AgWater Solutions Project
Case Study

Agricultural Use of Ground Water in Ethiopia: Assessment of Potential and Analysis of Economics, Policies, Constraints and Opportunities

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The AWM Project
The AgWater Solutions project was implemented in five countries in Africa and two states in India between 2008 and 2012. The objective of the project was to identify investment options and opportunities in agricultural water management with the greatest potential to improve incomes and food security for poor farmers, and to develop tools and recommendations for stakeholders in the sector including policymakers, investors, NGOs and small-scale farmers.

The leading implementing institutions were the International Water Management Institute (IWMI), the Stockholm Environment Institute (SEI), the Food and Agriculture Organization of the United Nations (FAO), the International Food Policy Research Institute (IFPRI), International Development Enterprises (iDE) and CH2MHill.

For more information on the project or detailed reports please visit the project website http://awm-solutions.iwmi.org/home-page.aspx.

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Abbreviations

AAU	Addis Ababa University
EGRAP	Ethiopian Groundwater resources Assessment Programme
EIGS	Ethiopian Institute of Geological Survey
ENGDA	Ethiopian National Ground Water Database
IAEA	International Atomic and Energy Agency
MOWE	Ministry of Water and Energy
PASDEP II	Poverty Alleviation and Sustainable Development Programme II
UNDP	United Nations Development Program
WWDSE	Water Works, Design and Supervision Enterprise
WWCE	Water Works and Construction Enterprise

EXECUTIVE SUMMARY

Ethiopia is a country of great geographical diversity and geological complexity. High rugged mountains, flat-topped plateaus, deep gorges, incised rivers and rolling plains are the pre-dominant physiographical features. Since the country is located in the tropics, the physical conditions and variations in altitude have resulted in a great diversity of climate, soil and vegetation. The highlands on each side give way to vast semi-arid lowland areas the east and west and south. The ground water potential of the country is shaped by two complex phenomena of geological formation and the diversity of the topography, climate and soil.

Several studies and ground water potential assessments indicate the rechargeable or replenishable ground water potential of the country is in the order of 2.6 billion cubic meters (BCM). More recent emerging studies and implementations like that of Addis Ababa, Kobo and Raya well field indicate the potential is far greater. Estimations of the ground water require a good understanding of the regional geology, hydrology, hydrogeology, hydraulics of ground water flow.

Recent project studies for irrigated agriculture at Kobo, Raya, and Adaa Bechoo indicate the regional ground water aquifers are deeper; water movement crosses surface basin boundaries (basin transfer) and contains large reserves of groundwater. It is estimated that the ground water reserve of the Kobo Girana Valley is in the order of 2.5 BCM, while the reserve of Raya contains 7.2 BCM. The Estimated annual recharge at Adda Bechoo is in the order of 965 million cubic meters (MCM) of which the majority comes from Abbay Basin. This emphasizes the importance of understanding the regional groundwater aquifers and movement when considering ground water assessment and development for highly water consuming agricultural use.

The use of groundwater for agriculture in the country is low. Assessment of data from 8,000 boreholes from federal sources and the regional water bureaus indicate over 80% of the groundwater use is for domestic water supply. The depth range of assessed wells indicates most wells are shallow (most 83%) and have low yield in the order of less than 10 lps (>60%).

Given the emerging regional approach to groundwater assessment and evaluation, the majority of the shallow wells in the country may not provide adequate scientific information for understanding deep groundwater aquifers. Therefore, as seen from the studies of Kobo, Raya and Adaa Becho groundwater, deep monitoring and production wells are providing essential data over two to three year observation periods.

Currently, groundwater use for agriculture is emerging as an important water resource for agriculture in rainfall deficit areas. The Directorate of Groundwater Development Studies and Management of the Ministry of Water and Energy plan to develop 9 irrigation projects in the country. These are at different phases of study. According to this implementation plan, over 8,000 ha of land will be developed as a pilot study using groundwater in the coming five years (2010/11 to 2014/15). MoWE also plan to drill more than 90, 000 test wells, 28,000 monitoring wells and over 370,000 meters of production wells (not given in

terms of number of wells). This will require additional institutional and human capacity development, technology procurement and transfer. The knowledge and capacity gap in the country is believed to be high at both professional and technician levels. Without such capacity, it will be difficult to develop and sustain ground water study and development.

The coverage and scale of the available geological and hydrogeological maps over the country is not favorable for understanding regional groundwater. Only 50% and 39% of the country is covered with geological hydrogeological maps at a scale of 1:250,000. The available groundwater database is not well known and not much used by experts and institutions. This software, known as Ethiopian National Ground Water Information Database (ENGDA) contains information on more than 3,000 boreholes and is available at the Department of Hydrology (MoWE). New ground water software known as ENGWIS, believed to be more flexible, is under development and will be launched soon.

The current human resource situation in the management and development of groundwater in the Regional State Water Bureaus is generally characterized as insufficient. A minimum of 31% (281 out of 895) of all job positions are currently vacant. The capacity gap in the country shows a dire shortage as we go down to the lower levels of administration. The current human resource situation in the Zonal Water Resources Office shows a shortage of 54% (579 out of 1076), while the district situation is the worst with a human resources shortfall of 61% (7,447 out of 12,140). When it comes to town water supply service areas and public enterprises, the situation is similar with relatively better coverage. In the same year, the Town Water Supply Service offices stand at a shortfall of most 25 % (1002 out of 3740), while the public enterprises such as Water Works and Construction Enterprise (WWCE), Water Works Design and Supervision and Enterprise (WWDSE), and Water Works Development Enterprise (WWDE) shows a shortfall of 34% (512 out of 1503). In almost all the water bureaus, public enterprises and private consulting firms, the required professionals are mainly hydrogeologists and water supply engineers.

There is no recorded data on drilling costs over time and it is difficult to analyze any trend. However, based on the information available from private drilling companies (Hailemichaeel, 2004), the cost of well drilling has been decreasing. As indicated in section 2.2 of this report, drilling costs were reported (in ESRDF projects) to be falling in Tigray between 1998/1999 (Birr 1,400/m equivalent to USD 84 USD[1]). This was due to the establishment of regional enterprises and increasing competition from the private sector. However, in the remote region of Benishangul-Gumuz, the costs of contracted drilling were still around Birr 1,350/m.

In general, the cost of deep well drilling has decreased from Birr 2,000/m to Birr 1,200/m. For shallow wells, normally below 30 m, the cost is reduced from birr 1,500/m to Birr 900/m. Well construction quality has deteriorated due to the high competition. Steel casings of poor quality have been used by some contractors. As there are no standardized designs and specifications, competition in prices has greatly affected quality (Hailemichael, 2004). The cost of drilling after the recent devaluation of the Ethiopian Birr has increased the cost from 2,000 to 3,000 Birr/meter depending on the distance and type of rock formation.

[1] All exchange rates are expressed in terms of current rates of 1USD=16.5 Birr

Generally, the cost of drilling machines is over 800,000 USD (T3W rigs). The initial capital cost is very expensive, but companies are encouraged by the government to import tax free.

The planning and implementation of irrigated agriculture using ground water sources is highly encouraging. There are robust planning documents and ongoing studies at federal well as regional state government levels. There are, however, valid concerns that may impede development efforts. The most important concern is the limitation of knowledge and information available on the extent of the potential ground water. Secondly, the available human and institutional capacity to plan, develop and manage is limited in quantity and quality. Thirdly, drilling equipment and associated spare parts are hard to get and limited in number. It is suggested that the government of Ethiopia should invest in developing institutional and human capacity. The most important areas of human capacity development are hydrogeology, water supply engineers, geologists and drilling technologies and associated technician skill development.

The initial capital cost of drilling rigs and spare parts are discouraging private companies. It is important to provide some kind of long-term loan schemes for private companies for importing deep drilling rigs and to establish spare part distributors within the country. Alternatively, private public partnership schemes can be forged between public agencies and private companies. This will expand the coverage of ground water drilling activity and guarantee availability of spare parts, which will contribute to ongoing efforts on irrigated agriculture development.

1. GROUNDWATER WATER OCCURRENCE IN ETHIOPIA

1.1. Introduction

Ethiopia has a complicated hydrogeologic environment and complex groundwater regime. Until recently, many experts believed that extensive aquifers usable for large-scale exploitation of groundwater were unlikely to exist. This claim, which was almost a consensus, has recently been disputed due to a paradigm shift in methodology. There are indications that some aquifers in the count have large deposits of groundwater . This paper provides an overview of the potential groundwater availability from past papers and recent approaches and studies. The paper will present the status of the groundwater use focusing on agricultural water use. The available groundwater technologies, institutions and the direction of future groundwater use for agriculture are discussed. The report draws on the literature from within the country and groundwater well information collected from Regional State Water Bureaus.

1.2 Geologic succession in Ethiopia

Ethiopia forms a part of the major structural unit of the earth's crust referred to as the "Horn of Africa". This unit comprises the Arabian Peninsula, the Red Sea, the Gulf of Aden, Djibouti, Somalia and the northern part of Kenya. The geological history of the Horn of Africa is closely related to the rest of the African Continent but does differ significantly in some respects.

The geology of Ethiopia is strongly influenced by two major episodes.

a) The Arebo-Ethiopian swell in the Eocene to early Oligocene,
b) The major rift faulting movements throughout the African Rift system from Miocene to quaternary.

The Great Rift System of Africa bifurcates the Africa lowlands of Ethiopia with major escarpments trending north and east respectively. The original land mass thus divided into two plateau units by the rift system: the western and eastern plateau.

Much of the plateau region in Ethiopia lies above 2000 m altitude and comprises areas with structurally horizontal table land. The Rift Valley itself is an extensive graben with evidence of recent volcanism in the north and bounded by impressive steeped horsts of the plateau on the west and southeast margins. The Rift Valley widens at the intersection of the East African Rift, the Red Sea and the Gulf of Aden where it is called the Afar Triangle.

A brief Summary of Geological Succession in Ethiopia (V. Kazmin, 1973) is presented below (Table 1.1).

Table 1.1. Geological succession in Ethiopia

Epoch	Age	Rock Formation
Paleozoic	Pre-Cambrian	Post–tectonic granitoids, syntectonic granitoids, various grades and types of schist, gneiss, unaltered sedimentary rocks and igneous intrusions referred to as basement complex.
		Upper Paleozoic Triassic sandstone, shale, glacial deposits.
Mesozoic	1.Southern Sidamo sediments	Mount Fikkyu formation, Dibigia & Ganale Doria formation
	2. Eastern and Western Ogaden Sediments	Hamanlei series, Urandab series, Gabredere series, main gypsum
	3. Central plateau sediments	Amba Aradam Formation, Antalo Group. Adgirat Sandstone, Gumburo series
Cenozoic	1.Tertiary Volcanics	Alkaline granite and syenite, Megdala group, trap series
	2. Tertiary Sediments	Dogali formation, desert formation. Dunishub Formation, Red sea series, Jessoma sandstone, Auradu series, Teleh series, kalakah series
	3. Quaternary Volcanics	Basaltic flows and related spatter cones. Basaltic intermediate and flesic Volcanics. Quaternary sediments.

Source: WAPCOS, 1990 P.AII-3

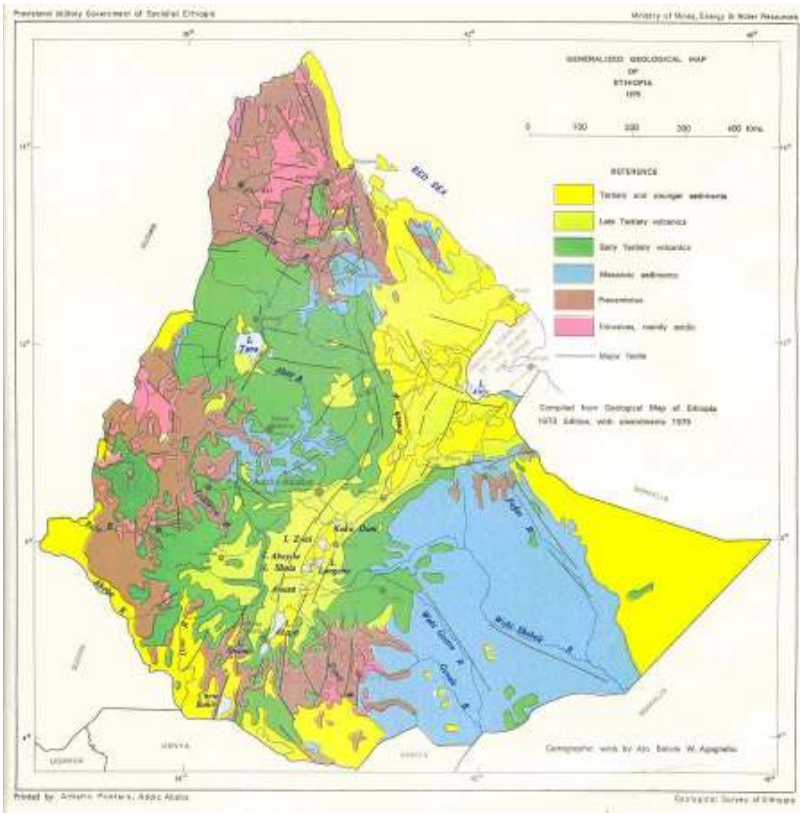


Figure 1.1. Geological map of Ethiopia (includes both Ethiopia and Eretria)

Major portion of Ethiopia is a high plateau consisting of massive non-porous volcanic rocks with escarpments of sedimentary rocks. The geological areas of the highlands (>1500 m altitude) is approximately 445,000 km^2. The basement metamorphic and igneous rocks, with no primary porosity, cover the lowland plains and the valleys. The availability of groundwater in non-porous rocks is localized within joints, fissures and weathered portions. The depths are highly restricted. The movement of groundwater is compartmentalized and the yield from wells is highly variable (WAPCOS, 1990).

