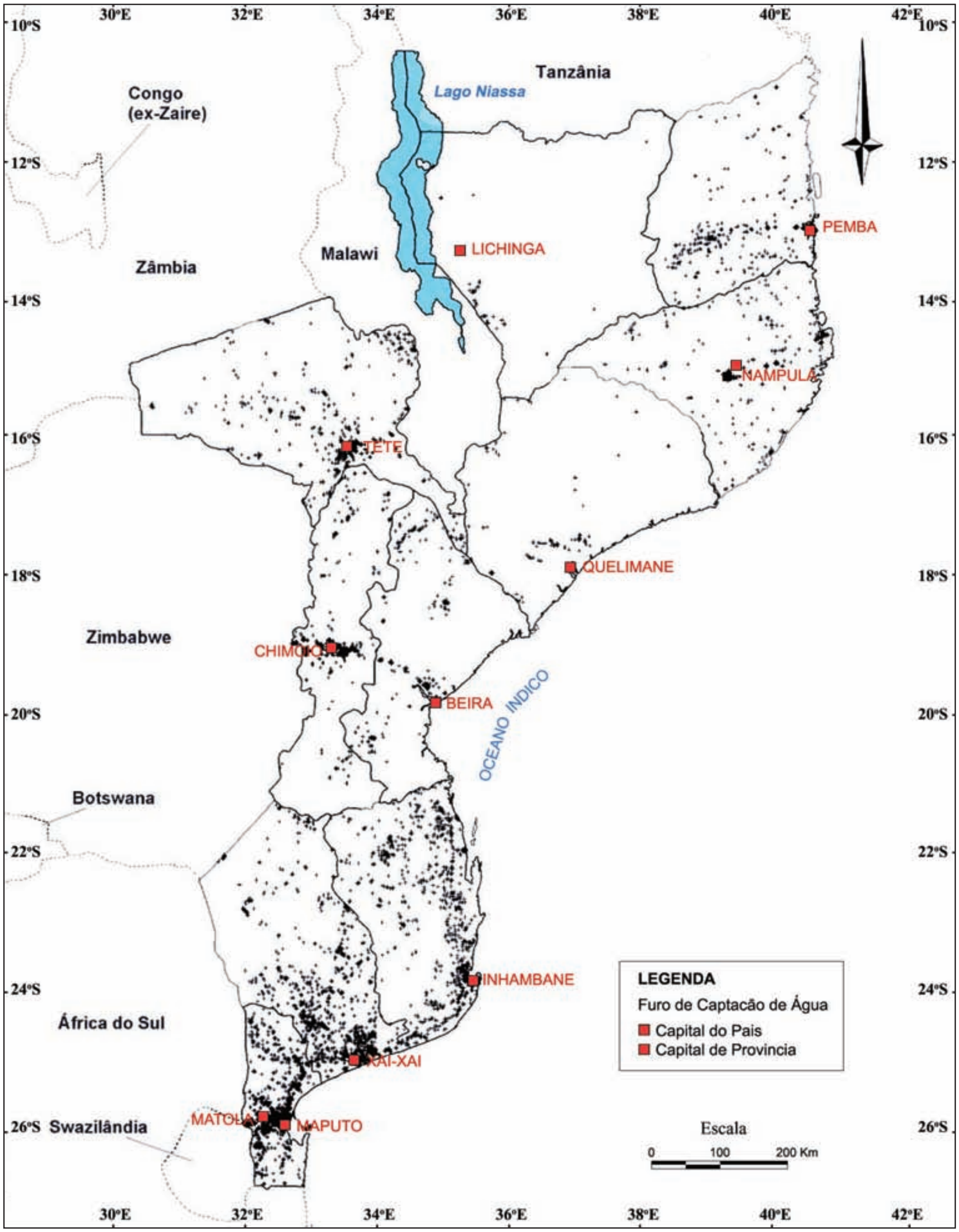

Figure 8.2 Map with distribution of boreholes/wells for groundwater extraction (Source: DNA, 1999)

Cost of groundwater development

The design of boreholes most frequently used in Mozambique for rural groundwater development projects has a PVC casing / filter of 4” (101 mm) internal diameter right to the bottom. The Afridev manual pump is recommended for communal boreholes with dynamic level not deeper than 45-50 m. There is not a single standardized manual pump for dynamic levels deeper than 50 m, but in many cases the Afrideep pump is being used. For irrigation, submersible pumps are preferred though the 4 inch design often hampers installation of more powerful pumps and the limited electrical grid impedes more use of these pumps. More suitable 6 inch casing brings considerable more costs (at least 30% more) as there is little demand and few contractors have them.

The most common drilling technique is down-the-hole air-rotary percussion for hard rock and mud drilling for the southern sedimentary areas. An extensive survey conducted by WSP (2005) in various provinces showed a mean borehole depth of 46 m (range 31-55 m) and average price of USD 155 m^{-1} (range USD 136-166 m^{-1}). Most of these boreholes are equipped with Afridev hand pumps and are mainly for domestic water supply. For irrigation purposes, basically only electrical submersible pumps are considered. There are a limited amount of suppliers (all imported) with price ranges depending on the pump specifications. A simple 1 $m^3 hr^{-1}$ pump can cost about USD 1,000 and 10-20 $m^3 hr^{-1}$ pumps can be up to USD 3,000, depending on the diameter and capacity. Installation is normally done by the contractor that is constructing the borehole and prices depend on the number of boreholes and the location in the country.

Shallow wells are limited in numbers throughout the country. They are typically with a diameter of around 1.5 m with typical depths of 5-7 m, but can reach to 15 m. Following the government guidelines, most shallow wells are equipped with Afridev hand pumps or rope pumps. Cost information is sparse, but an estimation of USD 3,500 for a properly constructed well seems valid (without a pump) (AfDB, 2005). Large diameter (more than 2 m) shallow wells are scarce and little is known about their use for irrigation. Most shallow wells used in small scale irrigation are traditional wells; hand dug and without any lining or reinforcement. Water is typically extracted with a bucket. The cost of these shallow wells is mainly determined by the labour input to the construction and the well depth. Though hard to estimate as it is done informally, the cost is thought to be varying from USD 50-200.

In Table 8.1, the cost of borehole (excluding cost of negative attempts across the provinces is provided. Recent studies indicate higher costs, as drillers are contracted on a no-cure-no-pay basis. This approach is hampered because success percentages in drilling projects remain poorly documented, as only positive boreholes are registered (defined as at least 1 m^3 hr^{-1}). Exemptions are particular projects such as ASNANI with reported 80 percent success in two northern provinces (though with great variation, with certain districts as low as 36%) (ASNANI, 2009).

Table 8.1 Indicative prices per province

Province	Average bore hole depth (m)	Price per meter, including VAT (USD)	Price of bore hole (USD)
Maputo	46	136	6,251
Gaza	55	143	7,890
Inhambane	54	155	8,358
Manica	41	155	6,346
Sofala	43	151	6,493
Tete	31	159	4,915
Zambezia	31	162	5,032
Nampula	40	155	6,191
Cabo Delgado	37	166	6,146
Niassa	38	166	6,312
Country average	46	155	6,393

Source: WSP (2005)

Groundwater utilization

Domestic purpose

Groundwater is the main source of water for most rural water systems and for the towns of Pemba, Xai-Xai, Tete and Chokwe. According to the national census carried out in 2007, about 60 percent of the population in Mozambique use groundwater for domestic water supply (see Table 8.2). Groundwater is mostly extracted through hand pump mounted boreholes (14.1%) and open shallow wells (46.8%) and is used for drinking water in rural areas. Tapped water (10.4%) is also partly produced from groundwater. Surface water from rivers and lakes is only used by 17.1 percent of the households. As there are no forms of monitoring or controlling groundwater use, there is no quantitative or quantitative information available. Reliable estimates on the available resources are also non-existent (AfDB, 2005). A prognosis by DNA, (2006) indicated over 17,000 boreholes throughout the country in 2010.

Table 8.2 Sources of domestic water supply in Mozambique

Water source	% population
Traditional wells	46.8
Borehole and protected shallow wells	14.1
River/stream/lake	17.1
Public standtap	10.4
Yard connection	8.2
In-house tap connection	2.0
Springs	0.1
Rainwater	0.6
Others	0.7

Irrigation

Irrigation is important in Mozambique as climate is inconsistent with variable rainfall combined with high potential evaporation. The risk of harvest loss in rainfed agriculture exceeds 50 percent in all regions south of the Save river, and can reach up to 75 percent in the interior of the Gaza Province. The central and northern regions of the country have more appropriate conditions for rainfed agriculture, where the probability of good harvests during the wet season is 70-95 percent. The regions north of the Manica Province and the south of the Tete Province have a risk of loss of harvest in rainfed crops of more than 50 percent and are excluded from this centre north region (FAO, 2005).

In 1987, water use for irrigation in the country was estimated to be 1,472 km^3 yr^{-1}. Of this water, only 2 percent was estimated to be groundwater (DNA, 1987). The use of groundwater is low because groundwater in found mainly in the sandy coastal plains where the soil is often poor, and in alluvial valleys where surface water is often more conveniently available. More than half of the potential irrigable land is in the Zambezi valley. Other basins included in the estimate were the Limpopo/Incomati, Pungué/Buzi, small rivers in Zambézia, and the Lugenda and other rivers in Niassa and Cabo Delgado (World Bank, 2007). Principal irrigation systems in the country are at Chokwe and the sugar plantations at Incomati, Maragra, Buzi, Mafambisse and Luabo, covering a total of some 59,000 ha and all being irrigated with water from nearby rivers. Groundwater is only used for irrigation to a very limited extent, in the family smallholder sector (FAO, 2005). Some known examples of groundwater irrigation, though all are of marginal importance, include 1 km^2 small scale farming in Manica Province, small private horticulture farms growing fruits and vegetables in Maracuene, use of spillage water from hand pumps for mini irrigated plots (Nampula Province) and shallow wells used in and around Maputo.

Livestock watering

Shallow wells and to a lesser extent boreholes are used for the watering of livestock in the rural areas which are not close to surface water. This is the case in most parts of the country, with the exception of the upper Pungué basin in Manica Province, the Zambezi delta, and parts of the Zambézi, Nampula and Niassa provinces. Although there is no information on how much groundwater is used for this, if the livestock numbers across the country is any indication, it means that this figure should not be underestimated. Nevertheless, groundwater is regarded as the secondary source, as often the effort of lifting groundwater is considered greater than the effort of moving elsewhere with the livestock for a surface source. For example, in dried up river beds, shallow wells are dug for cattle to drink from (e.g. Chicualacuala district, Gaza Province) and some cattle troughs have been linked to drainage of hand pumps like in Changara district, Tete Province.

Institutional and legal framework

The Water Law (Law 16/91) states that the natural resources of soil and subsoil and the continental waters are the property of the state and not of the public domain. The Water Law does not deal with specific aspects related to the use of groundwater. The more relevant Law (Law 17/91) is the one that established the Regional Water Administrations (ARA's), which delegate the daily operations and management responsibilities with respect to the national water resources to five autonomous and financially independent institutions, each one covering a series of basins. The National Water Policy from 1995 (GOM, 1995), which covers principal policies with the main aim being to guarantee the attainment of sustainable water supply and sanitation, was updated in 2007 (GOM, 2007). Together with the water law it is stipulated that (i) water supply and sanitation services should be provided in accordance with the demand and economic capacity of the users; (ii) tariffs should permit the recovery of operational and maintenance costs, and later contribute to investment and sustainability of the systems; and (iii) as far as possible water supply and sanitation services should be decentralized to autonomous local agencies.

The national water resources strategy (DNA, 2006) has, as its objective, the proper implementation of the water policy for water resources management. This also reinforces that the ARA's are the main body responsible for the allocation of water for any use, including allocation of groundwater for irrigation. Concerning the agricultural side, one of the main documents defines plans for a green revolution in Mozambique with its main objective to increase the production and productivity of small providers for an improved food supply in a sustainable and competitive manner. Groundwater though, is not mentioned in any specific way (MA, 2008).

Conclusions and Recommendations

Groundwater plays a significant role in the supply of drinking water but is only used sparsely for irrigation in Mozambique as the country still has enough area that can be developed under irrigation using surface water resources. Additionally, large areas in southern Mozambique are deemed unsuitable due to salinity problems. Secondly, it seems that the lack of information (resulting in an unknown risk of low yield and/or high drilling costs) is a larger constraining factor than the actual potential of the groundwater. Besides this, there is a general consensus that surface water is more cost effective for irrigation than groundwater. The potential for large surface water irrigation schemes are still present in Mozambique and thus the interest for groundwater is low. Even so, there is little knowledge on the usage of groundwater around non-perennial rivers. Groundwater is mainly used for subsistence farming, except in certain labour intensive areas around Maputo. Legislation of groundwater abstraction is in its infancy in Mozambique. Capacity is presently very limited and technical assistance and capacity training in this is essential. Groundwater is probably underutilized as potential users do not have access or knowledge of the potential in their area.

Knowledge gaps still exist within institutions and administrative departments assisting in the development of Mozambique. It can be concluded that statistics about surface water flows can be achieved by having agriculture as an active stakeholder element in the *Sistema de Informação Nacional de Água e Saneamento* (SINAS) initiative. The information about groundwater and the link to on-going agro-livestock census would be helpful, especially in analysing to what extent agriculture and livestock is dependent on groundwater. The communications between the government administrations will help the ARA's in collecting abstraction rates and monitoring the extent of groundwater development and use. The information technology tools like Remote Sensing and GIS activities will play a vital role, in particular related to the updating of hydrogeological data. Ideally, efforts should also be made to create a new hydrogeological map. A major challenge is posed by the deteriorating status of the land due to the usage of saline water for agriculture in the Mozambique. Awareness has to be raised on the risks and limitations of using brackish water for irrigation in order to avoid further deterioration of the land. In addition, promoting the use of crops that are better resistant to higher salinity will go a long way in supporting this awareness campaign. Further research on alternative methods for groundwater usage and replenishment should be considered. Options such as sand dams, aquifer recharge and underground dams could assist in increasing groundwater availability, in particular, for livestock.

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CHAPTER 9

NIGER

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General description of Niger

Geography

Niger is a landlocked country located between latitude 11°37' N and 23°33' N, and between longitude 0° E and 15° E with an area of 1,267,000 km^2. The country is bordered in the north by Libya, Chad to the east, Nigeria in the south, Benin and Burkina Faso in the south west, Mali in the west, and Algeria in the north west. According to the current administrative and territorial architecture on decentralization, Niger has 8 regions (Agadez, Diffa, Dosso, Maradi, Tahoua, Tillabéry, Niamey and Zinder), 36 districts and 265 councils.

Physiography and climate

The climate of Niger is predominantly Sahelian, dependent on the movements of the inter-tropical convergence zone. The rainfall is unimodal and falls between the months of

May-June and September-October with large spatial and temporal variability. Annual rainfall varies from 800 to 900 mm in the south west to less than 100 mm in the north. Average temperatures in the country vary from 16°C to 43°C. Evaporation is high and estimated to be 2,560 mm yr^{-1}.

In general, Niger has four main climatic zones that coincide with the agro-ecological zones of the country. These are the Sahelo-Sudanian, Sahelian, Sahelo-Saharan and the Saharan zones. The Saharan zone to the north of the country is most prominent as it covers 77 percent of the country. The annual precipitation in this zone is less than 150 mm and major agricultural activities include irrigated farming and nomadic pastoralism. The Sahelo-Saharan zone covering 12 percent of Niger's total area is conducive to pastoralism and its annual precipitation ranges from 150 mm to 300 mm. The Sahelian zone covers 10 percent of Niger's total area, receives 300 to 600 mm of annual precipitation, and is conducive to agro-pastoralism. Finally the Sahelo-Sudanian zone at the southern tip of the country covers about one percent of Niger's total surface area, receives 600 to 800 mm of annual precipitation and is conducive to the most intensive agriculture, including animal husbandry.

Soils in the country are generally poor. Most farmlands are deficient in organic matter and phosphorous. The soils are affected by continuing loss of fertility and acidification, water and wind erosion, a low water storage capacity, alkalinity and salinization. Lithosols are found on steep mountain areas and high plateaus (Aïr, Ader Doutchi, Continental terminal). Fossil valleys (Dallols, Gulbi, Korama), river valleys, Komadugu, lake Chad and Manga depressions are characterized by hydromorphic soils and vertisols. Total farm area is estimated at 270,000 ha, of which 140,000 ha lies within the Niger river valley.

Drainage

About 90 percent of Niger's total renewable water resources come from outside the country. The average annual rainfall is about 151 mm (equivalent to 191.3 km^3 yr^{-1}) (FAO, 2005). The main source of surface water is the Niger river, which lies mostly outside the country. This river cuts across the south eastern part of Niger on about 550 km and it is primarily exploited to irrigate a limited land area put under rice cultivation. There are seven hydrological units including the Komadougou Yobe and the Niger rivers, the latter being the only permanent water source. In addition, there are 200 semi-perennial to perennial lakes but their use depends highly on the erratic annual rainfall.

According to FAO (2005), the total renewable water resources (TRWR) of Niger are about 33.65 km^3 yr^{-1}, of which surface water contributes 31.15 km^3 yr^{-1} and groundwater contributes the remaining 2.5 km^3 yr^{-1}. The internal renewable water resources are estimated at 3.5 $km^3 yr^{-1}$ and the TRWR per capita is 2,248 $m^3 yr^{-1}$ (2009 estimate). The annual renewable water resources are extremely irregular and difficult to preserve as many areas of the country experience arid and semi-arid climate conditions. Only a fraction of the renewable water resources is currently used because of technical, economic and geopolitical reasons.

On average, the Niger river provides 29 $km^3 yr^{-1}$ of renewable surface water to Niger (FAO, 2005). This constitutes about 93 percent of the total surface water resources of the country. This volume has fluctuated a lot due to the drought cycle observed over the past decades. Observation data from Niamey gauging station show that from 1929 to 1991, the average volume was 28 $km^3 yr^{-1}$ and average volume for the periods 1929-1968 and 1969-1991 were 32 $km^3 yr^{-1}$ and 23 $km^3 yr^{-1}$, respectively (FAO, 2005). The most significant lake in the country is Lake Chad, located in the extreme east of the country. This lake has been shrinking and has disappeared within the country's boundary since 2004. Small amount of Niger's surface water resource is held in 20 dams, with an annual total volume of 0.1 km^3 (FAO, 2005). Several of the dams are no longer functioning due to siltation.

Total annual water withdrawal in Niger in the year 2000 was estimated at 2.364 km^3, representing about 7 percent of the total renewable water resources. Agriculture took a giant share of 2.08 km^3, followed by municipal water supply (0.2922 km^3), and lastly industry with 0.0327 km^3 (FAO, 2005).

Socio-economic context

The population of Niger is estimated at about 16.47 million people (July 2011), with annual growth rate of 3.6 percent (CIA, 2011). About 49.6 percent of the population is below the age of 15 years; 48 percent between 15 and 64 years and 2.3 percent 65 years and over. About 90 percent of the population is located in an area 200 km wide along the border with Nigeria where the volume of rainfall is more favourable for crop production and livestock grazing (UNDP, 2007). Three of the 8 administrative regions (i.e., Maradi, Zinder and Tahoua) are home to 62 percent of Niger's population, while two regions (Tillabéry and Dosso) account for a quarter of the national population. About 7 percent of Niger's population lives within the Niamey City Council. About 77 percent of the population live in rural areas where economic and social development are extremely low, life expectancy is less than 55 years, adult literacy is about 29 percent and infant mortality is 820 per 100,000 live birth (CIA, 2011).

Niger's economy depends on subsistence agriculture, livestock, re-exports trade and uranium (CIA, 2011; UNDP, 2007). The country is one of the poorest countries in the world with minimal government services and insufficient funds to develop its resource base. According to UNDP (2007), 63 percent of Niger's citizens live below the poverty line of 1 USD a day. Food insecurity and a lack of proper housing pose acute problems. The economy is frequently disrupted by extended droughts common to the Sahel region of Africa.

Sector contribution to GDP in the year 2010 was as follows: agriculture (37.1%), industry (15.5%) and services (47.4%) (CIA, 2011). On a whole, GDP purchasing power parity is USD 11.05 billion (2010 estimate); while that of per capita GDP purchasing power parity is USD 700 (2010 estimate). Labour force by occupation is agriculture (90%), industry and commerce (6%) and government (4%) (UNDP, 2007). Crop production activities in the country are mainly concentrated in the south in the Sudan zone within a strip of 200 km wide that receives the highest amount of rainfall. The main activity in the Sahelo-Sudanian zone in the north is livestock grazing. Only 3.5 percent of the land is arable (4,500,000 ha) and irrigation is practiced only on 85,663 ha (UNDP, 2007). The agricultural production systems are very extensive and every year 70,000 to 80,000 ha new land is occupied for mainly subsistence farming by smallholders. Slash and burning practices are widely spread and 85 percent of the rainfed crop production is used for household consumption.

Groundwater resources

Hydrogeology

The geology of Niger comprises mainly the Precambrian basement shield, which occurs in the west of Niger (bordered by the river Niger) and in the north it is partly concealed by dunes and 'cover' sands; and the sediments of the Iullemeden basin found in the eastern and central parts of the country (Machens, 1967) (Figure 9.1). The basement shield can be divided into *Prebirimian, Birimian* and *dolerites* of younger age. The *Prebirimian* consists of migmatites, granulites, and amphibolites, which are found only as local enclosures within the batholiths of the more recent *Birimian.* The *Birimian* formation covers most of the region. It consists large of batholiths and thick layers of argillic schists, greywackes and sericitoschist series, with rather weak metamorphisms. The batholiths are composed of granites, granodiorites and quartz bearing diorites. Schists with high metamorphism and intercalations of magmatic rocks occur locally between the *Prebirimian* and the *Birimian* formations. According to Machens (1967), the *dolerites* are of younger age and were formed during a phase of fracturing of the basement shield.

The sedimentary formation in the Iullemeden basin can be divided into (a) series of *Infracambrian* age, (b) the Perm to Cretaceous "*Continental intercalaire*", (c) the upper

Cretaceous to lower Eocene "*Continental hamadien*", (d) the Eocene to Pliocene "*Continental terminal*", and (e) Quaternary *alluvial deposits, Regs, dunes* and *sand* deposits (Machens 1967). The *Infracambrian* series overlay the basement shield horizontally and occur only to a small extent near the Niger river. The "*Continental intercalaire*", located at the western edge of the Aïr, can be divided into 4 groups, namely, the Perm to Triassic arkose of Izegouandane, the Jurassic sandstone of Agadez, the lower Cretaceous claystone of Irhazer and the vast lower Cretaceous group of Tégama, which is composed of sandy, clayey or calcareous fluvial indurated sediments. According to Machens (1967), the "*Continental hamadien*" sediments trace the Iullemeden basin with an almost circular pattern. They are divided into (a) the upper Cenomanien and lower Turonien consolidated sandy-clayey gypsum and carbonates at the edge of the Tegama group, (b) the upper Turonian white limestone and marls, (c) the lower and middle Sénonien limestone and claystone banks, (d) the upper Sénonian sandstones, mudstones and shales, (e) the lower Eocene marine carbonates and claystones, and (f) the undifferentiated Continental hamadien deposits, which are composed of claystone, sandstone, limestone and conglomerates.

The "*Continental terminal*" is found in the central part of the Iullemeden Basin, with thickness ranging from a few decimetres at the edge of the *Birimian* to about 450 m in the centre of the basin (Machens, 1967). It comprises (a) the siderolithic series of Adar Doutchi with kaolinitic iron-rich claystone and a maximum depth of 80 m, (b) the clayey-sandy series with lignites, (c) the undifferentiated lower *Continental terminal*, and (d) the upper clayey sandstone series, with a maximum thickness of 50-100 m and consisting of a mixture of quartz, iron-oxides and kaolinite.

Several types of *alluvial deposits* can be distinguished in Niger. These are: (a) recent deposits of various composition found along the Niger river and its tributaries, (b) various terrace generations at the Niger river and ancient Niger tributaries, (c) the Dallols with alluvial sand and clay deposits representing ancient Pleistocene river valleys originating from the Aïr, that were later covered with small dunes and (d) alluvial plains of Pleistocene age with quartz gravels in the region south of Maradi (Graef, 2000; Bergoeing and Dorthe-Monachon, 1997; Thevoz et al., 1994; Bui, 1986).

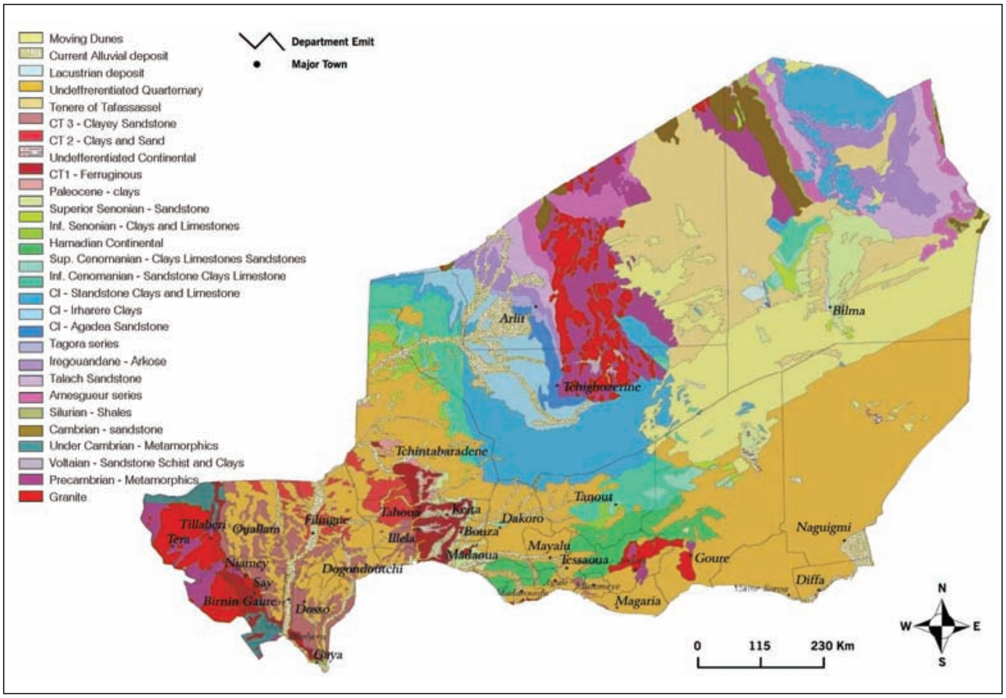

Figure 9.1 Simplified geological map of Niger (Source: Ministere de l'eau, de l'environnement et de la lute contre la desertification 2009)

Groundwater systems

The aquifer system in Niger can be classified as continuous and discontinuous aquifers. The continuous aquifer consists of the *Continental Terminal, Continental Intercalaire, Sandstone D'agades, Sandstone De Teloua,* and Sandstone Primaires. Key characteristics of the continuous aquifers are presented in Table 9.1. The *Continental Terminal* aquifer consists of clay and clayey sandstone with sand. It is an unconfined aquifer which extends across the whole of the Niger basin. The *Continental Intercalaire* aquifer is composed of sandstone, clayey sandstone, sand and clay and has a thickness of 500-700 m. In some areas, this aquifer is shallow with an impervious clay layer on top, transforming it into a confined aquifer. It is believed that in the Tegema Region, these aquifers contain large volumes of water that are currently not being used because they are deep seated (CIEH, 1986). The *Sandstone D'agades* aquifer contains confined aquifers that sometimes create springs. In between D'agades and In Gal, the waters of this aquifer are of good quality but in the western part of the country, the waters of the *Sandstone D'agades* aquifer are more brackish. Recharge to this aquifer from precipitation is negligible. The *Sandstone De Teloua* aquifers are located in the northern part of the country and are mainly confined, having depth of between 30 and 90 m. Finally, the Sandstone Primaires are found between the basement of Air and the sandstone of Teloua. The major sandstone and/or sandy aquifers include *Nappe de l'ordovicien'* which is high yielding, covers a large area but as it is deep, is so far unexploited; the *Nappe du De'vonnien superieur'*, has lower yields and covers less area than *Nappe de l'ordovicien'*; *'La nappe des sandstone de Farazekat' (Viseen inferieur)*; and *'La nappe des sandstone de Tagora'* (Nmurien).

Table 9.1 Characteristics of the continuous aquifers in Niger

	Renewable resources ($Mm^3 km^{-2} yr^{-1}$)	Surface area (km^2)	Natural renewable resources ($Mm^3 yr^{-1}$)	Recharge (mm)	Storage coefficient ($x10^{-3}$)	Draw down (m)	Exploitable reserves (Mm^3)
Continental Terminal	0-0.05	96,100	1,220	13	1-8	1/3 of sat. depth	39,770-91,510
Continental Intercalaire *Confined aquifer*	n.d	164,560	n.d	n.d	0.1-0.5	100	28,210-60740
Continental Intercalaire *Water table*	0-0.05	222,660	650	3	5-10	10	111,330-222,660
Sandstone D'agades	0.5-1	27,270	n.d	n.d	0.5-0.8	100	13,640-27,270
Sandstone De Teloua	0.05-0.1	26,460	n.d		0.1-0.2	100	1,320-2,650

n.d: no data.
Source: CIEH (1986)

The discontinuous aquifers are represented by the voltaic basement in the south, the Air in the north and small stony/hilly areas in Maradi and Zinder. The voltaic basement aquifer is formed by the Precambrian formation and it is composed mainly by schists, basalts, quaternary, green rocks, granites, etc. These aquifers contain groundwater in fractured zones (CIEH, 1986). The Air aquifers are mainly alluvial aquifers found along hydrographic network. However, in places where alteration of kalionite has been noted, the infiltration rate has declined. Finally the *Maradi* and *Zinder* aquifers are shallow and recharge is mainly from runoff due to the sandy nature of the topsoil.

There is little information available on the mechanism and rates of groundwater recharge in Niger. The shallow aquifers of the country are mainly recharged by seasonal rainfall and flooding (Perry, 1997). The recharge mechanism in most areas is most likely to be pistons-flow as this is typical of recharge behaviour in the Sahara/Sahel areas (Scanlon et al., 2006). Generally, recharge rates of aquifers in most areas of the country are low and can only support the use of traditional or improved manual technologies (e.g., treadle pump) for lifting water. However, in some locations, hand-dug lined wells and tube wells fitted with mechanized pumps have been installed and these are yielding sufficient water (Perry, 1997).

Table 9.2 presents recharge rates for specific studies at different locations in south west of Niger. Bromley *et al.* (1997) reported a mean recharge rate of 13 mm yr^{-1} for the *Continental Terminal* aquifer in south-west of the country, using the chloride mass balance approach at one location covered with Tiger bush vegetation. Using a combination of tritium tracer (^{3}H), carbon tracer (^{14}C) and water table fluctuation (WTF), Fraveau *et al.* (2002) obtained recharge rates of 1-5 mm yr^{-1} in areas of natural savannah ecosystem in north west of Niger. Ludec *et al*. (2001) obtained high recharge rates (10-47 mm yr^{-1}, with average of 20 mm yr^{-1}) for areas in south west Niger, where the natural savannah vegetation was replaced with millet fields and fallow periods. CIEH (1986) reported recharge rates of 13 mm yr^{-1} for the *Continental Terminal aquifer* and 3 mm yr^{-1} for the *Continental Intercalaire* and the *Maradi* and *Zinder* aquifers.

Table 9.2 Groundwater recharge for specific areas in the south west of Niger

Study area	Area (km^2)	Estimation method	Rainfall (mm yr^{-1})	Recharge (mm yr^{-1})	Source
South west Niger	3,500	Model based on WTF, ^{14}C, ^{3}H (10-year)	567	1-5	Favreau *et al*., 2002
South west Niger	-	^{14}C		3	Leduc *et al*., 2001
	8,000	^{3}H		6	
	-	WTF		10-47 (20)	
South west Niger	-	CMB	564	13	Bromley *et al*., 1997

Source: Scanlon *et al*. (2006)

Groundwater quality

There is little information available on the quality of groundwater in Niger. In a study of groundwater quality in the south west of Niger, which analysed data from more than 100 wells monitored for more than 3 years, Hassan (2010) reported that salt contents of groundwater in the Quaternary alluvial deposits in the Niger river valley and the *Continental Terminal* (clayey to sandstone) on the left bank of the Niger river are generally low. Measured electrical conductivity were in the range of 180 μS cm^{-1} to 3,030 μS cm^{-1} for the Quaternary alluvia deposits and 36 μS cm^{-1} to 1,338 μS cm^{-1} for the *Continental Terminal (CT)*. Groundwater in the CT aquifer was mainly the calcium carbonate type, with average temperature 30.6°C and pH in the range of 3.7 to 7.1. The alluvia aquifers contain mostly calcium and magnesium bicarbonate waters, with pH between 5.7 and 7.9 and average temperature of 29.6°C.

A study conducted on chemical and bacteriological pollution of groundwater in Niamey (a city of some 700,000 inhabitants) by Chippaux *et al.* (2002) using 22 wells and 24 boreholes revealed that, the shallow aquifers located on each bank of the Niger River and connected to the wells presented high levels of oxidizable nitrogen and bacteriological pollution (coliform and *faecal Streptococcus*), thereby rendering the water unfit for human consumption. Groundwater from the deep aquifers fitted with pumps was also found to be polluted though to a lesser extent, compared to the shallow aquifers and faecal pollution increased after the rainy season. The pollution is attributed to the inadequate sanitation facilities in Niamey and the seepage of polluted materials.

Groundwater development and utilization

Groundwater abstraction

Groundwater abstraction structures in Niger are wells and boreholes. Two types of wells exist in Niger, namely, the hand-dug tube well and modern well. The hand-dug tube well is a traditional groundwater abstraction structure, which is unlined and may be supported with wood. It is a low-cost water source for small farmers and widely used in the country. This technology is inexpensive and quickly installed. Depending on the aquifer and soil conditions, hand-augured tube wells can yield up to 14 m^3 hr^{-1} (Perry, 1997). The modern wells are lined with concrete rings or bricks with mortar to improve safety and water quality. Sonou (1997) reported that, as part of a Lower Tarka Valley project, 700 washbores and drilled tube wells were constructed throughout Niger by 1993. Niger government estimates indicate that the rural population, which accounts for about 78 percent of the total population, is served with modern wells that comprise 13,000 cement-lined wells, 7,000 machine-drilled boreholes fitted with hand pumps, and many small-scale piped supplies. Figure 9.2 shows the location of water abstraction points throughout the country. Most of the wells, boreholes and dugouts are found in the Sahelian and the Sudan zones along the border with Nigeria. These locations are not only home to most of the country's population but also areas where irrigation is practiced for dry season vegetables cropping.

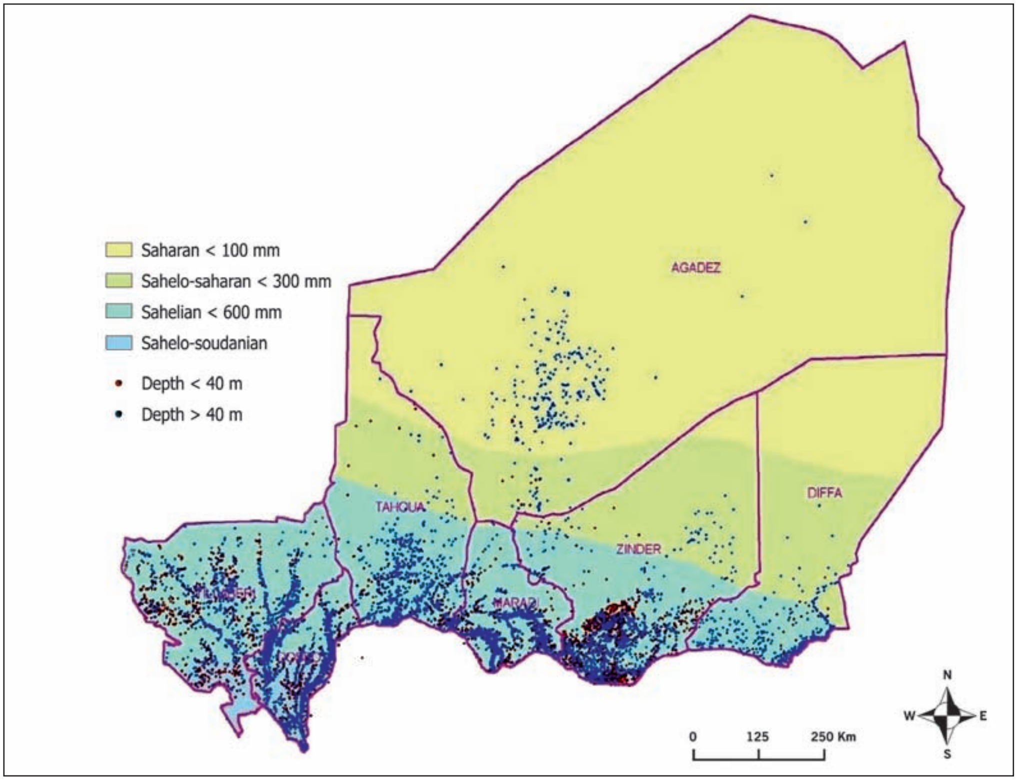

Figure 9.2 Location of water points (Source: Ministere de l'eau, de l'environnement et de la lute contre la desertification 2009)

There are many types of water-lifting devices used in Niger, both manual and mechanized. In the 1970s, bailers (also known as Zimbabwe bucket pumps) made of a metal or PVC tube with a loop in the top and flap valve in the bottom were introduced to lift water from hand-drilled wells. These are manual devices that are still used in many wells in Niger, although some have been superseded by locally made treadle pumps (foot or hand operated suction or suction/pressure pumps) or even motor pumps. Maintenance of treadle pumps can be done by users themselves or in local workshops. Since 2005, the rope pump which can lift water from 20 m (compared to the treadle pump limit of 7 m) has been locally manufactured and promoted in Niger. Traditionally, the numerous market gardeners in Niger had used calabashes to lift water from the open wells, but as soon as people realized they could water their crops more efficiently, the hand- augured wells and treadle pumps became popular. Another manual water lifting device used for drawing groundwater in Niger is the Volanta hand pump, which can lift water from wells that are deeper than 40 m (even up to 110 m deep). In case of occasional breakdowns, the local distributor gives privatised support on request to local maintenance groups or individuals for repairs.