1.3 Aquifers and Aquifer Classification.

The distribution of groundwater is mainly shaped by two factors, rechargeable rainfall and the nature of geological formations shown in Figure 1.1. The geological formations that store and transmit groundwater (the recharge) are called aquifers. According to WAPCOS (1990), the aquifers of Ethiopia are grouped into three categories based on their regional extent, lithological homogeneity and hydrologic properties. The three categories are hard rock aquifers, consolidated sedimentary rock aquifers, and unconsolidated aquifers.

a) Hard Rock aquifers

These aquifers with no primary porosity are capable of storing water within their weathered, jointed and fractured zones. They are often recharged from overlaying alluvium and weathered zones. The groundwater occurs in free dynamic condition (water table aquifers). Hydraulic conductivity is in the range of 1 to 40 meters per day. The yield is limited. Approximate area of such aquifers is 358,000 km^2.

b) Consolidated Sedimentary rock aquifers

Consolidated sedimentary rock aquifers have moderate primary porosity and interangular permeability. The aquifers are regionally extensive and capable of yielding considerable discharge. The exploitation of aquifers is constrained by the recharge rate and chemical quality of the water. Generally, the rock types are limestone (karstic type) and sandstone. The hydraulic conductivity is less than 100 m/day. These aquifers occupy an area of most 456,000 km^2.

c) Unconsolidated Aquifers

Unconsolidated aquifers are comprised of valley sediments with unconsolidated sand, gravel and river alluvium. They are fairly extensive in river valleys and flood plains along abandoned river channels, river terraces and delta regions. The groundwater is partly under pressure and their recharge is associated with stream flows. The river valleys of Awash, Barka, Mereb Gash and Tekeze Angereb have considerable flood deposits consisting of sand, gravel and silt. The area occupied by such aquifers is 432,000 km^2. The hydraulic conductivity is greater than 100 m/day.

Hailemariam (2004) presented the above aquifer types in some detail indicating the groundwater condition in terms of depths and safe yields. The information is extracted from an inventory of boreholes and water supply schemes and supports the findings of other studies that the aquifer systems of Ethiopia are mainly discontinuous and isolated. The

temporal and spatial variation of groundwater occurrence is very high and disparity of depths and yields is very high between wells located within short distances as well.

Table 1.2. Aquifer and aquifer classification

Aquifer system	Average depth to tap water	Average specific yield (lit/sec)	Location	Aquifer description
Weathered and fractures intrusive and old Precambrian rocks (granite, metamorphose rocks, etc.)	30-60	1-2	Western, south-western	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. In general the depth of groundwater tapping this aquifer system is between 15 to 60 meters and most wells drilled in this aquifer do have an average yield of 1-2 lit/sec whenever thick weathered part exists on a fractured mother rock.
Sedimentary rocks (Mesozoic sand stone, karstic limestone,)etc	200-300	2-5	Eastern, south-eastern	These are thick layers of Mesozoic sedimentary rocks (only in some areas Palaeozoic rocks exist) that have different layers of sand stone, marl, limestone, shale and conglomerate[2]. The primary porosity developed is very poor for some of the layers (limestone) while secondary porosity and karistification is very common in the limestone. Therefore, good yield of water is extracted from the karstified limestone and the sand stone. However, due to the location of these layers deep underground, wells striking these aquifers are very deep to as much as 400 meters while the average depth being 250 meters.
The tertiary volcanics (having primary and secondary porosity)	50-250	2-6	Central, eastern and western highlands	These types of aquifers have both primary and secondary porosity with a well tapping groundwater to a depth extending to 250 meters. There are successive layers of aquifer systems and the upper most part, if tapped, is yielding smaller amount of water (0.5 to 1 lit/sec). If drilled deeper, the occurrence of groundwater increases. 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 highly fractured rocks and as a result a favorable situation for groundwater recharge and occurrence exist.

[2] The Palaeozoic rocks cover an insignificant part of the country and their importance as aquifers is unknown.

Unconsolidated sediments (alluvial, colluvial, in situ developed soils, lacustrine sediments)	20-100	1-5	Mostly in the Rift Valley, western low lands, river valleys, isolated depressions throughout the country	These are lacustrine and alluvium deposits of the flood plains and valley fills. They are very important hydrogeologic formations that are used to be very good sources of groundwater in Ethiopia. The grain sizes of the alluvial deposits vary from fine grains of clay to gravel with horizontal and vertical variation in grain sizes. As they are located exposed to the surface seasonal recharge by direct rainfall is occurring and as a result they are good sources of groundwater. Due to their nature of deposit, these sediments are not homogenous and isotropic. Besides, the extent and depth varies within a short distance as they are deposited on the existing irregular surfaces of an old topography. The average yield of the wells dug or drilled in these formations have a yield of 1-5 liters/sec and the depth to abstract groundwater is between 20 to 100 meters. These types of aquifers exist in the rift valley, in the river valleys and isolated grabens.
In situ developed soils	5-20	0.1-1	Throughout the country but especially in the highlands and midands	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 HDWs 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. Springs from these types of soils have an average yield of most 0.1 lit/sec.

Both WAPCOS and Hailemariam aquifer classifications originate from the hydrogeological map of Ethiopia produced by the Ethiopian Institute of Geological Survey (EIGS, 1988). This map is one of the comprehensive works in the hydrogeology of Ethiopia with a scale of 1:2,000,000.

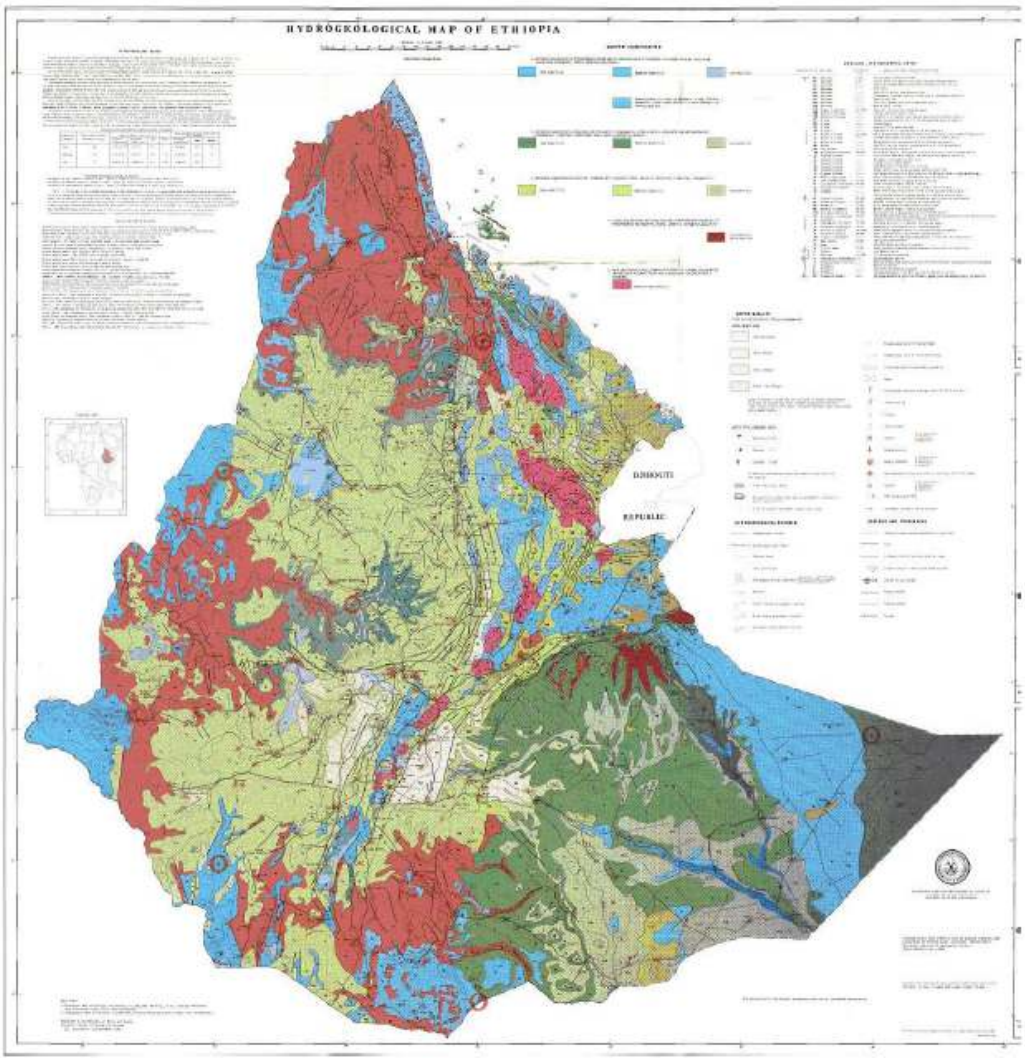


Figure 1.2. Hydrogeological map of Ethiopia

Currently, Geological Survey of Ethiopia has patches of hydrogeological maps (Figure 1.2) of the country with a scale of 1:250,000.

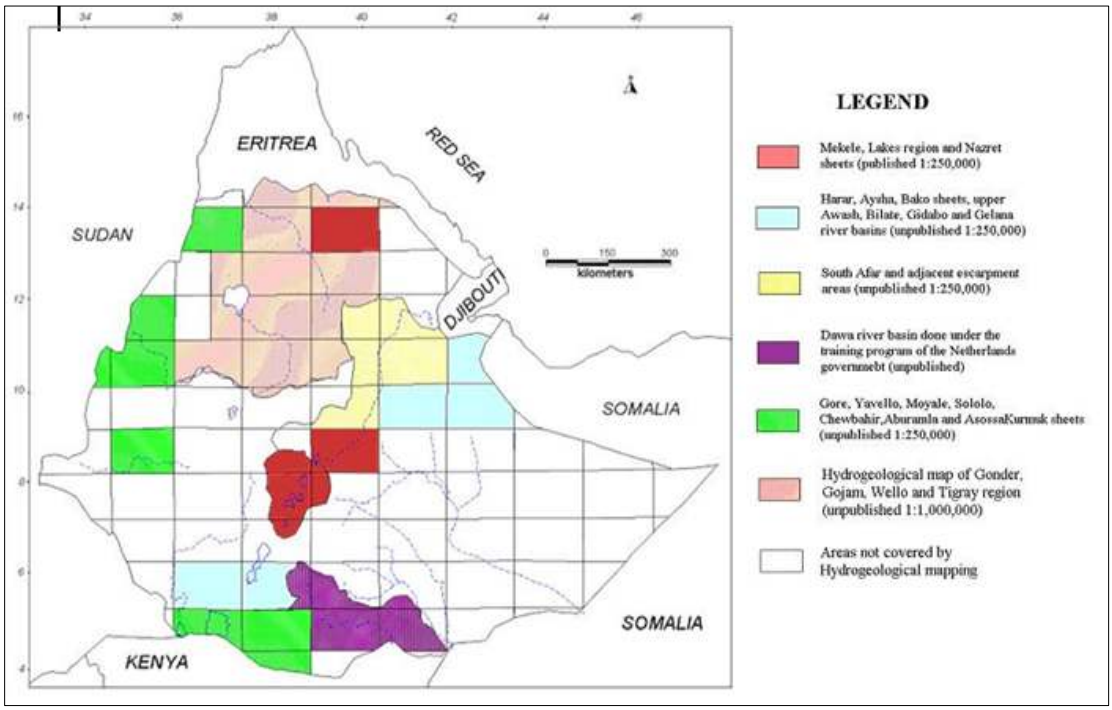


Figure 1.3. Hydrogeological map of the regions

An attempt to describe the groundwater regions in Ethiopia based on geologic formations supplemented by hydrologic and meteorological data is given. According to WAPCOS (1990), five groundwater regions can be identified:

1. Western Highlands – Region 1
2. South-eastern Highlands – Region 2
3. Central Lowlands Including Gulf of Aden – Region 3
4. Lower Rift Valley and Afar Regions – Region 4
5. Outer Lowlands – Region 5

The existing hydro-geological map provides preliminary qualitative information on the type and formation of aquifers in general. Currently, relatively large numbers of boreholes are available in the country through several water supply and irrigation projects. The experience and capacity of groundwater study, exploration and conceptualization is also growing. It is essential to produce an up-to-date comprehensive hydro-geological map. Given the limited information and the small-scale nature of the previous maps, we cannot discern adequate information or accurately convey our findings to decision makers as to where and how much groundwater is available. That is why the current assessment by WWDSE produces significant variation in its study for specific projects in Kobo, and Raya (discussion with WWDSE groundwater expert).