The vast majority of mechanized pumps used in Niger are motorized centrifugal pumps. One of the drawbacks to this technology is that the ideal suction lift as documented in the manual is 6-7 m but a survey of motorized farmers around Maradi revealed that the net suction head is actually between 2 and 5 m (Gay, 1994). For suction head of 2-5 m, the abstraction rate is not that high, compared to what would have been abstracted if the suction was at around 6-7 m. Low abstraction rates limit the potential for irrigated agriculture and increase the pumping cost as pump users will have to run the engine at slower than optimal speed to better match the pump's discharge capacity with the yield of the well. This increases the fuel consumption per cubic meter of water pumped.

Cost of groundwater development

The unit cost of digging and lining large diameter wells depends on the depth of the wells, the hardness of the formation, the difficulty of access and the distance from the capital. It is therefore difficult to give one single price for well digging even within the country. In discontinuous aquifers, it is always necessary to drill a reconnaissance borehole to detect the presence of water before digging a well (FAO, 1986). Typical costs of installing wells from development agencies and the Office des Eaux du Sous-sol / Office of Underground Water Sources (OFEDES), the Niger's special authority for construction of wells, are shown in Table 9.3.

Table 9.3 Costs of installing wells and boreholes in Niger

Organization/project	Location	Unit cost (USD m^{-1})
OFEDES	Maradi-Zinder	365
PHV project	Dosso	370-503
Sahel Consult	Sediment deposits	200-300
	Hard rock	260-360
USAID Report	Niger	157

Source: World Bank (2007)

A hand-augured well, fitted with a treadle pump costs from USD 120 to USD 460. These costs include the hand-auguring service, which covers the labour, transport, screen and casing materials-costing from USD 50-300 (Kerstin, 2006). Prices vary according to the depth, diameter, distance and materials used. The fact that drillers tend to work locally means their transport costs remain low and that they are likely to be familiar with conditions in the locality. Success rates for drilling vary: a driller in the Tarka Valley quoted a success rate of 70 percent to 80 percent, while a crew in Golom quoted 89 percent (Kerstin, 2006). Often the farmers themselves select the sites and bear the costs of drilling dry wells.

Groundwater utilization

The groundwater resources of Niger are used for domestic, agricultural and industrial purposes though information could not be found on the volumes used by each sector. Generally, about 98 percent of the groundwater abstracted in the country is used for drinking, livestock and agricultural purposes. The remaining 2 percent is used by industry. Groundwater is abstracted from different productive aquifers in the country.

Domestic purpose

The major source of domestic water supply in Niger is hand-dug wells. In 1988, about 92 percent of drinking water supplies in the country came from groundwater sources while only 8 percent came from surface water sources (FAO, 2005). Estimates from government sources show that in addition to the countless traditional wells, the rural population (78% of the total population) is served with modern wells comprising 13,000 cement-lined wells, and 7,000 machine-drilled boreholes fitted with hand pumps. The government assumes that a modern well supplies water to about 250 users. There is no official figure for the functionality rate of hand pumps, but several stakeholders in NGOs and government indicate that in some areas, as few as 20 percent of the hand pumps are functional.

Irrigation

Regularly hit by drought and famine, a majority of Niger's population depends on rainfed agriculture. Small-scale irrigation undertaken on a limited scale, primarily in southern Niger, provides some security from famine. Some of the market gardeners, who traditionally used calabashes and leather bailers to water their crops, are now using improved water-lifting devices. Shallow groundwater irrigation has significantly increased over the past decades in the south west and along the border with Nigeria.

Institutional and legal framework

The use and protection of water resources in Niger are regulated by the March 2nd 1993 Law No. 93-014 defining the water regime. This law was revised in December 7th 1998 and the new Law No. 98 - 041 was adopted mainly to account for recommendations from international conferences on IWRM. The October 2nd 1997 Decree No. 97-368/PRN/MH/E was promulgated in order to reinforce the implementation of the Law No. 98-041. The second Article of the Law No. 98-041 stipulates that any usage of water, creation and development of any hydraulic structure must be planned and developed in a context of hydrological or hydrogeological basin in order to minimize any negative impact on the hydrological cycle, the quantity and quality of the resource.

In Niger, three ministries share most of the activities related to planning, mobilizing, developing and managing water resources. These ministries are: Ministry of Hydraulics, Ministry of Agricultural Development and Ministry of Livestock and Animal Husbandry. Competencies are shared amongst the ministries. The Ministry of Hydraulics is in charge of assessing the quantity and quality of water resources in the country. It is also responsible for domestic supply in urban as well as in rural areas. The Ministry of Agricultural Development takes care of agricultural water (irrigation development and management) and the Ministry of Livestock and Animal Husbandry is responsible for pastoral water development.

Conclusions and Recommendations

Niger is the driest country in the Sahelian-Saharan region. The country has limited surface water resources, with only one perennial river, the Niger river. The country relies predominantly on groundwater resources for domestic water supply. Information on the water resources of the country, particularly the groundwater resource is very limited. Groundwater quality and quantity need to be carefully researched, taking into account the fact that people often use the same water supply for both drinking and farming. The potential for contamination of shallow groundwater from excreta disposal, fertilizers and pesticides, needs to be thoroughly examined. The threat from over-exploitation and depletion of shallow groundwater as more motorized pumps are being used for groundwater irrigated market gardening also needs attention.

There is considerable potential for hand drilling technologies that can penetrate harder formations and drill to greater depths, and for corresponding water lifting technologies. Hand percussion drilling and rope pumps could provide water to numerous small communities in Niger, which are currently not included in government plans. These technologies could also benefit other countries in Sub-Saharan Africa. Donor and government organizations are encouraged to invest in the development of technologies that can be manufactured and marketed locally. A gradual process is required wherein needs are understood and local capacity is built. The matter of whether to provide support in the form of credit or subsidies needs careful consideration to avoid the creation of artificial 'project driven' markets.

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CHAPTER 10

NIGERIA

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General description of Nigeria

Geography

Nigeria is located on the west coast of Africa, south of the Sahara between latitudes 4°10' to 13°48' N and longitudes 2°50' to 14°20' E with the Atlantic Ocean bordering the southern coastal region and Niger Republic at the northern border. The western and eastern boundaries are Benin Republic and Cameroon respectively. Nigeria occupies a land area of 923,768 km^2 and exhibits a great variety of relief features encompassing uplands of 600 m to 1,300 m on the Jos plateau, the north central and the eastern highlands; and lowlands of less than 20 m in the coastal areas extending as far inland as 60 km from the shoreline. Covering an average distance of 1,120 km from south to north, Nigeria displays physiographic regions of varying characters in relief, nature and spatial distribution. Nigeria is currently divided into 36 states with Abuja as the federal capital.

Physiography and climate

The climate in Nigeria ranges from semi-arid in the north to humid in the south. The country has a tropical climate characterized by the hot and wet conditions associated with the movement of the Inter-Tropical Convergence Zone (ITCZ), north and south of the equator (Omotosho, 1988). The country experiences consistently high temperatures all year round with mean monthly temperatures during the day sometimes exceeding 36°C, while the mean monthly temperatures at night fall below 22°C. Rainfall distribution over space and time becomes the single most important factor in differentiating the seasons and climatic regions. Except for the coastal zone, where it rains all year round, rainfall is seasonal with distinct wet and dry seasons. The mean annual rainfall along the coast in the south east is 4,800 mm while it is less than 500 mm in the north east (although the recent rainfall at the Maiduguri station measured 670 mm), very much similar to the long-term average and 20 percent higher than the average for the Sahel drought period (Goni *et al*., 2001). But in the extreme north west, close to the border with Niger Republic, approximately 350 mm of rainfall is recorded (Adelana *et al*., 2003). In general, the country can be delineated into 8 agro-ecological zones (see Table 10.1).

Table 10.1 Agro-ecological zones of Nigeria with some climatic characteristics

Zone description	% of country area	Annual rainfall (mm)	Monthly temperature (°C) (day - night)
Semi-arid	4	400- 600	33-32
Dry sub-humid	27	600-1,000	31-21
Sub-humid	26	1,000-1,300	30-23
Humid	21	1,100-1,400	30-26
Very humid	14	1,200-2,000	28-24
Ultra-humid	2	> 2,000	28-25
Mountainous	4	1,400-2,000	29-14
Plateau	2	1,400-1,500	24-20

Source: FAO (2005)

Socio-economic context

Nigeria, one of the richest and the most populated countries in Africa, ranks 146 (out of 174 countries) in the UNDP listing of the Human Development Index (1999). With a relatively low life expectancy at 50 years, and a low per capita income at USD 315 in the year 1997, it is indicative of the low level of development despite its rich resources. Growth of output has not only been low with an average of 2.5 percent annually between 1975 and 1995, but inadequate to prevent declining living standards. Indeed, per capita income for Nigerians was higher in 1975 at USD 350, than in 1998 when it was at about USD 315. Population in Nigeria is 162.5 million (July 2011 UN Est.) and has recorded an increase of 57 million from 1990 to 2008 and accounts for about 18 percent of the total population of Africa (UN DESA, 2011). The United Nations estimates that the rural and urban population in 2009 was at 51.7 percent and 48.3 percent respectively with a population density of 167.5 people km^{-2}.

Agriculture is a major source of economy and livelihood providing employment for 70 percent of the Nigerian population. Nigeria's wide range of climate variations allows it to produce a variety of food and cash crops. The staple food crops include cassava, yam, corn, coco-yam, cow-pea, beans, sweet potato, millet, plantain, bananas, rice, sorghum, and a variety of fruits and vegetables. The leading cash crops are cocoa, citrus, cotton, groundnut (peanut), palm oil, palm kernel, benniseed and rubber. They were also Nigeria's major exports in the 1960s and early 1970s until petroleum surpassed them in the 1970s. The main export destinations for the Nigerian agricultural products are Britain, the United States, Canada, France and Germany.

A significant portion of the agricultural sector in Nigeria involves cattle herding, fishing, poultry, and lumbering, which contributed more than 2 percent to gross domestic product (GDP) in the 1980s. Land holdings are small and scattered, and farming is carried out with simple tools. Large scale agriculture is not common in Nigeria despite the abundant water supply, a favourable climate and wide areas of arable land. However, agriculture contributed 32 percent to GDP in 2001 and 42 percent economic growth between 1997 and 2001 (Sanyal and Babu, 2010).

Groundwater resources

Hydrogeology

Figure 10.1 shows a generalized geological map of Nigeria. The country's geology is made up of two main rock types: Basement complex and the Sedimentary basins, which are equally dispersed. Other minor formations are the Volcanic plateau and the River alluvium. In the basement complex terrain (comprising the west, north central and the south east blocks) rock types are predominantly of migmatitic and granitic gneisses, quartzites, slightly migmatised to unmigmatised meta-sedimentary schists and dioritic rocks (Rahaman, 1989). The sedimentary rocks overlying the basement complex (in the south, north east and north west) consists of arkosic, gravely, poorly sorted and cross-bedded sandstones (Cretaceous and Tertiary). The full description of the geology of Nigeria is reported in Kogbe (1989) and Petters (1982) with recent reviews and descriptive overviews in the literature (Obaje, 2009; Adelana *et al.*, 2008)

Figure 10.1 Generalized geological map of Nigeria (Source: Adelana *et al.,* 2008)

<u>Basement complex</u>

This formation is present in both northern and southern Nigeria. In northern Nigeria, the Precambrian Basement Complex is divided into four distinct groups: (i) the Kano-Minna comprising of parts of Kano, Katsina, Sokoto, Zamfara, Plateau, Niger, Bauchi, Kaduna, Benue and Kogi states, (ii) the Lokoja-Ilorin area including parts of Kwara and Kogi states; (iii) the Gboko-Jalingo area forming parts of Adamawa, Yobe, Benue and Katsina states and (iv) the Mubi-Gwoza area containing parts of Adamawa, Benue and Katsina states. In the north, the rocks are composed of gneisses, migmatites and granites, with extensive areas of schists, phylites and quartzites while in south they consist of migmatite-gneiss complex which is predominantly migmatites, banded gneisses and granite gneisses with relicts of metasedimentary and metavolcanic rocks (Oyawoye, 1972; Rahaman, 1989).

Sedimentary basins

Nigeria is underlain by seven major sedimentary basins: Calabar Flank, Dahomey and Niger Delta basins which are along the coast and the Benue Trough, Chad, Nupe and Sokoto (SE Iullummeden), more to the interior. The north western Nigeria sedimentary basin, representing the south eastern sector of the Iullemmeden basin (Mali-Niger-Benin-Nigeria) and known locally as the Sokoto basin, covers an approximate area of 6,400 km^2 (Adelana *et al*., 2008). The sedimentary rocks of the Sokoto basin range in age from Cretaceous to Tertiary and are composed mostly of interbedded sand, clay, and some limestone; with the beds dipping gently towards the north west. In the north eastern sector of Nigeria, the Bima sandstone is the oldest of the Cretaceous sediments, which is a thick sequence of continental sandstone deposited during the Albian – Cenomanian times. These sediments range from poorly sorted, thick bedded feldspathic sandstones and conglomerates to the fluviatile and deltatic sediments. In southern Nigeria, the sedimentary basin is partially divided into western and eastern portions: The Lagos-Osse and the Niger Delta basins, which were not completely separated from each other, and hence the occurrence of similar stratigraphic units in both basins (Adelana *et al*., 2008; Oboh-Ikuenobe *et al.*, 2005). The Cretaceous sediments of the Benue basin represents a linear stretch of sedimentary basin running from around the present confluence of the rivers Niger and Benue to the north east, and bounded by the basement complex areas in the north and south of the river Benue (Offodile, 1989).

Volcanic plateau

Lava flows cover parts of the Jos plateau and extensive areas in other plateaux in Plateau and Bauchi states of Nigeria. In this area the rock types are mainly olivine basalts, scoriaceous lavas and tuffs (Du Preez and Barbers, 1965). In the Jos plateau basaltic lavas often overlie coarse alluvium in ancient river valleys. One plateau (Sugu plateau) is formed by a succession of trachytes, rhyolites and tuffs, which occur in association with flat-lying arenaceous sediments, resulting in a sequence over 300 m thick (Du Preez and Barbers, 1965). Others are formed in a similar manner but no sediments associated with their formation.

These all formed the Fluvio-Volcanic-Series described by Akujieze *et al*. (2003). One interesting fact on the Tertiary rocks of the Fluvio-Volcanic-Series is the occurrence of intense chemical weathering and lateritization.

River alluvium

Alluvial deposits cover the valleys of rivers and streams. Deposits range from the thin discontinuous sands occurring in the smallest streams to the thick alluvial deposits of rivers Niger and Benue; these may occupy strips of country up to 15 km wide on each side of the river (Du Preez and Barbers, 1965). The thickness and nature of the alluvium however varies with the type of rivers. The sediments composing river alluvium include unconsolidated gravel, coarse and fine sand, silt and clay. Bedding is sometimes complex and are described as lenses of coarse sand of varying thickness and lateral extent alternating with less pervious material or clay. In northern Nigeria, many river channels are underlain by coarse sand, especially in the middle reaches, where marked lowering of hydraulic gradients often occur (Du Preez and Barber, 1965). In places where stream gradients are very low, alluvial sediments consisting of fine sand, silt and clay are present.

Groundwater systems

The distribution and flow of groundwater is controlled by geological factors such as the lithology, texture and structure of the rocks; and also hydrological and meteorological factors such as stream flow and rainfall. Aquifer distribution in Nigeria is categorized into two systems: basement fluvio-volcanic aquifers and sedimentary aquifers. Details of the various hydrogeological basins are presented in Offodile (1992) and Akujieze *et al.* (2003). There are eight major regional aquifer systems, 30 local and minor aquifers and 36 aquicludes, aquitards, and aquifuges in Nigeria. These eight mega regional aquifers have an effective average thickness of 360 m, with a range of 15–3,000 m at a depth range of 0–630 m below ground level, with an average depth of 220 m (Akujieze *et al*., 2003). Yields from major aquifers in Nigeria are presented in Table 10.2.

The sedimentary basins generally form the most prolific aquifers. The depth of the water table in unconfined parts of the Sokoto basin is typically 15-75 m (Adelana and Vrbka, 2005). Artesian conditions occur in confined aquifers at 75-100 m depth at the eastern edge of the basin especially around Argungu but with piezometric levels going down further west to about 50 m below surface (Adelana *et al.*, 2002, 2003, 2006a). Significant groundwater ages (in excess of 3000 years) have been found for some confined groundwaters from the Sokoto basin (Geyh and Wirth, 1980; Oteze, 1989a,b, 1991; Bassey *et al*., 1999). Artesian conditions also exist in the Chad basin, where three main aquifers have been identified: an upper aquifer at 30-100 m depth, a middle aquifer (eastern part of the basin) some 40-100 m thick occurring from 230 m depth near Maiduguri and a lower aquifer consisting of 100 m of medium to coarse sands and clays at a depth of 425-530 m. Earlier reporting showed the upper and middle aquifers are exploited intensively in the Maiduguri area (UN, 1988). Overexploitation of the aquifers in the Chad basin has led to a recent decline in groundwater levels and has necessitated drilling to greater depths in order to tap the lower aquifer (Goni, 2008). Isotopic evidence suggests that groundwater from the middle and lower aquifers are old (20,000 years or more) and are not being actively replenished by modern recharge (Maduabuchi *et al*., 2003; Edmunds *et al*., 2002). In the Anambra basin south east of Lokoja, coarse Cretaceous sandstones form a good aquifer which is largely unconfined in its northern part but becomes artesian further south (UN, 1988). Groundwater levels are typically 60-150 m deep. Good aquifers are also present in the Tertiary and Quaternary sediments of the southern coastal areas, the best being the Tertiary 'Illaro Formation' composed of sands with occasional beds of clay and shale. An unconfined shallow aquifer also exists at less than 30 m in much of the area near the coastal area (UN, 1988).

Table 10.2 Regional aquifer systems and yields in Nigeria

Main aquifers	Yield (L s^{-1})
Ajali Sandstone aquifer	7-10
Benin Formation (coastal plain sands) aquifer	6-9
The Upper aquifer (Chad Formation)	2.5-30
The Middle aquifer (Chad Formation)	24-32
The Lower aquifer (Chad Formation)	10-35
Gwandu Formation aquifer	8-15
The Kerrikerri Sandstone aquifer	1.25-9.5
Crystalline fluvio–volcanic aquifer	15

Source: Akujieze *et al*. (2003)

The Basement Complex in Nigeria is comparatively less developed. Olorunfemi and Fasuyi (1993), identified five aquifer types in this formation, which include the weathered aquifer; the weathered/fractured (unconfined) aquifer; the weathered/fractured (confined) aquifer; the weathered/fractured (unconfined)/fractured (confined) aquifer and the fractured (confined) aquifer. The mean groundwater yield for the aquifer types varies from 0.83 L s^{-1} for the weathered layer aquifer to 3 L s^{-1} for the weathered/fractured (unconfined)/fractured (confined) aquifer. An optimum borehole depth for the typical basement complex is 60-70 m (Olorunfemi and Fasuyi 1993).

Groundwater recharge

Available estimates of recharge from the different regions in Nigeria are summarized in Table 10.3. Recent estimates use a combination of simplified empirical equations, stream-flow hydrographs, water table fluctuations, base-flow recession methods (Adelana *et al.*, 2006a) as well as chloride-based methods supported by stable isotope data (Adelana *et al.,* 2006b). In the Crystalline basement of south western Nigeria, groundwater recharge conditions are crucial for understanding the groundwater flow regime and infiltrating conditions. Studies in north western Nigeria showed considerable depletion in isotopic content (^{18}O and ^{2}H) and low deuterium excess in groundwater, reflecting the contribution of old meteoric water that recharged the Cretaceous aquifers in Pluvial times (between 5000 and 15000 year BP) (Adelana *et al.,* 2002). However, present day recharge has been demonstrated for the alluvial aquifer in the area. Estimates from chloride mass balance method confirmed recharge rates are unevenly distributed over the area. In the Chad basin in north east Nigeria, there was also isotopic evidence of palaeo-recharge in the deep confined aquifers (Edmunds *et al.,* 2002, Maduabuchi *et al.,* 2006).

Table 10.3 Summary of the range of recharge values for different regions in Nigeria

Region	Mean annual rainfall (mm)	Recharge estimates (mm yr^{-1})	Method	Reference
North West	600	4-28	Empirical, streamflow, CMB	Adelana *et al.,* 2006a
North East	500	14–49	Unsaturated zone Cl profile, Stable Isotopes	Edmunds *et al.,* 2002
Hadejia/Nguru	200-600	73–197	Water budget	Goes *et al.,* 1999, Acharya & Barbier 2002
Kano-Maiduguri	530	169	Soil moisture deficit	Ndubuisi 2007
South East	1,800	281-1,047	Simplified recharge, equations, baseflow recession analysis and water balance method	Uma 1988
SE (Owerri urban)	2,152	446-667	Simplified calculations	Ibe *et al.,* 2003
SW (Ile-Ife/Middle Osun valley)	1,480	191-225	Empirical equations	Omorinbola 1986
SW (Kwara)	1,200-1,400	158-605	Empirical, Stable Isotopes profile	Adelana *et al.,* 2006b

Source: Adelana *et al*. (2006a)

Groundwater quality

Generally, groundwaters in most of the aquifers in Nigeria are fresh with low concentrations of total dissolved solids (< 500 mg L^{-1}). However, groundwater is exposed to active pollution in major cities and rural communities of Nigeria due to increased urbanization, indiscriminate waste disposals, intensive agricultural practices and industrial activities. Adelana *et al.* (2008) reviewed the literature on groundwater pollution cases in Nigeria from 1980 to 2008, and this revealed that various agro-chemicals and wastes have degraded groundwater quality. In the review of the British Geological Survey, Sangodoyin (1993) found poor bacteriological quality of groundwater close to sites of waste disposal in Abeokuta area, highlighting the potential impact from other pollutants. High concentrations of total dissolved solids, with particular impacts of calcium, chloride and nitrate, in shallow groundwaters resulting from abattoir sites were reported in Sangodoyin and Agbawhe (1992). Increased concentrations were noted around 250 m from the sites of contamination. Edet and Okereke (2001) found groundwater with total dissolved solids concentrations up to 1,250 mg L^{-1} in the coastal part of the Niger delta. Ajayi and Umoh (1998) also found concentrations of total dissolved solids for groundwater from Ondo State in the range 1,300-1,500 mg L^{-1}. Table 10.4 summarizes the water quality of groundwater in Nigeria.

The data (600 samples) indicate that the average concentrations of most elements investigated are higher than the WHO (1998) guideline values for domestic and agricultural uses. This excludes the saline groundwater which has concentrations higher than the WHO (1998) guidelines.

Table 10.4 Groundwater quality in Nigeria

Parameter*	Min	Max	Mean	WHO Standard
pH	6.04	7.05	0.58	6.12
Conductivity (μS cm^{-1})	30.16	635.36	270.63	1,500
Dissolved Solids	10	413.92	164.83	1,000
Sodium	0	202.09	30.35	200
Potassium	0.02	52.29	8.07	30
Calcium	1.04	55.6	20.16	200
Magnesium	0.2	46.01	9.98	150
Chloride	0.87	82.55	25.34	250
Bicarbonate	4.64	237.79	71.5	380
Sulphate	0	87.38	21.03	400
Nitrate	0	97.22	18.38	10
Iron	0.04	12.01	1.28	0.3
Manganese	0.05	0.58	0.2	0.1

*All units in mg L^{-1} except for pH or unless indicated.
Source: Edet *et al.* (2011)

Groundwater development and utilization

Groundwater abstraction

Generally, boreholes drilled in the crystalline rocks of Nigeria have low yields and a reputation for failures. The performance of 256 boreholes drilled in different parts of the crystalline rocks of south west Nigeria were reviewed to determine their failure characteristics. One hundred percent success was claimed for 105 boreholes constructed by one driller. Out of 111 other borehole records supplied by three other drillers 35 were abortive, representing a failure rate of 32 percent. In contrast, 24 owners of 40 boreholes reported 24 failures representing a failure rate of 60 percent (Ajayi and Abegunrin, 1994). Table 10.5 provides details of the boreholes drilled during the period 1989-2002. The common causes of borehole failure and poor yield in the crystalline rocks of south west Nigeria are seasonal variations in water level, improper casing of the overburden, damage to pumps and other system failures such as blocked pipelines and malfunctioning tanks (Adelana *et al.,* 2008). Non-penetration into the water bearing horizon also features as a cause of borehole failure, especially where exploration techniques are not employed prior to drilling. Detailed explanation on the causes of borehole failure and increased failure rate are presented in the work of Fellows *et al*. (2003).

There are up to 1,000 private sector drilling companies in Nigeria (UNICEF/WHO, 2005). Drillers have realized the benefits of small light duty rigs and are using them where appropriate. Of the sampled rigs, 30 percent are made in Nigeria. Manual drilling was found to be more cost effective than mechanized drilling where feasible. Unfortunately, contract packages tend to be small, discouraging long term investment in equipment. Boreholes are often drilled deeper than they need to be and there is a tendency to specify geophysics on all drilling sites even where it is not necessary. The capacity for proper supervision in terms of experienced personnel and equipment is limited at state level, and post-construction monitoring is rarely undertaken. It is suggested that proper construction, operation and maintenance of boreholes will reduce the incidence of borehole failures in crystalline rocks of south west Nigeria.

Table 10.5 Statistics of borehole information in Nigeria

Period	No. of boreholes drilled	No. of boreholes with screens	Success rate (%)
1989-2002	16,827	13,903	93

Source: Adelana *et al.* (2008)

Cost of groundwater development

The construction costs for sustainable supplies by borehole systems are relatively high. The prices range from USD 2,600 to USD 6,300 for 4”/5” boreholes fitted with hand-pumps. The cost of motorized boreholes with diameter of 6” to 8” varies from USD 3,300 to USD 13,000 depending on the support structures associated with such projects. Adekile and Olabode (2008) showed that the cost of drilling a 110 mm diameter 50 m deep lined borehole was 459,740 Nigerian Naira (about USD 3,065). A comparative cost between a large and medium African rig is shown in Table 10.6.

Table 10.6 Comparative borehole drilling cost using medium to large capacity drilling rigs (to drill a 60 m hand pump extraction hole in crystalline rock)

	Conventional African rig (USD/ borehole)	Reduced diameter Africa rig (USD/borehole)
Capital costs	3,133	633
Drilling of borehole	1,770	1,285
Labour	600	400
Operation and maintenance per year	3,333	333
Total cost	8,836	2,652

Source: Eduvie (2009)

Groundwater utilization

Water resources in Nigeria are already under stress and the country is slowly becoming a water-scarce nation. According to Population Reports of 1998, Nigeria is among the 48 countries expected to face water shortage by the year 2025 (Population Reference Bureau, 2000). With an estimated population of 111.7 million people in 1995, the water per capita in Nigeria stood at 2,506 m^3 yr^{-1}. The per capita water availability is expected to drop to 1,175 m^3 in year 2025 with a projected population of 238.4 million people.

Domestic purpose

Nigeria, during the 1960s, 70s and even early 80s was providing treated drinking water to the people of Nigeria. But with growing population, poor planning and corruption, the professionalism of the Ministry of Water Works was diverted and it turned into an incompetent and 'do-nothing' entity. Nigeria has abundant fresh water: groundwater, rivers and lakes that can be channelled by the Ministry of Water Works through treatment plants so as to provide sufficient quantity of quality water to the population. Application of chlorine and filtration procedures will make it ready for human consumption.

In order to meet the MDGs especially for water supply, one borehole could serve 230-500 people living within 500 m radius of the water point. Given that 50 percent of the population lives in rural areas, which are to be served with hand-pump boreholes, Nigeria will need at least 140,000 boreholes to serve its 70 million people living in rural areas alone.

Irrigation

Estimates of irrigation potential in Nigeria vary from 1.5 to 3.2 million ha. Recent estimates suggest a total of about 2.1 million ha, of which about 1.6 million ha is irrigated from surface water and 0.5 million ha irrigated from groundwater (FAO, 2005). However, as far as groundwater is concerned, it should be mentioned that while the extractable water resources are sufficient for up to 0.5 million ha in the north of Nigeria, areas suitable for irrigation with groundwater have, as yet, not been fully assessed across the country.

During the dry season, many farming families in Nigeria cultivate small areas in *fadamas* (valley-bottom) using traditional methods that involve water manually drawn from shallow wells or streams. Major *fadama* areas are located along the flood plains of the Niger, Sokoto Rima, Benue, and Yobe rivers. In the late 1980's, the Agricultural Development Projects (ADPs) began the promotion of pumps and tube wells, which allows for the extraction of increased amounts of water, resulting in more than 80,000 pumps (each irrigating 0.5 and 1.0 ha) being distributed by 1992. From 1993 onwards, the National Fadama Development Project (NFDP) built on the ADPs' achievements, continued the promotion and by the end of the project in 1999, over 55,000 pump sets had been distributed with an equipped area of about 1 ha per pump.

The Special Program for Food Security (SPFS) of the FAO commenced in 1999 with a pilot phase including 280 ha in three villages in Kano state, where farmers were provided with motorized pumps and tubewells to enable them to engage in irrigated agriculture in the *fadama* lands. The project adopted a participatory community development approach, wherein farmer groups are primarily responsible for planning and owning the project. After the success of the pilot phase, the project was extended in 2002 to 109 sites in all the 36 states. The area equipped for irrigation in 2004 was 293,117 ha, comprising 238,117 ha of full or partial control irrigation and 55,000 ha of equipped lowlands, i.e. improved *fadamas*. About 75 percent (218,840 ha) of the equipped area was actually irrigated in 2004. Non-equipped flood recession cropping is being practiced on 681,914 ha, bringing the total water managed area to 975,031 ha. Surface irrigation in its various forms (basins, borders and furrows) is used predominantly for water application in both public and private irrigation schemes. The impact of this is seen in the reduced area under sprinkler irrigation from 3,570 ha in 1991 to about 50 ha by the end of 2004 (FAO, 2005).

Livestock watering

The estimated domestic ruminant population in Nigeria has been put at 13.9 million cattle, 34.5 million goats, 22 million sheep (both accounting for 35.2% of the total population of the world's small ruminants) equine and camels account for 3.6 percent and 0.6 percent of the livestock population respectively (RIM, 1992). Nigeria is the largest livestock producer in Sub-Saharan Africa. Ethiopia and Sudan have the largest livestock population in the African continent (Lamorde, 1998). There is less information about use of groundwater for livestock consumption and maintenance.

Institutional and legal framework

Nigeria does not have a centralised institution in charge of water management. Instead, there are eleven independent bodies in Nigeria associated with one form of water management or another (Akujieze *et al*., 2003). These management bodies have significant overlaps in terms of interest and jurisdiction and face a lack of co-ordination and co-operation (Akujieze *et al*., 2003). There are eleven River Basin Development Authorities (RBDA's) in Nigeria. These were established to manage and monitor activities in the river catchments and the management units. The river basin authorities do not have sufficient scope and coverage of hydrogeological units that could facilitate proficient groundwater management.

Decentralization is the defining feature of water administration in Nigeria, leading to different ministries and agencies at different levels, administering laws but lacking adequate coordination (FAO, 2005). The functions of the RBDAs related to irrigation are defined in the River Basin Development Authorities Act No. 35 of 1986. The Environmental Impact Assessment Decree No. 86 of 1992 lists drainage and irrigation as a mandatory study activity, thus prescribing that environmental impact assessment is to be carried out for all irrigation projects in Nigeria. The Water Resources Decree No. 101 of 1993 gives the Federal Ministry of Water Resources (FMWR) significant power to control and coordinate activities for proper watershed management and resource protection as well as for public administration of water resources. It confers to the FMWR the responsibility to make proper provision for adequate supplies of suitable water for agricultural purposes in general and irrigation in particular.

The Water Resources Act, 1993 vests the ownership of all water sources affecting more than one state of the federation, as well as all underground water throughout the Federal Government of Nigeria. By virtue of this law, the waters of all Nigeria's transboundary rivers and lakes belong to the federal government. Notwithstanding such federal ownership, by virtue of section 2 of the Act, any person may take water without charge for his domestic purpose or for watering his livestock.

While some legislation exists, it is hardly implemented. Groundwater is generally taken as being a 'Free gift from God'. Therefore more often than not, those exploiting this natural resource for the provision of potable water supply have taken no action to protect its quality as well as ensuring its sustainable management (Adelana *et al.,* 2008). Even though the demand for groundwater is becoming higher in both rural and urban centres in Nigeria, the management of the aquifers or wells is not closely monitored. For example, borehole maintenance and monitoring functions are not assigned to any of the existing agencies.

Groundwater development challenges

With many of the surface water now polluted, focus on the importance of groundwater as a drinking water source has to increase. While regional plans and rules exist to protect surface waters, legislation for groundwater protection is in its infancy in Nigeria and requires much improvement. Hanidu (1990) emphasized the need to settle the ownership of water through legislation before any meaningful strategy could be adopted. Water resource legislation exists in Nigeria but its impact is yet to be felt in terms of true ownership and usage of the nation's water resources. The existing confusion over the legal ownership of water as a resource has been identified as impeding irrigation development in Nigeria (FAO, 2005). This is because water legislation in Nigeria is use-oriented dealing with navigability, shipping and domestic use. For example, the Decree 101 and water-related regulations are based solely on socio-economic factors and not necessarily on scientific research such as, groundwater vulnerability or pollution. Federal, states and local government programmes need have been critiqued for not formulating or implementing policies addressing on-site effluent disposal (Adelana *et al*., 2008).

The requirements of Decree 101 of 1990 have stimulated investigations on issues such as impact assessments of waste disposal sites on groundwater quality. These investigations are aimed at existing or recognised potential problem sites but are often only 'token' investigations carried out by companies or corporations, to meet their obligations under the federal, states and local government conditions of award of contracts. Nigeria has standards for neither the evaluation of existing landfills or for the investigation of potential sites for solid waste disposal. In some cases, it is also difficult to find the party responsible for degrading the resource or it is difficult to get such a party to assume liability. This alone emphasizes the need for a proactive approach to assess groundwater vulnerability under present conditions.

National plans and rules are to assist the local government or municipal councils to carry out their functions relating to resource management. Unfortunately this is still a game of chance under the present water management policies in Nigeria. There is a need to restate and reform any existing law relating to the use of land and water as this will help to promote the sustainable management of natural and physical resources, including groundwater. Sustainable management must ensure that resources are sustained for future generations and adverse environmental effects are avoided, remedied, or mitigated. Therefore, it is the responsibility of the national and regional water councils to implement the water legislation or Decree 101 (based on current scientific evidence) and incorporate aspects relating to management of groundwater to prevent groundwater contamination.

According to Adelana *et al.* (2008), emphasis is to be placed on groundwater protection in order to prevent deteriorating conditions of the main aquifers in Nigeria. The assessment of aquifer vulnerability and sensitivity to pollution on a national scale is very necessary in Nigeria under the present conditions to inform policy and legislative reviews. The most important approach to aquifer protection is in raising public awareness, which in turn, may result in positive reactions or more informed land use decisions. Groundwater vulnerability should be a dominant factor for analysing alternatives to a particular groundwater quality plan and the response to a particular pollution event. Vulnerability assessment can also aid the zoning, or assigning the range for acceptable activities to the land surface. Aquifers with high sensitivity should be monitored closely while aquifers with low sensitivity may not require detail monitoring. In addition, permits or consents for activities having environmental impacts should have more demanding conditions imposed on them in areas of high sensitivity as opposed to low sensitivity. Conditions may refer to quantities, treatment and containment of contaminants or limitation of the activity to a certain time period.

Conclusions and Recommendations

Nigeria has ample water source (224 km^3 yr^{-1} surface water and 50 million km^3 yr^{-1} groundwater). However the inability to harness, treat and make available potable water for use all over the country, accounts in part, for the poor economic development and social well-being within the country. The total surface run-off is estimated to be 250 km^3 of which less than 5 percent is reportedly utilised, mostly by the agricultural sector which accounts for almost 70 percent of total withdrawals. The latest irrigation potential estimate gives a total of about 2.1 million ha, of which about 1.6 million ha is from surface water and 0.5 million ha is from groundwater (FAO 2005). In 2004, while the total area equipped for irrigation was 293,117 ha, only 75 percent of the area equipped was actually irrigated (218,840 ha). Of this, 183,000 ha irrigated was under the private small scale or improved *fadama* and about 35,840 ha were under the Federal Government irrigation schemes.

Waste management presents problems in mega cities like Lagos and others in Nigeria which are linked with economic development, population growth and the inadequacy within and inability of municipal councils, to manage the resulting rise in industrial and domestic waste. Haphazard industrial planning, increased urbanization, poverty and lack of competence of the municipal government are seen as the major reasons for high levels of pollution in major Nigerian cities. Some of the 'solutions' have been disastrous to the environment resulting in untreated waste being dumped in places where it can pollute waterways and groundwater. In terms of global warming, Africans contribute only about one metric ton of carbon dioxide per person per year. It is perceived by many climate change experts that food production and security in the northern Sahel region of the country will suffer as semi-arid areas will have more dry periods in the future.

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CHAPTER 11

SOMALIA

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General description of Somalia

Geography

Somalia lies on the eastern side of the Africa in a region popularly known as the Horn of Africa where it is bound by the Indian Ocean on the east and north east, the Gulf of Aden in the north, Ethiopia in the north west and Kenya to the east. Somalia covers an area of about 638,000 m^2 and has one of the longest seashores in Africa (about 4,000 km). It is bound by latitudes 10°31' N and 2°30' S and longitudes 40°50' and 50°42' E. Somalia is the only country in the world that has no form of centralized government and has been in a state of civil war for the last 14 years. The country is divided into 17 administrative regions and further subdivided into 73 districts. Before the civil war broke out in 1990, the country was under a military government that leaned more towards a communist system.

Physiography and climate

The whole of southern Somalia, south of Gedo and up to the Indian Ocean in the east is a large plain. The narrow strips along the Juba and Shabelle rivers are alluvial plains. The north east strip of the Shabelle river is a plateau. The northern section of the country is a mixture of plains, alluvial plains, plateaus, hills and mountain foot ridges. The plateaus occur mainly to the east of the area bordering the Indian Ocean as well as in the Sool and Sanaag regions, while hills and mountain foot ridges occur mainly at the tip bordering Djibouti and the Gulf of Aden.

Somalia has five main agro-climatic regimes. The southern tip of the country, south of latitude 0'4" S receives the Steppe warm winter rains. Between 4'34" N and 0'4" S the area receives the Steppe warm summer rains except for an area between 2'55" N and 0'30 N and east of 43'10" E up to the Indian Ocean which has a Steppe warm climate. Rest of the area to the north of the country (north of 4'34" N) is a desert, except for a small area toward Djibouti on the border with Ethiopia which receives Steppe warm rain and a very small area between 46'47" E, 10'25" N and 48'46" E, 10'6" N which receives Steppe cold summer rain. The southern part of the country receives an average annual rainfall of 200 mm to 700 mm with the rainfall of 700 mm occurring around the southern tip of Juba river. The area north of Hudur and up to Garowe receives an annual rainfall averaging 200 mm. The eastern border with the Indian Ocean, north of Garowe receives an average rainfall of about 100 mm. North of Garowe, the rainfall uniformly increases from 100 mm on the shores of Indian Ocean to about 500 mm to the border with Djibouti and Ethiopia. Rainfall recharges the upper unconfined aquifer, which in many cases is not more than 20 m below the ground surface.

The area to the west of Juba river is covered mainly by shrubs and between Juba and Shabelle rivers is covered by shrubs and open trees. This also happens to the north of Shabelle river up to the northern edge of Mudug region. Around the borders of Mudug, Nugaal and Bari regions, sparse herbaceous vegetation occur in a narrow strip. The rest of the area in the north is covered with sparse shrubs except the area toward Djibouti on the border with Ethiopia where the area is covered with shrubs.

Drainage

Only two permanent rivers, Juba and Shabelle, exist in Somalia. The Shabelle river enters Somalia from Ethiopia near Belet Weyne at point 45'5" E and 5'4" N and moves south east to Jowhar town at 45'19' E, 2'5" N where it curves to the south west above Mogadishu at 45'8" E, 2'19" N before it disappears at point 43'16" E, 1'1" N, east of Buaale. Juba river enters Somalia to the east of Hudur at 41’58” E, 4’15” N; runs to the south through Buaale at 42’31” E, 1’21” N, before finally entering the Indian Ocean just north of Kismayo at 42’23” E, 1’51” S. There are many other dry beds, which only carry water for a few hours after rainfall events. These originate from Kenya, Ethiopia and others inside Somalia also.

Socio-economic context

According to the Somalia Watching Brief (2003), population estimates for Somalia vary from 6.8 million to 10.3 million with about 65 percent of the population residing in rural areas. Population density is 16 inhabitants km^{-2} and the annual population growth rate was 2.3 percent between 1990 and 2002. The CIA estimated the GDP at USD 5.9 billion and annual growth of about 2.6 percent for 2010. The estimated GDP per capita is at USD 600 (CIA 2008). About 43 percent of the population lives on less than one USD per day, with about 24 percent of this found in urban areas and 54 percent living in rural areas. In Somalia, agriculture is the most important economic sector. It contributes about 65 percent of the GDP and employs 65 percent of the workforce. Livestock contributes about 40 percent to GDP and more than 50 percent of export earnings (CIA, 2008). Other principal exports include fish, charcoal and bananas, while sugar, sorghum and corn are products for the domestic market (CIA, 2008). The local production of mainly sorghum and maize does not meet the food demands and it is estimated that another 200,000 tons of cereals are needed to meet the domestic food demands of 500,000 tons. Maize and sorghum production has been on an average, 60 percent below the pre-war average. The main cash crops are bananas, lime, cotton, rice and sugarcane, while the main food crops are sorghum, maize, sesame, rice and beans. Rainfed as well as irrigation yields are low due to low seed quality, lack of farming skills and lack of mechanized farm inputs.

Groundwater resources

Hydrogeology

The groundwater conditions in southern Somalia which forms the greater part of the catchment area are largely influenced by the geological, landform and climatic conditions in Kenya. Similarly the status in the north is heavily influenced by the conditions in Ethiopia, which affects both surface and groundwater resources. The southern tip of Somalia is one of the richest in the country in terms of groundwater resources. Many shallow wells with good quality water exist and it is believed to be one of the major factors that influenced the location of the regional capital, Kismayo. The southern tip of the country is formed of lagunal deposits of Quaternary Aeolian age. The rest of the area between Kismayo and Gedo along the Kenya border is formed from a mixture of basement system gneiss rock, crystalline limestone and Plio-Pleistocene sediments. The basement system gneiss rock mainly occurs on the southern section of this area while consolidated silts and the crystalline limestone cover the northern area. The sediments are most likely a result of depositions from the rivers originating in Kenya and Ethiopia during Quaternary, Precambrian and Pleistocene age. Near Gedo, Quaternary volcanic rocks are predominant. This extends further to the east of the country. A narrow strip to the north east and along the Shabelle river is covered with rock of Cretaceous age.

The geology of the area between Juba and Shabelle rivers is mainly formed of crystalline limestone, aeolian cover sands and a basement system of undifferentiated gneiss rocks. The tip area where the two rivers meet is covered mainly by unconsolidated and undifferentiated sediments while the crystalline deposits cover most of the remaining area. The northern area of Somalia is covered by basement system of gneiss rock of undifferentiated type in many areas covered by Aeolian sand deposits and large grained sandstones. The gneiss basement rock covers the border area with Ethiopia toward Djibouti while the sandstones cover the rest of the border area with Ethiopia. Most of the other areas are covered with crystalline limestone, especially to the east. A little area toward Djibouti is covered with the basement gneiss rock and aeolian cover sands. Pockets of undifferentiated and unconsolidated sediments are also found in the area. The basement rock is from lava that originated from Precambrian volcanic actions. The basement rock is of both basic and ultra-basic nature. Along the Indian Ocean coast, unconsolidated and undifferentiated sediments occur from Kismayo in the south, stretching to Hobyo in the north. Beyond Hobyo all along the coastline through the Gulf of Aden, crystalline limestone forms the major rocks.

Groundwater systems

Aquifers occur in crystalline basement rocks and in sedimentary formations, both regionally and locally. The regional sedimentary sequences range in age from Jurassic to Miocene. The local sedimentary occurrences are of Quaternary age. In the southern regions, groundwater occurs mainly in fissures which appear to be better developed in the north. In the south the basement is peneplained and large areas are covered by red lateritic sand and this surface is drained by numerous dry riverbeds. Numerous hand-dug wells tap the associated alluvial aquifers. The boreholes drilled in the weathered basement however have low yields. Jurassic limestones and sandstones have extensive outcrops in the southern region adjoining the basement complex and in the mountainous zone in the north. Groundwater occurs in fissures, bedding planes and karstic cavities. The Jurassic aquifers have a reasonable overall potential whereas significant differences exist between the aquifers in the upper and lower Jurassic formations. In a study reported by Gibb and Partners (1980), the aquifer characteristics for the country are summarized as follows:

- Cretaceous sediments contain aquifers of various types. Similarly in the Jurassic aquifers, the water quality can be variable;
- The Eocene in central Somalia forms part of the Ogaden basin at depth and lies unconformably on upper Cretaceous Yasoomman sediments. In the north they have widespread occurrence where they form a series of limestone, marl, gypsum and anhydrite. These sediments are water bearing with porosity ranging from intergranular to fissured;
- The Oligocene Miocene sediments occur extensively in central Somalia. These sediments are stratigraphically undifferentiated due to lack of paleontological evidence; however three aquifer systems have been identified on a lithological basis. A lava outflow from Ethiopia is present at depth in the central area. The basalt provides a confining layer beneath which groundwater from the Yasoomman and Oligocene Miocene sediments occur. In general, this deeper aquifer has better quality water than the aquifer overlying the basalt;
- The Quaternary sediments have been classified into two major groups. One group is of alluvial origin such as the Shabelle and Juba river alluvium together with the major togga beds and outwash fans. The rest are undifferentiated and comprise lacustrine, lagoonal, coastal dunes and calcareous reef deposits. Shallow wells are commonly dug in these formations, especially along the coast, dry beds and old river channels. Where recharge from rivers occurs, these aquifers are particularly productive.

The potential for groundwater development in Somalia may be classified into four levels: productive aquifers, moderately productive aquifers, limited production and no production. Within these four levels, the nature of the formations across the three regions of the country (southern, central and northern) can be distinguished as follows:

<u>Groundwater systems in southern Somalia</u>

i. *Productive intergranular aquifers:* The lower Cretaceous Cambar formation, which only outcrops in the south west of the country, is potentially a high yielding intergranular aquifer. The sandstones range from being porous to very compact and have a total thickness of 450 m. They lie unconformably on the Jurassic sediments where they form a ridge. Although only tapped by one borehole, the groundwater potential of this formation would appear to be very good and further exploratory drilling is necessary to confirm this. The specific capacity of this borehole is 1,300 m^2 d^{-1} and the EC of the groundwater is 900 μS cm^{-1}. In the Shabelle and Juba river valleys, the Quaternary alluvium is extensively exploited through both drilled and hand-dug wells for agriculture and livestock watering purposes. The water quality can however be highly variable, ranging from good to saline. Groundwater contributes to the Shebelli river flow during the dry seasons, upstream of Jalalaqsi and downstream of AW Dhegle; in the area in between, groundwater levels are below the river and the river provides a major source of recharge for the aquifer. Adjacent to the Juba river, groundwater levels are near the river level with the aquifer being recharged during periods of high flow. The alluvium on the left bank of the Shabelle thins out in the Balcad area putting the river in close contact with the Quaternary sand dune aquifer. This provides a high recharge zone for the sand aquifer, which together with the natural seepage from the bed of the river provides the main water source abstracted by two major well fields of some 25 x 10^6 m^3 yr^{-1} for Muqdisho water supply;

ii. *Productive fissured aquifers:* The Jurassic Baydhabo formation is the only productive fissured aquifer with good potential. This karstic limestone outcrops around the basement complex of the Burr Uplift. The total thickness reaches 800 m with the lower 200 m being sandstone with interbedded shale and marl. This formation has excellent recharge potential and the aquifer conditions are unconfined at the outcrop, becoming confined when covered by the Canoole formation. This aquifer forms a spring line at the basement complex contact with depths to water increasing northwards from approximately 5 m at the escarpment. The upper 600 m of the Baydhabo aquifer has an EC in the range 900 to 2,500 μS cm^{-1} while the salinity increases to approximately 10,000 μS cm^{-1} below this depth. Borehole yields range from 3.6 to 21.6 m^3 hr^{-1} with a mean of 13.6 m^3 hr^{-1};

iii. *Moderately productive intergranular aquifers:* With the exception of the sand dune aquifer adjoining the Shebelli near Muqdisho, the development of groundwater by boreholes from Quaternary aquifers is less extensive due to the limited available recharge from rainfall and because of problems of saline intrusion coastally and along togga beds;

iv. *Moderately productive fissured aquifers:* The Jurassic Waajid formation is a quartzitic limestone and sandstone with marls and clay in the upper parts. The total thickness is 500 m and only the lower portion is water bearing, with EC in the range 1,500-5,000 μS cm^{-1}. The potential for recharge of the aquifer section is high at outcrop through sinkholes and dolines. The uppermost clay and marls are normally dry and act as an aquiclude. Boreholes completed in the lower formation have a low yield, 0.5 m^3 hr^{-1} to 5 m^3 hr^{-1}. Overlying the Waajid is the Garbaarrey formation. This sandy limestone with gypsum bands has a total thickness of 700 m. The water quality in this formation is generally poor with EC of approximately 10,000 μS cm^{-1}. Boreholes have been developed in this aquifer and yields range from 1.5 to 20 m^3 hr^{-1}. The Cretaceous limestone of the main Gypsum formation is typically karstic, and outcrops in an arc at the edge of the Xuddur-Baardheere basin where it is sometimes capped with basalt. Shallow wells in the karstic depressions have EC in the range 2,600 to 4,600 μS cm^{-1} and are commonly highly polluted. Groundwater levels are in the range 20-80 m below ground level and boreholes completed with a depth less than 70 m commonly yield groundwater with an EC around 3,200 μS cm^{-1} at a rate of about 4 m^3 hr^{-1}. Salinity however increases with depth and has an EC of 16,000 μS cm^{-1}, at 250 m. This formation outcrops extensively in Ethiopia and in Somalia, forms the eastern edge of the Xuddur-Baardheere basin and south western edge of the Ogaden basin; its thickness is approximately 500 m;

v. *Moderately productive fissured/intergranular aquifers:* To the north west of the Burr uplift, the Mudug-Marka Suite of Miocene age is exposed. These sandy limestone with sand and gypsum, yield groundwater with an EC from 1,135 to 9,250 μS cm^{-1} and the thickness of the formation is uncertain but in the range 50 to 500 m;

vi. *Limited groundwater resources:* The Precambrian basement complex outcrops in the Burr region in the south. Fracture aquifers yield small quantities of poor quality water with EC up to 34,000 μS cm^{-1}. Groundwater is generally developed in this area from hand-dug wells in the numerous alluvial togga beds. A spring line at the contact of the Jurassic limestone aquifer and basement complex yields good quality water with yields ranging from 0.4 to 16.6 L s^{-1} and EC up to 2,900 μS cm^{-1}. The lower Cretaceous Mustaxiid formation is a fossiliferous marly and gypsiferous limestone, which has thickness of 200 m and outcrops to the north east of the Xuddur-Baardheere basin. Shallow wells yield small quantities of water with an EC normally greater than 10,000 μS cm^{-1} except at Halgan where it is in the range of 400-5,000 μS cm^{-1}. This aquifer has a low permeability and poor infiltration potential. The Fer formation is predominantly gypsum with intercalation of sandstone. The total thickness is 60 m and it yields highly saline water with EC of about 40,000 μS cm^{-1}. Overlying the Fer is the Beled Weyne formation. This sandy limestone and gypsiferous marl has a limited outcrop, is some 200 m thick and has a low permeability. The groundwater quality is poor with EC ranging from 4,000 to 7,000 μS cm^{-1}. The Miocene Paleocene basalts overlay the Cretaceous sediments and when located in depressions, can be water bearing. The water quality is normally poor having an EC greater than 4,000 μS cm^{-1};

vii. *No groundwater resources:* The Canoole formation is a series of marl, shale, sandstone, mudstone and thin limestone. It acts as an aquiclude and contains saline water with EC normally greater than 30,000 μS cm^{-1}. The total thickness of this formation is 500 m and it outcrops in an arc around the Baydhabo region.

<u>Groundwater systems in central Somalia</u>

i. *Productive intergranular aquifers:* The Yasooman formation outcrops in a broad north to south band and forms the edge of the Ogaden basin. The sandstone and sand achieve a thickness of 500 m and the formation has large exposures in Ethiopia where its elevation rises to approximately 1,500 m from 400 m in Somalia. Recharge to this aquifer is from direct rainfall, which increases from 200-500 mm yr^{-1} in the higher lands of Ethiopia. The Yasoomman in part is covered by dense karstified limestone, which allows rapid infiltration into the highly permeable formation. Aquifer conditions range from confined to unconfined. The total depth of boreholes penetrating this formation range from 70-340 m with groundwater levels ranging from 137 m below ground level to approximately 3 m above ground level in the free flowing artesian boreholes. The quality of the groundwater is good with EC ranging from 1,500-3,500 μS cm^{-1}. Specific capacities of up to 122 m^2 d^{-1}, have been measured with yields of up to 140 m^3 hr^{-1}. This aquifer is considered to be one of the best in Somalia. Groundwater occurrence is widespread in the Quaternary shallow gypsiferous aquifer and is extensively exploited by shallow hand-dug wells. The water quality can be good after rainfall but deteriorates with time, with many wells going dry. The depth to water is in the range of 4-20 m and the EC is between 1,500 and 12,300 μS cm^{-1}. The majority of the wells are constructed in the depressions associated with Gaalkayo and Dhuusamarreeb ancestral drainage systems;

ii. *Moderately productive intergranular aquifers:* Along the coast, a freshwater lens in the sand aquifer overlying seawater is extensively tapped by shallow wells and boreholes yielding water with an EC in the range of 600 to 3,200 μS cm^{-1};

iii. *Moderately productive fissured/intergranular aquifers:* The Oligocene/Miocene Basal limestone is between 100 and 200 m thick and contains an aquifer, which is normally confined. Boreholes penetrating this formation are between 150 and 250 m deep with the rest water levels ranging from 3 m above ground to 60 m below ground level. The specific capacity of the boreholes ranges from 2 to 200 m^2 d^{-1} yielding water with an EC normally in the range 2,000 to 3,000 μS cm^{-1}. Overlying this formation is the Mudug Beds. These are predominantly gypsiferous sand and sandy clay with a thickness of 10-200 m. The aquifer is predominately saline with EC ranging from 900 to 26,000 μS cm^{-1}.

Wells penetrating this formation are between 120 and 350 m deep and the rest of the water levels are between 17 and 88 m below ground level. The aquifer characteristics range from being confined to semi confined and the wells tested have specific capacities in the range of 2 to 260 m^2 d^{-1}. The third of the three aquifers identified in the Oligocene/ Miocene succession is the Limestone aquifer. This unit is a karstic limestone varying in thickness of 20-200 m. Borehole depths penetrating this formation range from 70-200 m and the groundwater EC is between 2,000 and 14,250 μS cm^{-1} (more commonly, 2,500 μS cm^{-1}). Excessive pumping can result in the rising of the saline groundwater from the underlying Mudug Beds. The specific capacity of the boreholes in this formation is in the range 12-75 m^2 d^{-1}. As discussed earlier, underlying these Oligocence/Miocene sediments and confined by basalt are the Eocene and Upper Cretaceous Yasoomman aquifers which in general have better quality water than the Oligocene/Miocene aquifers.

Groundwater systems in northern Somalia

i. *Productive integranular aquifers:* Along the Gulf of Aden coast is a thin strip of Quaternary sand ranging in width from 0-10 km. To the west of Berbera, an alluvial plane, up to 90 km wide has been formed by the erosion of the mountain range and joins the coastal sands. The numerous toggas, which flow toward the gulf, provide a source of recharge for these aquifers and the depth of groundwater ranges from just above sea level at the coast to 140 m inland, depending on ground elevation. In the toggas, the EC ranges from 900-2,500 μS cm^{-1} and the specific capacity of the boreholes constructed range from 100 to 900 m^2 d^{-1} with aquifer transmissivity of 3,500-5,200 m^2 d^{-1}. The aquifer potential of recent alluvial deposits of the major toggas in the mountain area is good although the Ged Dheeble basin is at present being over pumped for supplying water to Hargeisa. The total depth of the boreholes constructed in the basin range from 20-100 m with water availability from 6-40 m below ground. The specific capacities of the boreholes are from 20 to 144 m^2 d^{-1} yielding water between 0.1 and 5 m^3 hr^{-1} with EC ranging from 317 to 550 μS cm^{-1}. Boreholes constructed in the upper Waheen togga have total depth of 40-80 m with water levels from 2-4 m below ground. Discharges range from 4-34 m^3 hr^{-1} with specific capacities of 20-100 m^2 d^{-1}. For the remaining plateau and valley areas, several hand-dug wells and tap water from the Quaternary sediments are located mainly along togga beds;

ii. *Productive fissured aquifers:* The Jurassic limestone and sandstones range are intensively fractured, karstic and the aquifers sustain numerous springs with yields ranging from 0.2 to 37.5 L s^{-1}. The water quality is good with EC in the range of 1,100 to 2,100 μS cm^{-1}.

The groundwater potential of these Jurassic sediments, which have a total thickness of 1,220 m, has not been evaluated by drilling but is likely to be good;

iii. *Moderately productive inter-granular aquifers:* To the west, the Nubian sandstone is exposed and has a thickness ranging from 200-1,700 m. In the east, a Cretaceous sandy limestone of thickness of 500-700 m has good groundwater potential. However, no information concerning its water bearing properties is available. The Nubian sandstone formation is well faulted and has several springs, some of which are thermal. The formation however has a disappointingly low yield, in the range of 1 to 4 m^3 hr^{-1}, with a specific capacity of about 2 m^2 d^{-1}. The total depth of the boreholes constructed range from 60-300 m (commonly 200 m), with the groundwater level some 100 m below, and yield water with EC in the range of 1,100-5,500 μS cm^{-1};

iv. *Moderately productive fissured aquifers:* The Auradu series of Lower Eocene age is a massive limestone, well fissured, faulted and karstic on cliff outcrops. In the mountain region it gives rise to many springs with good water quality. The spring discharges commonly range from 10-30 L s^{-1} and have an EC between 450 and 1,500 μS cm^{-1}. The limestone has a thickness of 380 m and the depth to water is often greater than 90 m. Boreholes constructed on the Haud plateau have produced disappointing results with the depth to water greater than 250 m. At Burco however, boreholes approximately 200 m deep have yields of some 10 m^3 hr^{-1} and specific capacities as high as 280 m^2 d^{-1}. The Taleex formation of the middle Eocene comprises of massive anhydrite with limestone and gypsum intercalations and is commonly karstic. In the mountain area, there are many springs with discharges ranging from 0.1-47 L s^{-1}. Majority of the yields are however less than 8 L s^{-1}. In the Nugal valley and Taleex plateau, several boreholes have been drilled into this formation with total depth of 40-100 m, the total thickness of the formation being 250 to 300 m. The specific capacity of the boreholes tested range from 20 to 250 m^2 d^{-1} with yields from 15-30 m^3 hr^{-1}. Some aquifer tests have been carried out to determine the transmissivity, which is in the range of 400-1,100 m^2 d^{-1}. The depth to water in the boreholes range from 6-14 m and the EC of both the mountain springs and valley-plateau aquifer is approximately 3,000 μS cm^{-1};

v. *Moderately productive fissured/intergranular aquifers:* The Karkar series of the Upper Eocene age comprises of limestone, marl and chert and have a thickness of 260 m and are sometimes cavernous. The Karkar covers large areas in the mountains where there are numerous springs with EC in the range 1,100-1,800 μS cm^{-1}. Discharges depend on season, ranging from 4- 14 L s^{-1}. Boreholes drilled into this formation on the Sool and Sool Haud plateaus have produced poor results with the water depths in the range of 100 to 300 m. It is considered an aquifer with poor potential in this area. Boreholes drilled at Qardho have a total depth of 90-250 m with water levels commonly at 140 m below ground level. EC is in the range of 1,750-5,000 μS cm^{-1} and fluoride concentrations are high. Well yields are in the range of 1- 40 m^3 hr^{-1} with specific capacities being 34-60 m^2 d^{-1}. Pumping tests show the transmissivity to be 40-45 m^2 d^{-1}. The Oligocene Miocene sediments of the middle and upper Daban and Hafun series are exposed. There are no hydrogeological data for these sediments, however it is considered likely that they will have similar hydrogeological properties to those in the southern region;

vi. *Limited groundwater resources:* The basement is more intensively fissured and the aquifer water quality is better than in the south, with EC in the range of 330-8,000 μS cm^{-1}. Springs have yields in the range of 0.1-13.2 L s^{-1} and EC from 300-5,900 μS cm^{-1}. The lava flows are Pliocene to Pleistocene in age and the water quality from the basalts can have highly variable EC, ranging from 450-16,000 μS cm^{-1}. Some trapped alluvial sediments within the lava flows yield limited quantities of water with an average EC of 3,000 μS cm^{-1};

vii. *No groundwater resources:* There is almost a complete lack of shallow wells away from the togga beds in the north indicating an absence of shallow groundwater in these areas. Exploratory drilling indicates that groundwater is at least 300 m below ground level in the Nubian sandstone aquifer.

Groundwater quality

The most common method used for abstracting groundwater in Somalia is the hand-dug well. This has often resulted in very poor quality water, being used by people and livestock with the EC value commonly exceeding 10,000 μS cm^{-1}. This is further complicated by the commonly encountered poor sanitary conditions surrounding the wells, resulting in high levels of pollution. Springs are also utilized as groundwater sources and these too are commonly polluted. High concentration of dissolved solids which are generally present throughout Somalia, have necessitated the introduction of relaxed water quality standards. Based on electrical conductivity, wells exceeding 3,500 μS cm^{-1} are too brackish for human use. Wells designated only for animal use have a limit of 7,500 μS cm^{-1}. There is a high probability that water of good quality can be found inland within a narrow band along the edge of the gypsum deposits and in the limestone formations west of the Shabelli river. Water from drilled wells in these areas is of the quality that might be used for drinking, irrigation, and cattle. In other areas it is more likely that water from wells is suitable only for cattle. In the Bay region, very small difference exists in the chloride concentration between wells in the Limestone plateau and in the basement complex. In these two areas there exists a 60 percent probability of finding water with a chloride concentration below 800 mg L^{-1} whereas in range lands the lowest chloride level is around 120 mg L^{-1} and the highest 1,200 mg L^{-1}.

Only 5 percent of the wells in the Bay region can be considered to have sulphate waters. The few sulphate water wells are scattered over the entire area, thus indicating that they may be due to local pockets of gypsum. And in the central rangelands, 25 percent of respondents reported water with sulphate concentration in the range of 200 to 500 mg L^{-1}. The concentration of bicarbonates in the Bay region is high, at about 500 to 1,000 mg L^{-1}. Bicarbonate waters are primarily found to the west of the karstic springs and wells. The bicarbonate wells are also found in the limestone formation west of the Shabelli river and in the zones between the gypsum/anhydrite deposits. There are however other water types in these areas, but the location of the bicarbonate waters support the conclusion that at the thinner edges of the main gypsum deposit, limestone formations influence the water quality.

Groundwater development and utilization

Groundwater abstraction

Groundwater in Somalia is abstracted from springs, wells, boreholes, dams and berkads (underground tanks) (Figure 11.1). The area to the west of Juba river and the area between Juba and Shabelle rivers have more springs than other water sources. The coastal areas however, have more boreholes and wells than springs. This is particularly the case around Kismayo and Mogadishu. The area to the north of Shabelle river, up to the border with Gulf of Aden has more boreholes and wells than dams and berkads. The northern area of the country bordering Ethiopia has more berkads than any other type of water source though all types are available in all the regions. Lower Juba, Bay, lower Shabelle, middle Shabelle and Hiran regions are generally rich in groundwater and have many springs spread out in the regions. Similarly the northern part of Mudug and the coast of Nugaal region have many springs. All other regions have sparsely spaced springs. The existence of the different abstraction structures follows the rainfall pattern. Where there is sufficient rainfall, dams and berkads are more common. Where rainfall is inadequate, boreholes and wells are more common. Presence of boreholes and wells depends on whether they were developed by the community themselves or through support received from the government. Where the government was involved (particularly near major towns) there are more boreholes than wells in an attempt to abstract the deep confined aquifers, reportedly of good quality water and unlimited quantity.

Most wells on the other hand abstract from the shallow unconfined aquifers. Between the two layers of aquifers, saline water is normally present, which the shallow wells do not tap but in case of boreholes, this must be drilled through to reach the deeper confined aquifers with good quality water. Table 11.1 shows the distribution of groundwater sources in Somalia. There are about 13,500 wells and 2,400 boreholes in Somalia.

Table 11.1 Hand-dug well and borehole numbers in Somalia

Region	Hand dug Wells	Boreholes
Lower Juba	590	280
Middle Juba	400	240
Gedo	680	60
Bay	570	90
Lower Shabelle	880	10
Middle Shabelle	610	330
Hiran	130	80
Bakol	610	40
Galgaduud	1,350	240
Mudug	570	210
Bari	1,430	100
Nugaal	450	110
Sool	1,330	70
Sanaag	1,250	160
Togdeerrer	700	110
Woqooyi Galbeed	1,130	220
Awdal	890	120
Total	13,570	2,470

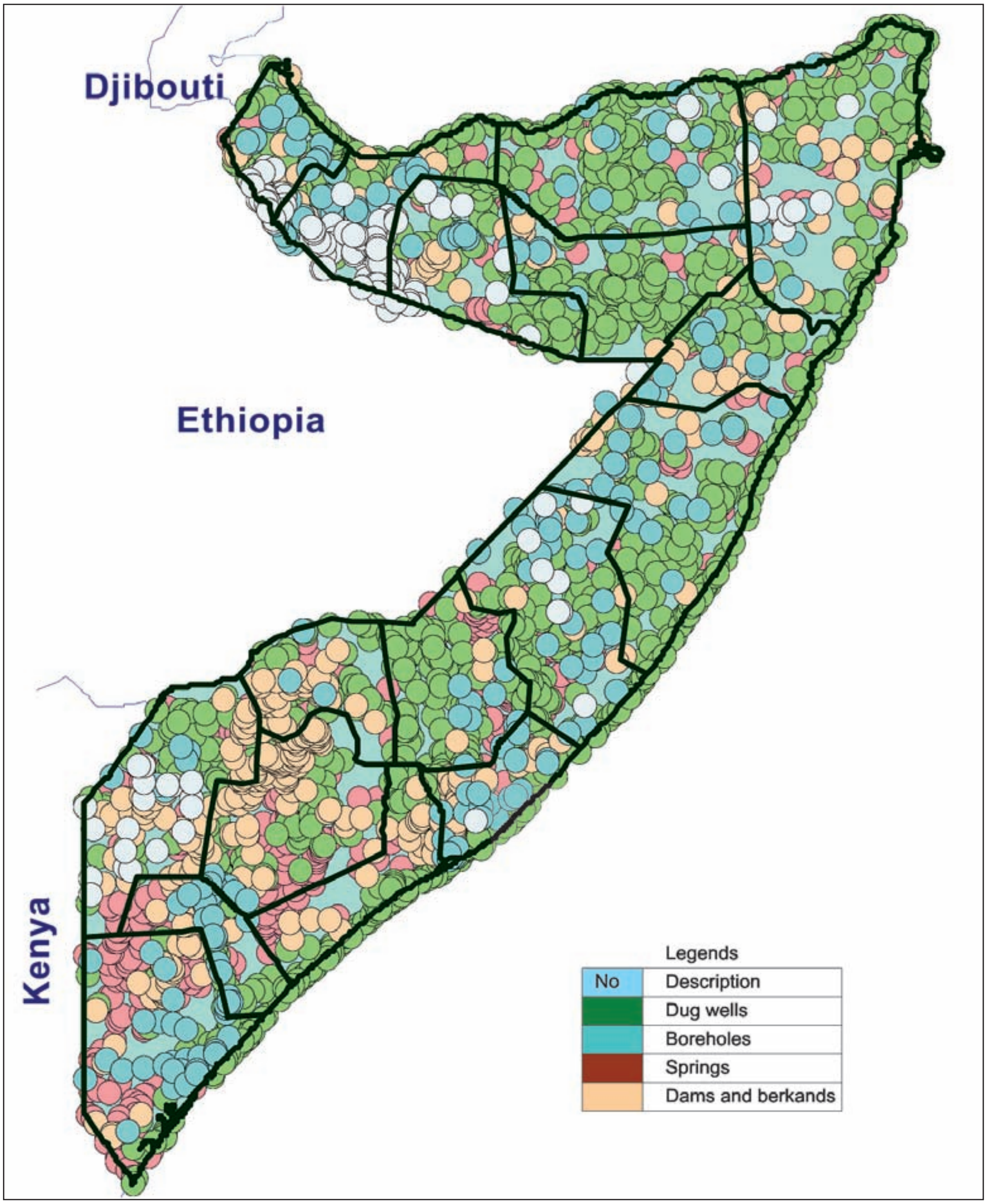

Figure 11.1 Water points in Somalia (Source: Food and Agriculture Organization 2005)

Cost of groundwater development

Costs associated with groundwater development comprise site exploration, drilling and installation in Somalia, are presented in Table 11.2. These figures draw from the "Comprehensive Groundwater Development Project (CGDP)" primarily focusing on the domestic, livestock as well as irrigation use of the resource. The overall purpose of the CGDP was to strengthen the capability of the Water Development Agency (WDA) to install, operate and maintain rural water supply systems and the specific goal was to develop the water resources base in the designated priority areas across Somalia.

Table 11.2 Cost of groundwater development in Somalia

Description of work	Prices (USD)
Site selection	68.9-112.6
Well drilling and logging	1,485-2,425
Well testing	
Final installations	81.4-133
Operation and maintenance	1,378-2251

Source: MMAR (1985)

Groundwater utilization

<u>Domestic purpose</u>

Total water withdrawal is estimated at 3,298 $km^3\ yr^{-1}$ (2003), of which, agriculture (irrigation and livestock) accounts for 99.5 percent. In the rural areas, domestic water supply is derived from surface dams, boreholes, shallow wells and springs; often distributed by donkey carts to households. During the dry season, groundwater is the main supply for domestic and livestock use and is only supplemented by surface water when and where it is available.

<u>Irrigation</u>

Agricultural water abstractions are mainly limited to partially controlled irrigation schemes. Of the abstractions for agriculture, livestock use accounts for around 0.03 $km^3\ yr^{-1}$ (FAO 2005). Under the present condition, surface water withdrawal amounts to around 96 percent and groundwater withdrawal is about 4 percent of the total water withdrawal. In the dry season, due to scarcity of water resources, the competition for the resource is high and groundwater supplies are often severely stressed (FAO 2005). The area equipped for irrigation was 200,000 ha in 1984, of which 50,000 ha was under the full/partial control surface irrigation and 150,000 ha under the spate irrigation. These estimates are still valid today, though much of the infrastructure is not used. The actual area irrigated is only around 65,000 ha. Irrigated agriculture is mainly practiced along the Juba and Shabelle rivers. In their upper sections both rivers have deep riverbeds and pumps are used to draw water for irrigation purpose. The lower sections the rivers are embanked, which allows for gravity-fed irrigation, especially along the Shabelle. Pumps are used by those who can afford it during periods of low discharge.

A large potential exists for the use of existing shallow wells for subsistence crop production. Unfortunately, the rural population does not use vegetables as the main food and thus there is little initiative to use the wells for vegetable production that could be very viable. The transportation sector has completely collapsed across the country and the roads leading to main towns and vegetable markets bear serious risks associated with security issues. This situation further discourages the population from engaging in vegetable production.

Livestock watering

The livestock population in Somalia relies on groundwater. From the distribution of water points in the country, it can be estimated that half of the animal population rely of groundwater. Others rely on dams and berkads. Only a small portion relies on the two rivers, Juba and Shabelle since they traverse a small portion of the country. Livestock include cattle, camel, donkeys, sheep and goats. Reports of studies commissioned by the World Bank, Food and Agriculture Organization and the European Union in 2004 shows that in 1990, there were about 55 percent of Somalian population directly engaged in livestock production and another large segment employed in related services. Thus the livestock sector is a main source of livelihood. Some 70 percent of Somalis live in rural areas of which about 55 percent are pastoralists and agro- pastoralists, 24 percent are crop farmers and one percent, fishermen. FAO data indicate that there are 37.5 million grazing animals in Somalia. This is equivalent to 15 million tropical live units (TLUs). Camels are the most important in terms of biomass (41%) followed by goats and sheep combined (35%) and then cattle (24%). Considering that half of the livestock rely on groundwater, it can be concluded that 4 million people and 19 million livestock are reliant on groundwater.

Institutional and legal framework

Previously, a National Water Centre had been established in Mogadishu under the Ministry of Minerals and Water Resources through an FAO project funded by UNDP. The Centre acted as a National Archive for all water related studies and contained a comprehensive library of study reports. This centre along with the Water Development Agency (WDA), also under the Ministry of Minerals and Water Resources, dealt with water resource management in Somalia. The WDA was responsible for groundwater development nationwide except for the capital area and had a team of geologists, hydrogeologists and drilling rigs and crews to carry out groundwater related activities. The Centre collapsed following the 1990 civil war, which has left Somalia without an internationally recognized government up to the present time.

In Somalia there are no uniform constitutional and legal rules governing social or economic behaviour, except for a 1971 law governing the Water Development Agency. In Somalia, a draft Water Act and a Water Policy were prepared in 2004. The ownership of land and water is based on the Somali social organization where each clan is associated with a particular territory. The law says that water is a public property but allows for appropriation and usage acquired through administrative permits.

In northeast Somalia, the Ministry of Pastoral Development and Environment is responsible for natural resource management, including the use of surface water and groundwater resources. It developed the strategic plan for sustainable natural resource management for 2002-2004. Canal committees and water use associations exist in some areas, but there is no clear pattern of water allocation rights and fees. On most of the small irrigation schemes with hand-dug canals, canal committees exists and these schemes are better maintained compared to the large-scale irrigation schemes, which were maintained by former government departments. Lack of sustainable irrigation management is also due to the fact that the land is irrigated by people who have no previous experience of irrigation.

Conclusions and Recommendations

Hand- dug wells are the most common method of abstracting groundwater in Somalia, often resulting in poor quality water being used by people and livestock. This water, in addition to having high EC values, exceeding 10,000 $\mu S\ cm^{-1}$, is also highly polluted due to the commonly encountered poor sanitary conditions in the vicinity of the wells. Springs being another groundwater abstraction point are also polluted. These traditional water sources are supplemented on a wide scale, by both rainwater and runoff fed reservoirs, which range from natural hollows, hand-dug underground reservoirs to over-ground structures with capacities in excess of 30,000 m^3.

The construction of boreholes throughout the country has brought great benefits to the rural villages providing permanent, normally unpolluted water for domestic use. However, when used for cattle watering, many ill effects have come up such as the abandonment of hand-dug wells and reservoirs and overgrazing. Boreholes are expensive to construct and have high running and maintenance costs. In areas where good quality shallow groundwater exists, a hand- dug well construction and rehabilitation is relatively inexpensive to achieve. With proper design, this would provide a source of unpolluted water. Subsurface dams and collector wells, tapping sand rivers and Togga beds are at present in use but in limited numbers. A program to accelerate the construction of such structures would be very useful. The construction of boreholes for rural water supply in areas with potential aquifers yield and good quality water should be continued. Drilling of boreholes for livestock watering needs careful planning, to overcome overgrazing problems. Watering points should not be too far apart and the problems associated with operation, maintenance and provision of fuel should be considered. Setting up multi-disciplinary teams would be most effective in developing appropriate strategies for a groundwater resource development program.