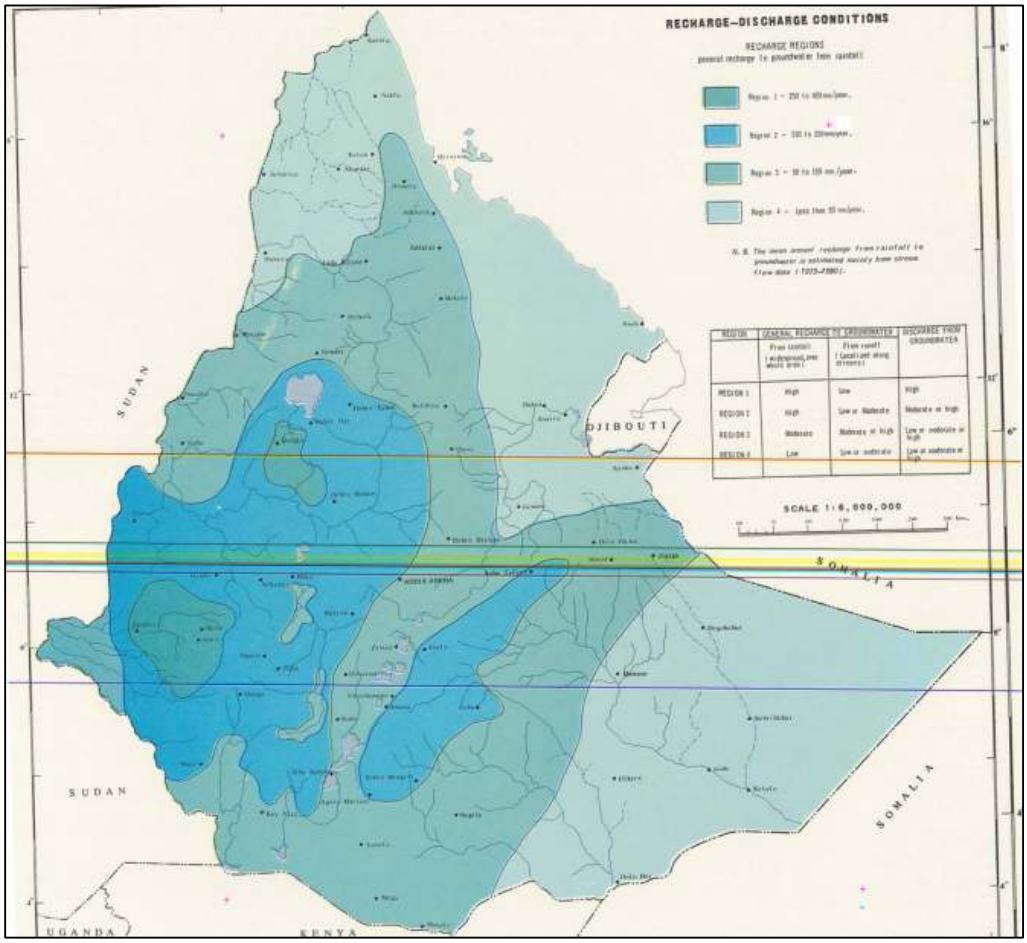


Figure 1.4. Ground water regions of Ethiopia

2. PREVIOUS STUDIES OF GROUNDWATER IN ETHIOPIA

2.1. Review of past studies

Several organizations and researchers studied the hydro-geological condition of Ethiopia. Among them are the studies of the Ethiopian Institute of Geological survey (EIGS), the United Nations Development Programme (UNDP), Halcraw, Electroconsult and others.

From 1974 to 1976, a hydro- geological survey was carried out by the Ethiopian Institute of Geological Survey (EIGS) in Mekele Area covering an area of 18,000 km^2 between 13^0–14^0 north latitude and 39^0–40.3^0 east longitude. From this, a Hydrological Map of Mekele Area (1:250,000) was prepared (WAPCOS, 1990). Geologically, this area consists of metamorphic, sedimentary and igneous rocks. The transmissivity of the rock fractures was found to range from high (875 m^2/day) in alluvial terraces to very low (<1 m^2/day) in fresh unfractured metamorphic rocks and intrusive rocks. Groundwater in the area was found to pre-dominantly contain bi-carbonates and sulphates.

In January 1982, the EIGS and UNDP conducted a study on the Lakes Region (Ziway, Abijata, Shalla and Awassa). The Lakes Region is covered by volcanic rocks, such as basalts, ignimbrites, trachutes, rhyolites and pyroclastics. In the lowland areas, extensive areas of

lucastrine sediments are found overlying the ignimbrites of the rift floor having variable hydraulic conductivity. The groundwater movement is established as moving north towards Lake Shalla (the deepest lake in Ethiopia). Some groundwater from adjacent areas of Lake Awassa and Bilate River Basin also move towards the lake. High fluoride concentrations in surface and groundwater were encountered in large parts of the area. Due to high salinity, alkalinity and fluoride content, waters of Lake Langano, Abijata and Shalla were considered as neither fit for drinking nor for irrigation. The reports also show that the groundwater in the lowlands of these areas was similar.

The hydrogeology of Nazareth area carried out by EIGS (1974 – 1980) shows the area consists of Nazareth group of rocks with Mesozoic sedimentary formations. Some alluvial and lucastrine sediments were also identified. The problem of groundwater quality is not acute (fluoride content less than 1.5 ppm) except some isolated pockets with fluoride contents greater than 5 ppm around Wonji, Methahara and Wolenchiti areas. The permeability and yield in these areas are highly variable.

The UNDP, in collaboration with the Government of Ethiopia, also conducted a study during the period 1972 to 1974 in Awash Basin with the objective of assessing groundwater, reviewing groundwater and surface water potential, and offering suggestions for delineating potential groundwater areas. Investigations in the Aledeghi Plain showed that there were adequate groundwater supplies estimated to be available for domestic and livestock needs. The extent of groundwater resources was not assessed in the study. The study concluded that in Erer-Gota area, limestone beds below the base of the major uplifted area could contain potable water and WAPCOS recommends drilling boreholes in these areas.

The flood plain and delta of the lower Awash Valley has been recommended as a potential groundwater area from the delineated groundwater areas. And this delineation report suggested three areas for future groundwater studies:

- Tendaho – Assayta segment;
- Lower delta from Hedaitole to lower Gamari in E-W direction and from Amadugora to Lake Bario in a N-S direction; and
- Inter-montanne valley – in the south eastern corner of Dit Bahri, Kutubala and across the mouth of the valley, south east of Kutubala.

The study also contained valuable information regarding the hot springs of Ethiopia.

In Melka-Sedi Amibara area, groundwater studies were stated by Ital Consultants in 1970. Since then, groundwater levels in the area were recorded intermittently. The data are incomplete and boreholes have been abandoned. It is stated in the report that a possibility exists of identifying two sets of aquifers below the Amibara Plain.

Another extensive study by EIGS since 1970 to 1984 reviewed by WAPCOS shows the following:

i. The regional geologic mapping of sedimentary rocks in the Harar. Awash Valley region indicated that the prospects for groundwater appear to be good in the area.
ii. The hydro-geological information, including borehole logs, water analysis, was documented.
iii. A borehole at Hagere Mariam drilled to a depth of 38.3 m produced a yield of 5 m^3/hr. The productive zone was found to be 4.5 m. The lower part of the basalt proved unexpectedly compact and impermeable. Another borehole located a few kilometers southwest of Suropa found water in the decomposed fractured granite gneiss underlying and alluvium filled valley. The yield varied from 18 l/min to 45 lit/min.
iv. In the Dire Dawa area, 185 springs with discharges varying from 1 to 50 l/min have been identified.
v. During the year 1983-84 a hydro-geophysical survey for groundwater was carried out in Gelana and Gidabo Basins which helped in determining the geological structure and aquifer characteristics of the area.
vi. Up to 1984, a total area of 253,000 km^2 has been hydro-geologically investigated in Ethiopia.

It was WAPCOS (1990) that first employed various approaches for the estimation of groundwater resources for almost the entire part of Ethiopia. Five assessment approaches were implemented to quantify the potential annual rechargeable ground water. Accordingly, an estimated 21 to 27.5 MCM is the total replenishable annual ground water volume. This estimate by WAPCOS is believed by many professionals and academics to be underestimated.

2.2 Current Ground Water Studies

International Ground Water Conference, Addis Ababa (2004)

A recent international groundwater conference in Addis Ababa (2004) brought forward many challenges and issues. One important achievement of the conference was it brought together hydrogeologists and other groundwater specialists from all over Ethiopia and beyond. A total of 94 papers and posters were presented from different regions across the country, notably from Tigray, Amhara, Benishangul, and SNNPRS. Comparison of drilling success rates in the regional state government shows high success rates in Tigray and Amhara States (70-75% in Tigray and 84% in Amhara), lower success rates in Benishangul (31%). Drilling costs were reported (in ESRDF projects) to be falling in Tigray between 1998/90 and 2004. This was due to the establishment of the Regional Enterprise and increasing competition from the private sector. However, in the remote region of Benishangul-Gumuz, the costs of contracted-out drilling were still around Birr 1,350/m. Several regions were said to be experimenting with shallower depths and smaller diameters than before, packaging and clustering of drilling contracts, use of PVC casings rather than steel where possible, and other cost reduction measures. In one case, it was argued that test pumping should not be carried out on shallow (hand pump) boreholes. In Amhara, although 75% of drilling is carried out using DTH, it was suggested that rig versatility (DTH combined with mud rotary) and capital cost and ease of maintenance should be important considerations in choice of technology.

The Geological Survey of Ethiopia presented the current status of hydrogeological mapping as is shown in Figure 4. The ambitious Ethiopian Groundwater Resources Assessment Programme (EGRAP) was described, together with various contributions made by IAEA, USGS, UNDP and Norad in partnership with GSE and MoWR. The Ethiopian National Groundwater Database (ENGDA), a Microsoft Access-based system, was installed in GSE, MoWR and AAU in 2004. Currently, the database, which was installed at least in the then Ministry of Water Resources, has been abandoned and another ground water information system is underway.

Some presenters focused on ways of surmounting the challenges posed by drilling in Africa by emphasizing high safety factors in rig specifications (especially pull-back), and techniques such as simultaneous casing for heterogeneous formations. Others argued for a relaxation of borehole designs and specifications, and simpler equipment. In the latter case, the now often-repeated call is for small diameters, shallow depths, PVC casings instead of steel, or no casing at all in hard rock, limited development and test pumping; all aimed at driving down the costs of hand pump boreholes. Unfortunately, the assumptions behind some of these arguments are that Sub-Saharan Africa is essentially crystalline rock, and that we are drilling exclusively for hand pumps; neither of which hold true in Ethiopia. Nevertheless, many of the points made were helpful in those situations where shallow boreholes for rural hand pump water supplies are possible. The combination of hard-rock drilling technology (DTH) with the development the India Mark II hand pump achieved this “revolution”, the ingredients for success being listed as:

- Political will;
- Continuous support by external support agencies;
- A strong industrial base;
- Skilled human resources;
- The involvement of the private sector;
- An extensive program of work;
- Informed technical choice;
- Good logistical control;
- Standardization;
- Good communications and infrastructure; and
- Effective monitoring and evaluation.

Some of the ingredients are present, or potentially so, in Ethiopia, many are not. Furthermore, Ethiopia’s geology generally presents more challenging drilling.

ENGDA -Ethiopian National Groundwater Database

The Ministry of Water Resources (now called the Ministry of Water and Energy), developed a national groundwater database to capture the ground water characteristics of the country. The first National ground water database, known as Ethiopian National Groundwater Database (ENGDA) was established. ENGDA was started in 2003 by USGS experts in collaboration with the Ministry of Water Resources (Hydrology Department) under the project ETH/8/007 which was supported by the International Atomic Energy Agency (IAEA) and finalized in January 2005.