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CHAPTER 12

SOUTH AFRICA

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General description of South Africa

Geography

South Africa occupies the southern tip of Africa, its coastline stretching more than 2,500 km from the desert border with Namibia on the Atlantic (western) coast southwards around the tip of Africa and then north to the border with Mozambique on the Indian Ocean. For the country of South Africa, latitude of 29°00' S and longitude of 24°00' E denotes its geographical alignment. The low lying coastal zone is narrow for much of that distance, soon giving way to a mountainous escarpment (Great Escarpment) that separates the coast from the high inland plateau. In some places, notably the province of KwaZulu-Natal in the east, a greater distance separates the coast from the escarpment. Although most of the country is classified as semi-arid, it has considerable variation in climate as well as topography. The country is subdivided into nine provinces: The Eastern Cape, Free State, Gauteng, KwaZulu-

Natal, Limpopo, Mpumalanga, Northern Cape, North West and Western Cape. In this chapter, though general information has been given for South Africa as a country, there is a specific focus on Limpopo province. Limpopo is the new name of the erstwhile Northern Province. It is situated at the north eastern corner of South Africa and shares borders with Botswana, Zimbabwe and Mozambique. It forms the link between South Africa and countries further afield in Sub-Saharan Africa. Limpopo can be divided into sub regions for better understanding of its geography: The Northern, Lowveld, Central, Southern, Western and the Bushveld regions.

Physiography and climate

South Africa is bordered by Botswana and Zimbabwe to the north, Mozambique and Swaziland to the north east and east, the Indian Ocean to the south east and south, the Atlantic Ocean to the south west and west and Namibia to the north west. The total land area is 1,223,201 km^2. South Africa's climatic conditions generally range from Mediterranean in the south western corner of South Africa to temperate in the interior plateau and subtropical in the north east. A small area in the north west has a desert climate. Most of the country has warm, sunny days and cool nights. Rainfall generally occurs during summer (November through March), although in the south west around Cape Town, rainfall occurs in winter (June to August). Temperatures are influenced by variations in elevation, terrain, and ocean currents more than latitude. Temperature and rainfall patterns vary in response to the movement of a high pressure belt that circles the globe between 25° and 30° S latitude during the winter and low-pressure systems that occur during summer. Rainfall varies considerably from west to east. In the north west, annual rainfall often remains below 200 mm. Much of the eastern Highveld in contrast receives rainfall of 500 mm to 900 mm yr^{-1}, while occasionally rainfall exceeds 2,000 mm. A large area in the centre of the country receives about 400 mm rain on an average and there are wide variations closer to the coast. The 400 mm "rainfall line" has been significant because land east of the rainfall line is generally suitable for growing crops and land west of the rainfall line for livestock grazing or crop cultivation on irrigated land.

The plateau is generally highest in the east, dropping from an elevation of 2,400 m in the basaltic Lesotho region to 600 m in the sandy Kalahari in the west. The central part of the plateau comprises the Highveld, which is between 1,200 and 1,800 m in elevation (FAO 2005). South of the Orange river lies the Great Karoo region. The soil of South Africa has been classified using a hierarchical system (Soil Classification Working Group 1991) and include a large number of soil bodies which range from black, smectitic clay on dolerite to yellow, kaolinitic clay on Beaufort sediments. Climate-soil combinations mean that only 12 percent of the total land area or 14.6 million ha could be considered as cultivable. The cultivated area, however, calculated as the sum of arable land and land under permanent crops, was about 15.7 million ha in 2002. The reason is that sometimes land with uncultivable soils are also cultivated (FAO 2005).

Socio-economic context

According to the CIA's World Factbook, the population estimate for South Africa was 44.2 million (July 2006), of which approximately 46 percent was rural and 54 percent urban. The annual growth rate is estimated at about 1.2 percent. The average population density is 37 inhabitants km^{-2}, ranging from 21 in rural areas to more than 100 inhabitants km^{-2} in more densely populated urban areas (FAO, 2005). South Africa is a middle-income, emerging market economy, with an abundant supply of natural resources; well-developed financial, legal, communications, energy and transport sectors; a stock exchange that is the 18th largest in the world; and modern infrastructure supporting a relatively efficient distribution of goods to major urban centres throughout the region. Growth was robust from 2004 to 2007 as South Africa reaped the benefits of macroeconomic stability and a global commodities boom, but began to slow in the second half of 2007 due to the electricity crisis and the subsequent global financial crisis', impacting the commodity prices and demand. GDP fell nearly 2 percent in 2009. Agriculture contributes 2.8 percent of the GDP, with the service industry contributing 30.8 percent and other services like metal products, chemicals, food and beverages, electrical machinery, motor vehicles, textiles and printing and publishing contributing 66.8 percent of the GDP (CIA, 2010). GDP per capita is about USD 7,000.

A comparison of various social indicators of Limpopo vis-à-vis South Africa is shown in Table 12.1 and it is evident here that Limpopo is a relatively poverty-stricken rural area, where only about 76 percent of households have access to piped water. Development Bank of South Africa (2000), using census data and a poverty line of R800 household expenditure per month, estimated that about 57 percent of South Africans are living in poverty while 78 percent of the population in Limpopo lives below the aforesaid poverty line. The poverty calculation done by May (1998), estimated a somewhat different poverty line of R352 per adult equivalent per month, and found that 50 percent of the South African population can be classified as poor while the estimated poverty rate in Limpopo was 62 percent (May, 1998). The unemployment rate in Limpopo is higher than the South African average (Table 12.1). The percent population in Limpopo province indicates that about 90 percent of the population lives in villages and is exposed to high health risk due to infection and other diseases. Water is therefore a strategic resource for this province.

Table 12.1 Social indicators for South Africa and Limpopo (1996/97/98)

Indicator	South Africa	Limpopo
Population (Census, 1996) (Million)	40.58	4.93
Population growth rate (%)	2.08	2.31
Urban population as percentage of total	53.7	10.95
Infant mortality rate	41	53
Total fertility rate	2.7	3.2
Percentage of population < 15 yrs	34.33	42.75
Life expectancy at birth	63	63
Non-urban economic active population as percentage of total economic active population	32.9	82.8
Total unemployment rate (%)	33.8	45.9
Doctors per 10,000 population	2.9	1.5
Hospital beds per 1,000 population	4	3.1
Diseases:		
Percentage of HIV infected women at antenatal clinics	22.8	11.5
TB cases per 100,000 population	-	286
Malaria cases per 100,000 population	22,950	4,814
Tuberculosis cases per 100,000 population	63,136	1,947
Typhoid cases per 100,000 population	425	98
Viral hepatitis cases per 100,000 population	1,042	109
Human Development Index	0.672	0.566
Gini coefficient (for income)	65	66
Infrastructure:		
Percentage households with access to electricity	57.3	36.2
Percentage households with access to piped water	79.8	75.5
Percentage households with access to sanitation	82.5	77.8
Percentage households with access to telephones	28.6	7.4

Source: DBSA (2000)

Groundwater resources

Hydrogeology

Shallow, weathered and/or fractured-rock and relatively low yielding aquifer systems are underlain over 80 percent of South Africa. By contrast, appreciable quantities of groundwater can be abstracted at relatively high rates from dolomitic and quartzitic aquifer systems located in the northern and southern parts of the country respectively, as well as from a number of primary aquifers situated along the coastline.

Groundwater systems

Aquifer types

The aquifer systems in South Africa can be divided into two major types: primary and secondary aquifers.

Primary aquifers: The primary aquifers are: (1) coastal sand, gravel and unconsolidated material along the South African coast, such as area along the west coast at Port Nolloth, Doringbaai, Lambertsbaai, Langebaan, Atlantis, Cape Flats, Gansbaai, Bredesdorp, Stilbaai, Alexandria, Boesmansriviermond, Kidds beach, Richards bay; (2) sand and gravel along stream beds such as those along the Crocodile and Caledon rivers, at De Aar, De Doorns, Rawsonville, Pietersburg (Polokwane), Messina, and Makatini Flats (Kok, 1991). Typical characteristics of primary aquifers are as follows:

- Usually shallow unconfined systems and groundwater surface in the aquifer is at atmospheric pressure (100 kPa);
- Mostly consist of unconsolidated material, usually less than 30 m thick;
- Contain 1 to 20 percent water by aquifer volume;
- Recharge rate is generally high. Some 15 to 30 percent of rainfall would infiltrate into aquifers;
- Geohydrological characteristics of aquifer do not vary greatly over short distances;
- The transportation of contaminants in the primary aquifers is slow because of high effective porosity;
- Significant attenuation of pollutants is expected in the clayey portion of aquifer;
- Borehole yield from porous flow aquifers is negatively correlated to the clay percentage within the aquifer.

Secondary aquifers: The degree of fracturing of rocks in South Africa is dependent upon the tectonic history of rocks as well as the rock composition. For example, competent rocks, such as dolerite and quartzite, fracture more readily than incompetent or ductile rocks, such as dolomite and shale. The magnitude of fracturing does not necessarily determine how much water an aquifer can transmit. It is estimated that at depths greater than 60 m, about less than one percent of the fractures transmit significant amounts of water. However within quartzitic rocks, significant yields are possible at greater depths. Typical characteristics of secondary or fracture flow aquifers are:

- Fractured flow aquifers are either confined or unconfined aquifers. The confined aquifers are overlain by sediments or rock of confining nature, which limits direct recharge from rainfall;
- They belong to shallow systems, usually less than 60 m thick and in exceptional circumstances can be about 200 m thick;
- The quality of water in deeper fracture flow system is not good for human consumption;
- They contain between 0.001 and 0.1 percent water by aquifer volume;
- Recharge from rainfall is low, totalling between 1 and 5 percent of annual rainfall;
- Characteristics of aquifers as well as borehole yields vary greatly over short distances;
- Contaminants travel comparatively faster in the fractured flow aquifers;
- Pollutants are not attenuated in the fracture.

The dolomite aquifers are situated predominantly in the north west province of South Africa, from (east) Ventersdorp to Mafikeng (west). Dolomite consists of strata 200-1,900 m thick, composed of dolomitic rock. Dolomitic aquifers provide ideal sites for high yield boreholes. They can be exploited for urban supplies and irrigation on a larger scale than groundwater in other hard rock formations. Dissolution channels that develop along fractures within dolomite can extend to surface; this affects the recharge characteristics of the aquifers. Since dolomitic aquifers are not protected by overlying geological formations, they are particularly vulnerable to pollution due to their thin soil cover and high transitive characteristics.

In Limpopo province, most of the aquifers are secondary and a few are primary. The primary aquifers are found along the Crocodile river and Polokwana (formerly Pietersburg). Some 90 percent of aquifers in South Africa, including Limpopo, are secondary or fracture aquifers. About 3 percent of the province comprises karst aquifers. The rest of the province is underlain by fractured and intergranular and fractured aquifers (personal communication Willem Du Toit, DWAF, June, 2003).

Aquifer yield, recharge and groundwater potential

The aquifer yields show a great deal of variation in South Africa. Yields from boreholes in South Africa can vary from low to very high and can be classified according to their potential for use (Table 12.2).

Table 12.2 Index of aquifer yield, South Africa

Index category	Range (L s^{-1})	Potential Use
Low	< 1	Stocks, gardens, and domestic use
Medium	1-5	Limited development potential
High	6-20	Small community
Very high	> 20	Large scale water supply

Source: DWAF (1998)

Vast areas of South Africa have boreholes that produce low yields (1 L s^{-1} or less) and large areas underlain by Karoo sediments and most other sedimentary basins fall in the low-yield category. The “high” and “very high” yield categories (as shown in Table 12.2), fall within the “major aquifer” category. Medium yield corresponds to the “minor aquifer” category. The last “low yield” falls within the “poor aquifer” category. High yield boreholes (with yields in excess of 5 L s^{-1}) are very rare to come by in South Africa. Boreholes with such high yields are sited scientifically and are located on very favourable structures, such as faults or along dolerite dykes. Dolomitic rocks usually can yield vast amounts of water. Sometimes, such yields can exceed 100 L s^{-1} in many cases. For example, in the gold mining industry where dolomite water is abstracted, yields are in excess of 500 L s^{-1}. Some examples of yield characteristics for major aquifer types in South Africa are provided in Table 12.3 and these values are proposed to be used for planning or designing purposes, as they reflect the favourable yield conditions from boreholes sited scientifically.

Table 12.3 Examples of favourable yield characteristics for major aquifers, South Africa

Aquifer Type	Typical yield range (L s^{-1})
Alluvial deposits	3-8
Coastal sands	3-16
Karoo sediments	1-3
Karoo dyke	3-6
Table mountain sandstone	1-10
Dolomite (Karst)	20-50
Granite (weathered)	5-10

Source: DWAF (1998)

The long-term potential yield of boreholes depends upon the amount of recharge to the groundwater from rainfall, impoundments and streams. Recharge quantity ranges from 1 to 5 percent of the annual rainfall. In some aquifers such as dolomites and sedimentary hard rock in mountain catchments, it can be as high as 25 to 31 percent (Sami and Murray, 1998). The other important property of South African aquifers is that they are extremely vulnerable to pollution due to the following reasons:

- Recharge occurs freely through infiltration from rainfall, ponds and from seepage through dumps;
- All usable groundwater occurs within 60 m of the surface;
- Since 90 percent of the aquifers are secondary, contaminants travel at 10 to 1,000 times faster than porous flow system in primary aquifers;
- Contaminants or pollutants travel in preferential flow-paths, dictated by the water table gradient, fractures and geology of the aquifers.

Aquifer yield in Limpopo

Most aquifers in Limpopo are poor and their yields are not very different from the national average. An index of yield from boreholes in Limpopo is given in Table 12.4. Some 60 percent of the area has boreholes yielding less than or equal to 0.5 L s^{-1}. Only 20 percent of the area has boreholes yielding up to 1.5 L s^{-1}. Another 20 percent area has high-yielding boreholes, the yield being between 10 and 20 L s^{-1}. However, the Limpopo average is much lower than the national average (compare Tables 12.2 and 12.4). Groundwater is used extensively for irrigation and rural water supplies. Dolomitic aquifers occur in the Crocodile basin as well as Blyde river area. Relatively large quantities of water are abstracted from sandy aquifers along the Crocodile, Limpopo, and Sand rivers.

Table 12.4 Index of aquifer yield, Limpopo

Index category	Yield (L s^{-1})	Area coverage of the Province (%)
Low	0.5	60
Medium	1.5	20
High	10-20	20 (as obtained in some special projects)

Source: Personal communication with Eberhard Braune, Geohydrology Division, DWAF, 6 June, 2003

Groundwater quality

South African industries consist primarily of mining, automobile assembly, metalwork, machinery, textiles, iron and steel, chemicals and foodstuffs. Some industries operate with old technologies with associated pollution problems. The South African mining industry is a large consumer of water resources and probably the most direct cause of groundwater pollution through acid mine drainage (Bourne, 2002). Conrad *et al.* (1999) found that intensive animal husbandry has impacted on groundwater quality at the field sites studied. Nitrate was the most common agricultural contaminant found in the groundwater sampled. Nitrate distribution and nitrogen isotopic analyses indicate the most important source to be sludge, manure and soil biota. In addition, there were significant levels of potassium, ortho phosphate and faecal microbes. The contamination levels were associated with the livestock concentration and irrigation of effluents; sometimes this pollution has been found to be as high as 156 mg L^{-1}. High nitrate levels (> 10 mg L^{-1}) were also found in the groundwater. Irrigation return flow can cause the salinization of groundwater in irrigated aquifer systems. For example, significant salinization has been reported in groundwater underlying the irrigated lands of Great Fish Sundays river basin; total dissolved salts (TDS) ranged from 2,000-3,400 mg L^{-1}. At the Vaalharts irrigation scheme, the estimated volume of water that percolated to the water table annually was 63 million m^3, carrying nearly 30,000 tons of dissolved salts. This has resulted in increased groundwater salinity, a rise in the water table and also waterlogging issues.

Groundwater development and utilization

Groundwater abstraction

Borehole drilling is an on-going activity in the province. According to information provided by the Groundwater Information Project (GRIP), there are about 35,000 boreholes in the Limpopo province and their number is growing every day. Some 20 boreholes per day or 100 boreholes per week are drilled. The success rate is about 66 percent; one out of three boreholes would be dry. According to them, there are some 2,191 villages in Limpopo and there are some 6 to 10 boreholes per village. This means there are between 13,000 and 22,000 boreholes in rural areas alone (this includes old homelands of Lebowa, Venda, and Gazankhulu). The National Groundwater Database shows a total number of 29,259 boreholes in Limpopo with a yield record. This probably represents only about 20 to 30 percent of all boreholes. This means there are probably far in excess of 100,000 boreholes in Limpopo.

The life span of a borehole depends on various factors namely, construction of the borehole, rate at which it is pumped (over-pumping can generate many problems such as drying-up, collapsing, incrustation of the fractures and casing openings/perforations by iron bacteria or carbonate), and maintenance of the pump and infrastructure. Most of the problems are related to improper borehole construction (insufficient casing, insufficient protection at surface, lack of gravel packs, etc.). Considering all these points, the life of a borehole can range from 1 to 5 years. However, if a borehole is properly constructed and operated at a sustainable rate then the productive life can be far longer.

Cost of groundwater development

Cost of borehole drilling and pump installation

The cost of borehole drilling depends on many factors such as depth, topography, type of rocks, and other factors. A typical borehole in Limpopo is about 72 m deep; these are found where igneous or metamorphic rocks predominate. In areas underlain by sedimentary rocks, a typical borehole could be 200 m deep. However, sedimentary rocks are less common in Limpopo. For abstraction, there are predominantly two types of pumps used in the Limpopo province: constant displacement or mono-type; and the submersible pump. The mono-type pump has typically been installed in the province. This pump may be powered by either diesel or electrical power. Since a diesel motor can be used, it has been used extensively in rural areas where electrification is yet to be done. This makes it a very popular pump in the province. However, as electrification is approaching in many areas, it is being replaced by electricity operated pump, and the submersible pump is gaining popularity. The submersible pump runs on electricity and is more easily secured and thus less susceptible to theft. Its installation cost is also lower compared to mono-type. Typical costs for drilling and installation of pumps are shown in Table 12.5 while estimates of maintenance and operation (running) cost are given in Table 12.6

Table 12.5 Overall costs (in USD) from drilling to pump installation, Limpopo

Particulars	Pump Type	
	Mono-Type	Submersible
Drilling	1.19 - 1.43	1.19 - 1.43
Borehole development	0.59 - 0.95	0.59 - 0.95
Pump testing	0.83 - 1.43	0.83 - 1.43
Cost of pump and motor	2.97 - 7.14	2.02 - 3.21
Cost of pump installation	2.38 - 3.57	0.59 - 0.83
Total costs	7.97 - 14.51	6.42 - 9.40

Source: Personal communication with Robert Crossby, Geocon, Consultant, 25^{th} June, 2003.
Currency conversion rate used: 1 RAND = 0.12 USD

Table 12.6 Estimates of maintenance and running costs of pumps (in USD), Limpopo

	Constant Displacement		Submersible
Particulars	Diesel	Electrical	Electrical
Maintenance Costs in USD (12 months)	1,055	589	6.1
Running Cost in USD			
Diesel (0.84 L hr^{-1}) 7358.4 L yr^{-1} X R3.30 L^{-1}	2,888	-	-
Electricity Cost in USD 1.5 kW, 400V 8760 hr plus 14% VAT	-	641	641
Total yr^{-1} in USD	3,944	1,230	647
Total $month^{-1}$ in USD	328	102.55	53.9

Source: Personal communication with Robert Crosby, Geocon Consultant, August 4^{th}, 2003
Currency conversion rate used: 1 RAND = 0.12 USD

The cost of borehole drilling depends on a number of factors. Drilling cost of a typical borehole (72 m deep and 16.5 cm diameter) is estimated between USD 1,190 and USD 1,430 per successful borehole. At times, it can be as high as 2,380 USD or more. The cost of encasing the borehole can range between USD 595 and USD 952. Encasing is followed by pump-testing, which is estimated to be between USD 833 and USD 2,379. The cost of drilling by the Department of Water Affairs and Forestry (DWAF) is expected to be higher because it includes expenses such as salaries of personnel and other materials. For a 165 mm diameter borehole, the average cost is estimated to be USD 38.67 m^{-1}. For a 72 m deep borehole, it will cost USD 2,784 which is almost twice of the cost in the private sector.

Groundwater utilization

About 90 percent of groundwater in South Africa occurs in secondary aquifers, which are weathered and fractured rocks; these rocks lie directly beneath the surface to the depth of less than 50-60 m. The quantity of water stored in the saturated parts of the weathered and fractured rocks is small and permeability of secondary aquifers is low. As a result, the yield of borehole is also low. This water is sufficient to provide water on farms for domestic use, for livestock watering, for irrigation on a small scale and to supply water to small communities or towns. The census surveys over the years have indicated a definite pattern of groundwater use in South Africa (Table 12.7). About 78 percent of groundwater is used for irrigation. It was observed that the average increase in the irrigated areas was 4 percent yr^{-1} between 1949 and 1976; while between 1974 and 1976, the average growth was 4.9 percent yr^{-1} (DWAF, 1986). The growth in groundwater use is stimulated by the electrification of rural areas. The urban use, although very small (4%), is significant to note as about 105 towns across South Africa use groundwater exclusively. Some towns use both surface and groundwater. Two biggest users of groundwater are Rand Water Board and Municipality of Pretoria. The total urban use is estimated to be 70 million $m^3\ yr^{-1}$. For Limpopo province, at the aggregate level, about 60 percent of the total water (462.2 million m^3) is used for irrigation; 1.8 percent for livestock; 2.5 percent for rural communities; 6.5 percent for municipal uses; and finally 6.9 percent for mining uses (Table 12.8).

Table 12.7 Breakdown of groundwater use by sectors, South Africa, 1980

Water use sector	Use ($Mm^3 yr^{-1}$)	Percentage of total (%)
Urban use	70	3.9
Rural domestic use	120	6.7
Stock-watering	100	5.6
Irrigation	1,400	78.2
Mining and quarries	100	5.6
Total	1,790	100

Source: DWAF (1986)

Table 12.8 Groundwater use in Limpopo by WMAs

Use	Limpopo WMA ($Mm^3 yr^{-1}$)		Lebata/ Levuzu MA ($Mm^3 yr^{-1}$)		Oliphants WMA ($Mm^3 yr^{-1}$)		Crocodile West & Marice WMA ($Mm^3 yr^{-1}$)		Aggregate ($Mm^3 yr^{-1}$)	
Irrigation	131	(63)	9	(16)	79	(69)	56	(67)	275	(59.5)
Livestock	2	(2)	1.2	(< 1)	2	(1.5)	56	(4)	1.2	(1.8)
Rural communities	53	(25)	38	(66)	20	(18)	6	(7)	117	(25.3)
Municipalities	12	(6)	8	(14)	2	(1.5)	8	(10)	30	(6.5)
Mining	9	(4)	2	(3)	11	(10)	10	(12)	32	(69)
Total	208	(100)	57.2	(100)	114	(100)	114	(100)	462.2	(100)

Note: Figure in parenthesis is the percent value
Source: Personal communication with Robert Crosby, Geocon Consultant, August 4th, 2003

There are three different users of groundwater in the province: smallholders, commercial farmers, and municipalities. Municipalities use groundwater in conjunction with surface water and it is difficult to estimate their dependence on groundwater. A rough estimate is that 50 or 60 percent of total water use is dependent on groundwater. The smallholder is 100 percent dependent upon groundwater, as he/she happens to grow subsistence crop primarily for self-consumption. There are a number of commercial farmers who obtain water from dams such as Loskop, Tzaneen, and Njelele. Many of them also have boreholes as backup especially during droughts and subsequent water restrictions. More than 80 percent of them depend on groundwater only and this number could rise to 90 percent during droughts. In Limpopo water management area, some 131 million m^3 of groundwater is applied to irrigate an area of 20,630 ha, as detailed in Table 12.9. Estimates of total water use and water recharge are given in Table 12.10. About 1,433 million m^3 yr^{-1} is recharged and about 32 percent (462 million m^3) of it is used for different purposes.

Table 12.9 Irrigated areas by groundwater in different WMAs of Limpopo

WMA	Area (ha)	Groundwater use (Mm^3 yr^{-1})
Limpopo	20,630	131
Letaba/Levubu	1,840	9
Oliphants	16,400	79
Crocodile west and Marico	11,700	56
Total	50,570	275

Source: Personal communication with Robert Crosby, Geocon Consultant, August 4th, 2003

Table 12.10 Groundwater use and recharge status, Limpopo Province

Area	Estimated recharge (Mm^3 yr^{-1})	Total use (Mm^3 yr^{-1})	Groundwater remaining (Mm^3 yr^{-1})
Limpopo	702	208 (28)	503 (72)
Lebata & Levuvhu	291	57 (19)	236 (81)
Oliphants	303	114 (34)	200 (66)
Crocodile west & Marico	137	83 (32)	64 (47)
Total for the Province	1,433	462 (32)	1,003 (68)

Note: Figure in parenthesis is the percent value

Source: Personal Communication with Robert Crosby, Geocon Consultant, August 4th, 2003

Institutional and legal framework

The Water Act provides for fundamental transformation of water resource management and governance, through decentralization of the responsibility and authority for water resource management to appropriate, representative, regional and local institutions. The Minister, as trustee of water resources on behalf of the National Government, has overall responsibility for all aspects of water resource management in South Africa. For practical reasons, the Minister can delegate these responsibilities to departmental officials, water management institutions, water boards and so on. The Department of Water Affairs and Forestry (DWAF) is responsible for administering all aspects of the Act on the Minister's behalf. This role will diminish as regional and local water management institutions are established. The eventual role of the DWAF will be to provide national policy and regulatory framework and maintain general oversight of the institutions' activities and performance. As time goes on, the DWAF will withdraw from direct involvement in the development, financing, operation and maintenance of water resource infrastructures. In the long run, the responsibility for operating and maintaining infrastructure will be transferred to other agencies such as catchment management agencies and water user associations.

After a countrywide consultation, 19 Water Management Areas (WMA) were established with the Catchment Management Agencies (CMAs) being the statutory bodies with jurisdiction in a defined WMA. At a local level, the association of water users is promoted. They are expected to be financially self-supporting through the water use charges paid by the members. A water user association falls under the authority of the CMA in whose area of jurisdiction it operates. All irrigation boards, subterranean water control boards and water boards established for livestock watering purposes in terms of the 1956 Water Act, must be transformed to become water user association or disestablished. The responsibilities for operating and maintaining schemes that are of local importance are to be handed over by the DWAF to the water user associations. In addition, the Minister has established three institutions to implement international agreements in respect of the development and management of shared water resources with other nations. A water tribunal established in 1998, is an independent body with a mandate to hear and adjudicate appeals, mainly against administrative decisions made by responsible authorities and water management institutions. The water tribunal has jurisdiction everywhere in the country.

Water rights in South Africa have evolved over time, starting from the customary system through the apartheid era, to the current law. Groundwater of the country is managed under the National Water Act (1998). Prior to the new Water Act, the groundwater in South Africa had been managed as a separate entity from surface water. Furthermore, it was primarily given the status of private resource. This led to unsustainable management and subsequent resource degradation. The new Water Act attempts to redress this problem of groundwater mismanagement by providing a new approach to its management. These include protection of all significant water resources, resource sustainability, and integrated water resource management. Although it is uncertain whether resource sustainability can be achieved practically, it is understood that the principle of resource sustainability in conjunction with resource protection are of paramount importance to successful groundwater management over the long run. To facilitate the development and management of groundwater, new wells need to be registered with the Department of Water Affairs and Forestry (DWAF). To ensure compliance with general requirements and to protect the public, all drillers are required to register as well. In areas, which are environmentally sensitive, a permit to drill is to be obtained from the DWAF. Groundwater use is therefore to be carried out in the context of adequate catchment management plan, based on an understanding of sustainable yield of local groundwater resources.

On the new Water Act, water is to be priced and a pricing strategy is to be developed toward setting water use charges for funding water resource development, management and use of water works, through the equitable and efficient allocation of both surface and groundwater. All authorized users of water are required to be registered with the Department of Water Affairs and Forestry (DWAF). The Act determines that any person registered in terms of regulation or holding a license to use water must pay all charges imposed under the pricing strategy for that particular water use. It is on this registered water use that the water resource management charge is levied. The charges are levied based on the principle of user pays so as to reduce the burden on the National tax payer. Previously this was fully funded by the treasury.

Water resource management charge

According to the pricing strategy of the DWAF published in 1999, all water uses will be charged in principle. There are 11 categories of water uses identified in the country. However, initially only two types of uses were subjected to billing. These include: 1) surface and groundwater 2) stream flow reduction activities by commercial forestry. The Water Resource Management (WRM) charges (VAT excluded) for the financial year 2003/2004 for the domestic and industrial sector averaged 1.13 cents m^{-3}, for irrigated agriculture 0.63 cents m^{-3}, and forestry 0.55 cents m^{-3}.

Groundwater development challenges

Groundwater pollution

The demand for clean water is increasing by 3 percent yr^{-1} in Southern Africa. Increasing population and improved quality of life (leading to greater water use), reduces the quantity of water available per person, unless additional water source can be made available (Ashton *et al.*, 2001). Groundwater can meet at least some of this growing demand, particular in the provinces of Northwest and Limpopo. However, the increasing dependency on groundwater is threatened by the increase in contaminants due to rising population and urbanization, along with increasing industrialization. The groundwater contamination may be microbiological, organic or inorganic in nature. The contaminants can reach the aquifer through a variety of pathways (Xu and Braune, 1995) and through different sources including industrial, agricultural and community wastewater.

Groundwater depletion

Groundwater is an extremely important resource for many rural communities in South Africa. Decreasing flow in the rivers and springs during dry season and dry periods, as well as widespread problems of surface water pollution in both urban and rural areas has made groundwater an important resource to depend upon. Although groundwater supplies only a small portion (15%) of South Africa's total water requirements, it constitutes the sole supply to more than two-thirds (65%) of the population, residing in 300 towns across the country. However, overuse of the resource is causing the fall in water table and adding to the cost of groundwater abstraction.

In South Africa, 'alien' vegetation is becoming a major threat to groundwater, wherein about 25 million acres (10 million ha) of land have become infected with alien weed that uses almost 7 percent of country's total run-off than the indigenous plants it replaced; and with implications on groundwater recharge. This problem was fixed through various clearing and control methods by the Working for Water Programme launched by the National Department of Water Affairs and Forestry.

Conclusions and Recommendations

Groundwater contributes about 15 percent of the total water use in the country but constitutes as the sole supply to more than two-thirds of the population of the country; some 300 towns in South Africa exclusively depend upon groundwater. Most of this resource is concentrated in the provinces of Limpopo and Northern Cape. Groundwater is an important resource for rural development and reconstruction activities. This becomes especially important in the context of Limpopo, a poverty-stricken region in South Africa where providing access to drinking and irrigation water to rural people is the number one priority. In terms of aquifer types, more than 90 percent of aquifers are secondary types in South Africa including Limpopo, where the yield levels are low. In 60 percent of the area, the maximum water yield is about 0.5 L s^{-1}, while in 20 percent area, the yield is 1.5 L s^{-1}. The remaining 20 percent show yields of 10 to 20 L s^{-1}. However, the groundwater in the province is sufficient to provide for domestic use, for livestock watering, for irrigation on a small scale, and to communities. Irrigation uses up to 78 percent of the groundwater in the province. The use of groundwater in rural areas is increasing as more villages are electrified. The urban use of groundwater is just 4 percent of the total. However, 105 towns in Limpopo depend primarily on groundwater. Water use for other sectors is as follows:rural domestic use 6.7 percent; livestock watering 5.6 percent; mining and quarries 5.6 percent.

Two major problems that beset groundwater are pollution and depletion. Pollution can emanate from industries, agricultural activities and community waste. Industrial pollution is common in the urban sites, especially in coal and mining sector. Agriculture and animal husbandry is the source of non-point pollution. Community sanitation system can also pollute groundwater. Overuse of the resource is resulting in falling water table. As a result of these problems, the government and other institutions have responded in various ways to protect the groundwater.

It is estimated that there are 35 to 40 thousand active boreholes in the province, with an additional 100 boreholes per week being drilled with a success rate of 66 percent. In the 2,191 villages of Limpopo, there are 6 to 10 boreholes in each village; thus totalling to 13 to 21 thousand boreholes in the province with an estimated life span of 1 to 5 years.

The cost of pump depends upon the type of pump. Of the two types of pumps popular in Limpopo, the mono-type is the most popular type installed in the province. This pump runs on diesel and is good for rural areas with no electrification. However in areas which have electricity, people are switching to the submersible pump for various reasons. Firstly, it is cheaper with a maintenance cost lower than that of mono-type; secondly, the submersible pump is less susceptible to theft. The total costs (costs of pump, motor, and installation) for mono-type pump comes to about 5,354 USD to 10,707 USD as opposed to 3,807 USD to 5,592 USD for the submersible pump. The entire costs from drilling to pump installation for both pumps are as follows: mono-type, 7,971 USD to 14,514 USD, submersible, 6,424 USD to 9,399 USD. The operation and maintenance cost comes to 329 USD, 103 USD, and 59 USD, for mono with diesel, mono with electric and submersible with electric power respectively. Over all, the monotype pump is almost three times costlier than the submersible pump. There can be significant differences in the overall costs from drilling to pump installation, depending upon the choice of pump.

As per the new Water Act, water pricing strategy is to be developed to generate funds for water resource management, and aiming for equitable and efficient allocation of water. All authorized users of water are required to be registered with the Department of Water Affairs and Forestry (DWAF) and must pay all charges imposed under Pricing Strategy with respect to the specific use. Water resource management charges relate to activities required to regulate, manage, and maintain the water resource or catchment. The charges are levied based on the principle of user-pays where as previously it was fully funded by the treasury. Initially the Department of Water Affairs and Forestry is responsible for the water resource management tasks, but over time it will be delegated to the Catchment Management Agencies (CMA).

The non-recurring upfront costs related to situation analyses, establishment of CMAs and public participation is excluded from price setting and the administrative cost (personnel and professional) taken into account. Water users in Limpopo pay a water levy on a 6 monthly basis ranging from 0.55 cents m^{-3} for forestry to 1.13 cents m^{-3} for domestic or industrial use on average.

The legal and institutional framework for groundwater in South Africa has developed over the last 300 years. Groundwater was considered as the absolute property of the landowner with some exception. The riparian principle superseded the state control. During apartheid, the hybrid system developed; this was completely changed with the democratic rule in 1994. As per new Water Law, the national government is the custodian of this resource and riparian principle is squelched. Groundwater is also to be subjected to a system of allocation that promotes equitable and sustainable development. The new Water Act attempts to redress the problem of groundwater mismanagement by protection of all significant water sources, by ensuring sustainability and by taking the integrated water resource management approach. This is done by dividing the entire country into 19 Water Management Areas (WMAs) and Catchment Management Agency in each WMA to look after the water resources. A three-tier hierarchy of water management institutions is thus created to manage the water resource. This includes the Minister and Department of Water Affairs and Forestry followed by the Catchment Management Agency and then other water management institutions.

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CHAPTER 13

TANZANIA

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General description of Tanzania

Geography

The United Republic of Tanzania (6°00' S, 35°00' E) consists of the mainland and Zanzibar, which is made up of the islands Unguja and Pemba. Its total area is 945,090 km^2. The country is bordered in the north by Kenya and Uganda, in the east by the Indian Ocean, in the south by Mozambique and in the west by Rwanda, Burundi, the Democratic Republic of the Congo, and Zambia. The Indian Ocean coast is about 1,300 km long, while to the north west there is a 1,420 km shoreline of Lake Victoria, in the centre west there is a 650 km shoreline of Lake Tanganyika, and, in the south west, 305 km shoreline of Lake Nyasa is present. The highest point in the country is Mt. Kilimanjaro. It also takes in part of the largest lake in Africa, Lake Victoria, and the second deepest lake in the world, Lake Tanganyika.

Physiography and climate

The terrain comprises of plains along the coast, a plateau in the central area that ranges between 1,000-1,500 m above mean sea level (AMSL), characterized by gently sloping plains and plateau broken by scattered hills and low lying wetlands. The north east border with Kenya is dominated by Mt. Meru (4,565 m AMSL) and Mt. Kilimanjaro (5,895 m AMSL). Towards the south is the Central Plateau reaching elevations above 2,000 m AMSL. The mountain range of the southern Highlands separates the Eastern Plateau from the rest of the country. The lowest point is in lake Tanganyika. The vegetation of Tanzania comprises of typical savannah species, and wooden grasslands are scattered throughout the country. Woodland, grassland and bush land account for about 80 percent of the total land area. Cultivable area is estimated to be 40 million ha or 42 percent of the total land area. According to the World Reference Base for Soil Resources (WRB), Tanzania has 19 dominant soil types. Cambisols are the most extensive soils in the country, covering 35.6 percent of the area and mainly in the mid-western and south eastern parts of the country. Cambisols are characterized by slight or moderate weathering of parent material and by absence of appreciable quantities of illuviated clay, organic matter, aluminium and/or iron compounds. The other dominant soils by percentage coverage include Acrisols (8.63%), Leptosols (8.11%), Luvisols (7.26%), Ferralsols (6.32%), Vertisols (5.02%) and Lixisols (4.95%).

The climate varies from tropical along the coast to temperate in the highlands. There are two types of seasonal rainfall distribution: (i) the unimodal type, where rainfall is usually from October/November to April, found in the central, southern and south western highlands and the (ii) bimodal type, comprising two seasons: the short rains (*Vuli)* fall from October to December, while the long rains (*Masika*) fall from March to June. This type occurs in the coastal belt, the north eastern highlands and the Lake Victoria basin. Mean annual rainfall of the country is 1,071 mm, with highest rainfall (between 1,000-3,000 mm) occurring in the lake Tanganyika basin and in the southern highlands. Zanzibar and the coastal areas are hot and humid and average daily temperatures are around 30^{o}C; October to March is the hottest period. Sea breezes however temper the region's climate and June to September is coolest with temperatures falling to 25^{o}C. In the Kilimanjaro area, temperatures vary from 15^{o}C during May to August to 22^{o}C during December to March.

Drainage

Tanzania has nine major drainage basins: Lake Victoria, Pangani; Ruvu/Wami, Rufiji, Ruvuma and southern Coast, lake Nyasa, lake Tanganyika, Internal drainage and lake Rukwa basin. River regimes follow the general rainfall pattern. River discharge and lake levels start rising during November-December and generally reach their maximum in March-April with a recession period from May to October/November. Many of the larger rivers have flood plains, which extend far inland with grassy marshes, flooded forests, and ox-bow lakes. About 5.7 percent of the total land area of the United Republic of Tanzania is covered by three large lakes (Victoria, Nyasa and Tanganyika), which also form the borders to neighbouring countries. Total renewable water resources amount to 93 $km^3 yr^{-1}$, of which 84 $km^3 yr^{-1}$ are internally produced, and 9 $km^3 yr^{-1}$ are accounted for by the Ruvuma river, which flows over the border from Mozambique (Ramonyai and Konstant, 2006). Renewable groundwater resources are estimated at 30 $km^3 yr^{-1}$ (Ramonyai and Konstant, 2006).

Socio-economic context

The 2002 Population and Housing census showed that Tanzania had 34.4 million people in 2002 with an average growth rate of 2.9 percent yr^{-1}. The population projections show that Tanzania is expected to reach 63.5 million in 2025 (URT, 2009). Rapid population growth impacts on the water resources coverage and because of that, the per capita water use has been decreasing over time. The World Bank indicators show that in 2008 Tanzania had 1,977.22 m^3 per capita water use yr^{-1}, however due to population growth, increase in water demand to meet requirements for various socio-economic activities, pollution and climate change, this amount will decrease to about 1,500 m^3 per capita yr^{-1} by 2025.

The Tanzanian economy indicated stable growth between the early 2000s to now, growing between 4.5-7 percent. GDP per capita is about USD 500 (UN Data). Agriculture contributes 42 percent of the GPD; with the service industry, especially tourism contributing 40 percent; and industry 18 percent of the GDP (CIA, 2010 est.). Agriculture provides work for 14.7 million people, or 79 percent of the total economically active population and 54 percent of agricultural workers are female. Small scale subsistence farmers comprise more than 90 percent of the farming population, with medium and large scale farmers accounting for the rest. Owing to the vast coastline and many lakes, fishing is an important agricultural subsector as livestock is, due to large areas of grassland in Tanzania. Livestock for instance, accounted for 5.9 percent to total GDP in 2006, of which beef, dairy and other stock provided 40, 30 and 30 percent respectively. The industrial sector which contributes to 18 percent of the total GDP comprises of the manufacturing, mining and quarrying, construction, and utilities (electricity and water supply) sub-sectors.

Groundwater resources

Hydrogeology

The general geology of Tanzania comprises mainly the Precambrian (Archaean, Proterozoic) and Phanerozoic (upper Palaeozoic, Mesozoic and Cenozoic) formations (Figure 13.1). The Precambrian basement rocks of Tanzania consist of Dodoman system, Nyanzian system, Kavirondian system, Usagaran system, Bukoban system and Plutonic rocks (JICA, 2008). The Dodoman system is the oldest formation in Tanzania, which consists of schist gneiss and migmatite and mostly distributed around the Dodoma region. The rocks for Dodoman system are very dense and not easily weathered, the recharge mechanism is through the fracture zone and drilling depths is estimated to be 70 to 120 m. The Nyanzian system consists of metamorphic rocks, which was metamorphosed from sedimentary and igneous rocks. They are distributed in Shinyanga, Nzega, Igunga and Iramba districts. Nyanzian system is surrounded by granite at many places and these areas have many fractures that are suitable for groundwater recharge with drilling depths estimated to be 40-100 m.

The Kavirondian system consists of quartzite and phyllite and the outcrops of the rocks are confined at limited area near Nzega. The metamorphic rock called “Usagaran” is distributed in the northern parts of Arusha, Manyara, and Dodoma regions. It consists of older granitic and sedimentary rocks that were metamorphosed by the orogenic movement of intrusion of granites and these rocks crop out the large area of the eastern part of the Internal drainage basin, with drilling depths estimated to be 40-250 m. The Bukoban system consists of sedimentary rocks which are mudstone, shale, sandstone, etc. Exposures of the rocks are confirmed at the limited area in the southern part of the Bahi swamp. Finally, the Plutonic rocks consist of granite and granodiorite, gneissose or migmatitic rocks and are widely distributed from the central to the western part of the Internal Drainage Basin.

The Kainozoic (Cenozoic) formations are associated with the late Neogene, lacustrine sediments, terrestrial sediments, fluviatile sediments, marine sediments and alluvial sediments deposited in the lakes and shallow basins formed by the warping of the surface that accompanied rift-faulting movements. These sediments are distributed in the centre of each basin and characterized by low plane in topography. From central to the north western part of Tanzania, extensive volcanic activity in association with rift-faulting movements can be seen from Mt. Hanang, Mt. Kilimanjaro and northward into Kenya. Volcanic ash has high permeability making some of these, good recharge areas. Scoria and pyroclastic flow sediments have relatively high permeability; also the basaltic lava has many cracks that make them good recharge zones. Climatically, the areas receive much rainfall and have high water retention capacity. Being good recharge zones, water levels are relatively deep due to the thick volcanic ash and pyroclastic sediments which have high permeability. Drilling depths are estimated to be 100-250 m.

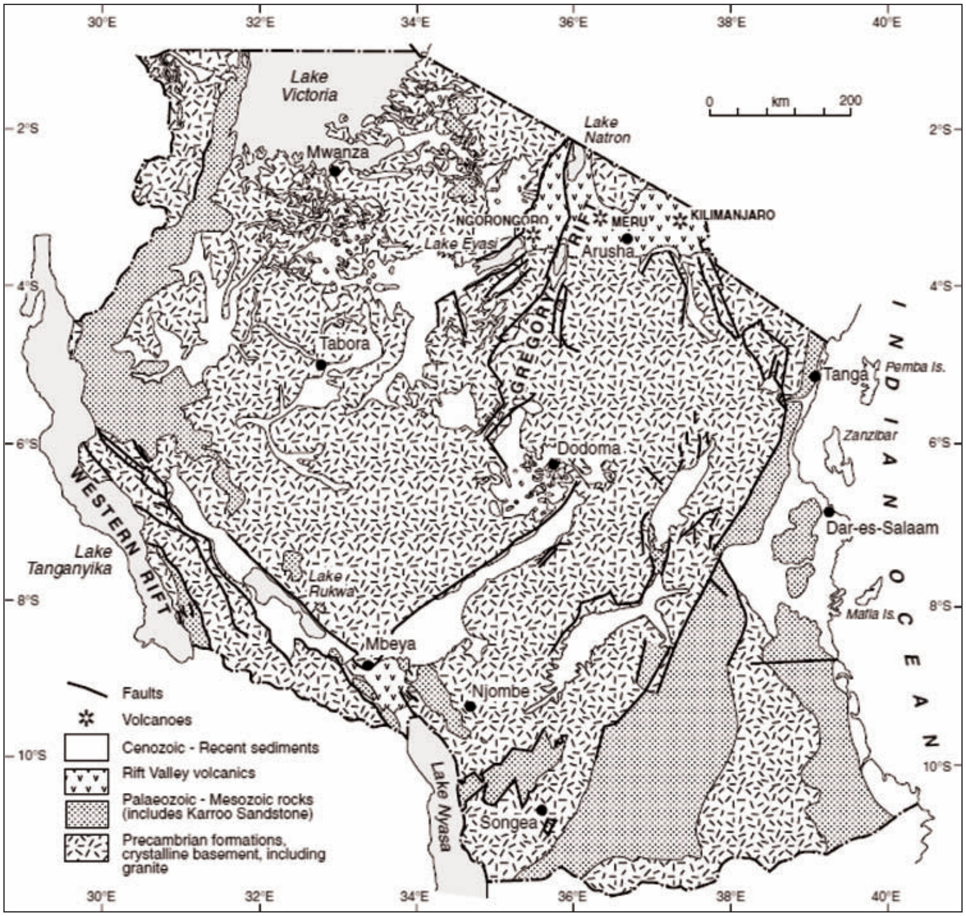

Figure 13.1 Simplified geological map of Tanzania (Source: British Geological Survey and WaterAid; www.wateraid.org/documents/tanzaniagw.pdf)

Groundwater systems

The occurrence of groundwater is largely influenced by geological conditions. About 75 percent of Tanzania (Kongola *et al*., 1999) is underlain by crystalline basement complex rocks which form the basement aquifers (for example the Pangani and Makutopora basins).

Other aquifer types include the Karroo (found in Tanga), coastal sedimentary formation of limestone and sandstone (e.g. Dar es Salaam), and the alluvial sedimentary sequence, which mostly include clay, silt, sand and gravel, and volcanic materials (e.g. Kahe - Pangani basins). The groundwater potential of each main aquifer type differs much from place to place or basin wise due to variability in aquifer formations and recharge mechanisms.

Baumann *et al.* (2005) provides a general overview of the stratigraphic sequence or the depth wise variation from the analysis of broad classification of the aquifer formations and the geologic data of the boreholes. The general aquifer formations in Tanzania are summarised in Table 13.1. Therefore, according to (Baumann *et al*., 2005), the following categorizations were revealed:

- In most regions and notably in Mtwara, Coast, Morogoro, Ruvuma, Shinyanga, Kilimanjaro, Kagera, Lindi, Mwanza and Mbeya the dominant water bearing formations are unconsolidated sand and gravels;
- In region such as Singida, Mara, Iringa, Kigoma, Dodoma, Rukwa and Manyara the water bearing formations are predominantly weathered and/or fractured granites/gneisses. Arusha is dominated by igneous rocks and the water bearing zones are mostly in weathered and fractured lava flows;
- In Tanga region, the semi-consolidated marine sediments and the Karoo sandstones are mostly the water bearing zones.

Table 13.1 Generalised aquifer formations and percentage area coverage in Tanzania

Category	Aquifer Type	Main Lithologic units	Area (%)
1	Old, Paleogene, Neogene and Quaternary sediments	Alluvial: sand, gravel, silt, mud Lacustrine: sand, sit, limestone, tuff Terresterial: sand, gravel, laterite, silcrete, calcrete; Fluviatile: marine, sand, gravel, silt, limestone	20
2	Volcano-Plutonic/ granite	Black clay soil, yellow altered ash, white pumice and ash breccias, paleosoil with clay and volcanic rocks, alluvial deposits, sand with basalt, weathered basalt	15
3	Plutonic-Metamorphic/ Gneiss rocks	Marble; quartize, graphitic schist, chlorite, amphibolite, mica and kyanite schist, hornblend biotite and garnet gneiss, acid gneiss, granulite, charnockite, magmatite; mudstone, shale and phylite, arkose, qartize, conglomerate, limestone	65

Source: Baumann *et al*. (2005)

The Old, Paleogene, Neogene and Quaternary sediments are mostly unconsolidated and semi-consolidated where the old sediments occur. The Volcano-Plutonic is mostly consolidated and the Plutonic-Metamorphic is also consolidated except when weathered. Since the formation is distributed extensively, large numbers of wells have been drilled into the Neogene aquifer. Neogene aquifer shows relatively higher yield with an average yield of about 24.5 L min^{-1}.

Boreholes drilled in the first and second categories described in Table 13.1, are expected to be fairly homogenous depth wise, mostly sediments in the first, and volcanic and granites in the latter. In the third category, typical sections usually include unconsolidated superficial deposits, weathered granites/gneiss, fractured granite/gneiss and solid bedrock. Figure 13.2 presents the distribution of aquifer categories by region. Where significant local deposits of sediments overlay the Plutonic-Metamorphic rocks, they constitute an isolated aquifer system. Therefore, while the generalised map could be used as a first approximation for an overall planning, borehole siting remains a-case-by-case issue due to variations in aquifer formations.

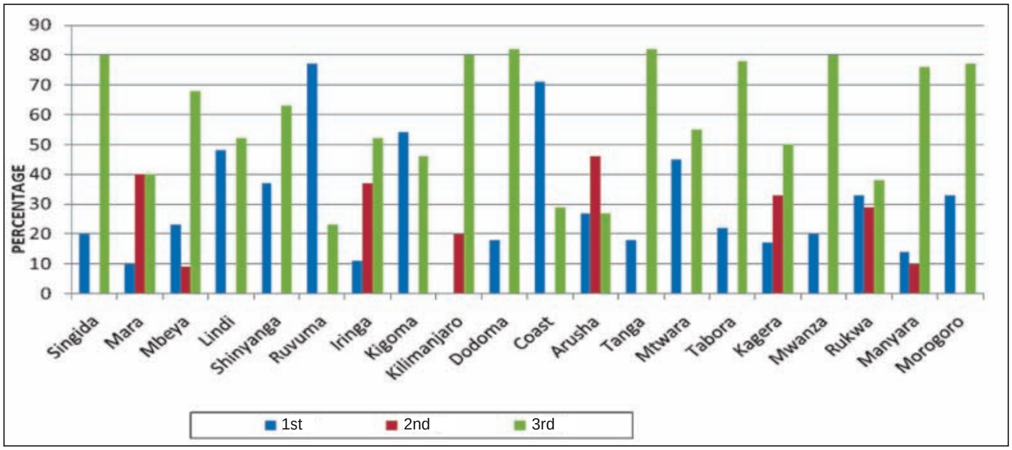

Figure 13.2 Distribution of aquifers by region in Tanzania (Source: Baumann et al., 2005)

The water yielding properties of rocks, unconsolidated sediments and other deposits depend on the interstices and voids which exist within such formations. The quantitative information on aquifer characteristics and recharge rates, including groundwater flow regimes, abstraction rates and quality controls are very uneven and generally incomplete. Information from limited pump test data available (e.g. Table 13.2) indicate that the aquifers have a range of transmissivity values from low to high values with hydraulic conductivity ranging from 1 m d^{-1} to higher than 16 m d^{-1} (Shindo, 1989 cited in Rwebugisa, 2008). The moderate variability in transmissivity values, which would undoubtedly be greater if data were more comprehensive, is attributable to the heterogeneity in aquifer system.

Table 13.2 Aquifer parameters from pumping test analysis (N=1988)

Aquifer thickness (m)	SWL (m)	Yield ($m^3 hr^{-1}$)	Duration (min)	Specific capacity ($m^2 d^{-1}$)	Transimissivity ($m^2 d^{-1}$)
41	26	16	840	1	93
32	26	52	840	8	841
57	23	79	840	10	671
85	22	28	840	3	490

Source: Shindo (1989)

Out of 850 boreholes drilled by Drilling and Dam Construction Agency DDCA in all of Tanzania during a period of 20 months (DDCA Database, 2003-2004 and 2004-2005), the deepest hole (dry) was 150 m in depth. Only 26 boreholes were drilled deeper than 100 m and a total of 50 boreholes were deeper than 80 m. The available data in the Dodoma borehole database covering 5,848 boreholes provided the means for estimating the depth and yield region wise. This basic information can be combined with the regional geology to provide an idea of the drilling depth, type of formation and the expected yield. These factors have a direct bearing on the drilling technology to be employed and have cost implications (Baumann *et al*., 2005). Figures 13.3 and 13.4 present the average depths and yield of boreholes respectively.

The average depth of all boreholes drilled in the 20 regions is 62.3 m. The average static water level of all boreholes drilled in the 20 regions is 16.5 m. According to Sadiki (2009), the yield of boreholes in Pangani basin range between 10 and 800 $m^3 hr^{-1}$. Depth of boreholes range between 20-200 m and the major aquifers are inadequate water productive (alluvial sediments–10%, sedimentary–4%, volcanic–1% and metamorphic rocks–85%).

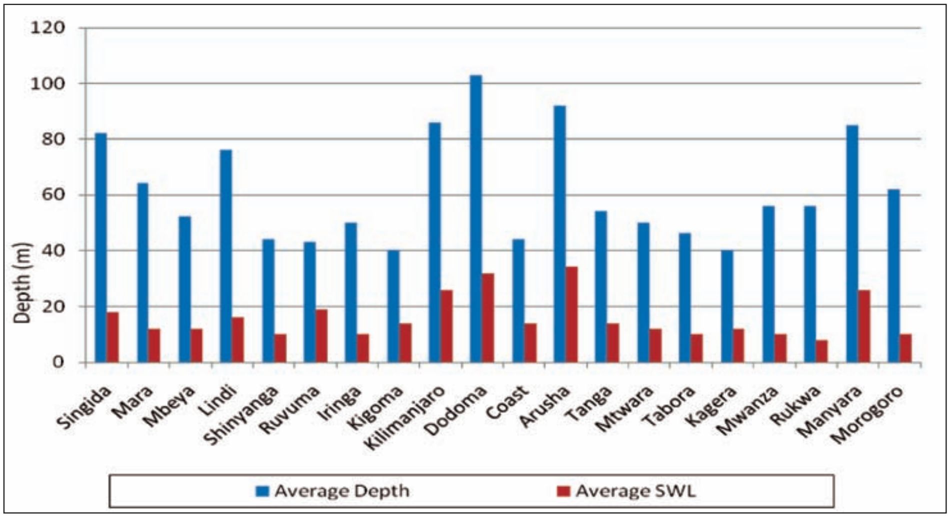

Figure 13.3 Borehole properties by region (Source: Baumann *et al*., 2005)

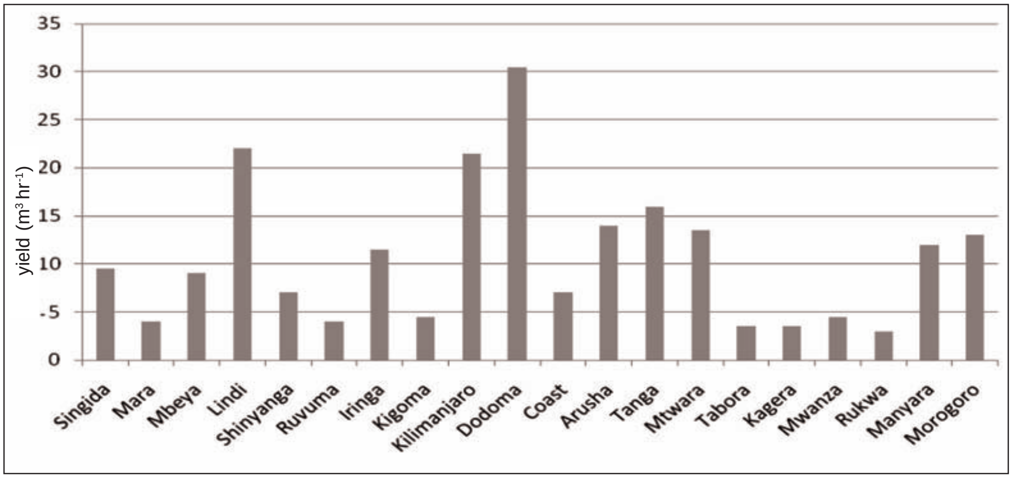

Figure 13.4 Yield by region in mainland Tanzania (Source: Baumann *et al*., 2005)

Groundwater recharge

Groundwater recharge is controlled by various factors including climate, geomorphology and geology (Rwebugisa, 2008). In most areas of Tanzania, recharge occurs most extensively in topographic high areas mostly by direct rainwater infiltration, preferential flows and through fractures. Most recharge areas include alluvial fans with coarsely grained sands, where enhanced high infiltration rates occur. In fractured rocks, flow is often localized in a few main flow paths that control most of the hydrological response of the aquifer. Presence of termite mounds (as observed in the Makutapora groundwater basin), in the pediment area and on the upland slopes adjacent to the fault systems acting as preferential flows of rainwater to infiltrate to the subsurface, enhance recharge (Shindo, 1989; Kashaigili *et al*., 2003). Nevertheless, there are limited extensive studies on recharge in Tanzania. Few detailed studies have been conducted over the years (e.g. Shindo, 1989, 1990, 1991 in Makutapora groundwater basin; Mjemah (2008) in Quaternary sand aquifer in Dar es Salaam; and JICA (2002) in Internal Drainage Basin).

The estimated recharge flux (Shindo, 1989, 1990, 1991; Kashaigili *et al*., 2003; Rwebugisa, 2008) in the basin range from 5-10 mm yr^{-1}, averaging to 1.3 percent of the annual rainfall. However, the area of the basin is just a fraction of the Tanzania mainland and owing to that the recharge rates are not applicable country wide. A study (Mjemah, 2008) in Quaternary sand aquifer in Dar es Salaam indicates that groundwater recharge may range between 0-570 mm yr^{-1} depending on the rainfall amount in that particular year. The average aquifer recharge for the period 1971 to 2006 is estimated at 240.7 mm yr^{-1}. Coster (1960) estimated groundwater recharge to be 10 percent of the total rainfall, and in many areas to be the maximum that can be expected, but that in other localities the percentage recharge may well fall to 4 percent or even below. A study by Sandstrom (1995) in Babati district indicate that during the wet years, almost all rainfall events generate recharge, *i.e.* the lightest rainfall events, representing 50 percent of annual total, also provided about 50 percent of all recharge. However during the dry years, recharge was only about 25 percent of the total rainfall.

Japan International Cooperation Agency (JICA) (2002), tried to estimate the groundwater recharge and basin evapo-transpiration at the river basin scale across the country, based upon hydrological information through a water balance analysis. The findings of the study are summarized in Table 13.3. The total groundwater recharge on annual basis is estimated at 3,725 million m^3, or just 0.4 percent of the rainfall (JICA, 2002). A general outlook on the various recharge estimates indicate that the values are greatly variable, location wise and are a function of the methods used. The estimated basin recharge (JICA, 2002) rates are very low and contain a great deal of uncertainty, implicating on groundwater development potential. Therefore, more detailed studies on groundwater recharge are imperative.

Table 13.3 Estimated recharge from hydrological balance by river basin

Drainage river basins	Catchment Area (km^2)	Inflow	Outflow			Drains into which system
		Annual Mean Rainfall* (mm)	Annual Mean Runoff* (mm)	ET from Basin** (mm)	Recharge*** (mm)	
Pangani River Basin	56,300	1,002	31.5	966	4	Indian Ocean
Wami -Ruvu River Basin	72,930	765	51.7	710	3	Indian Ocean
Rufiji River Basin	177,420	988	186	799	3	Indian Ocean
Ruvuma River and Sothern Coast Basin	103,720	1,050	20.5	1,028	2	Indian Ocean
Lake Nyasa Basin	39,520	1,673	345	1,324	4	Lake Rukwa
Internal Drainage Basin	153,800	619	36.6	577	5	Internal drain-age system
Lake Rukwa Basin	88,180	1,095	105	985	6	Lake Rukwa
Lake Tanganyika Basin	1,51,900	1,174	125	1,045	4	Atlantic Ocean
Lake Victoria Basin	79,570	1,111	18.6	1,087	6	Mediterranean Sea

* analyzed using data of 143 gauging stations
** estimated by deducting runoff and groundwater recharge from rainfall
*** tentatively estimated consulting the groundwater potential map in "RAPID WATER RESOURCES ASSESSMENT, 1995"
Source: JICA (2002)

Groundwater quality

Natural groundwater quality variations are controlled largely by geology. Groundwater in the rift zone of the north are typically alkaline and soft (low calcium and magnesium concentration) with high pH values and relatively high sodium concentration. Some areas are saline, although groundwater around the extinct volcano, Mount Meru, is reported to be generally fresh (TDS value usually less than 1,000 mg L^{-1}) (Issar, 1978). Groundwater from the ancient crystalline basement of central Tanzania also has high alkalinity and relatively high sodium concentrations and with slightly acidic to highly alkaline pH values 6.1 to 9.1 (Nkotagu, 1996a). Salinities vary but can be high with TDS between 1,000 and 3,000 mg L^{-1}. The high concentration of chloride (salinity) in groundwater is the main problem especially in the coastal and central regions of the country (like Singida, Shinyanga, Lindi and Mtwara), where there is a high evaporation rate and poor drainage. Groundwater from the recent sediments in the coastal plain is vulnerable to marine intrusion, particularly where groundwater pumping rates are high. Evidence of marine intrusion has been found in the coastal aquifer of the Kigamboni Peninsula (Dar es Salaam) with elevated chloride, sulphate and sodium concentrations and with TDS up to 1,700 mg L^{-1} (Nkotagu, 1989). In Lindi and Mtwara regions, high carbon dioxide in groundwater has been reported (Kongola *et al*., 1999), which causes groundwater to be corrosive. High iron content in groundwater has been observed in the Mtwara and Kagera regions (Kongola *et al*., 1999).

Fluoride concentrations in groundwater from both the volcanic terrains and crystalline basement rocks in the central plateau are known to be high and consequently far more information is available for fluoride than for other trace elements of significance to human health. Of the reported groundwater quality problems in Tanzania, fluoride is by far the most severe and widespread (Mato *et al*., 2000; Materu, 1996). It represents a major problem for water supply nationally. The problem occurs in both the rift zones in northern and south western Tanzania, associated with volcanic activity and in the crystalline basement complex of the central plateau. Concentrations as high as several tens to hundreds of mg L^{-1} have been reported for some groundwater and high concentrations have also been found in some rivers, soda lakes and hot springs in the rift zones. Such concentrations are extremely high, even when compared to other high fluoride groundwater provinces elsewhere in the world. Incidence of dental fluorosis is very high in these affected areas, and skeletal fluorosis is also serious in parts. Severe cases have been reported in Kitefu village, east of Arusha (Nanyaro *et al*., 1984). Fluorine rich minerals are abundant in the lavas, intrusions and ashes of the rift zone, and concentrations are much higher than in similar rock types elsewhere in the world (Kilham and Hecky, 1973). In addition, fine grained ash deposits present in the rift are readily leachable. Hot springs are also important sources and account for some of the most extreme concentrations observed in the groundwater of the northern rift zone. Some concentration of fluoride in groundwater from the major depressions also appears to have occurred through extreme evaporation of lake water and subsequent infiltration to the shallow aquifers. Fluoride build-up in groundwater from the crystalline basement of the central plateau, derives by dissolution of fluorine minerals (e.g. fluorite, apatite) and is facilitated by relatively low dissolved calcium concentrations. Concentrations in groundwater from the coastal plain appear to be low. Nkotagu (1989) quoted values in the range 0.002 to 0.38 mg L^{-1}.

Nitrate concentrations have been reported to be affecting groundwater quality in some areas of Tanzania (e.g. Shindo, 1990, 1991). However, the distribution of nitrate in groundwater nationally is not known. Nitrate levels of more than 100 mg L^{-1} have been reported in the Makutopora groundwater basin, Dodoma and Singida town (Nkotagu, 1996b;

Kongola *et al*., 1999). High concentrations (0.002 mg L^{-1} to 102 mg L^{-1} as N, mean value 34 mg L^{-1}) have been reported in both shallow and deep groundwater in the Dodoma area of central Tanzania (Nkotagu, 1996a,b). High values were linked to pollution from sewage effluents in the urban areas, with the pollutants penetrating to deep levels in the crystalline aquifer, via fractures.

Apart from geological control on the groundwater quality, there is also the influence of human activities on the natural quality of groundwater resources (Mato, 2002). The situation is more alarming in urban areas, which are growing at a fairly fast rate. The potential sources of groundwater pollution include domestic and industrial wastewater, leaching of leachate from solid waste dumpsites and mining tailings, storm water and poor agricultural practices (Mato, 2002).

Groundwater development and utilization

Groundwater abstraction

Boreholes in Tanzania are classified as shallow (0 - 30 m), medium (31-50 m), deep (51-80 m), and very deep (> 80 m) (Baumann *et al*., 2005). Generally, most boreholes are located in the internal drainage basin. The basin is characterized by semi-arid to arid conditions with rainfall less than 550 mm annually, making the dwellers dependent mostly on groundwater as the main source for water supply. Table 13.4 shows the borehole numbers per river basin while Figure 13.5 indicates the percentage of boreholes as per each class region wise. These classifications represent the groundwater conditions of the regions. The number of boreholes to be drilled, the aquifer distribution, and the borehole depth distribution can indicate the type of technology to be used in the different regions.

Table 13.4 Drainage basins and distribution of recorded boreholes in Tanzania

Name of basin	Number of boreholes drilled	Boreholes with high yield (> 900 L hr^{-1})
Pangani	325	292
Ruvu/Wami	892	522
Rufiji	440	268
Southern Coast/ Ruvuma	344	188
Inland Drainage	1,595	562
Lake Victoria	773	316
Lake Tanganyika	380	132
Lake Rukwa	263	128
Lake Nyasa	63	4

Source: Kongola *et al.* (1999)

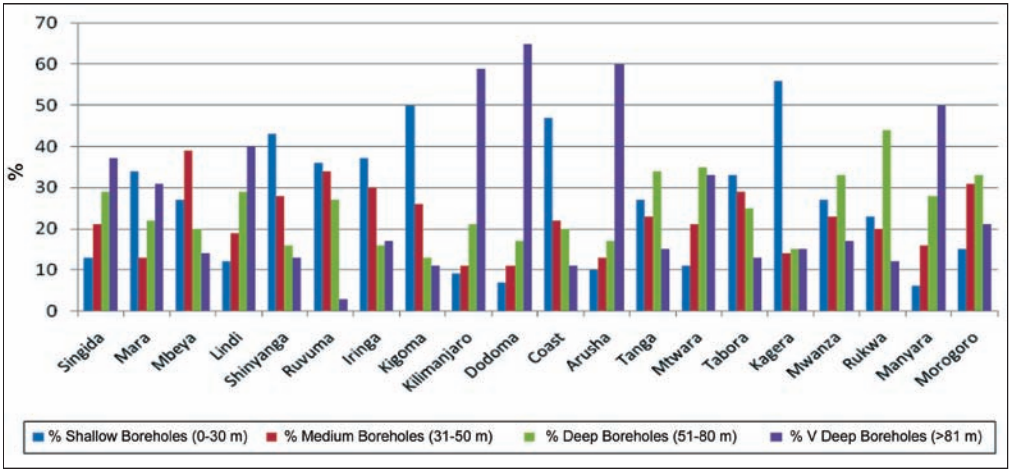

Figure 13.5 Borehole depth distribution by region (Source: Baumann et al., 2005)

The borehole database maintained by the Ministry of Water (MoW), records 9,242 boreholes as of 2003 (Baumann *et al*., 2005). The trend of construction of these boreholes is shown in Figure 13.6.

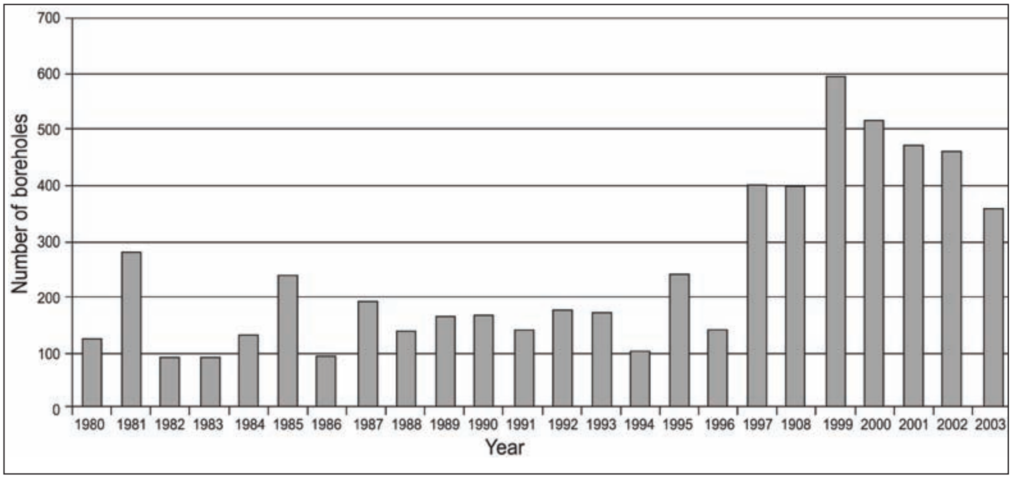

Figure 13.6 Boreholes drilled in Tanzania (Source: Borehole database in Dodoma Region, Directorate of Water Resources, Ministry of Water)

Concerning hand dug wells, analysis done by Baumann *et al.* (2005), showed that suitability depends on the static water levels. If the static water level is less than 8 m, shallow hand dug well fitted with hand pump is feasible. Some of the sites in Tanzania with high potential for hand dug wells are shown in Table 13.5. In few places in Tanzania, livestock watering mainly depend on shallow wells or hand-dug wells. Small scale farmers normally use low cost technologies to lift water from shallow groundwater wells (hand–dug wells) (up to 10 m) (FAO, 2007).

Table 13.5 Suitability for dug wells based on depth of static water level

Regions	Range of sites suitable for dug wells (%)
Ruvuma, Dodoma, Arusha, Manyara	20-30
Tanga	31-40
Singida, Mara, Iringa, Kigoma, Kilimanjaro	41-50
Shinyanga, Coast, Morogoro	51-60
Mbeya, Mtwara, Kagera, Mwanza, Rukwa	60-70

Source: Baumann *et al*. (2005)

Groundwater utilization

The major sectors that use groundwater in Tanzania are domestic (accounts for almost all groundwater use), industrial and agriculture through irrigation, livestock watering, fisheries etc. Table 13.6 shows the relative proportions of water used by these different sectors.

Table 13.6 Estimates of groundwater use in Tanzania

Sector	Amount used per day (m^3)	% of total use
Urban(domestic)	130,000	10
Rural (domestic)	625,000	50
Agriculture	130,000	10
Industrial and mining	30,000	2
Others (livestock, dry land fishing)	350,000	28
Total	1,265,000	100

Source: DWR (2010)

Domestic purpose

Groundwater development has concentrated mainly on shallow wells for domestic water supply in rural areas due to its easy and economical development as compared to surface water. It can also be developed where it is required. Furthermore, it is associated with low operation and maintenance costs and not much affected by drought unlike surface water resources. Owing to this, it is commonly used in the peri-urban fringes where there is no distribution network and in places with unreliable supply. In Tanzania, groundwater is an important water source supplying more than 25 percent of the domestic water consumption (JICA, 2002). Groundwater is the main source of water for most rural water systems and municipalities like Dodoma, Arusha, Shinyanga, Moshi and Singida, and of recent Dar es Salaam city.

Irrigation

Groundwater use for irrigation is estimated at about 130,000 m^3 d^{-1} (Kongola, 2008). About 88 percent of groundwater extracted from the Pangani river basin is used for irrigation, 4 percent for industrial use and 8 percent for domestic use (Mato, 2002). Groundwater is currently being used for irrigating sugarcane, paddy, horticulture, vegetables and flowers (e.g. Tanzania Planting Company, TPC-Moshi (over 7,800 ha), and sugarcane plantation and Kilombero sugar estates) (Mato, 2002; Eng. Omary Zonal Irrigation Engineer, Moshi, Pers. Comm.). According to JICA (2002), the gross potential irrigation area is estimated at 2.1 million ha. The areas most prospective for groundwater irrigation include:

- Mtwara, Coast, Morogoro, Ruvuma, Shinyanga, Kilimanjaro, Kagera, Lindi, Mwanza and Mbeya due to dominance of unconsolidated sand and gravel water bearing formations that permits good yields and the existence of suitable soil for agricultural crop cultivation;
- Singida, Mara, Iringa, Kigoma, Dodoma, Rukwa and Manyara due to predominance of the weathered and/or fractured granites/gneisses water bearing formations, including Arusha which is dominated by igneous rocks and the water bearing zones are mostly in weathered and fractured lava flows with suitable land for crop cultivation.

Livestock watering

In arid and semi-arid rural areas of Tanzania (e.g. Dodoma, Singida, Shinyanga, Mwanza, Tabora) livestock watering using groundwater is very common. These areas have limited surface water resources and receive rainfall averaging less than 550 mm annually. There are few boreholes and the majority depend on shallow wells (mostly hand dug wells) for the watering of livestock. Presently, there is on-going development of water sources for livestock use which is being facilitated through DADPS and other projects such as PADEP, DASIP, TASAF and the Ministry of Water.

Industrial purpose

Groundwater utilization for industrial use is more concentrated in urban areas, especially Dar es Salaam where about 80 percent of the industries are located. Due to inadequate water supplies many industries have opted for constructing private wells to augment surface water supply. Many industries in Dar es Salaam, for example, have private wells (Drilling and Dam Construction Agency, 2001). Similar trends are observed in Arusha municipality and the list is rapidly increasing for constructing private wells.

Cost of groundwater development

The cost (all costs including biding, installation, pump tests, water quality testing, etc.) for boreholes in Tanzania is about USD 6,000 for hand pumps and USD 12,000 for mechanised systems (Baumann *et al*., 2005). The review of tender documents revealed that there are inconsistencies in costs from different bidders. An example of the tender analysis provided by Baumann *et al*. (2005) showed that the cost per meter was USD 193.29 in Mpwapwa (hard rock) for a borehole with depths up to 70 m, USD 133.57 in Rufiji for boreholes with depths up to 100 m (sedimentary) and USD 99.98 in Rufiji for boreholes up to 50 m (sedimentary).

Other cost estimates obtained showed averages of USD 12,500 for a fully mechanized borehole: USD 5,000 to 7,000 for a borehole with a hand pump and USD 2,490 for shallow well with an installed hand pump (Baumann *et al*., 2005).

Institutional and legal framework

The control of water affairs in Tanzania is currently under the Ministry of Water (MoW). The regulatory and institutional framework for sustainable development and management of water resources (including groundwater) is provided for in the Water Resource Management Act No. 11 of 2009 (WRMA). The act outlines principles for water resource management, provides for the prevention and control of water pollution, and for participation of stakeholders and the general public in implementation of the National Water Policy of 2002. The act provides for the water resources management through a River Basin Management Approach that was adopted in Tanzania in 1980s. The management is set at five main levels; national, basin, catchment and sub-catchment levels, district level, and community or water user association level (URT, 2002). The policy advocates for an integrated approach in water resources and addresses participatory, multi-sectoral, multi-disciplinary river basin management and introduced the integrated water resources management (IWRM) principles into the management of the water resources of Tanzania.

Basin Water Boards may grant water use permits for the diversion, damming, abstraction, storage and use of water (section 43 of the WRMA). Irrigation, as a water user, will require a water use permit. The WRMA sets out provisions subject to which permits will be issued and these include provisions relating to quantities to be abstracted, water pollution, proper drainage of the land and review of permits in circumstances of water inadequacies. Permits will also be required for the abstraction and use of groundwater in any basin, taking into account the water demands in the basin (section 54 of the WRMA). Whether or not groundwater can be used for irrigation in an area will depend on the conditions set by the Basin Water Board in the permit. The conditions will be determined by taking into regard as to what is considered a safe yield from any aquifer for purposes of sustainable abstraction (section 61 of the WRMA) (URT, 2009). The irrigation sector will also have to deal with issues relating to the classification of water as required under section 32 of the WRMA. Depending on the class to which a water resource has been assigned, the use of the water from the particular resource must be subject to the need to meet the quality requirements for the source. Particular water uses for in-stream or land based activities may be prohibited or regulated in order to protect particular water resources. Despite law provisions, there is no specific provision for groundwater use by smallholder farmers.