ENGDA is implemented jointly by the Ministry of Water Resources, Addis Ababa University, and the Geological Survey of Ethiopia in close collaboration with the Regional Water Resources Development Bureaus, Water Works Enterprises and NGOs. The success of ENGDA is due to the on-going studies and sustaining the capabilities built through technical cooperation with the IAEA in the past several years. The success of these technical cooperation projects depends on the capability to collect, process, interpret and archive the relevant hydrogeological and hydrological data. ENGDA is a necessary tool critical to the successful implementation of the proposed Ethiopian Groundwater Resources Assessment Program (EGRAP) that has been submitted to the Government for approval. This project is aimed at mapping and investigating the groundwater resources of the entire nation within a period of 12-15 years.

ENGDA is implemented in Microsoft Access and is designed to input, store, analyze and report ground-water information. Ground water data stored in ENGDA includes site information, borehole details, water-level and water quality. The Ministry of Water Resources, Hydrology Department has a plan to train all regional water bureaus' and ground water related professionals so that all ground water data can be stored and managed systematically.

Currently, the sustainability of ENGDA's is a question mark. There is little news of the implementation of the database in the Ministry of Water and Energy. Currently, there is ongoing project to develop a new database system known as Ethiopian National Ground Water Information System(ENGWIS) under the directorate of Ground Water Development Study and Management of Ministry of Water and Energy, which may explain the near extinction of ENGDA. It was possible to access ENGDA which is currently available only at the hydrology department of the MoWE and waiting to be replaced by ENGWIS.

Additional ground water studies: ground water for agriculture

The government embarked on enhanced development of groundwater for agricultural mostly in drought prone areas (PASDEP II, 2010). In the last five years, studies of four selected ground water studies covering a total of 35,261 km^2 have been completed (Kobo Girana: 2,850 km^2; Raya Valley: 1,411 km^2; Adaa Becho: 17,000 km^2; and Aladage; 14,000 km^2). According to the five year PASDEP II plan for groundwater, more than nine projects are being considered for development (MoWE, 2010). The first phase of the study in the coming five years has put 8,000 ha to be developed as a pilot (MoWE, 2010).

3. GROUNDWATER POTENTIAL OF ETHIOPIA

Ground water potential of Ethiopia is controversial and there is no consensus so far as to the estimated exploitable groundwater potential. It varies from WAPCOS estimate of around 2.5 BCM to preliminary national estimates of Ayenew and Alemayehu (2001) to 185 BCM. This extremely high discrepancy in the potential is a challenge to the experts and decision makers. Some of the studies are presented in the preceding section.

3.1 Basin Ground Water Estimation – WAPCOS (1990)

It was WAPCOS (1990) that first time employed new approaches for the estimation of groundwater resources. Usually indirect methods are used due to the scarcity of data in almost all the potential areas of development. The methods seen are:

a) Base flow separation approach;
b) Subsurface drainage approach;
c) Recharge area approach;
d) Water balance simulation techniques; and
a) Base flow separation method.

a) Base flow separation approach

Stream flow originating from stored groundwater is referred to as groundwater runoff or base flow. The mean monthly stream flows are plotted for a gauging station selected as near the end of a basin or sub-basin as possible. The plotting is made in such a manner that two minimum points are reached during the year. These points are joined by a straight line and the volume below this line is computed as base flow or 'B' in Mm^3.

Such an approach adopted by WAPCOS (1990) and the base flow volumes for different river basins is shown in Table 3.1.

Table 3.1. Base flow volumes of river basins

Basin	Stream flow data used (No. of years	Base flow Volume: B (Mm^3)
Abbay	19	10,200
Rift Valley Lakes	4 to 20	2,217
Awash	15	2,240
Omo-Ghibe	21	2,785
Genale-Dewa-Weyib	5 to 6	454
Wabi-Shebele	6	1,108
Baro-Okobo	3 to 9	1,211
Tekeze-Angereb-Goang	9	1,791
Total		22,006

Source: WAPCOS 1990, P.AII -27

b) Subsurface Drainage Approach

Groundwater runoff contours for Ethiopia have been drawn by Karasic (1982). This map was superimposed on the river basins of Ethiopia and assuming groundwater representing the replenishable recharge (Q_G) in any basin, the value of Q_G for each basin has been computed and a map was produced (Figure 6.2)

Table 3.2. Basin-wise replenishable recharge (sub-surface drainage approach)

Basin	Area (Km^2)	Groundwater runoff ($l/sec/Km^2$)	Annual recharge, Q_G (Mm^3)
Abbay	201,300	2.05	13,014
Rift Valley Lakes	52,700	0.77	1,280
Awash	112,700	0.52	1,848
Omo-Ghibe	78,200	1.35	3,329
Genale-Dawa	171,000	0.33	1,780
Wabi-Shebele	202,700	0.32	2,046
Baro-Okobo	74,000	0.90	2,100
Tekeze-Angereb-Goang	90,000	0.74	2,100
	982,600		**27,497**

Source: WAPCOS 1990, P.AII -29

C) Recharge Area Approach

Groundwater storage is mainly due to infiltration of precipitation of seepage from streams and other water bodies. Major groundwater replenishment takes place through direct precipitation over the upland areas of the watershed. The seasonal fluctuations of water level depend on the rate of replenishment of the saturated zone. This rate is a function of precipitation, surface run-off, permeability of soil, drainage network, and antecedent moisture content of the soil and the slope of the land surface.

In recharge areas, gentle slopes seem to offer more favorable conditions. Moderate rainfall over an extended period of time accelerates infiltration. During heavy rains for short periods, the recharge is minimal. Thus WAPCOS (1990) suggests two factors which control the infiltration of precipitation and recharge to groundwater.

1. Physical factors, such the size, slope and geologic conditions of water shed, and
2. Climatic conditions which vary from season to season and year to year.

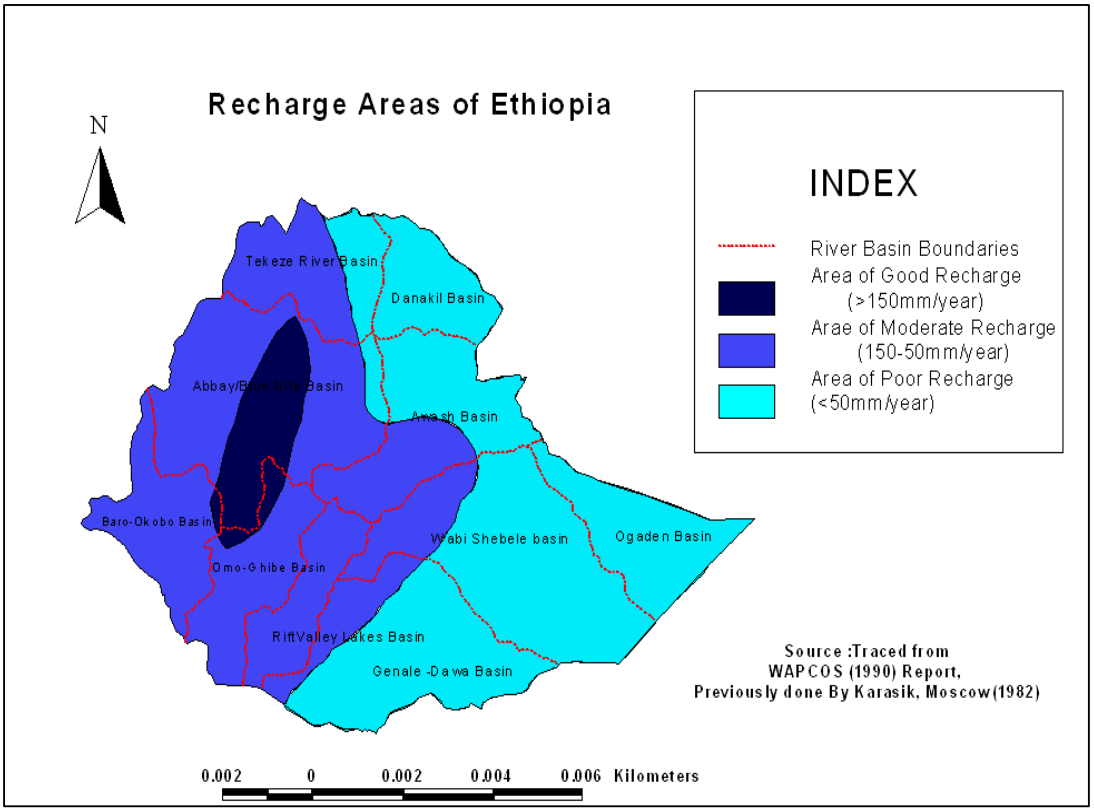


Figure 3.1. Recharge areas

Using the concepts above, WAPCOS tried to identify broad groundwater recharge and discharge areas in each basin. However, precise delineation of such areas could not be determined due to lack of information on seasonal water level changes. The basinwide extent of the recharge area and amount of recharge to groundwater expressed as percent of mean annual rainfall are given below (WAPCOS, 1990)

Table 3.3. Basin wise replenishable recharge (recharge area approach)

Basin	Mean annual rainfall (mm)	Extent of recharge area	% of rainfall recharging GW	Replenishable recharge Q_G (Mm^3)
Abbay	1,420	89,760	10	12,745
Rift Valley Lakes	1,135	15,840	5	898
Awash	850	22,400	7	1,332
Omo-Ghibe	1,469	35,811	8	4,208
Genale-Dawa	550	19,675	4	433
Wabi-Shebele	450	29,085	3	393
Baro-Okobo	1,590	10,581	4	673
Tekeze-Angereb-Goang	819	35,816	3	870
Danakil	455	4,316	2	39
				21,591

Source: WAPCOS 1990, P.AII -32

Judging from significant recharge estimate variations provided from several of the studies, the potential groundwater of the country varies significantly and it is difficult to establish the facts. However, it is widely reported that Ethiopia possesses usable groundwater potential in the order of 2.6 BCM. Not only are the yield levels of water wells too low (less than 5 liters per second), but wells are generally too deep to justify economic exploitation of groundwater resources for irrigation purposes in Ethiopia (WAPCOS, 1990).

Various studies have been done to explore the hydrogeological condition of different places in the country with a view to quantifying the groundwater potential of each place selected by the study team (EIGS, UNDP, Halcrow, Electro-consult: cited in WAPCOS, 1990). Most studies were carried out in the 1970's and 1980's through bilateral cooperation and UNDP support. The WAPCOS (1990) compilation and estimation of the groundwater potential of the country is more comprehensive than any previous study.

While studying the national water master plan, WAPCOS (1990) made an effort to quantify the total ground water potential using various direct and indirect empirical approaches that include i) base flow separation approach, ii) subsurface drainage approach, iii) recharge area approach, iv) water balance simulation techniques and iv) base flow separation method. As shown in Table 3.4, all the techniques give fairly comparable estimates. The total estimated ground water recharge locked in the sub surface may vary between 21.5 to 27.5 BCM. More than 50% of the potential ground water is locked in the Blue Nile Basin. The western part of the country has a total estimated potential of well above 75%, while the eastern highlands, including Awash Basin, covers the other 25%. While the figure indicated as the usable potential ground water may be arguable, the available studies suggest Ethiopia's groundwater potential is not easily used and the aquifer systems are not extensive. Table 3.3 (WAPCOS, 1990) gives usable groundwater potential.