Groundwater development challenges

According to various studies (Mato, 2002; Kongola, 2008; Sadiki, 2009), the current problems facing groundwater resources exploration, development and management for urban and rural dwellers in the country include:

- Deteriorating quality (i.e. aquifer degradation) as a result of pollution;
- Overexploitation (in some cases e.g. parts of Makutopora basin supplying Dodoma municipality are showing declining water levels);
- Decrease of yields in boreholes (e.g. some of boreholes in Sanawari area, operated by the Arusha Urban Water and Sanitation Authority);
- Poor workmanship during construction of boreholes which leads to caving in of boreholes and opening up deeper aquifers to pollution sources;
- No established safe distances between human activities and positions of boreholes;
- Inadequate public awareness on the importance and potential sources of pollution of groundwater resources;
- Inadequate institutional arrangement to regulate groundwater resources;
- Role of private sector in groundwater development and management not yet well recognized;
- Limited data availability: data is scattered, fragmented and usually incomplete;
- Unreliable and inadequate groundwater monitoring networks;
- Inadequate groundwater resources management plans;
- Increased climate variability and change, bringing about uncertainty in terms of rates of replenishment.

As listed above, there are many potential problems facing groundwater resources exploration and exploitation in Tanzania. There are limited information existing on the present state of quantity and quality of groundwater. Before groundwater can be used on a large scale for irrigation or other uses, extensive research is needed.

Conclusions and Recommendations

Groundwater development has concentrated mainly on shallow wells for domestic purposes over a wide part of the country (mainly rural areas). They are also commonly used in the peri-urban fringes where there are no distribution networks and in places with unreliable water supply. Most boreholes are located in the internal drainage basin. The basin is characterized by semi-arid to arid conditions with rainfall less that 550 mm annually, making the dwellers dependent mostly on groundwater as the main source for water supply. The review has revealed that in areas where the static water level is less than 8 m, shallow hand dug well fitted with hand pumps are feasible. The cost for boreholes is about USD 6,000 for hand pumps and USD 12,000 for mechanised systems. Groundwater has not been extensively used for irrigation largely due lack of information on potential groundwater irrigation locations, availability of surface water resources as well as inadequate understanding of groundwater resources leading to inappropriate development of groundwater. There is a need for a more comprehensive assessment of available groundwater resources and establishing the groundwater potential for irrigation in Tanzania.

Findings from this study have revealed numerous issues with regards to groundwater development and management in Tanzania. These include the need for detailed groundwater studies to be carried out, to assess the available groundwater, recharge potential and to establish the groundwater potential for irrigation in Tanzania. With the likely increase in the use of groundwater, there is a need to enhance the collection, storage and sharing of existing groundwater information from completed studies in a more integrated way, through a database management system.

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CHAPTER 14

UGANDA

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General description of Uganda

Geography

Uganda is located in East Africa along the Equator, between longitudes 30° E and 34° E and latitudes 1° N and 1° S as shown in Figure 14.1. It is bordered by Tanzania to the south, Kenya to the east, Sudan to the north, Democratic Republic of Congo to the west and Rwanda to the south west. The country covers an area of 249,000 km^2, 20 percent of which is covered by surface water resources including, most notably, the Lake Victoria.

Physiography and climate

Uganda is characterized by an undulating topography formed by flat topped hills with wide concave valleys (Tindimugaya, 2000). Topographic elevations vary between 600 m AMSL in the western rift valley and 4,800 m AMSL at the top of Mount Rwenzori. The average elevation of Uganda is 1,200 m AMSL. Rainfall in

Uganda exhibits spatial and temporal variability due to changes in altitude and the influence of regional and local factors. Mean annual rainfall in Uganda is 1,200 mm and rainfall is controlled by a number of systems that include the Inter Tropical Convergence Zone (ITCZ), the subtropical anticyclones, monsoonal winds, the moist westerlies from Congo amongst other factors (Basalirwa, 1995). Rainfall in Uganda exhibits a bimodal distribution with rains falling during two rainy seasons. The short rains occur between September and November while the extended rains occur between March and May. Evaporation is higher (about 130 mm per month) than rainfall for most of the year except during March - April and September - October, that are periods of highest rainfall.

Soils in Uganda are derived from Pre-Cambrian granitic gneiss and associated saprolite, with upland areas underlain by dismantled ferricrete (Brown, 2007). Dark sandy clays are found in the seepage zones at the valley bottoms whereas grey loam sand overlying sandy clays are found in areas of low relief. Yellow sands are found on the sloping wetland margins whereas more weathered, kaolinitic, red sandy loam to clays are characteristic of the topographically raised grounds. Vegetation in Uganda varies greatly due to human influence. Apart from the protected forests, natural vegetation in many places have been modified due to high population density, need for agricultural land and other economically driven landuse practices (Marchant and Taylor, 1997). In most of Uganda, vegetation is dominated by grass, banana plantations, maize, coffee plantation and eucalyptus trees, used for building poles and firewood. Papyrus swamps are found along the river channels but many of these are being drained for agriculture and cattle rearing. Most of the wetlands are natural sponges and reservoirs in which run off and seepage accumulate. Wetlands in the country are sources of many small rivers and streams and serve to regulate discharges, the result of which is visible in the variations in discharges out of the catchment.

Drainage

The hydrology of Uganda is closely linked to the hydrology of river Nile. It is characterized by seasonal as well as inter-annual variations in river flows. There are 8 major surface water basins in Uganda located in four Water Management Zones of Kyoga, Albert, Victoria and Upper Nile. The 8 basins are Albert Nile, Aswa, Kidepo, Victoria, Kyoga, Albert, George and Edward, and Kyoga Nile. The drainage network is complicated by the effects of tectonic movements associated with the formation of the rift valley. The major drainage of Uganda today is to the north into the river Nile. However, at one time in history the major drainage direction was towards the river Congo before the formation of Lake Victoria. The generally low gradients across much of central Uganda lead to impeded drainage and swamp formation.

In Uganda, significant water resources originate from precipitation as well as inflows from the upstream countries of Burundi, DR Congo, Kenya, Rwanda and Tanzania. Uganda is thus both a downstream and upstream country in the Nile system and almost all its water resources are shared with other countries. The main surface water bodies in Uganda are: Lake Victoria, Lake Kyoga, Lake George, Lake Edward and Lake Albert. Surface water bodies and seasonally flooded areas account for 20 percent of the land area of Uganda.

Socio-economic context

Uganda's population is estimated to be close to 35 million people, growing at about 3.6 percent annually. It has a high dependency ratio as 50 percent of the population is below the age of 14 years. Uganda's GDP is USD 500 per capita (UN Data). The major contributors to Uganda's GDP are the services sector (about 51%), industry (about 25%) and agriculture (about 24%) (NDP, 2008). The agricultural GDP has been expanding but the sector's share in GDP has declined from over 50 percent in the early 1990s to 23.7 percent in 2008-2009. Of the 5.13 million households in Uganda in 2002, 75 percent were engaged in agriculture, and 68 percent of all households derived their livelihoods from subsistence agriculture. Under agriculture, the fishing and livestock subsectors are of prime economic importance. Fishing is the second leading foreign exchange earner after coffee (NDP, 2009). More than 1.2 million people depend on the fishing sector in Uganda (NDP, 2009). The livestock subsector is estimated to contribute about 15 percent to the agricultural economy, representing about 5 percent of the overall national GDP (MWE, 2009). The industrial sector comprises manufacturing, mining and quarrying, construction, and utilities (electricity and water supply) sub-sectors. Uganda's industrial sector is growing and in 2007, it contributed USD 2.9 billion (about 25% GDP) to the economy and employed 7.6 percent of the working population.

Groundwater resources

Hydrogeology

The geology of Uganda is dominated by Archean and Proterozoic rocks of high grade metamorphism commonly referred to as "Gneissic-Granulitic Complex (Figure 14.1). These rocks underlie more than two thirds of the country (Schlüter, 1997). The rest of the country is underlain by Paleoproterozoic Buganda-Toro metasediments, the Mesoproterozoic Karagwe-Ankolean (Kibaran), the Neoproterozoic sediments and the Tertiary to Recent sediments that have filled parts of the down-faulted Albertine rift valley in the west of the country. Tertiary carbonatites and Cenozoic volcanics related to rifting occur along the eastern and western borders of the country.

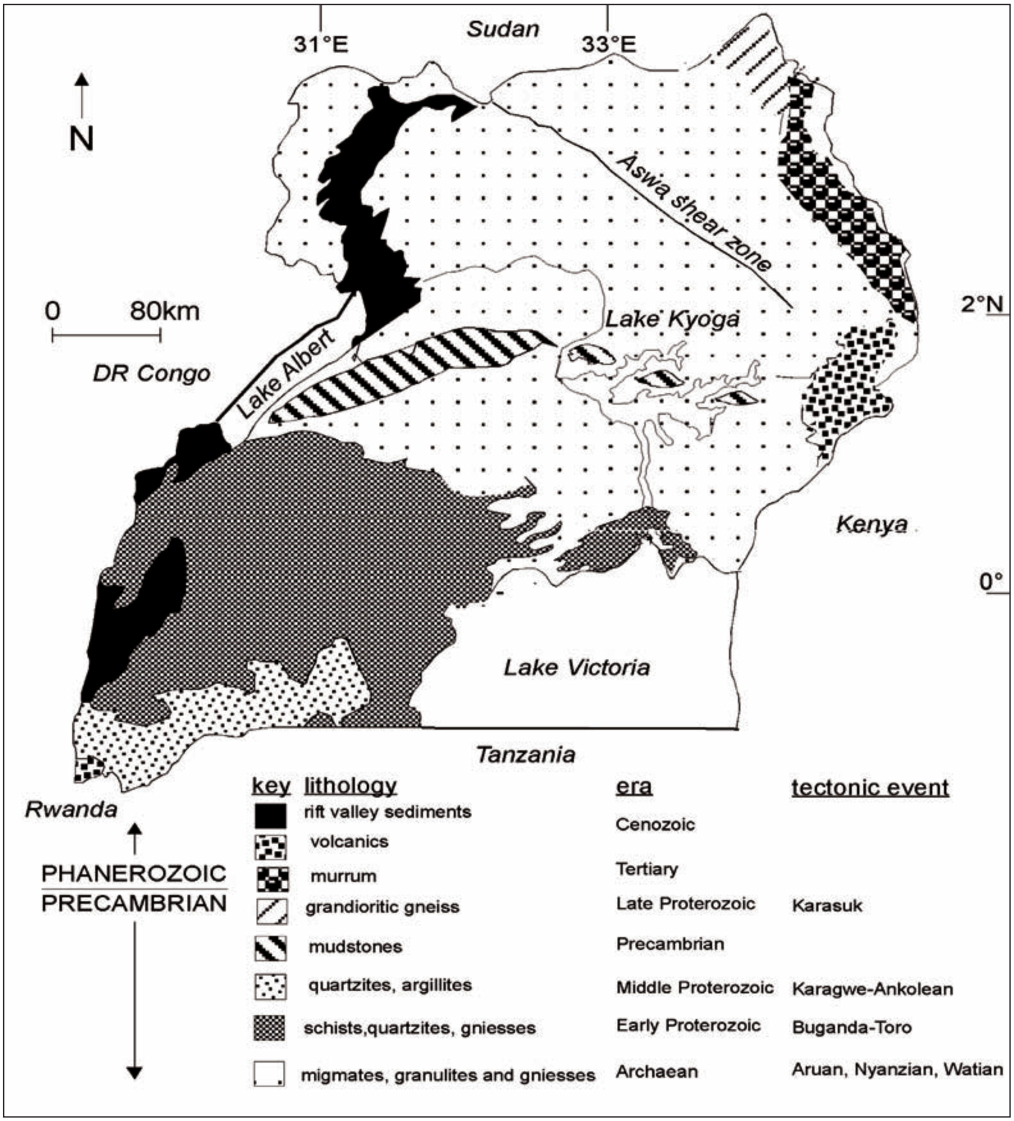

Figure 14.1 Generalised geological map of Uganda (Source: Schlüter 1997; Taylor and Howard 1998)

Groundwater development in Uganda is greatly influenced by the varied geological conditions which consist of very old Precambrian rocks that underlie over 90 percent of the country, Cenozoic rift valley sediments and Tertiary and Pleistocene volcanics that occur in a few areas and cover less than 10 percent of the country. Hydrogeological conditions are typical of Precambrian basement terrain and the most productive aquifers occur in the weathered overburden (regolith) and in the fractured bedrock (Figure 14.2). Boreholes are typically installed into the fractured bedrock and in the interface between the weathered zone and the bedrock; while shallow wells are drilled in the weathered zone. Intensive groundwater abstraction (> 5 m^3 hr^{-1} per borehole), especially for town water supplies is restricted to areas where the bedrock is highly fractured and the weathered zone possesses moderate to high permeability and significant storage. Fluvial sediments found along river channels also form productive aquifers where the sediments are medium to coarse-grained. Schematic profile of a typical basement regolith aquifer system is presented in Figure 14.2.

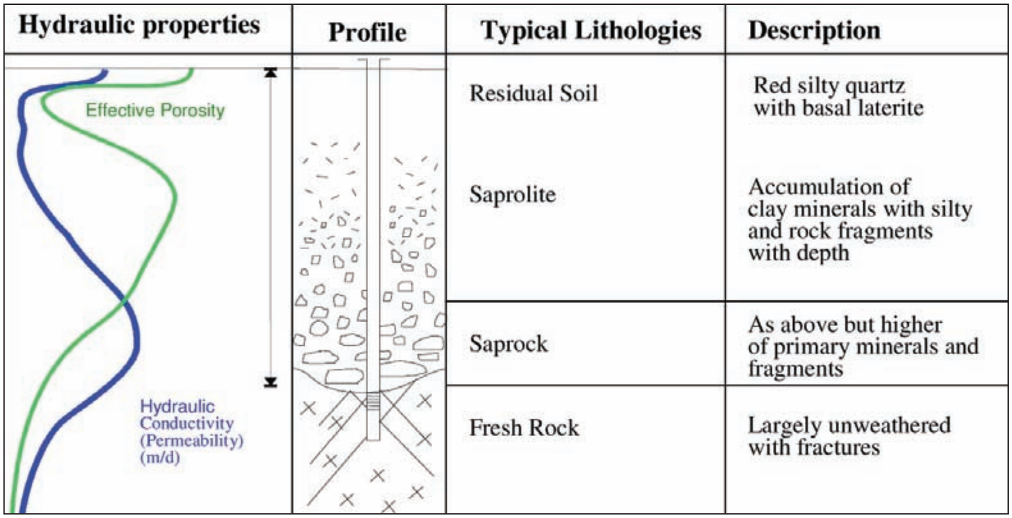

Figure 14.2 Schematic profile of a typical basement regolith aquifer system (Source: Chilton and Foster 1995)

Groundwater systems

There are three different types of aquifers in Uganda, namely, fluvial, weathered and fractured bedrock aquifers (Tindimugaya, 2008). Fluvial aquifers are formed after weathering of the bedrock and deposition of the coarse-grained material along river channels. Weathered bedrock aquifers are formed by the weathering of the bedrock, forming unconsolidated soil. Fractured bedrock aquifers are formed by weathering and fracturing of the bedrock due to tectonic forces and water action. Fluvial, weathered and fractured bedrock aquifers in Uganda have evolved over years by tectonically controlled weathering and stripping (Tindimugaya, 2008). Deep weathering of the bedrock yields a thick weathered regolith and induces sub-horizontal fissures, whereas stripping partially erodes the weathered overburden, giving rise to a discontinuous regolith and fluvial deposition of coarse-grained clasts in river channels. Evolution of weathered and fractured bedrock aquifers have previously been recognised and characterised but existence of fluvial aquifers in deeply weathered terrains in humid tropics has largely been ignored. Recent field investigations identified, for the first time, a highly productive aquifer comprising coarse-grained, fluvial sediments, in palaeochannels of river networks truncated by Miocene to Pleistocene rifting (Tindimugaya, 2008). Palaeochannel sediments are present to a limited extent on stripped surfaces but can feature in significant thicknesses along former river channels on deeply weathered surfaces.

Evidence for existence of fluvial aquifers with high specific capacities (> 20 $m^2 d^{-1}$) composed of gravels and coarse sands within palaeochannels has been compiled from various areas, located east and west of the Western rift valley. The fluvial aquifers have the highest yields in Uganda (> 50 $m^3 hr^{-1}$) and feature the thickest regoliths. Areas with the highest prospects for obtaining high yielding boreholes in Uganda are therefore those that are associated with palaeochannels which are known to be good conduits for groundwater flow in arid and semi-arid areas. Their existence in the humid tropics, though, has been reported only in a few areas with direct and detailed studies in India and Australia (Mohammed *et al*., 2003; Sinha *et al.,* 2000; de Broekert and Sandiford, 2005). Distribution of the palaeochannels has been demarcated based on the drainage network before and after tectonic uplift and drainage reversal in Uganda, to provide guidance for further work related to development and management of groundwater in the fluvial aquifers.

The weathered aquifer system in Uganda is unconfined whereas the fractured bedrock aquifer is leaky and the two aquifers form a heterogeneous aquifer system (Tindimugaya, 2008; Taylor and Howard, 2000). The alluvial aquifer is unconfined, highly permeable and relatively homogeneous due to well sorted sediments associated with fluvial deposition.

Based on commonly used analytical models (Theis, Cooper-Jacob, Theis recovery, Hantush, Neuman and PTFIT program), aquifer hydraulic properties have been estimated in various aquifers in the country (Tindimugaya, 2008; Taylor and Howard, 2000; Tindimugaya, 2000). The aquifer hydraulic properties estimated from the seven methods were highly variable for the weathered and fractured bedrock aquifers but relatively consistent for the alluvial aquifer. The results further indicate that the determined hydraulic properties of the weathered and fractured bedrock aquifers are sensitive to the employed model. Average transmissivity and storage coefficient values for the weathered aquifer are 16 $m^2 d^{-1}$ and 0.21 respectively.

The average transmissivity and storage coefficient values for the fractured bedrock aquifer are 14 m^2 d^{-1} and 0.014 whereas the average transmissivity and storage coefficient values for the alluvial aquifer are 34 m^2 d^{-1} and 0.1 respectively. In general, aquifers in Uganda have low transmissivity (Table 14.1).

Table 14.1 Aquifer properties for various aquifers in Uganda

Aquifer type	Average transmissivity (m^2 d^{-1})	Average storativity
Weathered	16	0.21
Fractured bedrock	14	0.014
Fluvial	34	0.1

Source: Tindimugaya (2008); Taylor and Howard (2000)

Estimates of borehole yields in Uganda are normally based on airlift and pumping test carried out during drilling of boreholes. Borehole potential can be assessed by a means of a number of borehole parameters such as the regolith thickness, aquifer yields and rest water levels. Borehole yields for various areas in Uganda have been assessed (Tindimugaya, 2008; Taylor and Howard, 2000; Tindimugaya, 2000). The results show that individual borehole yields vary randomly and depend on the nature of the aquifer and fracturing of the bedrock. Aquifer yields range between 0.1 and over 50 m^3 hr^{-1}. The lowest yields are found in areas underlain by weathered and fractured bedrock aquifers found almost all over the country (Kigwe catchment, Iganga and Mitano catchment). Highest yields are generally found in areas underlain by fluvial sediments in palaeochannels (Mitano catchment, Hoima, Mubende, Lukaya and Ntungamo). Borehole yields in areas underlain by weathered and fractured bedrock are therefore generally low (< 2 m^3 hr^{-1}) but may be higher where there are very deep weathering and more extensive fracturing of the bedrock. Areas of fluvial deposition have aquifers with borehole yields that vary depending on the grain size and degree of sorting of the sediments but are generally much higher than those in the areas underlain by weathered and fractured bedrock (Table 14.1).

Groundwater recharge

Previous recharge studies in Uganda have employed a number of methods including soil moisture balance, water level fluctuation, isotope methods, chloride balance, flow modelling and baseflow separation (Howard and Karundu, 1992; Taylor and Howard, 1999; Tindimugaya, 2000). The recharge studies show that upon reaching the land surface, most of the precipitation (70-90%) is returned to the atmosphere by evapotranspiration and the reminder stays at the land surface and contributes to surface flow *via* runoff and to groundwater recharge *via* infiltration through the unsaturated zone. Taylor and Howard (1999), further show that groundwater is recharged by heavy rainfall and that recharge events are effectively restricted to periods of heavy rainfall so that the magnitude of recharge is controlled more by the number of heavy rainfall events (> 10 mm d^{-1}) during the monsoons, than the total volume of rainfall. The percentage of rainfall that becomes recharge is highly variable and is influenced by a number of factors including weather patterns, properties of the soil, vegetation cover, topography, depths to the water table and the size of the study areas and the time when recharge estimates are made (Alley *et al.,* 2002).

The estimated annual groundwater recharge rates in Uganda are highly variable and range from approximately 10 percent of the annual rainfall in the deep weathering zone of central Uganda (Taylor and Howard, 1996; Tindimugaya, 2000) to approximately one percent of the annual rainfall in the zone of stripping in western Uganda (Taylor and Howard, 1999). Estimation of groundwater recharge rates can however be complicated by preferential flow paths in the unsaturated zone as well as temporal and spatial variability of the various factors. Use of multiple techniques is therefore normally recommended in view of uncertainties inherent in each method. Distribution of recharge in Uganda has been assessed based on the mean annual rainfall and overburden thickness. The mean annual groundwater recharge in Uganda is estimated to be 120 mm. The estimated groundwater recharge is presented in Figure 14.3.

Groundwater quality

Generally, the quality of groundwater in most parts of the country is of acceptable quality, especially with respect to its inorganic water quality. However, in several areas, groundwater has been observed to contain excess levels of aluminium, chloride, iron, manganese, zinc and hardness. Groundwater in a few areas also exhibits high levels of nitrate and chromium. Most groundwater problems are attributed to factors such as corrosion of borehole casings and raising mains; and seepage of sewage waste. Sewage wastes are generally responsible for elevated concentrations of chloride and nitrate, while corroded pipe work is responsible for the high concentrations of iron, zinc and manganese. In some areas, high concentrations of aluminium, iron, manganese and chromium are also associated with natural weathering of the aquifer matrix. With regard to total dissolved solids (TDS), iron and manganese, the quality of groundwater in the regolith aquifer appears to be slightly better than that in the fractured bedrock aquifer. There is also generally a presence of very high coliform counts in unprotected springs and open shallow wells, which is an indication of contamination.

Coliform counts well above the national and WHO guideline values are usually found in some protected springs and shallow wells. This is attributed to poor sanitary conditions around the sources and lack of protection of the source.

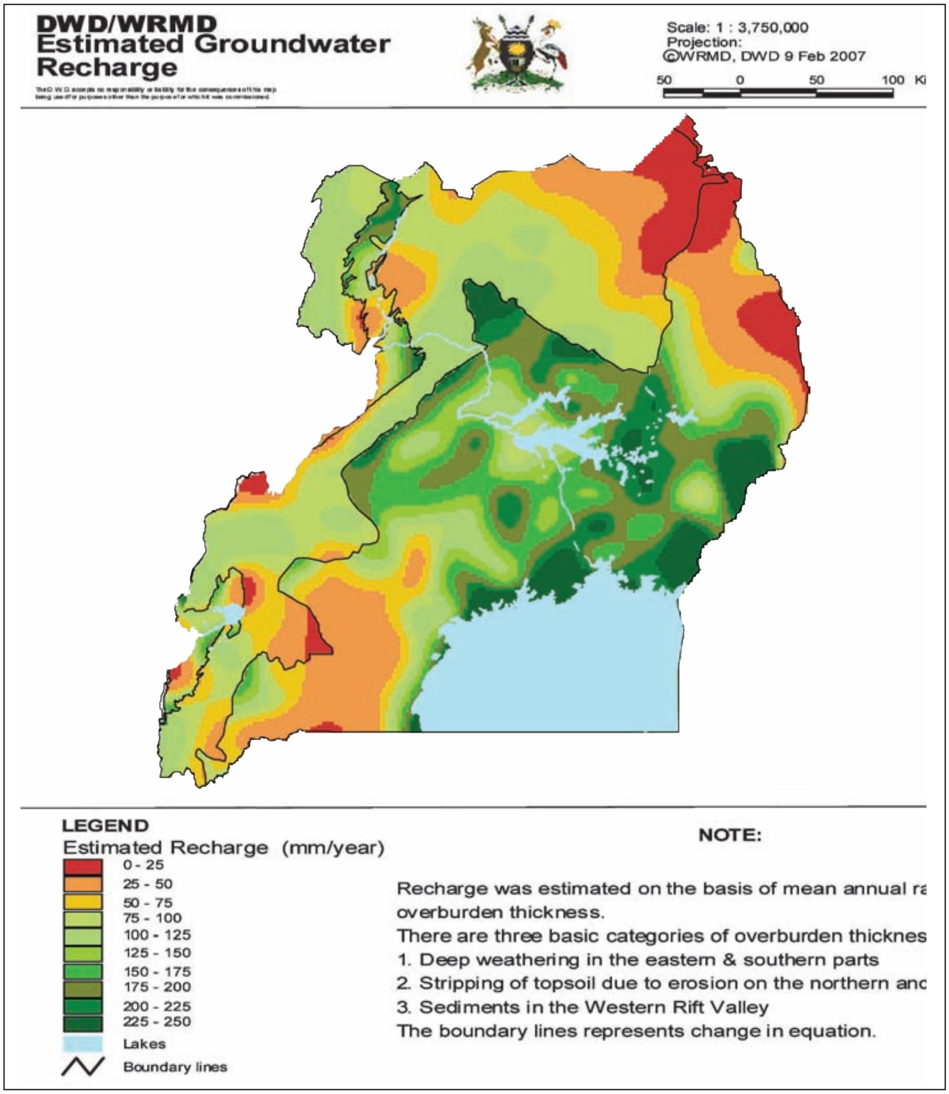

Figure 14.3 Distribution of groundwater recharge in Uganda (Source: MWE, 2009)

Groundwater development and utilization

Groundwater abstraction

Groundwater in Uganda is abstracted using boreholes, shallow wells and springs. Boreholes are small diameter wells that are deeper than 30 m while shallow wells are less than 30 m in depth and constructed in the unconsolidated formation. The average depth of boreholes in Uganda is 60 m, while shallow wells are on an average 15 m deep. Boreholes are normally installed with hand-pumps with capacity of one $m^3 hr^{-1}$ and their yields commonly range between 0.5 and 5 $m^3 hr^{-1}$. Springs occur either where the flow of unconfined groundwater is interrupted by an impermeable formation or where the head of confined groundwater is released by flow to the surface. There are 2 major types of springs in Uganda namely: contact and fracture springs. Fracture springs are usually very susceptible to contamination and drying up while contact springs are more reliable. The potential of shallow wells is quite high, especially in the valleys. Their potential is favoured by the thick regolith that is fairly coarse grained. In Uganda's experience, shallow wells are a very reliable source of water supply to the communities although precautions need to be taken to ensure that they are not contaminated.

Cost of groundwater development

The average cost of motorized borehole, hand pumped borehole, protected shallow well and a spring (MWE, 2009) are presented in Table 14.2, along with the breakdown of each of the major cost components. On an average the annual maintenance cost of hand pumped boreholes is USD 300 and covers the minor replacement of worn out parts and services of a caretaker and pump mechanic responsible for the preventive maintenance of the pump (MWE, 2009). The cost of groundwater development in Uganda is thus quite high and appears to be a limiting factor in groundwater development especially for irrigation.

Table 14.2 Cost for developing groundwater resources in Uganda (in USD)

Type of cost	Motorized borehole	Hand pumped borehole	Protected shallow well	Spring
Borehole siting	1,000	800		1,000
Actual drilling	7,000	6,400		
Cost of electric pump and installation	3,000	800	3,000	
Average cost	11,000	8,000*	3,000	1,000

*Annual maintenance of hand pump is USD 300

Source: MWE (2009)

Groundwater utilization

Domestic purpose

There are approximately 20,000 deep boreholes, 3,000 shallow wells and 12,000 protected springs in the country constructed mainly for rural domestic water supply. It is estimated that approximately 40,000 additional boreholes and 20,000 shallow wells are needed to meet 100 percent rural water supply coverage. Groundwater development for town water supplies in Uganda effectively began in the early 1990s with the formulation of the Rural Towns Water and Sanitation Programme under which 60 urban centres in the country were identified for piped water supply (MWE, 2008). Detailed hydrogeological investigations confirmed availability of adequate groundwater resources in eight out of the eleven towns which were subsequently developed based on the groundwater profiling. Additional towns have since been developed based on groundwater. By July 2006, there were 180 small towns in the country already considered for piped water supply, out of which 98 had functional water supply systems whereas 24 and 44 were at construction and design stages respectively (MWE, 2008). Out of the 98 operational water supply systems, 73 are based on groundwater, which is approximately 74 percent of the towns (MWE, 2008). The total number of groundwater sources supplying piped water to the 98 towns is 90 (66 deep boreholes and 24 springs).

Under the urban water supply and sanitation reform study, a need for a coherent strategy for implementing the reforms in the small towns' water and sanitation facilities was realised and the small towns that need to be provided with piped water during the next 15 year period were identified. By June 2006, a total of 782 small towns in the whole country including the 98 that already had operational piped water supply schemes, had been identified for provision of piped water (MWE, 2008). It is estimated that water source for over 70 percent of these towns (at least 550) will be based on groundwater, mainly through deep boreholes. The estimated population in urban areas to be served by groundwater is 1.8 million people. Thus, intensive groundwater development of water supply for town in Uganda based on high yielding deep boreholes has been on-going since the mid-1990s and is slated to increase drastically as the Uganda Government intensifies its efforts of providing safe drinking water to the urban population. The focus on groundwater for domestic water supply as opposed to surface water is due to the fact that groundwater is often available where it is needed, is of good quality and does not normally require treatment, and the groundwater based systems have low operation and maintenance costs.

Irrigation

Irrigation in Uganda is not widespread due to a number of reasons that include availability of adequate rainfall for about half of the year, high investment costs and unpredictable production returns. The total area under consolidated advanced irrigation is estimated at 10,000 ha. In addition, about 50,000 ha are under informal irrigation for rice cultivation on wetland fringes in eastern Uganda. Water supply here depends on the catchment runoff and is unregulated. Upland crop irrigation with small scale pumping systems is mostly limited to horticulture, but is not widespread. There is hardly any irrigation in Uganda that is based on groundwater because rainfall and surface water resources are adequate in most of the places and probably also due to limited understanding of the occurrence and distribution of aquifers and their potential. With the impacts of climate change resulting in more temporal and spatial variability in rainfall and surface water resources, the focus on groundwater as a source of irrigation is very likely to increase. Irrigation schemes are principally found in eastern Uganda and a few in north western and south western Uganda. Most of them are small scale except five that are medium scale.

Livestock watering

Records available at the Ministry of Water and Environment (MWE) indicate that over 1,000 water facilities for livestock production (301 dams and 750 valley tanks) were constructed in the last 50 years. In other areas of the country livestock water is supplied from rivers, streams and wetlands. Information available at the MWE (MWE, 2008) also shows that approximately 20 deep boreholes yielding an average of 8 $m^3 hr^{-1}$ have been constructed and installed with windmills for pumping groundwater for livestock watering in north eastern Uganda.

Institutional and legal framework

The existing legal and policy framework for groundwater development in Uganda includes the Constitution of the Republic of Uganda (1995), Water Act (2000), National Water Policy (1999) and Water Resources Regulations (1998) (Tindimugaya, 2004). The institutional framework includes the Ministry of Water and Environment with its Directorate of Water Resources Management in charge of groundwater resources management, and the Directorate of Water Development in charge of groundwater development; the four water management zones in the country; catchment management organisations and district local governments.

Currently the water sector in Uganda is undergoing reforms with the objective to ensure that services are provided and managed with increased performance and cost effectiveness, to decrease the government burden while maintaining the government's commitment to equitable and sustainable provision of services. The water sector reform was undertaken through four sub-component studies: rural water and sanitation development, urban water and sewerage services, water for production and water resources management. Of main relevance to groundwater development for irrigation is the water for production reform. Its study completed in 2003 came up with strategies and investment plans for providing water for multi-purpose use including agriculture. The strategy recommends construction of dams and reservoirs in strategic locations to improve the water security of the country. The strategy recognizes the importance of groundwater development where well yields are high, especially for livestock watering. Groundwater therefore is not promoted in the strategies as the source of irrigation water. However, with climate change impacts that have affected rainfed agriculture, the sources of water for small and medium scale irrigation will need to be revisited.

Groundwater development challenges

Although groundwater development is on a steep rise in Uganda like elsewhere in Sub-Saharan Africa, it is not known whether the current, intensive abstractions (300 to 600 m^3 d^{-1}) from well fields within the weathered and fractured bedrock aquifer systems are sustainable (Tindimugaya, 2000; Taylor and Howard, 1998). Increase in population, per capita demand for water, and pollution present serious challenges to the sustainability of groundwater abstraction for town water supplies. Considerable uncertainty also exists regarding vulnerability of weathered and fractured-bedrock aquifer systems to contamination from local land use practices such as sewage disposal. There are a number of key groundwater issues of concern in Uganda such as limited yields, pollution and unreliable information to plan groundwater development activities.

Several limitations thus hinder sustainable use and management of groundwater resources of Uganda (Tindimugaya, 2004). Aquifers are limited in yield, extent and hydrogeological characteristics in many areas, which imply that groundwater abstractions for irrigation or municipal water supplies may not be sustainable. However, recent identification of a high yielding aquifer in former river channels (Tindimugaya, 2008) implies that the potential for groundwater abstraction for irrigation exists in some areas but this needs to be confirmed. This will require confirmation of location of fluvial aquifers in former river channels and assessment of their potential for supplying water for irrigation. Cost-benefit analysis of accessing this water is needed. Similarly, pollution in peri-urban areas and poor understanding of the groundwater potential in most of the country pose serious problems.

Constraints to sustainable groundwater development include; (a) complex geology which makes understanding of the nature of groundwater occurrence and movement very difficult due to its movement within fractures and the weathered zone; (b) limited knowledge of groundwater resources; (c) limited technical capacity in terms of the number of groundwater professionals and also limited expertise due to the training they receive that includes a limited hydrogeological content; (d) limited financial resources for undertaking groundwater investigations and assessments; (e) poor quality groundwater data often collected by unqualified people who do not understand and appreciate the importance of the data (Tindimugaya, 2004). Although some of the constraints cannot be resolved in the short term, they can be brought to bear through taking appropriate measures such as undertaking more detailed groundwater studies, training and capacity building of key personnel and raising awareness.

Reliance on groundwater for domestic water supply in Uganda has increased greatly over the past years and is slated to increase further as the country tries to achieve its objectives of safe water for all by the year 2015. Although reasonable progress has been achieved in this endeavour, much still remains to be done with respect to the overall groundwater resources development, not least because of the lack of crucial data and information on the state of the groundwater resources. There are a number of problems that are threatening sustainable use of groundwater resources including pollution in peri-urban areas, lack of information on recharge and poor understanding of the groundwater potential in most of the country, etc., (Tindimugaya, 2004). In order to ensure that groundwater resources are sustainably developed, there are a number of opportunities which need to be harnessed, namely, creating an enabling legal and institutional framework, water sector reforms, decentralisation of implementation of water development activities from the central government to lower levels, privatisation, stakeholder involvement, and groundwater resources mapping programme.

Conclusions and Recommendations

The three main aquifers in Uganda are the weathered aquifers, fractured bedrock aquifers and alluvial aquifers. Previous studies in Uganda indicate that the weathered aquifer is unconfined whereas the fractured bedrock aquifer is leaky and the two aquifers form a heterogeneous aquifer system. But, fluvial aquifers have the highest yields in Uganda ($> 50\ m^3\ h^{-1}$) and feature the thickest regoliths and thus offer the highest prospects for obtaining high yielding boreholes in Uganda. Borehole yields in Uganda range between 0.1 and 50 $m^3\ h^{-1}$ and are lowest in areas underlain by weathered and fractured bedrock aquifers and highest in areas underlain by fluvial sediments in palaeochannels. Aquifers in Uganda have low transmissivity and storativity values ranging between 14 and 34 $m^2 d^{-1}$ and 0.014 and 0.21 respectively. Recent field investigations identified for the first time a highly productive aquifer comprising coarse-grained, fluvial sediments in palaeochannels of river networks. Palaeochannel sediments are of limited extent on stripped surfaces but can feature in significant thickness along former river channels on deeply weathered surfaces.

In Uganda groundwater is mostly used for domestic purposes and there are about 20,000 deep boreholes, 3,000 shallow wells and 12,000 protected springs installed for this purpose. Due to the importance of the livestock sector in Uganda, about 20 deep boreholes yielding an average of 8 $m^3 hr^{-1}$ have been constructed and installed with windmills for pumping groundwater for livestock watering in north eastern Uganda. However, there is hardly any irrigation in Uganda that is based on groundwater due to availability of adequate rainfall and surface water resources and probably due to limited understanding of the occurrence and distribution of aquifers and their potential.

Despite the current information available, it is recommended that detailed groundwater studies be carried out to assess the extent and potential of the aquifers in palaeochannels and those found in the rift sediments and their feasibility for abstraction for irrigation purposes. Similarly, the potential and feasibility of aquifers in weathered and fractured bedrock for sustaining small scale irrigation needs to be assessed. A comprehensive assessment of the actual potential for formal irrigation in Uganda should be carried out as a function of land and water (surface and groundwater) availability, demand projections of agricultural produce, hydrologic function and environmental value of wetlands as well as wetland use legislation, potential dam sites and economic feasibility.

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CHAPTER 15

ZAMBIA

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General description of Zambia

Geography

The Republic of Zambia is located in the southern part of the African continent with an area of 752,614 km^2 between latitudes 8^{o}5' and 18^{o}7' S of the equator and longitudes 22^o to 34^o E. It is an inland country and shares international boundaries with Mozambique and Malawi in the west, Tanzania in the north east, Democratic Republic of Congo DRC in the north, Angola in the west, Namibia in the south west, Botswana and Zimbabwe in the south. Of this geographical area, surface water bodies such as swamps, lakes and dambos cover 920,000 ha.

Physiography and climate

The Zambezi valley and Luangwa valley escarpments are mountainous and rocky, while the rest of the country is by and large, a level to gently undulating plateau with slopes rarely exceeding 3 to 5 percent. Interfluves mostly comprise deep weathered soils, which occupy large tracts of land of the main drainage systems consisting of the Zambezi, Luangwa, Luapula/ Chambeshi and Kafue rivers. The major drainage river is the Zambezi river, whose source is in the North Western province and flows through to the Indian Ocean via the Limpopo river in Mozambique. The Luangwa and Kafue rivers are distributaries of the Zambezi river. Chambeshi and Luapula rivers which form part of the Congo river drainage system, are other major rivers in Zambia. Some of these rivers (Luangwa, Zambezi and Luapula) are part of the wetland system (dambos). About 114 billion m^3 of total water resources exist in the country and of this total, 18 billion m^3 are groundwater resources whose exploitation remains largely limited to urban and peri-urban use for domestic and agricultural purposes. FAO, (2004) estimates that of the 1.74 km^3 of water abstracted for irrigation, only 12 percent is from groundwater.

Zambia has cultivable land of 42 million ha of which only 14 percent is cropped; and only 11.8 percent of Zambia's irrigation potential is utilized. Zambia has a water resource endowment for development of a wide range of crops, livestock and fish given the diversity of its agro-ecological regions. There are three agro-ecological zones in the country. Agro-ecological region 1 is the low rainfall region (less than 800 mm annually) in the valley areas; region 2 has moderate rainfall (800-1,200 mm annually) on the central and eastern plateaus, while region 3 covers the northern areas with annual rainfall above 1,200 mm. Rainfed agriculture has largely been undependable because of poor distribution of rainfall, often resulting in droughts, particularly in the southern half of the country. Major soil types include the black clays (vertisols) and sandy clays commonly found in the Kafue basin and the dambo areas. Red clay, sand veldt and clay loam soil are common in plateau areas. These soils are generally of moderate fertility status with no salinity problems. Land cover is divided into eight categories, namely forest, savanna, grassland, wetlands, agriculture, urban and water according to the land use map resource of Zambia. GIS - Landsat imagery taken in the year 2000 indicated that 67 percent of the land mass was occupied by grassland and 15.3 percent by forest. Others included savanna (13.1%), water resources (1.8%), wetland (1.2%), agricultural land (1.6%), urban infrastructure (1%) and barren land (0.1%).

Zambia enjoys a subtropical climate, which is characterized by two seasons: the cool and hot dry season and the wet season. The cool and hot dry season covers the period from May to October. During this season rainfall is absent and the need for irrigation utilizing both groundwater and surface water becomes critical. Mean temperatures vary from 16^oC to 21^oC. This season is split into a 'dry cool period' from May to July, also called the mid-winter season, that exhibits low temperatures averaging 16^oC and a 'dry hot period' from August to October with mean temperatures of 24°C. Mean daily temperatures of 30°C to 40°C degrees are common, particularly for low lying valley areas such as the Zambezi, Gwembe and Luangwa valleys. For this reason, these areas offer high potential for winter maize production under irrigation. Frost is usually registered in some parts of the country during the dry cool period. It occurs between November and April and is in every respect characterized by rainfall. December to January/February is the wettest months. Mean temperatures during this season are around 21°C.

Socio-economic context

Zambia has a population of 10.5 million, which during the period of 1999-2002 was growing at a rate of about 2.5 percent. It is estimated that farming provides livelihoods for 50 percent of the Zambian population among whom, over 70 percent are small scale farmers. The increasing population in recent years has resulted in increased demand for food and fibre resources. Zambia's agricultural sector is the key to the development of the Zambian economy and is the engine of growth for the next decade and beyond. Agriculture generates about 22 percent of the Gross Domestic Product (GDP) and provides livelihood for more than 50 percent of the population. The sector employs 67 percent of the labor force and is by far the main opportunity source of income and employment for women who constitute 65 percent of the rural population. The potential increase in rural incomes can reduce poverty. In recent years, the agricultural sector has also emerged as an important foreign exchange earner. In 1990, agricultural exports accounted for less than 2 percent of the total export value, but increased to 20 percent in 1999. Agriculture is therefore a key tool for poverty reduction. Other sectors of economic importance in Zambia are the mining sector, especially the copper mines and the services sector. According to the CIA's 2010 estimates, contributions to GDP from agriculture were about 20 percent, industries 34 percent and services 46 percent.

Groundwater resources

Hydrogeology

The geology of Zambia comprises various rocks and layers dating from over 1,000 million years ago (Precambrian era) to more recent times. These rock formations consist of igneous, sedimentary and metamorphic rocks. These geological formations include:

i. *Basement Complex:* The oldest system in Zambia is known as basement complex that is reported to be over 1,000 million years old (lower Precambrian). The basement complex consists of highly deformed gneiss, schists, quartzites, conglomerates, crystalline limestone, migmatites and granites. The basement complex mainly outcrops in the east and south eastern parts of Zambia and its distribution areas mostly coincide with the Bangweulu block. The basement complex is overlain by deformed Precambrian to lower Paleozoic sediment known as the plateau series and Mavu group. Due to the deformation, the basement complex is a high yielding aquifer;

ii. *Katanga group:* The age of the Katanga group ranges from late Precambrian to Cambrian (100 to 500 million years old). The Katanga group comprises shale, sandstone, dolomites, quartzites, limestone and conglomerates. The Katanga group is distributed in the northern and central parts of Zambia. The limestone component of this group is rich in groundwater. Example of this is the Lusaka limestone;

iii. *Lower Paleozoic group:* The Lower Paleozoic group overlies the Katanga group and is composed of sedimentary rocks such as shale, quartzites and arkose sandstone. This group is only evident in the western part of Zambia and the mid Zambezi valley during drilling investigations;

iv. *Karroo group:* The Karroo group is composed of tillites (fluvo-glacial origin, coal seams, mudstone, marls, conglomerate and basalt). The Karroo group corresponds to the carboniferous to Jurassic systems. The Karroo group is distributed along the Luangwa river and the western part of Zambia;

v. *Mesozoic group:* The basalt of the Karroo group is overlain by mudstone along the Zambezi river and to the west of Zambia. These layers have been judged to be Cretaceous in age based on discovery of certain fossils and are named the Mesozoic group. The thickness of the Mesozoic group has been estimated at up to 100 m. The distribution area of the Mesozoic group is normally shown as Cretaceous group. Example of its occurrence is the area near Chirundu in Chiawa is the Zambezi valley;

vi. *Cenozoic group:* The Mesozoic group is overlain in the large part of the extreme west of Zambia (Barotse basin) by Tertiary sandstone and Quaternary consolidated sand layers. These layers have been named the Cenozoic group. They are divided into two formations, namely the Zambezi formation of the lower part and the Barotse formation of the upper part. The “Kalahari sandstone” is a member of the Zambezi formation under Cenozoic group;

vii. *Intrusive Rocks:* Intrusive rocks of varying ages and types mainly intrude the Precambrian rocks. The majority consists of granite rocks and the remainder is gabbros, dolomites, syenites etc.

Groundwater systems

Groundwater potential analysis was carried out by Japan International Cooperation Agency (JICA) in 1995 to estimate the renewable groundwater storage of aquifers. Aquifers with primarily intergranular flow include the Kalahari beds and alluvium as well as limited zones within some Karoo sandstone units. Over much of western Zambia's Kalahari sands, groundwater occurs in shallow perched aquifers and deeper semi confined aquifers. Aquifers are best developed near present drainage systems where recharge occurs from both rainfall and surface flow. Laterally extensive alluvial deposits are associated with the major river drainages, particularly along the upper Zambezi near Mongu, and around lakes such as lake Bangweulu. In areas along the Luangwa river, Karoo sandstones are characterized by intergranular flow. Yields within this aquifer type are variable and reflect grain size, sorting, clay content as well as secondary fracturing in consolidated sandstones and range from 1 to 20 $L\ s^{-1}$.

Aquifers with flow in fissures and discontinuities include the sedimentary bedrock as well as Karoo basalt units within the country. The aquifer types include both fractured sedimentary and basalt units as well as fractured and karstic dolomite limestone units. The highest yielding aquifers in the country fall into the second group (dolomite and limestone) where yields range from 20 to > than 100 $L\ s^{-1}$. Due to the yield characteristics as well as the proximity of the aquifers to urban areas, this unit is the major source of supply for Lusaka, Ndola and Kabwe. Yield from fractured clastic and basalt lithologies of the Muva and Karoo super groups is more variable, but productive aquifers are locally developed (1 to 10 $L\ s^{-1}$). Basement aquifers are present in the south eastern portion of the country and are primarily formed in fractured and/or weathered zones in the shallow weathered mantle of bedrock. Borehole yields are low ($< 1\ L\ s^{-1}$), but are generally sufficient for hand pump installation, which forms the primary water supply in these areas.

Studies on groundwater resources in Zambia have come up with four major drainage basins: Zambezi, Luapula-Tanganyika, Kafue, and Luangwa as characterized in Table 15.1. Zambezi river catchment contributes about 50 percent of the total groundwater storage. 70 percent of this basin is composed of the Kalahari sands. Generally Kalahari sands form good aquifers because of their high porosity and good permeability. The Kafue river system has two important dams, the Itezhi-tezhi dam and the Kafue gorge dam, and the latter is used for hydropower generation. The best aquifers in this basin are the Kundelungu limestone formation, dolomite, and the upper loam dolomites formation. These aquifers are the best in Zambia and are most developed in Lusaka (Lusaka dolomite). The high yield of these formations is due to their karstic nature. Other aquifers with great potential in this basin are the Kafue sands and gravels along the Kafue river. In some areas, schist and quartzite often form good aquifers. In the plateau areas of the Luangwa river basin, fractured gneiss, granite, gneiss quartzite and schist are main aquifers for groundwater supply. Groundwater supplies from sandstone underlying the alluvial aquifers are in existence but are known to be blackish and this makes the water unsuitable for drinking. Finally the aquifers in the Luapula river and Tanganyika basin are composed of good alluvial deposits along the Luapula, Chambeshi and Tanganyika shores. On plateau areas, sandstones and quite often, weathered granite, form aquifers.

Table 15.1 Groundwater potential in Zambia

Characteristics	Drainage Basin				
	Luapula-Tanganyika	Luangwa	Kafue	Zambezi	Total
Surface area (km^2)	194,000	147,500	155,000	256,000	752,000
Mean annual rainfall (mm)	214	122	150	229	715
Groundwater through flow (m^3)	830,000	1,634,000	960,000	220,000	3,650,000
Vertical recharge (m^3)	41,500,000	33,020,000	24,450,000	64,030,000	160,080,000
Groundwater storage (m^3)	377,700,000	242,760,000	252,060,000	868,200,000	1,740,400,000

Groundwater recharge

Studies in Zambia have derived direct runoff and baseflow from total run-off using low frequency pass filter method. Contribution of baseflow to groundwater potential by province is shown in Table 15.2 whereas seasonal recharge of groundwater from effective rainfall (run-off) is summarized in Table 15.3. Increase of groundwater storage and baseflow were calculated independently. The coefficient of runoff reduces in inverse proportion to the size of the drainage area.

Table 15.2 Baseflow estimation by province

Province	Area (km^2)	Annual rainfall ($mm\ yr^{-1}$)	Baseflow in Rainy season ($10^9\ m^3\ yr^{-1}$)	Baseflow in Dry season ($10^9\ m^3\ yr^{-1}$)	Annual Baseflow ($10^9\ m^3\ yr^{-1}$)
Lusaka	22,084	857	0.3	1.1	1.3
Copperbelt	31,200	1,231	0.4	2.2	2.6
Central	94,483	947	1.1	5.0	6.1
Northwestern	125,280	1,127	2.1	8.6	10.6
Western	127,344	808	1.5	6.1	7.6
Southern	82,615	737	0.8	3.5	4.3
Luapula	45,292	1,259	1.0	4.1	5.1
Northern	143,146	1,138	2.7	11.3	14.0
Eastern	69,146	961	0.9	3.7	4.6
Total	740,590		10.8	45.5	56.3

Source: JICA, National Water Master Plan (1995)

Table 15.3 Seasonal groundwater recharge from run-off

Period	Period when groundwater table rises (December to February) (as % of annual rainfall)	Period when groundwater table falls (March to November) (as % of annual rainfall)
Change in groundwater storage	6.3	- 6.3
Baseflow	1.4	6.0
Recharge to groundwater table	8	0

Note: Recharge into groundwater table = Change in groundwater storage + baseflow
Source: JICA, National Water Master Plan (1995)

Groundwater quality

Natural groundwater quality in Zambia is generally acceptable for most uses, with limited cases of high salinity, primarily to the west of the country. Fluoride levels are above acceptable limits in some areas. The overriding quality problem in the country is contamination of aquifers from anthropogenic sources. Due to urbanization of much of the population, as well as uncontrolled growth in the cities, local aquifers are at high risk of contamination. Major dolomitic aquifers, which generally have shallow water tables and high rates of local recharge, are particularly vulnerable. There are documented cases of groundwater pollution in the Lusaka area with contamination sources including uncontrolled dumping in low lying (i.e. recharge) areas, uncontrolled industrial waste discharges, cemeteries and non-point pollution sources such as runoff in the urban environment (SADC Water Sector Coordination Unit, 2002). A legal framework exists to enforce regulations in terms of pollution of water resources within the Environmental Pollution Prevention Control Act (1990). However there is no quality monitoring outside the Lusaka area. There are also no set guidelines on protection zones for boreholes. In rural areas, there have not been significant problems. But in the urban areas, control of land use and waste handling is a pressing issue. For example a "temporary" dumping site in the Lusaka area in a known recharge area is yet to be closed by the authorities although the environmental council has noted that this is critical.

Groundwater development and utilization

Groundwater abstraction

Deep groundwater is mostly abstracted through boreholes, hand-dug wells, tubewells, while shallow groundwater is mostly abstracted through shallow wells and *dambos.* Groundwater lifting devices in Zambia are limited depending on many factors that include depth to the water source, availability of energy source, operation and maintenance cost of the equipment, the purpose/water use, and other socio-economic factors such as family income and size. These equipments range from electrically motorized pumps to manual lifting devices to wind-operated pumps. Table 15.4 shows the most commonly used pumps in groundwater abstraction indicating their cost, how they are energized and where they are normally used. There are several other types of deep well hand pumps in use. Hand pumps currently in use are not standardized. The Indian Mark II type is the most commonly used hand pump and has been recommended to be the best due to the availability of spare parts and relatively low cost. For small scale vegetable irrigation, the treadle pump has become very popular. It pumps from both surface and groundwater. The treadle pump finds its use wherever the water source is not more than 8m deep, and is especially suited to the *dambo* areas. Currently there are no statistics on how many treadle pumps are used to abstract water from underground.

Table 15.4 Common used pumps in groundwater abstraction

Pump type	Depth (m)	Energy source	Use	Avg. cost (USD)	Discharge and remarks
Submersible pump	50-120	Electrical motor/ gas/solar energy	Domestic irrigation livestock watering commercial	4,000	Moderately high discharge (1.5 to 30 L s^{-1}). Solar powered discharge (0.8 to 3 L s^{-1})
Mono pumps (Helical groove)	20-40	Electrical/Gas	Domestic livestock watering	2,500	Discharge (0.5 to 10 L s^{-1})
Windrass	15-30	Manual using a bucket	Domestic (rural) animal watering	800	Discharge depend on operator
Reciprocating pump	50	Electrical/Wind mill	Domestic	4,000	Discharge (1 to 15) L s^{-1}
Indian Mark 11	30-50	Human powered	Domestic (rural and peri-urban) animal watering	1,200	Flow rate (0.5 to 2 L s^{-1}). Most common pump for rural water supply more than 50,000 is in use.
Turbine pump	30	Electrical	Domestic irrigation	1,000	Flow rate (2.5 to 20 L s^{-1})
Treadle pump	8	Human powered	Small scale irrigation fish pond (draining and refilling)	100	Flow rate (1 to 2.5 L s^{-1}). About 3000 pumps are in use throughout the country
Rower /bumi pumps	5	Human powered	Rural water supply	500	Not very common
Small motorised pump	< 8	Petrol or diesel	Small scale irrigation		< 5 L s^{-1}

Groundwater utilization

Groundwater in Zambia, especially from boreholes, is used for various purposes (see Table 15.5).

Table 15.5 Percentage of groundwater use by purpose and province

Province	Irrigation	Rural Water Supply	Live stock	Urban water supply	Industrial	Commercial	Fisheries	Exploration	Observation
Lusaka	40	5	26	22	5	2	0	0	0
Central	40	19	29	5	4	3	0	0	0
Southern	28	38.5	26	3	4	0	0.5	0	0.01
Copper-belt	20	22	15	20	18	6	0	0	0
Northern	17	62	14	6	9	0	1	0	0
Eastern	17	57	18	6	1	1	0	0	0
North Western	9	80	11	0	0	0	0	0	0
Western	1	98	0	1	0	0	0	0	0

Source: JICA, National Water Master Plan (1995)

Domestic purpose

Out of the total population of 8.4 million people in 1995, about 36 percent (see Table 15.6) of the country's population depended on groundwater for their domestic use. Evidently more than half (51.9%) the population in the rural area rely on groundwater for domestic purpose and only 6 percent in the same category have piped water supply while 36.4 percent depend on the riverine systems. Groundwater supply is still the main source of water for domestic purposes in the rural areas as it is generally of good quality. Moreover rivers and streams are often found more than a kilometre away from village settlements and towns. This is so despite the abundant surface water supply enjoyed by the country. It is prevalent that surface water sources are contaminated and not good for direct consumption. Table 15.6 shows estimate numbers and yields of boreholes and shallow wells, mainly used in domestic water supply in Zambia.

Table 15.6 Groundwater supply ratios in rural areas of Zambia

Province	Number of "wells"		Total Yield (m^3 d^{-1})	Population	Water Supply Ratio (%)		
	Borehole	Shallow well			Ratio by borehole (%)	Ratio by shallow well (%)	Total (%)
Lusaka	2,570	400	1,872	157,633	24	8	31
Copperbelt	870	660	3,308	314,891	21	7	27
Central	890	620	3,821	507,428	16	3	20
North-western	170	950	1,831	333,234	6	9	14
Western	3,000	1,060	13,703	531,072	61	6	67
Southern	1,520	840	7,392	695,166	24	4	28
Luapula	200	1,130	2,161	442,034	5	8	13
Northern	240	1,130	2,305	736,876	4	5	8
Eastern	780	2,170	5,845	883,218	10	8	17
Total	10,240	8,960	42,238	4,601,552			

Source: JICA, National Water Master Plan (1995)

Irrigation

Both shallow and deeper groundwater is used for irrigation. Shallow groundwater, (1-2 m deep) is a very useful supply of water for farms located away from a surface water supply. This source that includes simple hand dug water hole also known as "scoop holes" which may be less reliable than surface water because there is no easy way of assessing whether there is enough water to ensure adequate irrigation except through pumping experience. However, the farmer is saved the cost of an expensive canal or pipe system to bring water from a more distant surface source. Most small scale farmers, particularly in the *dambos,* use shallow wells to irrigate their crops. There are about 3.6 million ha of *dambo* land in Zambia and about 100,000 ha of this is used for crop production by small scale farmers.

While deep groundwater is hardly used by small scale farmers in Zambia, a number of commercial farmers are currently using deep groundwater sources to irrigate as much as 300 ha per farmer using sophisticated centre pivot irrigation systems. Most of these farms are located along the line of rail between copperbelt and southern provinces of Zambia with the borehole yield recording 60 L s^{-1}, from such deep groundwater sources. The Irrigation Policy and Review Document advocates for commercialization of Zambia's irrigation sub-sector across all levels of farming. Hence, it can only be projected that the use of deep groundwater for irrigation purpose will increase in the near future.

Zambia's irrigation potential is 2.75 million ha based on the water availability and soil irrigability. From this potential, it is believed that 523,000 ha can be economically developed. Since time immemorial, small scale farmers all over the country have practiced informal irrigation in their gardens, i.e., they applied water in an casual way, using buckets, watering cans and hose pipes to grow vegetables, rice, bananas and some local sugarcane varieties along streams, rivers, and in *dambos*. This form of irrigation is usually not capital intensive, is farmer operated and is often spontaneous in origin, responding to the needs felt by individual farmers. Drought occurrences, for example, directly prompt the genesis of such irrigation methods. Areas irrigated in this manner are usually small in size, ranging from 100 to 200 m^2. However the introduction of treadle pumps has improved the efficiency of watering these gardens and farmers are now able to irrigate, using one treadle pump, area ranging from 1,000 to 2,500 m^2. Currently 155,912 ha of land is irrigated in Zambia, which is about 30 percent of the economical irrigation potential (FAO 2005). From this, 32,189 ha is under surface irrigation with the dominate crop being sugarcane. In Zambia, efficient water use technologies like drip (covers 5,628 ha with dominant crop, coffee) and sprinkler irrigation (covers 17,570 ha with dominant crop, wheat) systems are being adopted. Some of the small scale farmers use treadle pumps to irrigate areas of about 525 ha; it is estimated that more than 3,000 treadle pumps are in use.

<u>Livestock watering</u>

Water requirement for the livestock sector was estimated at 129,000 m^3 d^{-1} in 1995. This was based on livestock water consumptive use of 40 L per animal d^{-1} for cattle, 30 L per animal d^{-1} for pigs, 20 L per animal d^{-1} for sheep/goats and 0.2 L per bird d^{-1} for poultry production. The water requirement, especially for cattle, did not change significantly up to 2004, as the numbers stagnated due to diseases and drought.

<u>Industrial purpose</u>

Groundwater use for industrial purposes has been alluded to, in one of the earlier sections. Industrial and commercial use of groundwater accounts for only about 7 percent of total groundwater and this is mostly in the copperbelt and the northern provinces of Zambia. The copper mining industry accounts for more than 50 percent of the industrial use of groundwater and is used for refining and backwashing the copper and cobalt ores. This water that is mined together with the ore sometimes finds use in the commercial sector after undergoing some treatment especially against sulphur, heavy metals and chlorides. The northern province is a low industrial province and it uses groundwater in its tea and coffee processing industries as groundwater requires less treatment against impurities and it is used in controlled quantities. For the base scenario on industrialization, the total water requirement totals 2 million m^3 d^{-1} in 2005. Out of this about 12 percent (0.24 million m^3 d^{-1}) is from groundwater supplies (JICA National Water Master Plan, 1995).

Institutional and legal framework

The Department of Water Affairs in the Ministry of Energy and Water Development is the main public institution charged with overall water resources management in the country. For the department to implement the policies outlined in the Water Policy document of 1994, it was recognized that any institutional framework adopted by the water sector must be in line with the national development efforts and fit in with the existing government structure. The Water Development Board under the Department of Water Affairs is a statutory body appointed under Cap 312 of the Laws of Zambia to deal with surface water management. The major function of the Water Development Board is to control the use of surface water in the country by allocating water for different uses. Groundwater use is not yet included under this law and therefore not adequately monitored. However, the National Water Policy of 1994 proposed that the control of groundwater be included in the Water Act. So, currently, there is no policy supporting groundwater abstraction and this has led to indiscriminate siting and drilling of boreholes especially in Lusaka area as water rights only apply to surface water supply.

Other key stakeholders in groundwater development are the drilling companies (about 18 in Zambia), the National Water and Sanitation Council, the Environmental Council of Zambia and several other government departments. For example, the Department of Agriculture is responsible for dam construction for irrigation and livestock watering; National Council for Scientific Research for catchment studies and research on water potential and quality aspects; Environmental Council of Zambia for environmental management and enforcement of legislation; the Water Board for water allocations, etc. For water supply and sanitation services, the National Commission for Development Planning (NCDP) is responsible for resource mobilization, the Department of Water Affairs is responsible for rural and small township water supply, etc. In short, there is a diffused institutional structure in the general water sector development that is compounded by the lack of clear guidelines and coordination links. This situation has given rise to a number of problems regarding the management of the sector, including inadequate legislation.

Conclusions and Recommendations

More holistic approaches are required which go beyond the present knowledge on groundwater management and monitoring in the country. Currently, groundwater is not covered in the water resources monitoring system in Zambia while other water sources such as rainwater harvesting and surface runoff in streams and rivers are being monitored.

In view of inadequate information on groundwater development, a nationwide groundwater level observation and monitoring would be very useful to assess the groundwater development potential. The groundwater development potential obtained in the Master Plan should be examined and if necessary should be revised based on new data obtained on irrigation potential, domestic water sources, livestock watering point and industrial and commercial water use development trends. Further research is needed into groundwater quality, efficient well construction, groundwater observation, better drilling techniques, complete geological and hydrogeological mapping as well as safe groundwater abstraction. So far, Luapula and western province have not been fully mapped hydrogeologically in order to produce a complete quarter degree sheet (Water Sector Coordination Unit report, 2002). These are important options to tackle the groundwater problem at the country level. Scientific data on the actual groundwater exploration, development, cost reduction and sustainable utilization of groundwater through various measures discussed in the report, is still insufficient. The only reliable information in this area, is the Water Resources Master Plan, 1995, which is now quite outdated.

Groundwater level monitoring should be continued, as recent groundwater level declines have been reported in large cities, especially in Lusaka city. It is said that groundwater decline caused by over pumping is remarkable and existing water supply facilities will be damaged in the near future. From this view point, adequate groundwater monitoring becomes a priority. Effective counter measures like regulations against over pumping should be examined based on long term monitoring results and if possible included in the new Water Act on Groundwater Management to be implemented by government. An interdisciplinary approach is required in order to explore the groundwater potential. In considering the suitability of groundwater use for domestic, irrigation, livestock, industrial and commercial uses, existing water quality guidelines suggested by WHO (1992) and the Environmental Council of Zambia, should be adhered to by all stakeholders involved in groundwater quality monitoring, management and utilization.

Step drawdown pumping tests should be carried out by companies and institutions involved in groundwater development and exploration. Step drawdown test is conducted to determine the safe yield of boreholes and wells. If pumping rate exceeds safe yield, rock fragments enter into the borehole and are deposited at the bottom. This situation has been reported in some parts of Lusaka. Such cases occur rarely on boreholes equipped with hand pumps though. Effective use of wells and borehole database is desired for future groundwater development. Statistical information on hydrogeology and borehole capacity by district would easily be obtained from a well-kept and up-to-date database. Currently, this information is fragmented and its usefulness for actual groundwater development planning and scientific hydrogeological study cannot fully be realized. Types of groundwater lifting devices including hand pumps and treadle pumps should be standardized in terms of maintenance and repairs. Indian Mark II type is the best hand pump while the Money Maker treadle pump is currently the best foot pump for shallow wells with water levels less than 8 m. The government has already standardized the Indian Mark II type, therefore donors and individual groundwater developers with hand pumps should also standardize hand pumps to the same, in their support for groundwater development

Existing groundwater facilities are frequently not in use, for the reason that the maintenance of completed water supply facilities is not adequate, especially in rural areas. Therefore a local maintenance and management system for rural water supply facilities should be established to ensure continuous use and maintenance of the completed water supply facilities. Electricity and fuel tariffs on groundwater utilization should be considered critically to ensure the effectiveness of this resource for the purposes of large scale irrigation, industrial and commercial development as well as urban water supply development. ZESCO electricity tariffs on groundwater pumping are currently reported to be too high, as much as USD 200 per month depending on the depth and rate of groundwater abstraction. Capacity building through training of personnel (engineers and technicians in charge of borehole) on, site selection, machine operation and maintenance of equipment, to achieve development in this area is recommended. Establishment of a training centre with excellent trainers and adequate equipment is needed in order to achieve highly effective technology transfer related to groundwater development.

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CHAPTER 16

ZIMBABWE

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General Description of Zimbabwe

Geography

Zimbabwe is located between latitudes 15°40' S and 22°20' S, and longitude 25°10' E and 33°05' E. It is bordered by South Africa to the south, Botswana to the west, Zambia to the north, and Mozambique to the east; and it covers a total area of about 390,759 km^2. The country is divided by a central watershed that runs south west to north east, with the major rivers draining in to the Zambezi river in the north and the Limpopo river in the south. The central part of the country, the watershed region, has an altitude ranging from about 1,200 to 1,500 m above mean sea level (AMSL). This region, referred to as the highveld, is surrounded by the lowveld, a region with altitude of 500 to 900 m AMSL in the south east, south west, and north. To the south of the highveld, the change to the lowveld is gradual; with an area known as the middleveld lying in between the highveld and lowveld. The middleveld ranges in altitude from 900 to 1,200 m AMSL.

Physiography and climate

The country has a single rainfall season that starts in November and lasts till March. However, the rainfall pattern across most of the country is variable. The rainfall range is quite wide, with the low annual rainfall of about 400 mm recorded in the southern areas near the South African border, and high annual rainfall of up to 2,000 mm recorded in the eastern highlands along the border with Mozambique. Generally low rainfall is experienced in the lowveld areas and higher rainfall on the highveld and surrounding areas. The average annual rainfall on the highveld is in the range of 700 to 1,200 mm. The year has two distinct seasons, the hot summer from September to March with mean maximum temperature of about 30^{o}C in the highveld, and 35 to 40^{o}C in the lowveld; and the winter period lasting from May to August. Potential evapotranspiration is estimated at 1,400 to 1,600 mm in the eastern highlands; 1,600 to 2,000 mm in the highveld; and 2,000 to 2,200 mm in the lowveld areas. With the exception of the eastern highlands, potential evapotranspiration is higher than rainfall. For agricultural purposes, the country is divided into five natural (agro-ecological) regions, regions, I through V. The division is based on rainfall and soil suitability for agriculture, which defines their agro-ecological potential. The natural regions, rainfall, their areas of coverage, and farming systems are summarized in Table 16.1.

Socio-economic context

The total population of the country is estimated at about 12.9 million, of which 64 percent is rural (2004). A small percentage of the population lives on commercial farms. The estimated annual growth rate is about 1.02 percent. In 2002, population access to improved drinking water sources was said to be 100 percent in the urban areas and 74 percent in the rural areas (FAO, 2003). Agriculture is the cornerstone of the Zimbabwean economy and about 60 percent of the economically active population depends on it for employment. Women play an important role in agriculture and it is estimated that 70 percent of small scale farmers are women. The agricultural sector contributes about 17 percent to the country's Gross Domestic Product (GDP), 60 percent of the raw materials required by the manufacturing industry and 40 percent of the total export earnings (FAO, 2003). However, most communal farmers are located in areas of low and sometimes erratic rainfall. Irrigation can play a significant role towards increasing the agricultural productivity in these areas.

Table 16.1 Natural regions, rainfall, and agricultural production

Natural Region	Annual Rainfall	Area of region	Production	Farming systems
I	900 to > 1,000 mm	Eastern mountain zone, covering about 7,000 km^2 (less than 2% of total land area)	Specialized and diversified agriculture, mainly horticulture and forestry	Mainly commercial agriculture. Some communal agriculture as well
II	750 – 1,000 mm Short rainfall season in some areas, and some mid-season dry spells	Most of the central watershed area. Covers about 58,000 km^2 (15% of the total land area)	Crop production and intensive livestock production	More than 70% large scale commercial farming. 22% of region is communal land, and 4% small-scale commercial land
III	650 – 800 mm Region experiences mid-season dry spells	Middleveld area, to the south and north of central watershed. Covers 72,000 km^2 (19% of total land area)	Livestock production, fodder crops and cash crops. Marginally suitable for maize, tobacco, and cotton	49% large scale commercial farming. 43% of the land is communal land
IV	450 – 650 mm. Drought prone region. Dry spells during rainfall season	147,800 km^2 (38% of total land area)	Livestock production. Production of drought resistant crops	62% communal land, 34% large-scale commercial land, and 4% small-scale commercial land
V	< 450 mm. Rainfall is too low for crop production	104,400 km^2 (27% of total land area)	Cattle and game ranching	45% communal land; 35% large scale commercial; 25% national parks

Source: Owen (1989)

Groundwater resources

Hydrogeology

The bulk of the hydrogeological knowledge of Zimbabwe was generated during the National Water Resources Survey for the National Water Master Plan (Interconsult, 1986). This study covered, among other things, the regional evaluation of the groundwater resources across the country and the classification of the groundwater development potential. The hydrogeological information in this chapter is based largely on the Interconsult report. Zimbabwe is divided into 10 hydrogeological units, some of which are further divided into several sub-units described below and summarized in Table 16.2.

i. *The Archean Granitic and Gneissosse Rocks* is a very important unit in Zimbabwe as it covers about 60 percent of the country's land mass. This hydrogeological unit underlies a considerable proportion of the communal areas where smallholder farmers are located. The unit is present across all topographical ranges of the high-, middle-, and lowvelds, and across a rainfall range starting from less than 500 mm to greater than 1,200 mm. Associated soils are mostly sandy in nature. Aquifers found in this formation are those associated with secondary porosity and permeability. Groundwater occurrence is limited to areas with extensive weathering and fracturing;

ii. *The Greenstone Belt* occurs across a wide range of elevations and rainfall, from elevations above 1,100 m and rainfall greater than 1,000 mm in the middleveld to elevations below 600 m and rainfall less than 600 mm in the lowveld. The Greenstone Belt is a generally impervious rock mass. Groundwater occurrence in the formation is controlled by secondary porosity and permeability. Where fracturing and secondary porosity is well developed, aquifers are said to be of good potential;

iii. *The Argillites of the Piriwiri, Lomagundi, Tengwe River, and Sijarira Formations* are of minor hydrogeological significance. Groundwater occurrence in these formations is associated with secondary porosity and permeability. Groundwater is usually associated with bottomlands, where it occurs at depths less than 10 m. The groundwater development potential of these formations is limited to localized areas associated with fracturing;

iv. *The calcareous rocks of the Lomagundi and Tengwe River Formations* are limited to areas around Chinhoyi and Karoi in central Zimbabwe, at elevations ranging from 1,000-1,450 m and rainfall ranges between 600-800 mm yr^{-1}. It comprises of the Lomagundi dolomites and the limestone of the Tengwe river group;

v. *The Umkondo Group* is found in the high altitude areas in the eastern highlands in Nyanga, Chipinge, and Chimanimani. The aquifers associated with this group are typically hard rock aquifers with negligible groundwater potential;

vi. *The Karoo Sequence* is made up of various lithologies, each possessing different groundwater occurrence and development potential. The sequences are the Batoka basalt, the forest sandstone, and the escarpment grits of the upper Karoo; the Madumabisa mudstone, and the upper and lower Wankie sandstone of the lower Karoo. The Karoo underlies about 20 percent of the country and is widespread in communal areas. The Karoo formation is important as a potential rural water supply source;

vii. *The Cretaceous Formation* is found in the north eastern Zambezi valley and in the south east of Chiredzi along the border with Mozambique. The formation is restricted to areas with annual rainfall ranging from 400-600 mm. Groundwater is suitable only for single point water supply;

viii. *The Kalahari Sands* are found in the western part of the country, occupying the flat areas that have thick forest cover. In these areas annual rainfall is typically 600 to 800 mm. The sands are aeolian in nature, unconsolidated and are characterized by primary porosity and permeability. However the characteristic difficult drilling conditions associated with them, makes exploitation difficult. The aquifers can be developed for primary supplies and irrigation;

ix. *Alluvial Deposits,* found in the Save valley in south eastern Zimbabwe, along the Runde and Nuanetsi rivers, in the Zambezi basin in the north, and in the Umnyati and Sesami rivers in the Gokwe area of the north west, typically occur in the middleveld area where rainfall is less than 800 mm yr^{-1}. The deposits are unconsolidated sequences of clay, sand, and gravel beds of varying thickness ranging from 15 m to over 70 m. Thickness over 70 m has been reported in the Save valley. Alluvial deposits are characterized by variable water levels that represent local conditions, especially where groundwater in the deposits sustain river flows. Aquifer recharge is also influenced by river flow. The alluvial deposits have high potential for groundwater development and can be used for primary water supply, piped water supply systems, and small and large scale irrigation;

x. *The Mashonaland Dolerites* are associated with gneisses and granites and are found in Mashonaland East in central Zimbabwe, in northern Manicaland, and the north eastern part of the Masvingo province. Except for Masvingo, these areas are characterized by high rainfall of more than 800 mm yr^{-1}. Groundwater is associated with weathered and fractured zones in the rock mass.