Table 3.4. Usable groundwater potential

Basin	Annual replenishable recharge (BM^3)*				Usable groundwater potential			
	Sub surface drainage approach	Recharge area approach	Base flow approach	Adopted value	Extraction factor	Extractable ground Water (BM^3)*	% reduction for saline areas	Usable GW (BM^3)*
Blue Nile	13.01	12.7	10.2	12	0.15	1.8	0	1.8
Rift Valley Lakes	1.28	0.9	2.2	1.5	0.05	0.08	90	0.01
Awash	1.85	1.3	2.2	2	0.1	0.2	30	0.14
Omo-Gibe	3.33	4.2	2.8	3.5	0.05	0.18	0	0.18
Genale-Dawa	1.78	0.43	0.5	1	0.05	0.05	35	0.03
Wabi-Shebele	2.05	0.39	1.1	1.5	0.05	0.08	45	0.04
Baro-Okobo	2.1	0.67	1.2	2	0.05	0.1	0	0.1
Tekeze-Angereb-Goang	2.1	0.87	1.8	2	.1	0.2	0	0.2
	27.5	21.46	22.0	25.5		2.69		2.5

*Billion cubic meters
Source: WAPCOS 1990 P. AII-35

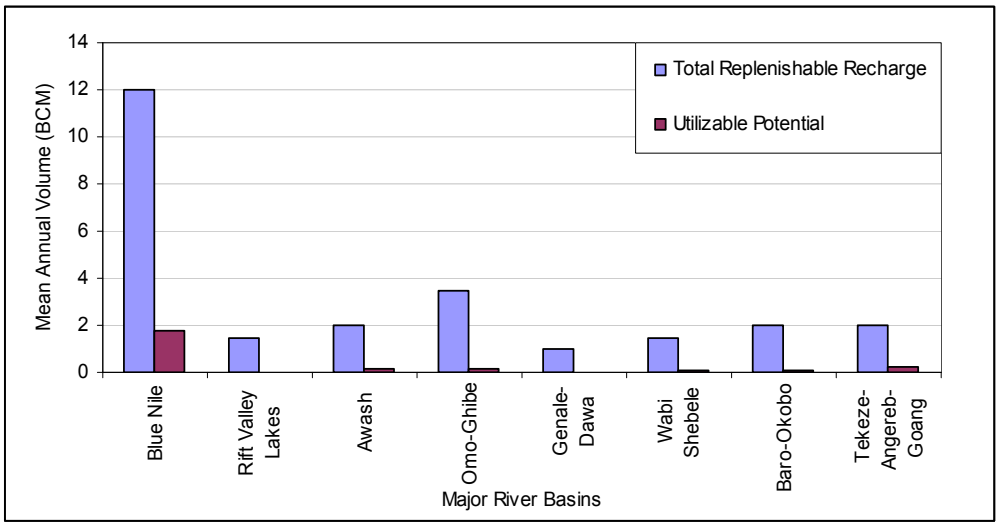


Figure 3. 2: Replenishable discharge of Ethiopian River Basins

3.2 National Ground Water Recharge Estimate – Ayenew and Alemayehu (2001)

Ayenew and Alemayehu (2001) presented totally different figures for the amount of groundwater recharge over the country on the basis of simplified assumptions. The general coverage of the recharge mechanism based on the geological cover of the country as: I) basement cover = 18%; ii) Paleozoic and Mesozoic cover = 25%; iii). tertiary volcanic = 40%; iv). quaternary sediments and volcanic = 17%. On the basis of these proportions, the main

source of recharge for the groundwater system is generally the abundant rainfall over the highlands. The major recharge occurs in the northeastern and southwestern plateau where annual rainfall is high and rapid infiltration is facilitated by the occurrence of fractured volcanic and to a lesser extent sedimentary rocks and thick permeable soils. The Ethiopian Rift acts as a discharging zone, which contains numerous perennial rivers, fresh and salt lakes, cold and thermal springs. With the exception of much of the Afar Depression, where the annual recharge is close to zero, the overview of the recharge over Ethiopia is summarized in Table 3.5 (Ayenew and Alemayehu, 2001).

Table 3.5. The overview of annual recharge in Ethiopia

Annual recharge (mm)	Location
250 - 400	Highlands of Illu-Ababora, Keffa and Wollega
150 - 250	Much of the Western and western and central Ethiopia and Arsi-Bale highlands
50 - 150	Much of Northern and northwestern highlands, central Main Ethiopian rift, southern and eastern regions between the Rift plain and the Arsi-Bale Highlands
less than 50	Southern Afar and the extreme northern end of the western lowlands

Source: Ayenew and Alemayehu, 2001

On the basis of various simplifying assumptions and 200 mm average recharge over the country, Ayenew and Alemayehu (2001) estimated the volume of groundwater reserve in the order of 185 billion m^3. This figure is far from many others estimates. It may be due to methodological error. It is difficult to assume ground water estimation from a simple water balance concept and the figure is not acceptable. It is estimated that the total surface water generated from the country is in the order of 122 billion m^3. It may be an exaggeration to think the total groundwater recharge is even greater than the surface flow generated from the country. Under normal circumstances, the proportion of the direct surface runoff is greater than the total groundwater proportion of the total rainfall. Therefore, it is more likely groundwater is higher than the WAPCOS estimate and lower than the 185 BCM.

3.3 Groundwater potential and methodology shift

The context of the groundwater studies in Ethiopia were generally based on the available data. Apart from the known limitations of the data, many professional experts and academics believe the past studies and exploration methods were constrained by two conceptual deficiencies. First, most recharge estimates and groundwater potential assessments used the base flow separation method as the principal assessment tool and relied on the output of the separation. This method falls short of providing accurate assessment of groundwater potential in cases of rivers contributing to groundwater (when groundwater level is well below the river bed). For instance, in an analysis of Awash River between Awash Falls to Melkasedi, the regional groundwater table is lower than the river bed by almost 20 m (discussion with WWDSE expert). This is an indication that Awash looses water from the river bed to regional groundwater aquifer. It is estimated that 50 to 200 MCM of water may be leaking to the regional groundwater aquifer from Awash River. Several rivers in Ethiopia are believed to have similar characteristics.

Second, most groundwater studies and explorations in the past used socio-economic approaches. The approach was simply to look for water around the socio-economic centers. The studies usually fall short of regional understanding and the output usually falls on a perched groundwater aquifer, which produces lower yields for shorter periods. The approach hinders our understanding of the assessment of the availability of regional groundwater systems on a larger scale. Therefore, the majority of the boreholes drilled likely fall under such a category. Interpretation and conclusion of the groundwater potential of the country or the region on the basis of such data sets is prone to misinterpretation of the perched groundwater resources. Engda Zemedkun (WWDSE groundwater expert) argues the approach and lack of appropriate data has limited our understanding of the groundwater potential of the country. Most groundwater potential figures given by WAPCOS and other studies are therefore incorrect and should be re-evaluated. Therefore, a shift in methodologies is required in conceptualization and understanding of the groundwater system in Ethiopia. Recent studies of groundwater of Kobo, Raya and Adaa Becho, follow regional groundwater system understanding approaches and have produced water yields far larger than initially thought. It is suggested that the following shifts are recommended to evaluate the national potential of ground water resources.

- Groundwater studies should focus on ***conceptualization of the groundwater system*** before estimating the potential groundwater resources based on local groundwater information. Researchers should attempt to understand the regional groundwater system considering larger areas of the hydrology, flow hydraulics and the subsurface geological system.

- The attempt to study and understand the national groundwater potential should be ***a process rather than a one-time study***. We should begin our understanding of individual groundwater systems on a project basis and accumulate our knowledge of the national potential. While national groundwater resources assessment from patchy data gives incorrect understanding, generation of adequate data sets for the entire country is expensive. For instance, the study of Raya, Kobo and Adaa Becho groundwater potentials has established the extent of aquifer system, the depth and direction of groundwater flow system and potential of exploitable groundwater. Systematic study and exploration of groundwater becomes a fruitful way of accumulating our understanding step by step. Excluding the recharge from the Becho Plain due to the maximum exploitation of the groundwater resource, the net available exploitable groundwater potential from Adaa Plain alone is estimated to be 1,046 MCM/year or 2.9MCM/day, which forms most 40 % of the national ground water estimate according to WAPCOS.

4. GROUNDWATER DEVELOPMENT AND USE

4.1. Experience of Ground Water Development and Utilization in the Country: Borehole Information

Data on over 7,000 boreholes were collected from the different regional offices and MoWE including the ENGDA data sets. Over 50% of the wells do not have depth information (Figure 4.1.). Of the total wells having depth information, 80% are shallow wells and the remaining 20% deep wells. It is anticipated that over 90% of the wells lacking depth information could likely be categorized as shallow wells as ground water development in the country was mainly geared towards developing domestic water supply to fulfill the Millennium Development Goals and the universal access to safe water. The depth distributions of the wells are fairly evenly distributed over the country without including the peripheral districts of the country.

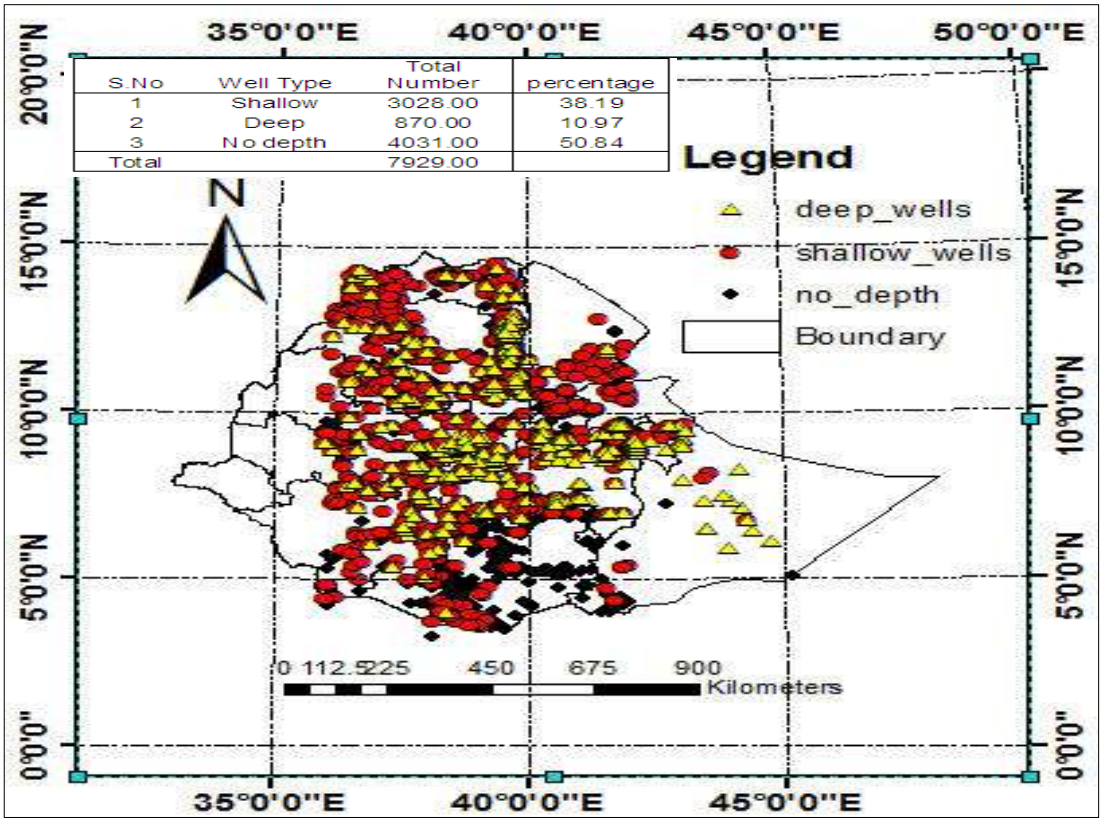
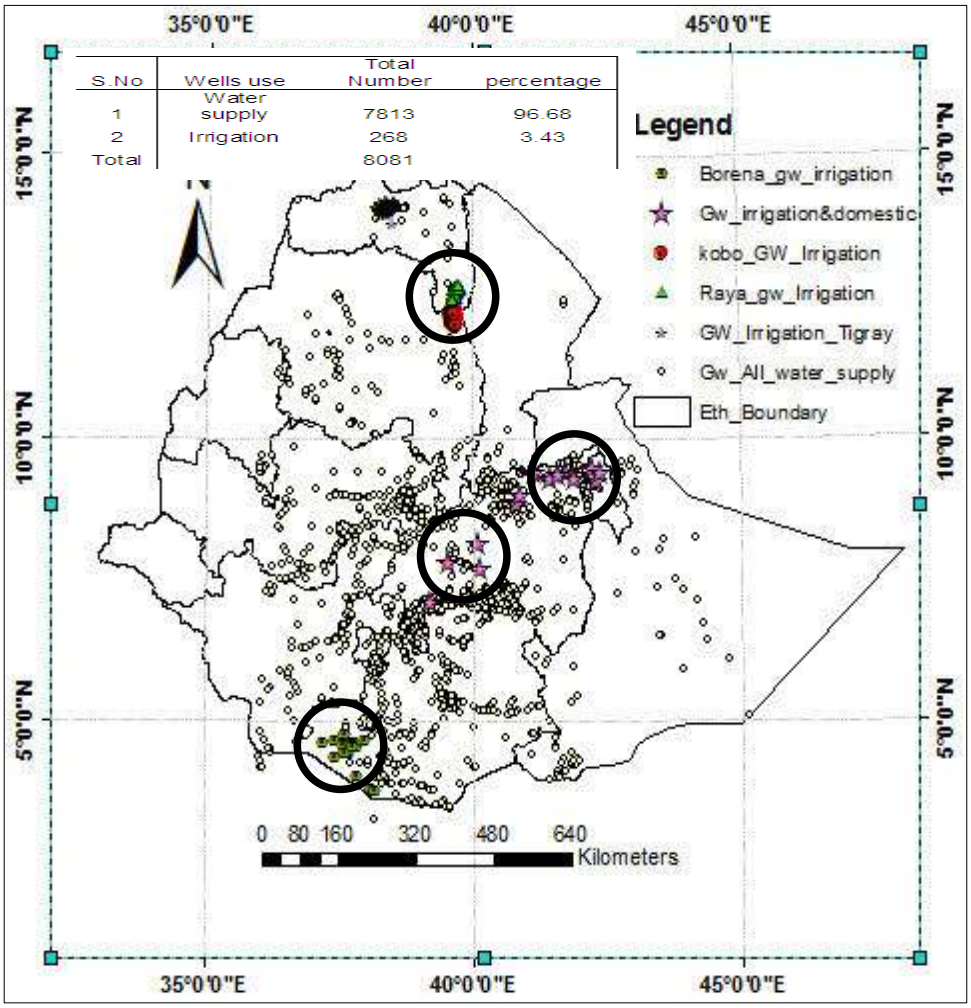


Figure 4.1. Classification of wells according to depth

The classification of the wells according to the benefits they provide shows currently over 95% of these wells are intended for domestic water supply. Less than 4 % of the ground water development is used for irrigation. As shown in Figure 4.1, the development of the ground water for irrigation is mainly in Borena in the south (Oromiya Regional State), Kobe (Amhara Regional State), and Raya (Tigray Regional State). These are the only implemented ground water development schemes and are expected to expand to other parts of the country such as Adaa Becho Plain, Teru, and Tana Beles sub-basins.



S.No	Wells use	Total Number	percentage
1	Water supply	7813	96.68
2	Irrigation	268	3.43
Total		8081	

Figure 4.2. Distribution of ground water use

Source: Author's data collection

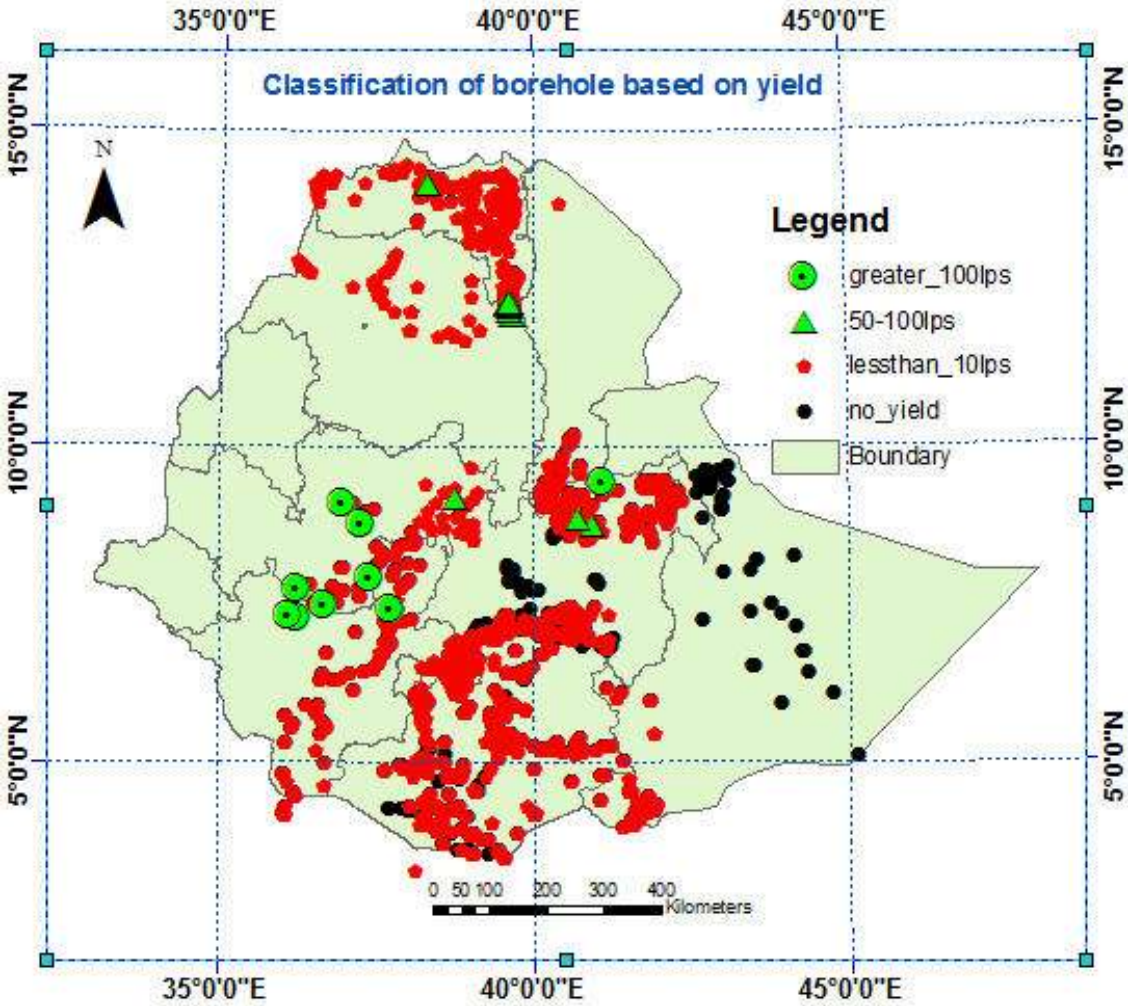


Figure 4.3. Classification of borehole based on yield.

4.2 Experience of Ground Water Development and Utilization for Agriculture

Experience of exploiting groundwater in the country for irrigation is limited. As of 2004, the total groundwater irrigated areas in the country did not exceed two hundred hectares of horticulture and flower farms (Aytenffisu and Zemedagegnehu, 2004). Reviews of the different studies on groundwater conditions indicate there is high potential for developing groundwater sources for irrigation in specific areas. These include alluvial fan deposits along the foot of the rift escarpments, flood plains and valley fills which are regularly recharged by seasonal runoffs from the highlands. The western escarpments of the Rift Valley that stretch from Showa Robit to Alamata (such as Shewa Robit, Raya-Kobo, Girana, Borkena, Mersa valleys), the vast alluvial plain that extends from Alaydege near the Awash flood plain to Dewele on the Djibouti border, the flood plains of the major and seasonal rivers and several fan deposits along the foot of escarpments. Most areas are located in drought prone regions. As it stands now, the used ground water is limited (Figure 3.3). Section 4.3 presents some of large-scale ongoing and planned ground water irrigation schemes.

4.2.1 Ground Water potential of Kobo Girana Valley

The main aquifer in the valley is unconsolidated sediment. Three aquifers or recharge areas are identified in the valley: the Waja-Golesha, the Hormat-Golina and Kobo-Gerbi recharge areas. The following table provides a summary of aquifer characteristics. According to the hydro-geological investigation report by Metaferia Consulting Engineers (2009), there is little information to validate the promise of Girana as potential groundwater sources. As shown in Table 4.1, a significant portion of the groundwater potential of the valley is the reserved groundwater with exploitable groundwater in the order of 700 to 800 MCM. However, the annual recharge remains within the range of 30 to 50 MCM. Therefore, caution is needed to sustain use of the available groundwater.

Table 4.1. Ground water potential of Kobo Girana Valley

No.	Parameters	Waja-Golesha		Hormat-Golina		Kobo-Gerbi	
		Range	Average	Range	Average	Range	Average
1	Sediment thickness, m	60-277	156	18-210	129	42-268	149
2	Aquifer thickness, m	20-160	100	20-150	90	No aquifer	
3	Transmissivity, m2/day		566		563 400*		
4	Water Table depth, m		17		22		47
5	Electrical conductivity, ms/cm		650		1300		3000
6	Potential for GW		Good		Good		Poor
7	Available Ground Water Potential, km^2						
	High		65.0		96.3		-
	Moderate		20.6		30.7		-
	Total		**85.6**		**51.3**		
8	Average Saturated thickness, m		139		107		
9	**Ground water reserve, MCM**		**1189.84**		**1358.9**		-
10	Exploitable GW , MCM (at 60% Sat. thickness)		713.90		815.34		
11	Annual Recharge, MCM		31.0		53.5		
12*	Annual Use, MCM (from reserve for 15 yrs)		48.0		55.0		

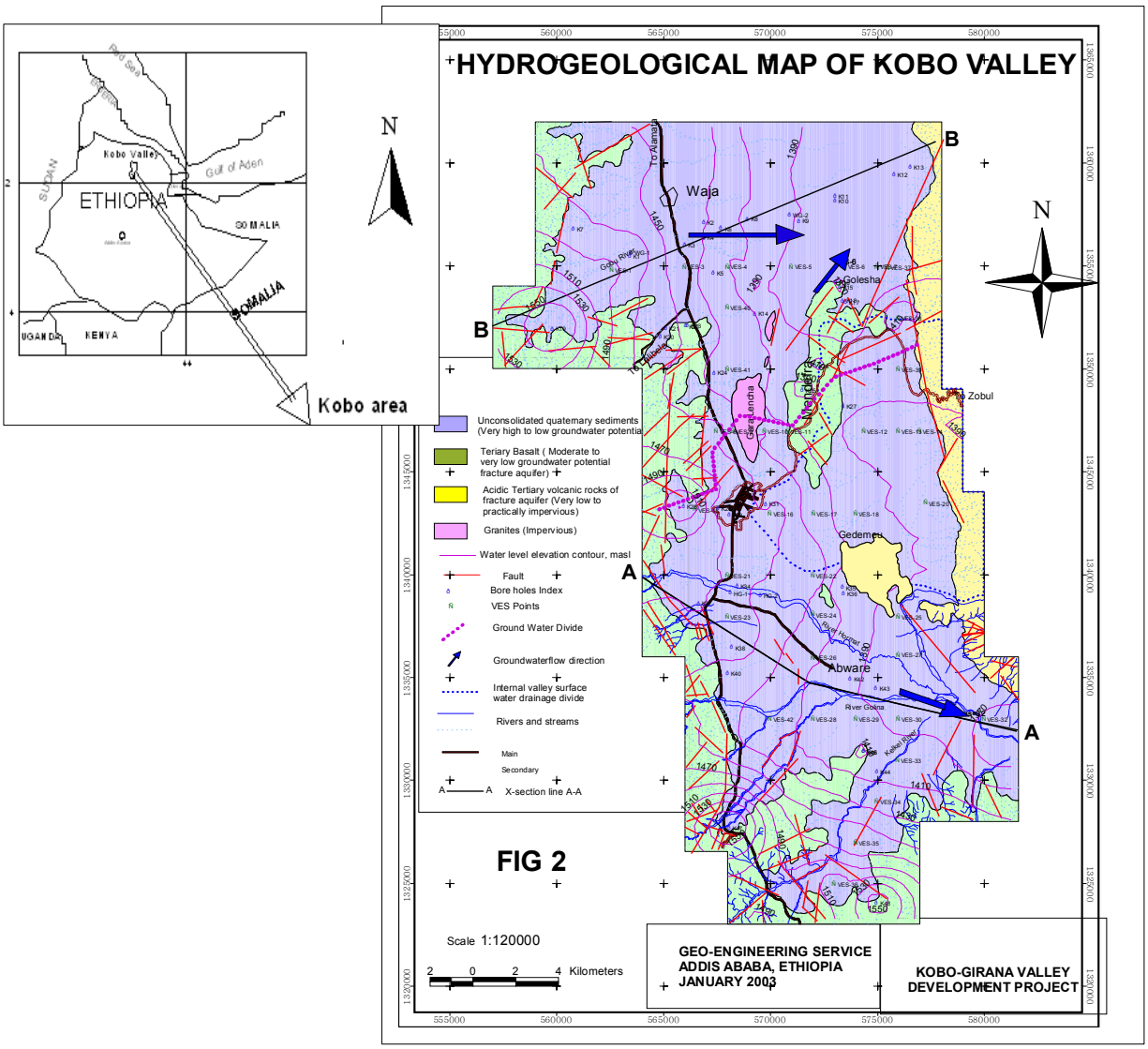


Figure 4.4. **Hydrogeological Map of Kobo (Source: GES, 2003)**

4.2.2 Groundwater potential of Raya Valley

Raya valley intermountain plain is found in the southern part of Tigray Regional State, Southern Tigray Zone in Alamata and Mahoni Woredas. The surface water catchment of the valley (Selen Wuha River basin) has an area of 2,576 km^2. The altitude ranges between 3,600 masl in the mountain ranges and 1,400 masl in the intermountain valley plain (Raya Valley alluvial aquifer). The Raya Valley alluvial aquifer is part of the Selen Wuha River surface water catchment of an intermountain plain which is part of the interconnected valleys of the Ethiopian rift system. It has a total area of 1,227 km^2, a trough bounded by the Ethiopian plateau and rift escarpment (western escarpment) at the west and Chercher Mountains in the east. The Raya Valley alluvial aquifer is a graben of sedimentary fill elongated nearly in a NNE-SSE direction along the Main Ethiopian Rift System which has a width of most 20 -25 kilometers and length of most 65 km (figure 1). The western plateau and escarpment which comprises the largest portion of the surface catchment which drains to Raya Valley Plain

alluvial aquifer are mainly composed of tertiary volcanic rocks. These rocks are highly disturbed by tectonic movements. The N-S faulting is responsible for tilting the rock formations with a general strike NE-SW and dipping to the SE direction. The Raya Valley alluvial aquifer is composed of loosely compacted sedimentary basin fill deposits. It has a high potential for agricultural development but the main problem being scarcity of surface water. The dominant type of agriculture is rainfed agriculture with supplementary irrigation using the floods flowing from the western mountain chains.