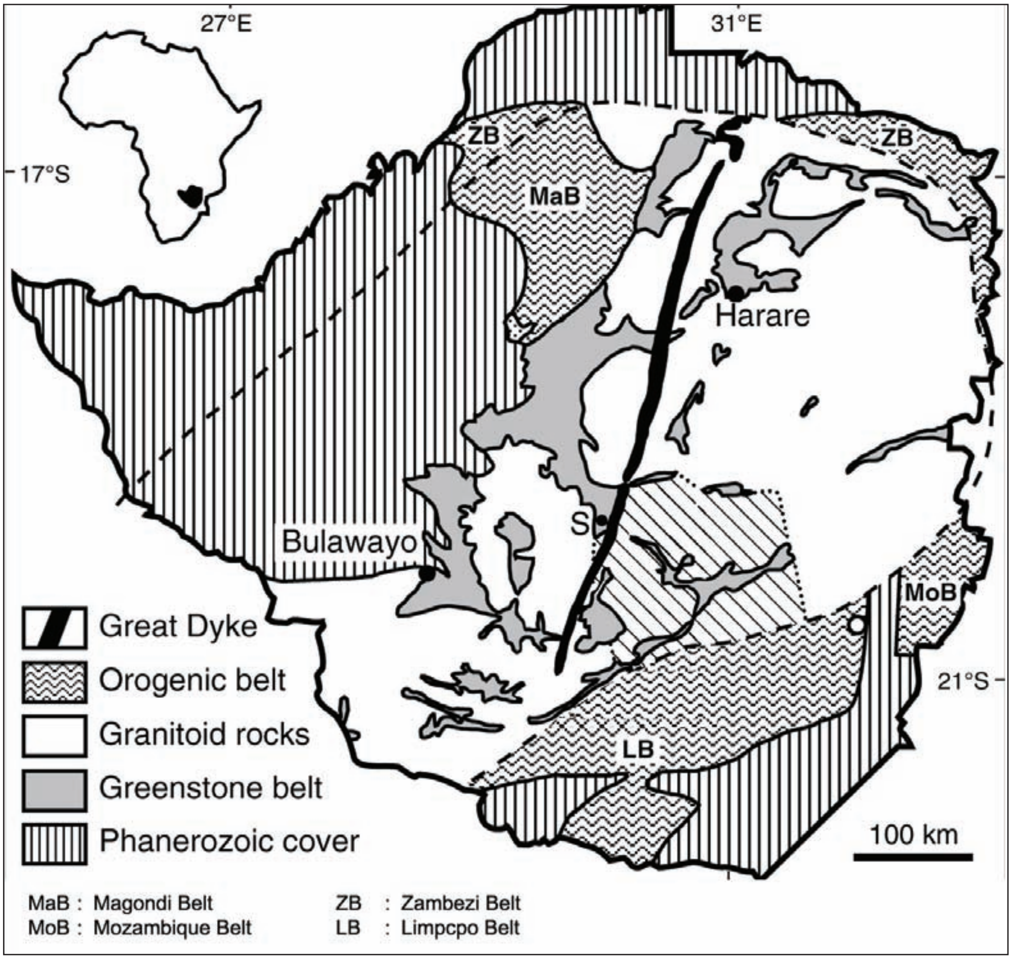

Figure 16.1 Geologic map of Zimbabwe (Source: http://economicgeology.org/content/103/5/981 F1.large.jpg)

Table 16.2 Hydrogeological formations in Zimbabwe

Formation	Sub-formation	Yield range (L s^{-1})	Water level depth range (m)	Average borehole depth range (m)	*Groundwater development potential
Archaean granitic and gneissose rocks		0.1 – 1.2	< 10 - > 45	30 - 35	Low
Greenstone belt	Bulawayan	1.2 – 2.9	5 - > 20	30 - 50	High
	Shamvaian	0.1 – 0.3	< 10 - > 20	40 - 60	Low
Argillites of the piriwiri, lomagundi, tengwe river, and sijarira formations		0.1 – 0.6	< 5 - > 20	50 - 70	Low
Calcareous rocks of the lomagundi and tengwe river groups	Tengwe river limestone	n.a.	n.a.	50 - 70	Moderate
	Lomagundi dolomite	5.6 – 27.8	n.a	60 – 80	High
Umkondo group		0.1 – 1.2	< 5 - > 20	40 - 70	Low
Karoo sequence	Batoka basalt	0.1 – 2.9	5 - > 20	30 - 70	Moderate
	Forest sandstone	0.1 – 5.9	< 5 - > 20	50 – 100	High
	Escarpment grit	1.2 – 3.5	< 5 - > 20	50 - 70	High
	Madumabisa mudstone	0.1 – 0.6	**< 5 - > 20	50 - 70	Low
	Upper and lower wankie sandstone	1.2 – 5.8	Artesian, with heads up to 45 m.	120 – 150	High
Cretaceous formation		0.1 – 0.6	5 - > 20	70 – 100	Low (suitable only for single point water supply)
Kalahari sands		1.2 – 11.6	5 - > 20	70 – 100	High
Alluvial deposits		1.2 - 81	5 - 40		High
Mashonaland dolerites		0.3 – 1.2	< 15	25 – 50	Moderate

* Groundwater development potential: i) *high (*suitable for primary supply, piped supplies, and small and large-scale irrigation schemes); *moderate (*primary supplies, small piped schemes and small-scale irrigation schemes); *low (*primary supplies from boreholes)

** Most boreholes have water levels below 20 m; shallow water levels are associated with drainage lines

Source: Interconsult (1986)

Groundwater systems

Groundwater in Zimbabwe is associated with primary and secondary aquifers and aquicludes that occur in the hydrogeological units described in the previous section. There are three main aquifers that are known to have significant water resources (Owen, 2004). These are dolomite aquifers found in the Doma, Lomagundi, and Chinhoyi areas associated with the dolomites; the Forest sandstone of the Karoo Sequence; and the alluvial aquifers associated with river systems.

i. *Dolomite aquifer:* Located on the highveld with high rainfall and good soils, the dolomites are commonly referred to as the Lomagundi dolomites. The yields in the dolomites range from 10 to 15 L s^{-1}, and the average depth to the water table is 80 m. This is a commercial farming zone and hardly any small scale farmers are found here;

ii. *Forest sandstone aquifer:* Found around Bulawayo and also in the Gokwe area in the north west of the country. The area around Bulawayo is largely a commercial farming area (livestock), while around Gokwe, there are some small scale farming areas. The Nyamandhlovu aquifer located about 40 km north of Bulawayo is one such aquifer. The yields in this aquifer range from 5-10 L s^{-1} and the depth to water table ranges from 10-80 m. In Gokwe however, the depth to water table is up to 500 m;

iii. *Alluvia aquifer*: Associated with the Save, Limpopo, and Zambezi river systems, the groundwater in the alluvial systems is controlled by primary porosity. The alluvial aquifers are of limited extent, covering only about 2,564 km^2 or 0.7 percent of the country's total land area. The alluvial aquifers are high yielding, with yields of up to 60 L s^{-1} (Owen, 2004). The depth to water table is less than 80 m here and they are used mainly to support both large and small scale commercial irrigation. Examples of such use are the Musikavanhu irrigation scheme and the middle Save Estates, operated by the Agricultural and Rural Development Authority (ARDA).

There is scant information on recharge in the various hydrogeological units across the country. In general, a recharge estimate of one percent of average rainfall is applied in groundwater resource management across the country. Sunguro (2004) estimated recharge for the Musikavanhu small scale irrigation project in the Save catchment in the south east lowveld using the chloride balance method. This is a typical alluvial aquifer with primary permeability. He found recharge in this area to be about 17 mm yr^{-1}, approximately 3.5 percent of the average annual rainfall. Isotopic studies of the Nyamandhlovu aquifer near Bulawayo in the western part of the country indicated recharge rates of 2.5 to 4 percent of the annual precipitation (Martineli and Hubert, 1996). The aquifer comprises of forest sandstone, is secondary and confined for the most part. Recharge occurs in one section where the aquifer is unconfined. Recharge to the alluvial aquifer systems has been studied extensively in the Save river alluvial system in the south east of Zimbabwe by Owen (1989). Groundwater in this system occurs in alluvial deposits of 60-100 m thickness (Boehmer, 1992). This aquifer is in an area of very low rainfall (average of 480 mm yr^{-1}). Rainfall plays a minor role in recharge. The source of recharge for this aquifer system is the Save river that rises further north in areas of higher rainfall. Recharge estimated using the chloride method is about 17 mm yr^{-1}, or 3.5 percent of the rainfall (Sunguro, 2004). This is higher than the estimate of one percent that is deemed applicable to most of the country, indicating other recharge sources in addition to rainfall. The Save river is not a perennial river, but flows throughout the year now, as it is used as a conduit of water from the Osbourne and Rusape dams upstream, to the commercial sugar estates in the south. It is some of this water that recharges the alluvial aquifer along the Save river. Technosynesis (1985) estimated that the recharge occurring from river flow along the Save river is about 600 L s^{-1} km^{-1} of river length. In general, the alluvial aquifers have water of good quality. They have high development potential and particularly for primary water supplies and also for small and large scale irrigation systems. They have been extensively developed in the Save river systems but are fairly underdeveloped in both the Zambezi and Limpopo river systems.

Groundwater quality

Water quality for the various hydrogeological units in the country is described in detail in the National Water Resources Survey Report (Interconsult, 1986). In general, most aquifers have water that is of suitable quality for drinking and irrigation. Water quality issues are considered in the perspective of the individual hydrogeological units described earlier. The Archaean granitic and gneissose rocks have water of good quality with no constraints for potable water supply. The Greenstone Belt formation generally has water of good quality. With the exception of reported excess manganese in some cases, all constituents are within the recommended ranges for drinking water quality.

The quality of water in the Batoka Basalt is generally good. It is neutral to slightly alkaline, but suitable for human consumption. The Forest sandstone, Madumabisa mudstone, calcareous rocks, and argillites formations all have water with suitable quality for human consumption. The lower and upper Wankie sandstones were found to have high fluoride content associated with recharge areas. However, further away from the recharge zones, the fluoride combines with calcium, precipitating as calcium fluoride. In the Nyamandhlovu aquifer, water is good for drinking. For irrigation purposes it has a moderate salinity hazard. Water quality in the eastern section of the Kalahari sand formation is of exceptional quality. Water quality decreases in the west, around the Hwange national park where the water is saline. This salinity coincides with areas of low rainfall.

In the deep alluvium associated with the Save valley, the water is mineralized, limiting its potential for human consumption and irrigation use. In some sections of the Save river (e.g. near the Musikavanhu small scale irrigation scheme) the groundwater is saline and unsuitable for human consumption. This localized salinity is associated with the lithological conditions. In other areas, the water in alluvial deposits is of suitable quality with no restrictions for its use for primary supplies. Water in the Mashonaland dolerites is also suitable for human consumption.

Groundwater development and utilization

Groundwater abstraction

Several abstraction methods are used with borehole installing methods being, either hand digging, hand drilling or motorized drilling, depending on the nature of the aquifers, the cost of drilling and installation of borehole, and cost involved in abstracting the water, among other things. In alluvial aquifers, most small scale farmers abstract groundwater from shallow wells, which are installed by the farmers themselves, or by well digging contractors (Owen, 1989). Well digging units were available locally in the 1980s and 1990s. Their availability currently could not be confirmed. Hand drilling equipment such as the Vonder Rig was made locally, and was available in 2000. For large scale operations such as on commercial farms, borehole installations are by commercial drilling operators who use motorized drilling equipment. Submersible and mono pumps are used for water abstraction. The pumps are imported and their cost is not fixed due to the volatility of the local currency. The bush pump, a locally manufactured pump, is also used in rural areas. These pumps cost between 1,000 and 1,500 USD per unit (FAO, 1997).

Boreholes in urban centers, at mines and on other private properties are equipped with pumps operated by electric motors. In some cases, diesel engines are used. In rural areas abstraction is by means of ropes and buckets and hand pumps in hand dug wells, boreholes equipped with hand pumps, and boreholes equipped with electric pumps where electricity is accessible. Unequipped hand dug wells are quite common, especially in *dambo* areas with shallow groundwater, and in the alluvial aquifer systems.

Cost of groundwater development

The costs of installing a borehole are highly variable across the country. The costs of installing and operating boreholes in 1995 are summarized in Table 16.3. The Zimbabwe National Water Authority (ZINWA), the national water governing body, also offers borehole drilling services to the public. The ZINWA charges are much higher than those of the private sector. They range from about 3,500 to 4,000 USD for a borehole depth of 40 m and a diameter of 15 to 20 cm (Sunguro, 2004). General enquiries to drilling service providers revealed that the cost of drilling in early 2004 ranged from about USD 1,833 to 2,667.

Table 16.3 Capital and annual operation and maintenance costs in USD (converted from ZWD at 1:10) of installing boreholes (1995)

Borehole depth (m)	Hand pump	Electrical Submersible			Diesel; Mono		
	0.5 L s^{-1}	1 L s^{-1}	3 L s^{-1}	5 L s^{-1}	1 L s^{-1}	3 L s^{-1}	5 L s^{-1}
30	2,700 150	3,100 600	3,700 1,100	3,800 1,400	5,700 1,900	5,900 1,900	6,000 1,900
60	4,300 200	4,800 900	6,200 1,600	6,400 1,900 (6,433)*	7,200 2,000	7,600 2,100	7,600 2,100
100	n.a. na	7,200 1,200	8,500 2,100	8,800 2,700 (7,633)	9,200 2,200	10,700 3,200	10,700 3,200
150	n.a n.a	n.d 1,500	n.d 2,900	n.d 3,500 (9,133)	n.d 2,500	n.d 3,500	n.d 3,500

n.a: not available n.d: no data *Figures in parenthesis are capital costs in USD obtained from telephone interviews in 2004, when exchange rate USD1: ZMD 6,000

ZINWA drilling costs are ZWD 21 to 24 million for a 15 – 20 cm diameter borehole.

Costs presented in this section are probably only an indication of the actual costs. While the cost estimates provide a good guidance, they depend on several factors and the actual costs are sometimes higher than these estimates. The factors influencing the cost of drilling include geological formation, actual depth and diameter of borehole, end usage (e.g. hand pump, piped reticulation), and energy source. The geological conditions are highly variable while in some cases specialized drilling equipment is required and this increases the cost substantially. Maintenance costs also vary significantly depending on demand, borehole depth, end usage, and energy source. There is also uncertainty in the costs due to the economic instability that currently prevails. From the indicative costs given above, it is clear that the use of groundwater for irrigation has high costs (capital, operation and maintenance) associated with it. These costs might be prohibitive for small scale farmers.

Groundwater utilization

The 1995, the National Action Report mentioned approximately 19,550 boreholes and 9,550 deep wells that were in use in the rural areas. The total abstraction from these boreholes and deep wells for domestic consumption was estimated to be about 35 million m^3 yr^{-1}. Commercial agriculture abstraction during the same year was estimated at 340 million m^3 yr^{-1}, while mining use of groundwater was estimated at 2.85 million m^3 yr^{-1} and industrial groundwater use was estimated as 10 percent of the total industrial water use, about 8 million m^3. Another estimate showed that the total groundwater use in 1995 was estimated at 392 million m^3, equivalent to about 10 percent of the total water use in the country (Sunguro *et al.,* 2000). In Table 16.4, the groundwater usage by various sectors is shown. However, this proportion could have been as high as about 20 percent as many private groundwater users were not accounted for. For the current situation, this figure can be considered conservative, as prior to the revision of the water legislation in 1998, all groundwater was considered private and abstraction records were not kept. Observations show increasing installation of boreholes by individuals for home gardening and domestic water supply as well as by large commercial and small scale agricultural farms (Sunguro, 2004).

Table 16.4 Estimated groundwater use by sector (1994)

Sector	Annual groundwater use (Mm^3)
*Rural	**27.7
Municipal	13.6
Agricultural	340
Mining	2.85
Industrial	8.1
Total	392.25

* Rural water use is both domestic and irrigation

** Excludes deep well abstraction of about 7 Mm^3 yr^{-1}

Domestic purpose

Groundwater is used extensively for domestic water supplies in rural areas. Boreholes and wells equipped with hand pumps are normally used for these purposes (Sunguro, 2004). The total number of boreholes and wells and the total abstraction used for this purpose is unknown (Sunguro, 2004); and 14 percent of the total boreholes and wells were reported to have dried up. Assuming borehole yields of 0.1 L s^{-1} over a 12 hour pumping period for each borehole, the total estimated abstraction in 1995 was about 27 million m^3 yr^{-1}. Deep well yields were estimated to be 0.07 L s^{-1}, giving an annual abstraction of about 7 million m^3. The total annual abstraction for domestic purposes in communal areas was thus estimated at about 34 million m^3. Sunguro *et al.* (2000) estimated this primary use to be 35 million m^3 yr^{-1}. Observations showed that number of boreholes and wells for domestic water supply has increased during the last decade but the total abstraction is not known.

Irrigation

In 1989, approximately 180,000 ha were irrigated in total within the country, of which 71,000 ha is estimated to be irrigated by groundwater (Owen, 1989). This area included about 20,000 ha of informally irrigated land in *dambos*. The area irrigated in each sub-sector is summarized in Table 16.5. About 964 million m^3 were abstracted annually for irrigation during the 1990s, making the groundwater contribution about 40 percent of irrigation water use.

Table 16.5 Total irrigated area (1989) and groundwater irrigated area in Zimbabwe

	Total irrigated area (ha)	Groundwater irrigated area (ha)
Large estates	33,600	n.a.
Large private commercial farms	100,800	50,000
State farms	7,200	n.a
Small-scale commercial farms	12,800	1,000
Communal area	5,400	n.a.
Informal (dambo)	20,000	20,000

n.a: not available
Source: Owen (1989)

The commercial use of groundwater for irrigation is limited to areas in the south east of the country in the middle Save region and also on the highveld, particularly around the Lomagundi areas with the high yielding dolomite aquifer. Additional commercial agricultural use of groundwater is around Nyamandhlovu near Bulawayo. On the highveld, most of the irrigation takes place in winter and only high value crops such as winter wheat, tobacco and horticultural crops are irrigated. Some farmers practice conjunctive use of groundwater and surface water in this region, using boreholes only when surface water is not available. The estimated irrigated area in the Highveld is about 500,000 ha (Chidenga, 2004). At the Lomagundi area, 30 million m^3 was used for irrigation, with groundwater contributing 90 percent. Estimates suggest that there could be about 17,000 ha of irrigated commercial land at Lomagundi.

Documented use of groundwater for small scale irrigation is limited to the areas in the south east of the country, in the Save river basin. The two well documented cases are the Musikavanhu and Nyanyadzi South Irrigation schemes, where by year 2000, about 881 ha were irrigated by groundwater (JIMAT Development Consultants, 2000). The water supply for these schemes was the Save alluvial aquifer and a total of 33 boreholes were installed to supply irrigation water to the schemes, with an estimated total abstraction of about 0.6 million $m^3\ yr^{-1}$. In the same catchment about 200 ha are under small scale irrigation at the Mutema Irrigation Scheme with a total estimated abstraction of 4 million $m^3\ yr^{-1}$ (Chidenga, 2004). Other groundwater irrigation practiced by small scale farmers is with the use of collector wells to abstract water from fractured basement complex aquifers where typical borehole yields are about 0.1-0.5 L s^{-1}. In addition, there is the use of shallow groundwater from *dambos*, widely practiced in rural areas, where about 20,000 ha of these small wetlands are informally irrigated by the shallow groundwater from *dambos* (Owen, 1989). The total groundwater abstraction for small scale irrigation accounts for about 2.5 percent of all irrigation abstractions in the country or 7 percent of the commercial groundwater irrigation and its use is usually limited to vegetables.

Institutional and legal framework

Until 1998, water resources management, development and regulations were the mandate of the Department of Water Resources Development (DWD). With the reform that took place in the water sector in 1998, a new body, the Zimbabwe National Water Authority (ZINWA), was formed. The ZINWA is now responsible for planning, development, and management of all water resources in the country. The functions of the ZINWA are controlled by the ZINWA Act (1996). The Department of Water Development remains responsible for only policy and regulations. The country is divided into nine catchments, with a catchment council managing each catchment. The catchment councils support ZINWA in controlling and managing water resources. The catchment councils are required to implement the regulations as set in the National Water Act. They report to the National Water Authority.

The legislative framework for water resources was updated in 1998. One of the major points of departure from the previous 1976 Water Act is the focus on groundwater, with a shift in recognition from being privately owned towards access as a public resource. As with surface water, groundwater users now need to apply for permits. To complement the National Water Act (1998), regulations and guidelines to control groundwater development and management were developed in 1999. The Water Act now requires a specific permit for abstraction of groundwater for purposes other than domestic use, which need only a general permit. Sunguro *et al*. (2000) shows details of the processes to apply for a groundwater abstraction permit and also to install a borehole, as stipulated by the Water Act of 1998.

Some challenges exist in the successful implementation of the Water Act. First, abstraction limits were set based on agro-ecological zones, but the problem is that, these zones do not always coincide with aquifer or hydrogeological boundaries. So while the agro-ecological delimitations provide a reasonable working unit, the limits of abstractions as given in the guidelines, might not carry much meaning if the aquifer in the area cannot support such a limit. Also, some of the high yielding alluvial aquifers are in natural regions IV and V (e.g. the Save river and Limpopo river alluvial systems). In these areas, it might be feasible to abstract more than the prescribed upper limits. In addition, ZINWA, the managing body, does not have adequate capacity to perform the functions specified in the groundwater management guidelines.

Groundwater development challenges

The problems related to the use of groundwater for irrigation can be broadly grouped into: (i) technical problems associated with the groundwater resource availability; (ii) groundwater quality; and (iii) economic issues. Often in areas where there is a need to develop groundwater for irrigation, the aquifer yields are prohibitively low or they are only capable of supplying water to small areas. In these areas, developing groundwater for irrigation is not economically feasible. Another problem is that of abstraction of the groundwater in some of the aquifers. In alluvial aquifers, for example, installation of wells is difficult as the aquifer material collapses into the well at levels below the water table (see Owen, 1989 for borehole installations in alluvial aquifers). In areas of deep groundwater, borehole installation costs are prohibitive. The quotes obtained in 2004 seemed reasonable for depths up to 40 m. Beyond this, the incremental charges that are at least USD 30 m^{-1} are extremely high (for small scale farmers) and perhaps discouraging. Recommended borehole depths in most aquifers are greater than 40 m. Also, water quality problems, while not prevalent in several aquifers, pose severe hazards in the Karoo aquifers where the water is alkaline and causes encrustation of borehole equipment.

In the commercial small scale irrigation schemes, the pumps used in boreholes run on hydroelectric power. The cost of power to operate pumps was found to be excessive in small scale groundwater irrigated schemes in the Save catchment. Chidenga (2002) made recommendations to switch to surface water and only use boreholes during drought periods as this would eliminate the cost of electricity and pump maintenance. It is not quite clear how severe a problem it is, but the maintenance of boreholes and pumps seems a problem in communal areas. In his study on the Save area, Chidenga (2002) noted that the farmers' lack of capacity to sustain the use, operation and maintenance of borehole supply schemes from a technological point of view. Electricity and diesel pumps used in Zimbabwe are imported and there are not many service providers for maintenance and repairs of the pumps. Most importers of pumps, who would supply some technical backup, are based in urban areas. Artisans who operate from the villages are sometimes incapable of the repairs and maintenance of the pumps.

Conclusions and Recommendations

Groundwater plays an important role in supplying irrigation water in Zimbabwe. This is particularly so during the dry winter period and also during drought periods. To date, its use is strategic and use of groundwater to irrigate is concentrated in specific areas. This strategic use is driven by the resource limitations. The extent of the resources available in most of the areas does not allow for massive scale development of groundwater, as is the case in India for example. A variety of factors influence the use of groundwater for agriculture. These include geology, geography/spatial variation, tradition and political economy. More than 60 percent of the country, where the rural population is concentrated and where there is a need for water, is underlain by aquifers with limited exploitation potential. At best these aquifers provide for single point water supply systems to support small gardens or for primary uses only. The areas that can be irrigated from groundwater are therefore limited.

The high yielding aquifers support large scale commercial agriculture in a significant way. Examples are the Lomagundi Dolomite aquifer, the Nyamandhlovu aquifer near Bulawayo, and the Save alluvial aquifer. It is estimated that groundwater is used to irrigate at least 17,000 ha on large scale commercial farms and at least 1,000 ha on small scale farms. This area is equivalent to nearly 11 percent of the total irrigated area (assuming about 160,000 ha of irrigation in all sectors). It is significant to note that there is a problem with estimating the component of groundwater irrigation in the country due to the conflicting nature of the irrigated area figures that are available. There seems to be much smaller areas under small scale irrigation with groundwater. However, this dynamic might change with the land reform process that is currently on going. Groundwater in Zimbabwe is generally of good quality for both domestic and irrigation uses. There are some localized problems of salinity and encrustation hazard to borehole equipment. Water quality is not a major constraint to groundwater use.

There are several drawbacks to the use of groundwater particularly for irrigation. These include:

i. Inadequate information for providing boreholes for rural communities. Often boreholes are incorrectly sited on the basis of available information. Most boreholes dry up during the dry season or droughts because the demand far exceeds the sustainable borehole yields;

ii. The high cost of equipment and of operating and maintaining borehole equipment. This real cost of groundwater irrigation prevents potential small scale users;

iii. Previously, boreholes for rural water supply (both primary and irrigation) were installed in an uncoordinated manner with minimum of information kept and shared with relevant institutions. This information needs to be collated and stored in a central warehouse such as the ZINWA. Implementing such a task would enable planners to have better knowledge of where unused or underused resources are located;

iv. Lack of inventory of institutions and the groundwater use data they hold. A more in-depth inventory and analysis of data available with various institutions would improve the current state of knowledge on groundwater use for agriculture;

v. Inadequate manpower to implement the regulatory framework and enforce regulations. The amount of data that will be presented to the catchment councils and used to monitor compliance is enormous. The ZINWA and the catchment councils do not appear to be adequately staffed to analyze this data and make appropriate decisions.

Given the limitations highlighted above, the role of groundwater in Zimbabwe should be seen as strategic and its use should be opportunistic. Due to variations in the resource available, groundwater use would be best explored where reasonable yields can be obtained, and where there is a need.

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CHAPTER 17

SYNTHESIS AND CONCLUSIONS

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The main premise for this book is that data on groundwater systems throughout SSA is sparse and the current low state of knowledge creates a barrier to sustainable groundwater development. This is in contrast to its high socio-economic and ecological importance. An important starting point for assessing the potential for expanding groundwater use is to consolidate, synthesize and review the existing information, which is often limited, dispersed and difficult to access. The groundwater conditions for 15 African countries have been drawn out here from a series of country reports, which has been a first endeavour for most case study countries. This study has thrown new light on the relative abundance of the groundwater resource and helped to consolidate existing knowledge on groundwater use and provide tools to support reasonable groundwater development and governance. Aquifers and areas suitable for development have been identified in many countries. Quantitative information on aquifer characteristics, groundwater recharge rates, flow regimes, quality controls and use is still rather patchy.

Groundwater is a critically important resource for human survival and economic development across the vast drought-prone areas of Southern, Eastern and Western Africa where better planning of groundwater use is vital for buffering drought impacts associated with climate variability and climate change to improve water (and economic) security. Groundwater is important primarily for domestic water use and sanitation services, though it also has use for other local purposes including livestock watering, community gardens and brick-making, which are essential to basic livelihood needs and thus to the alleviation of poverty. Despite the importance of small-scale farming in Africa, there is only limited information on the present and potential role of groundwater in irrigated agriculture.

The five West African countries included in this review (Burkina Faso, Ghana, Mali, Niger and Nigeria) are dominated largely by Precambrian basement comprising mainly of magmatic and metamorphic rocks. The occurrence of groundwater in these formations is associated with the development of secondary porosity as a result of chemical weathering, jointing, shearing, and fracturing. Groundwater that is suitable for use is stored within secondary pore spaces and fractures within the rocks. In West Africa, over 60 percent of all aquifers are discontinuous, and on average, less than 30 percent are continuous formations. The aquifers in the Crystalline basement rocks have the lowest yields, generally less than 0.5 L s^{-1}, although a significant minority of areas have yields that are in excess of 1 L s^{-1}. Highest borehole yields (> 20 L s^{-1}) can be found in thick sedimentary aquifers, particularly in unconsolidated or poorly consolidated sediments.

A major use of groundwater is for supply of drinking water to both rural and urban populations. This is particularly important in semi-arid countries located in the Sahelian zone, where surface waters are largely non-perennial and groundwater is vital for every aspect of daily life. Drinking water supplies sourced from groundwater for rural/small towns serve 33 percent of Ghana, 92 percent of Niger, 70 percent of Nigeria and 55 percent of Mali. Burkina Faso uses groundwater as the principal source of supply in small towns and rural areas. Groundwater is accessed by various means such as hand-dug wells, bore water extracted using hand pumps, motorized pumps, government/private network supply etc. While groundwater use for irrigation is largely limited, the scenario is expected to change in many cases as the development of groundwater to sustain agriculture is expected to grow in the short or mid-term. Even nowadays, small-scale groundwater irrigation mostly draws from shallow groundwater in floodplain environments which may dry up during periods of low rainfall. For example, wells have been developed informally for small-scale irrigation of cash-crops in the weathered basement aquifer in the White Volta Basin of Ghana. Small-scale irrigation, undertaken on a limited scale, primarily in southern Niger, provides some security from famine. Regularly hit by drought and famine, shallow groundwater irrigation has significantly increased over the past decades in the south west and along the border with Nigeria mostly for small-scale cultivation of vegetables but with limited medium scale cultivations as well.

The Southern countries (Malawi, Mozambique, South Africa, Zambia and Zimbabwe) feature mainly crystalline basement. Groundwater occurs in the weathered regolith and in the fractured bedrock. Due to their low storage capacity, poor water quality and the resulting water supply problems at a local level, the basement aquifers are often described as poor or minor aquifers, even though they are the source for supplying water to a large number of rural communities. The weathered and fractured aquifers have the lowest yields, generally less than 1 L s^{-1}, though in a significant minority of areas, yields can exceed 20 L s^{-1}. Highest borehole yields (> 80 L s^{-1}) can be found in thick alluvial aquifers. There are few patches of extensive groundwater use found in the Limpopo basin, karst aquifers of South Africa and similar limestone aquifers in Zambia and Zimbabwe.

In these relatively humid Southern countries, groundwater is mostly used for rural water supply and for mining in isolated areas. Drinking water supplies sourced from groundwater for rural/small towns serve 51 percent of Zambia, 70 percent of Zimbabwe, 65 percent of Malawi, 60 percent of Mozambique and 60 percent of South Africa. Irrigation demand for groundwater is expanding, although where surface water is abundant, this appears to be preferred. South Africa and Zimbabwe use the largest amounts of groundwater for irrigation. A good number of commercial farmers, such as around the Lusaka area in Zambia, use groundwater from boreholes for their irrigation and livestock production, while shallow wells are used mostly for rural water supply and recently very shallow wells (< 9 m deep) in floodplain areas have come into use for treadle pump and bucket irrigation. About 60 percent of the communal areas where small-scale farmers are located in Zimbabwe are on archaic granitic gneisses with low groundwater development potential. Most communal areas where small-scale farmers are located are characterized by low rainfall and there are no substantial groundwater resources for irrigation purposes. The total groundwater abstraction for small-scale irrigation accounts for about 2.5 percent of all irrigation abstractions in the country, or 7 percent of the commercial groundwater irrigation in Zimbabwe. Groundwater potential for irrigation is limited by the low yielding aquifers and is generally restricted to small gardens in many dambo areas in Malawi where the number of irrigation schemes is expected to increase rapidly, and many of these will depend on groundwater as a source of water supply. Groundwater is only used for irrigation to a very limited extent by smallholders in Mozambique and currently 59,000 ha are irrigated. In Zambia, groundwater use by small-scale irrigators occupy 111,525 ha, medium schemes 7,372 ha and large irrigation schemes 37,015 ha.

The East African countries (Kenya, Somalia, Tanzania, Uganda and Ethiopia) are underlain by Precambrian basement complex rocks over which younger rock formations have been deposited, and here the groundwater reserves are low. The main water bearing zones of the Precambrian are found within the structural discontinuities of various crystalline rocks. The fractured volcanic aquifers in the highlands, and the rift, alluvial valleys, have shallow, highly productive aquifer systems. These types of rocks have very low fracture permeability, while the depth of fracturing is shallow and accordingly groundwater in this type of aquifer is also shallow. Both confined and unconfined aquifers are the main source of shallow groundwater. The fractured volcanic aquifers in the highlands and the rift alluvial valleys offer shallow and highly productive systems with yields ranging from about 0.5 $L\ s^{-1}$ to 5 $L\ s^{-1}$. High yields (> 6 $L\ s^{-1}$) can also be found in the sedimentary basins.

Groundwater is the most important water source for a great majority of the population whilst the available data indicates limited irrigation use. In some arid and semi-arid regions it is the only source of water. Drinking water supplies sourced from groundwater for rural/small towns serve 85 percent of Ethiopia, 50 percent of Kenya, 70 percent of Somalia, 56 percent of Tanzania and 70 percent of Uganda. Groundwater in Kenya is used for many different purposes including human consumption, livestock watering, wildlife watering and crop production.

In Tanzania, groundwater use for irrigation is estimated at about 130,000 $m^3\ d^{-1}$ with substantial scope for expansion. There is no groundwater irrigation currently in Uganda but plans for expanding the area under irrigation and which could include groundwater in northern Uganda. In general terms, the limited use of groundwater for agriculture is due to availability of adequate rainfall and surface water resources, and probably due to limited understanding of the occurrence and distribution of aquifers and their potential. In the rural areas, domestic water supply is derived from surface dams, boreholes, shallow wells, and springs. During the dry season, groundwater is the main source for domestic and livestock use and is only supplemented by surface water when and where it is available.

Water management and development constraints

The constraints and knowledge gaps that grip SSA are numerous and common to many countries (Table 17.1). A major constraint in groundwater development is that the capacity in borehole siting is insufficient, mainly in areas of complex hydrogeological environments like crystalline basements. In these areas local surveys, which include the use of geophysical methods, are appropriate to improve drilling success. Therefore, it is essential to strengthen capacity, particularly in the West African countries where many of the aquifers are discontinuous, adding further risk to drilling projects. Most countries indicate that insufficient trained personnel with capacities in hydrogeology and geophysics, hinders groundwater development. Despite the importance of groundwater resources for water supply in the western region, major aquifers in large sedimentary basins are underdeveloped due to the great depth of the aquifer that adds to the drilling costs and the low level of skills in resources assessment. The demand for additional resources in the outlook of irrigation development should be considered, as some countries have initiated forward planning to augment their irrigated areas through the use of groundwater. The lack of professional standards in the drilling and pumping sectors in many countries is also regarded as a constraint. Costs of well construction and operation are high throughout Sub-Saharan Africa. The causes are difficult to single-out and include inappropriate well design, excessive drilling depths in some situations and insufficient use of low-cost technology options amongst others. Rural communities use traditionally dug wells to obtain water-supply for domestic use and livestock watering, but in some hydrogeological conditions they are prone to failure during drought. Drilling wells deeper is needed in those cases since groundwater remains the only viable option for improving water supply. In some places, pump maintenance is a problem and this requires technical assistance which is currently lacking. There thus seems to be a clear need for professional hydrogeologists and geophysicists in the region.

It is clearly obvious that knowledge about the groundwater resources, particularly in fractured rock settings, is lacking. It is also essential to assess the hydrogeological settings of major aquifers, i.e., the extent, type, replenishment rate, etc. The mapping of major aquifers is still incomplete and hinders development and management. On the other hand, commercial groundwater irrigation has often been beset by operational and/or economic problems, such as import restrictions on well equipment and spares, the absence of a related service sector, especially by escalating diesel-energy costs and supply problems, inadequate post-harvest crop handling, transport and access to markets.

Groundwater governance remains very weak in many countries due to the lack of awareness and inadequate knowledge about groundwater characteristics. Thorough and/or continuous monitoring on resource availability and water quality due to deficiencies in human and financial resources is largely absent. It is important to raise data monitoring up the priority list since it is indispensable for effective water resources management. Additionally, awareness needs to be raised on the relevance of groundwater monitoring among the relevant agencies and water users. In order to ensure continuation of the groundwater monitoring systems, it is essential to identify ways to mobilize internal resources (financial and human) and to update databases as is the urgent need for strategic (hydrogeologic and socioeconomic) assessment of its current utilization for water supply provision and for implementing the management actions needed to ensure future availability and greater integration with surface water supply.

Table 17.1 Major issues and information gaps for each country

	Burkina Faso	Ethiopia	Ghana	Kenya	Mali	Malawi	Mozambique	Niger	Nigeria	South Africa	Somalia	Tanzania	Zambia	Zimbabwe	Uganda
Poor understanding of the major aquifer systems and their development potential	■	■	■	■		■	■	■	■		■	■	■	■	■
Complexity in geology leads to development challenges (failed wells, low aquifer yields etc.)	■	■		■	■		■		■		■	■		■	■
Poor understanding of groundwater recharge and discharge		■			■	■		■	■				■		
Limited information on the extent of groundwater use by various sectors	■	■				■					■	■		■	■
Water quality problems in specific regions due to natural processes or pollution	■	■	■	■			■	■	■	■	■	■		■	■
Decreasing borehole yields and water levels due to overuse				■		■	■	■	■	■		■	■		
High cost of groundwater development / high running and maintenance costs of boreholes	■	■	■				■			■	■	■		■	■
Inadequate or fragmented data and information systems for effective planning and monitoring						■	■	■		■		■	■		■

	Burkina Faso	Ethiopia	Ghana	Kenya	Mali	Malawi	Mozambique	Niger	Nigeria	South Africa	Somalia	Tanzania	Zambia	Zimbabwe	Uganda
Poor well construction and lack of infrastructures and maintenance of water abstraction points		■	■				■		■		■	■	■	■	
Corruption associated with issuing drilling contracts			■		■										
Limited financial resources and personnel for carrying out investigations and assessments and to enforce regulations	■		■	■	■						■	■	■	■	■
Inadequate monitoring networks	■	■			■	■	■		■			■	■	■	
Poor institutional arrangements and policies to manage groundwater resources effectively	■		■		■	■	■	■	■	■		■	■		
Lack of expertise / capacity	■		■	■		■	■		■		■		■	■	■

Pathways forward

The most immediate challenge for SSA is to effectively develop and manage groundwater resources in a holistic manner that meets the needs of large and small water users and recognizes sustainability principles and the delicate interconnections and trade-offs between serving societal uses and the environment.

The first hampering issue is inadequate knowledge and capacity to enable effective planning, development and management of the resource. This can translate, for example, into an unknown or unacceptable risk of low yielding wells and/or high drilling/operating costs. The pathway forward naturally must entail acting upon the major data gaps identified herein to improve knowledge and strengthen capacity. Work to better understand the nature, extent and dynamics of the resource and its constraints are needed in most regions, as too are appraisals of groundwater recharge, groundwater use, sustainable yield, water quality and pollution risk. Qualified personnel (hydrogeologists, geophysicists, modelling specialists, drillers etc.) have a key role to play in evaluating and monitoring the resource and gathering information needed for effective decision making. Research and investigations of this kind are vital but not alone sufficient. There also needs to be data and knowledge transfer and capability improvement across water resources and other sectors (e.g. agriculture, energy, industry etc.), from the central level down to the local level.

The second hampering issue is the lack of institutions and policies to drive effective groundwater development and management. Improved governance can be greatly facilitated by concerted efforts to enhance the recognition of groundwater by governments, donors and other major players that would lead to changes in investment priorities and policies. Appropriate institutional frameworks are required to promote high quality borehole siting and drilling, promote low cost drilling techniques and to introduce licencing and permits for high water users, whilst at the same time, opening up access to groundwater for the poor through micro-credit and specifically targeted subsidies.

The key challenge that lies ahead is not only to address technical issues; it is also to use the knowledge gained to communicate and convince decision makers that, access to groundwater is an important and proven strategy for addressing the MDGs in terms of access to clean water, improved sanitation, and enhancing food and nutritional security and climate resilience.

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