Different studies have been conducted to evaluate the groundwater potential of Raya Valley Plain aquifer. Among the most comprehensive studies conducted are 1) German Consult, Kobo-Alamata Agricultural Development Program (German Consult 1977); 2) Raya Valley Integrated Agricultural Development Study Project, Hydrogeology (REST 1999); and 3) Review of REST 1998 (Dr. Gershanovich 2000). None of these have studied properly the central and eastern part of the valley plain (which comprises more than 50% of the alluvial aquifer of the valley plain) due to absence of boreholes that penetrate the alluvial aquifer to calibrate the geophysical investigation and evaluate the groundwater potential of these parts of the plain.

In the current study, a large number of borehole drilling and testing (aquifer test, profile borehole drilling and testing and production well drilling and testing) was conducted, which solved the problem of data gaps in the valley, especially in the central and eastern part of the valley. Raya Valley Plain alluvial aquifer groundwater modeling was carried out to determine the sustainable exploitable groundwater potential resources in the valley by conducting different scenarios of abstraction of groundwater in the valley plain.

The main previous studies are REST 1998 Raya Valley Development Project, Feasibility Hydrogeology Report and Review of the Feasibility Hydrology Report by Geshanovich 2000.

The feasibility hydrogeology study was conducted to evaluate the groundwater resource potential of Raya Valley Plain alluvial aquifer by reviewing previous studies, water points inventory, water quality analysis, geophysical investigation, and conducting pumping tests on existing wells. Based on the available previous data and data generated during the study, the following results were obtained:

- Recharge to alluvial aquifer was estimated to be 86 Mm^3/year;
- Total groundwater reserve of the valley alluvial aquifer is 7.2 Bm^3
- The water quality of the valley fulfils the Ethiopian standard of drinking water;
- Almost all the water samples analyzed from the groundwater are excellently suitable for irrigation;
- Applying an analytical mathematical method, the exploitable groundwater potential is estimated to be most 162 Mm^3/year

Due to limitation of borehole data in the central and eastern parts of the valley plain, the area was considered to have low transmissivity (less than 100 m^2/day). It was concluded that the transmissivity of the Raya Valley alluvial aquifer generally decreases in west-east direction. In addition, it was recommended to carry out additional geophysical investigation,

drill test wells at the central and eastern zones of the valley plain, and conduct continuous water level monitoring.

The Hydrology Report (REST 1998) was reviewed (Gershanovich 2000) and the following conclusions and recommendations were made:

- The boreholes of the feasibility report 1998 are partial and require fully penetrating wells, including the weathered part of the basalt bed;
- The density of the hydro-geological information is not sufficient for 1:50,000;
- No problem of water quality;
- The total exploitable groundwater potential is estimated most 130 Mm^3/year instead of 162 Mm^3/year;
- Recommended pilot project (2-3 well fields) of groundwater development, regional geological and hydro-geological investigations for further confirmation of the groundwater potential of the valley; and
- Further recommended design of production well, design of observation wells, borehole logging, well development, pumping tests, groundwater regime monitoring.

The recent study by WWDSE (2007) has considered all of recommendations of the feasibility report (REST 1998) and Gershanovich (2000) generated large additional data sets to fill the data gaps in the valley with better and quality data. Piezometer wells were drilled and data loggers were purchased and some installed recently.

The mean annual groundwater balance of Raya Valley Plain alluvial aquifer is summarized in Table 4.2.

Table 4.2. Summarized groundwater inflow and outflow in Raya Valley Plain alluvial aquifer

Inflow to Raya Valley alluvial aquifer		Outflow from Raya Valley alluvial aquifer	
Type of Inflow	MCM/year	Type of Outflow	MCM/year
Recharge from draining the volcanic mountainous as subsurface inflow	136.0	Groundwater extraction for community water supply and irrigation (2009)	2.5
Recharge from runoff seepage at the foot of the escarpment (upper part of the alluvial plain)	54.0	Evaporation from Gerjele swamp	8.9
Recharge from rainfall at the plain and irrigation return	68.0	Discharge of Waja Springs	2.8
		Subsurface outflow through Selen wuha zone (southeastern margin of the alluvial plain	243.8
Sum	258.0		258.0

The approximate exploitable groundwater resources of Raya Valley Plain alluvial aquifer is estimated to be 437 MCM/ year or 1,199,178 m^3/day for 10,000 days or 25 years of exploitation time, considering the Raya Valley plain alluvial aquifer to include a total area of 1,227 km^2. The estimate varies significantly from previous studies.

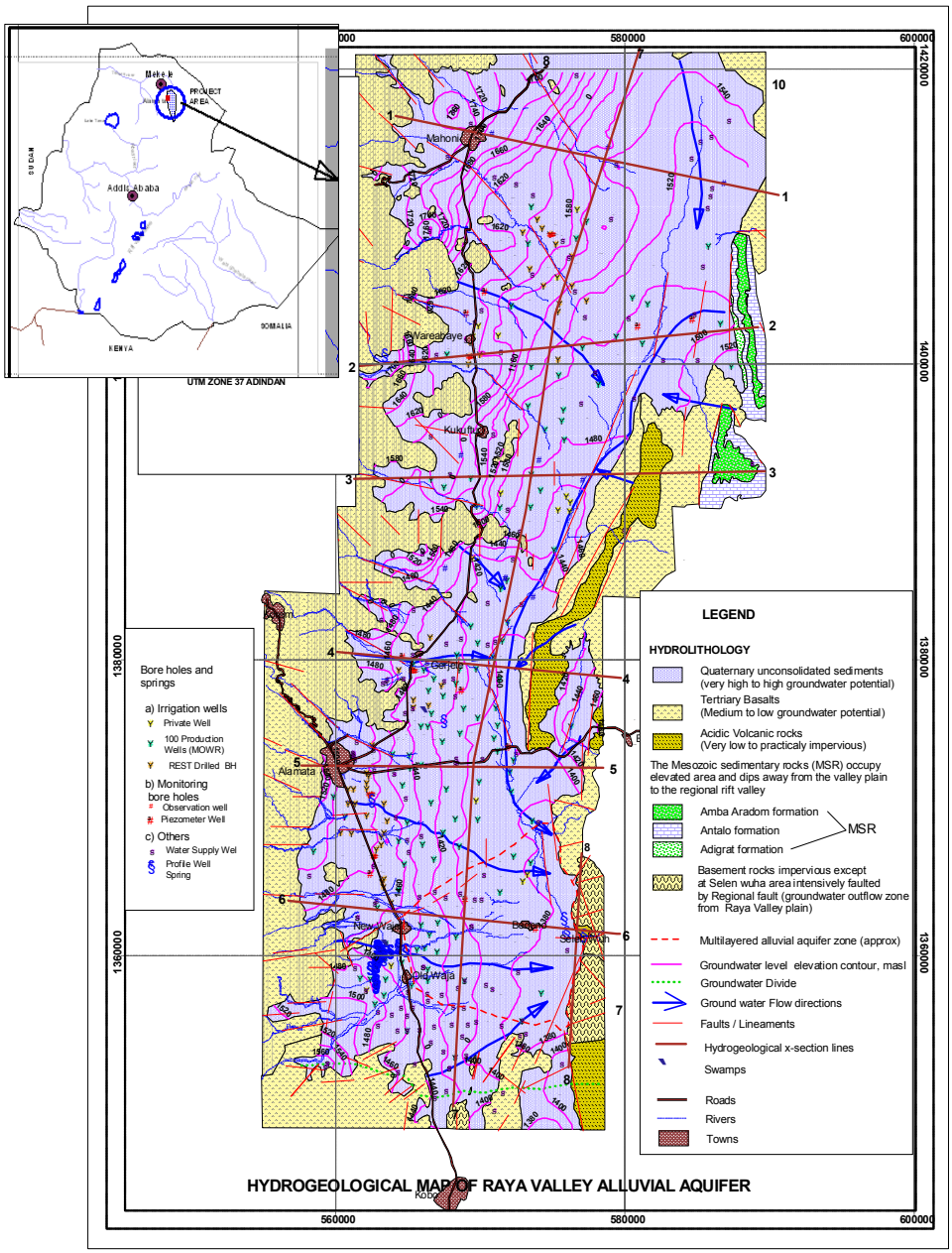


Figure 4.5. Hydrogeological map of Raya Valley

4.2.3 Groundwater potential of Ada'a Becho

Adaa Plain is located in the south between 40 to 90 km from Addis Ababa. Becho Plain is located southwest between 30 to 80 km from Addis Ababa.

Adaa-Becho Groundwater Resource Evaluation Project is one of the areas in the country designated for potential use of groundwater for irrigation. According to Zemedagegnehu *et al.* (2008), the recharge for the aquifer systems of these plains are partly in Abay Plateau with coverage of 7,000 km^2 and partly in Awash River Basin with coverage of 10,000 km^2. The general groundwater flow direction is NS through selective flow paths towards the northern part of Koka Dam area (Awash Basin). Three aquifer systems were identified in the project area; 1) alluvial and lacustrine sediment aquifer in Adaa Plain around Modjo and Debrezeit; 2) the upper basalt aquifer is distributed in upper Awash River Basin with a thickness of less than 50 m to over 400 m and transmissivity between 50 m^2 to 27000 m^2 and 3) a lower basalt aquifer composed of tertiary tarmaber scoraceous basalt. It was penetrated to a depth of 100 m at Melkakunture. It is highly productive with transmissivity values ranging from 100 to 1,700 m^2/day despite the partial penetration.

A hydrological and preliminarily numerical groundwater model indicated the inter-basin groundwater transfer accounts for the 50-70% of the net annual recharge to aquifer systems of the upper Awash River Basin from Abay Basin. The mean annual recharge from the upper Abay Basin is 370 mm^3, from upper Awash Basin up to Melkakunturi Station is 142 mm^3, from Akaki River is 22 mm^3, and from Mojo and Wedecha Rivers is 153 mm^3. The mean annual recharge of the Ada'a-becho aquifer system is estimated to be 687 mm^3 with 54% of recharge contributed by upper Abay Basin. On the basis of the water balance model, the mean annual rechargeable water into the Ada'a-Becho plains groundwater aquifers is more than 965 Mm^3 with 67% contributed by upper Abay Basin (Abay Plateau). Estimated annual recharge into Ada'a-Becho groundwater aquifers is given in Table 4.3.

Table 4.3. Estimated Annual ground water recharge into Adaa Becho

Watershed	Recharge watershed area (km^2)	Mean annual deep recharge rate (mm)	Mean annual rechargeable water (Mm^3)
Upper Abay	7,367	88	648
Awash up to	4,432	32	142
Melkakuntri	885	25	22
Akaki Brige	1,797	85	153
Mojo + Wedecha			
			965

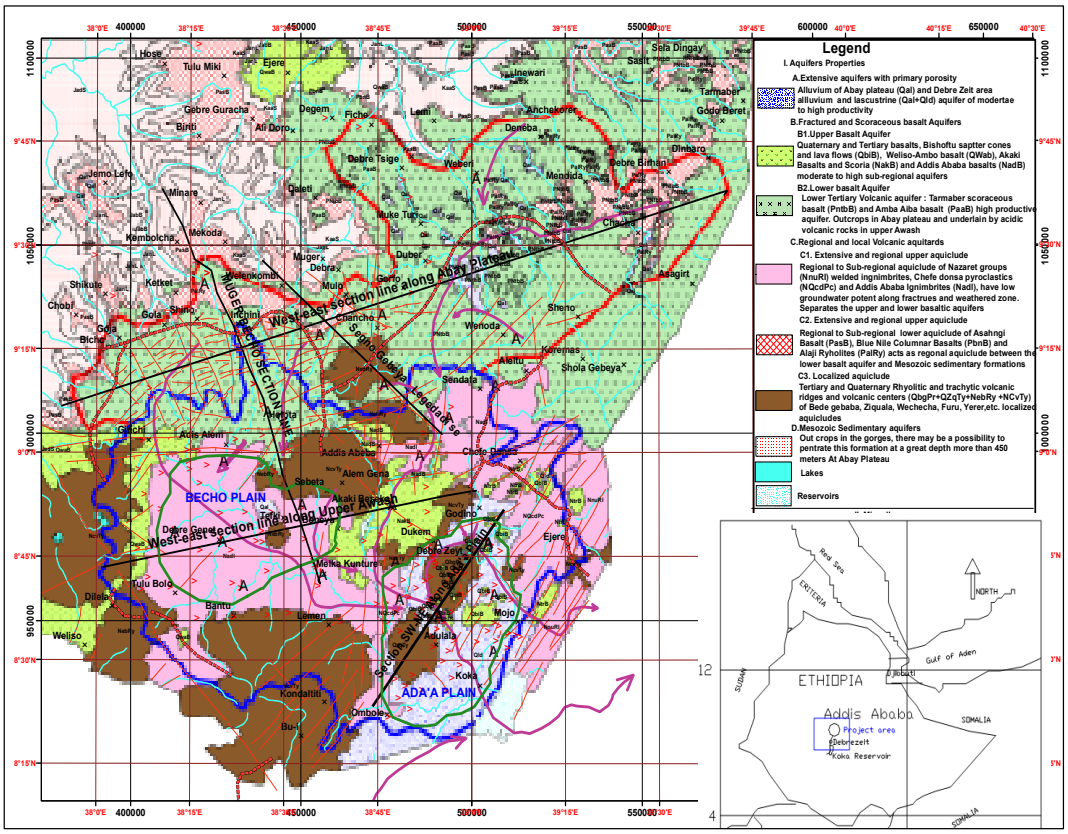


Figure 4.6. Hydrogeological map of Adaa Becho Plain
Source: WWSDE, 2008

4.4 Future development plan of ground water for agriculture

In the coming five year plan of the Ministry of Water and Energy implementation plan for groundwater development, nine groundwater projects are envisaged for irrigated agriculture. The plan incorporates four phase drilling and development activities. Accordingly, 93,000 meters of test wells, 28,000 meters of monitoring wells, 379250 meters of production wells are to be drilled. A total of 8,000 ha of land will be developed in various parts of the country as pilot ground water irrigation schemes.

Table 4.4. Development plan of ground water for agriculture

No.	Project Name	Unit	2010/11	2011/12	2012/13	2013/14	2014/15	Total
1	**Ada'a Bech GW Development**							
	1.1 Monitoring well drilling	meter	2000					
	1.2 Production well development	meter	10500	105000	10500			
2	**Alaydage GW Development**							
	2.1 Monitoring well drilling	meter	1000					
	2.2 Production well development	meter	12500	12500	12500			
	2.3 Pilot Irrigation Development	hectare	500	500				
3	**Rift Valley GW Development**							
	3.1 Test well drilling	meter	2000	1000			20000	
	3.2 Monitoring well drilling	meter	1000	1000			2000	
	3.3 Production well development	meter		7500	8750	7500	5000	
	3.4 Pilot irrigation development	hectare		500	500			
4	**Tana Beles GW Development**							
	4.1 Test well drilling	meter	1000	4000	8000	8000		
	4.2 Monitoring well drilling	meter	1000	1000				
	4.4 Pilot irrigation development	hectare		500	500			
	4.4 Production well development	meter		10000	10000	10000	5000	
5	**Upper Tekeze GW Development**							
	5.1 Test well drilling	meter	4000					
	5.2 Monitoring well drilling	meter		2000				
	5.3 Production well development	meter	14000	14000	14000			
	5.4 Pilot irrigation development	hectare		500	500	500		
6	**Katar GW Development**							
	6.1 Test well drilling	meter						
	6.2 Monitoring well drilling	meter						
	6.3 Pilot irrigation development	hectare						
	6.4 Production well development	meter						
7	**Welkite-Ambo GW Development**							
	7.1 Test well drilling	meter	12000					
	7.2 Monitoring well drilling	meter	8000					
	7.3 Pilot irrigation development	hectare		500	500			
	7.4 Production well development	meter		10000	10000	5000		
8	**Ogaden GW Development**							
	8.1 Test well drilling	meter	1000	4000	8000	8000		
	8.2 Monitoring well drilling	meter	1000					
	8.3 Pilot irrigation development	hectare			500	500	500	
	8.4 Production well development	meter			20000	20000	20000	
9	**Teru GW Development**							
	9.1 Test well drilling	meter	12000					
	9.2 Monitoring well drilling	meter	8000					
	9.3 Pilot irrigation development	hectare		500	500			
	9.4 Production well development	meter			10000	10000	5000	
	Total Test well drilling	**meter**	**32000**	**9000**	**16000**	**16000**	**20000**	**93000**
	Total Monitoring Well drilling	**meter**	**22000**	**4000**	**0**	**0**	**2000**	**28000**
	Total production well drilling	**meter**	**37000**	**159000**	**95750**	**52500**	**35000**	**379250**
	Total pilot level GW irrigation development	**hectare**	**500**	**3000**	**3000**	**1000**	**500**	**8000**

5 GROUNDWATER POLICY AND INSTITUTIONS

5.1 Policies and strategies

The Ethiopian water resources management policy provides for groundwater study and development in two sections of the policy document. Under 'Technology and Engineering' (section 2.2.3), the policy supports manufacturing and importing of drilling rigs, provides training and capacity building for development and operation of shallow well drilling. In 'Groundwater Resources' (section 2.2.6), the document provides support for studying the occurrence and distribution of groundwater and establishes regulatory norms for sustainable abstraction of ground water. The policy:

1. Provides a framework to identify the occurrence and distribution of the country's groundwater resources;
2. Provides a framework for sustainable abstraction of groundwater;
3. Provides norms, standards and general guidelines for sustainable and rechargeable management of groundwater;
4. Fosters conjunctive use of ground and surface water ; and
5. Promotes implementation of appropriate technologies suitable for water deficient areas to mitigate water scarcity problems.

The policy supports ground water assessment, development and operation mainly for shallow wells without explicit reference to drinking or irrigation water supply. Recent development strategies such as PASDEP (2006) and Water Centred Development Strategic Framework (2009) also include managed ground water development to contribute to the national growth and development.

5.2 Institutions

The main institutions involved in ground water assessment, development and operation include the Ministry of Water and Energy, the Ethiopian Geological Survey, the Regional State Water Bureaus, and NGOs. The Ministry of Water and Energy has a directorate of ground water assessment and development.

The institutional frameworks under which each operate is not clearly spelled out anywhere. There have been instances in irrigated surface water development where regional state governments undertake initiatives without fully understanding the national policies and regulations. Each regional state government has its own water development strategy. For better managed ground water development.

6. KNOWLEDGE AND CAPACITY GAPS IN GROUND WATER DEVELOPMENT AND MANAGEMENT

6.1 Knowledge and information gaps

The knowledge gap in groundwater development and management in the country is enormous. The major areas of knowledge and information gap include i) limited geological surveys; ii) incomplete information base on production; and iii) lack of monitoring and follow up. Gebrehiwot and Lulu (2004) also highlighted the absence of clear guidelines for

groundwater resource development and management. Consequently, more attention is given to operational activities than strategic tasks pertinent to groundwater resource development works.

Geological and hydro-geological maps are the basis of efficient exploration, development and use of groundwater resources and reduces uncertainty regarding the quality and quantity of available water. The coverage and the scale of the available geological and hydrological maps is however limited. Only 50% and 39% of the country is covered by maps respectively at a scale of 1:250,000. It will be an enormous task to develop countrywide maps with a higher scale.

6.2 Professional capacity gap

A sample survey of different water sector organizations in the country was conducted by JICA (in: EWTEC, 2009) and indicated the major capacity needs and gaps for the different categories of water sector organizations, particularly related to domestic water supply.
The current human resource situation in the management and development of ground water in the Regional State Water Bureaus is generally characterized as insufficient. A minimum of 31% (281 out of 895) of job positions are currently vacant or planned to be filled in the future. The capacity gap shows a dire shortage as we go down to the lower levels of administration. The current human resource situation in Zonal Water Resources Offices shows shortage of most 54% (579 out of 1076), while at the district level the shortfall is 61% (,,447 out of 12,140). When it comes to town water supply service areas and public enterprises, the situation is similar with relatively better coverage. In the same year, the Town Water Supply Service Offices had a shortfall of 25% (1,002 out of 3,740), while public enterprises such as Water Works and Construction Enterprise (WWCE), Water Works Design and Supervision and Enterprise (WWDSE), and Water Works Development Enterprise (WWDE) had a shortfall of 34% (512 out of 1503). In almost all the water bureaus and public enterprises, the required professionals are hydrogeologists and water supply engineers.

6.3 Technician skill capacity gap

JICA (2009) looked into the technical staff requirements during their survey and found a significant shortfall of drillers (chief drillers, assistant drillers) followed by relatively high requirements for hydrogeologists, electricians and mechanics. Similarly, the report indicated there is high requirement for water supply engineers and hydrologists in 12 consulting firms included in the study. The summary below (Table 6.1) provides the status of groundwater and related information and knowledge generated in the area of groundwater.

Table 6.1. Status of groundwater knowledge and capacity in Ethiopia

Issue	Status	Gaps
Geological surveys	• Geological maps (1:250000) 50% of the country. • Hydrogeological maps 39%; based on borehole information not on test drilling information. • Accelerated investment in assessment and exploration; implemented by MoWR and regions. • MoWR largely engages public enterprises such as WWDSE.	• Integrated groundwater exploration including test drilling for high potential areas; lowered pace in covering the remaining area through mapping: EGS not able to live up to its mandate. • Current assessment project wise and not linked to EGS set procedures.
Information base	• Limited knowledge on: • Very shallow and deep aquifers • Non reliable knowledge on shallow aquifers. • Water quality has not been well defined and mapped. • Scattered information on ENGDA discontinued. • NGIS recently started.	• NGIS most to be completed. • Communication and dissemination strategy/business plan.

EWTEC, 2009

Table 4.2. Status of Groundwater Knowledge and Capacity in Ethiopia (EWTEC, 2009)

Issue	Status	Gaps
Monitoring	• Not done; patchy and project based; not even in high intensity area as in Akaki. • Emerging uses of groundwater for irrigation and lowered pumping cost demands systematic monitoring.	• MoWR to Gazet priority areas for monitoring. • Clear responsibility for well field operators. • Link to NGIS.
Sustainable yields	• First estimates for number of aquifer systems but not for others. • No water balances.	• Confined prior to operation of well field. • Level and abstraction monitoring in line with confined sustainable yield. • Link to groundwater. management plans.
Exploitation	• Poor capacity to explore deep aquifers poor supply. • Public enterprises have poor capacity and management in complex well drilling complex exploration. • Problematic contract management observed from both sides - supervision/contract management.	• No (in-country) training on deep well drilling. • Limited number /no critical mass of organizations. • Good supervision (arrangements) missing.

Mechanical drilling	• Absolute shortage of drilling rings (conservative estimate is 200) – partly addressed by recent procurement drive. • Shortage of submersible pumps, generators and spare parts-gap in local maintenance capacity and supply of fast moving items.	• Drilling rigs – specific to conditions (deep wells/sediments). • Maintenance of drilling rigs to ensure continued operation.
	• Presumable relatively high cost of drilling compared to other African countries.	• Competition and little engagement of private sector.
	• Relatively high number of failed wells – 15% to 75% varying with regions.	• Analysis of well failure – probably related to lack of local engagement /technical supervision – in some areas due to water quality issues.
	• Discussion on standardizing well design started by MoWR.	• Standardization.
	• Drilling association just set up.	• Drilling association to become active partner in development of the sector.
Manual well development	• Limited well development even in high potential ultra shallow aquifer. • Dug well dominate.	• very shallow bore well technology – which allows deeper penetration. • TVETs engagement /private sector training. • Popularization of manual drilling – among others.

Table 4.6. Status of Ground Water Knowledge and Capacity in Ethiopia (EWTEC, 2009)

Issue	Status	Gaps
Expertise in groundwater development	• Pump tests not systematically done • 25-60% vacancies (JICA report).	• Training of: chief drillers, hydro-geologist and water supply engineers. • High capacity equipment for pump tests and well development.
Expertise in ground water management	• Ground water curricula recently being strengthened in five universities.	• Capacity to monitor in terms of manpower and equipment. • Centers of excellence in groundwater development.
Managed development	• Accelerated highly ambitious exploitation plans/concept for growing number of areas.	• Ground water management plans-with stakeholder engagement
Interlinkage with other sectors on demand side	• Land use planning process – based on started in Oromia, Amhara, Somale and Afar. • Growth corridors plans – large-scale development in select corridors. • UAP.	• Need to expand and need to broaden and put implementation perspective /EGRAP plus.

Interlinkage with other sectors on supply side	• Watershed improvements programs exits but no focus on recharge. • Irrigation development but not conjunctive.	• No systematic linkage and not all buffer techniques used. • Conjunctive management.
	• Integration with land use planning on supply side.	• Harmonize watershed programs with buffer management-differentiated.
GW protection	• Not there. • No specific guidelines for point or non point pollution.	• Protection zones in selected areas (legal backing). • Regulation around high priority point pollution.
Regulation	• Licensing procedure for well development in place but not known or systematically followed. • Civil code set the limit for regulation at 100 meter depth.	• Activation of licensing procedure-especially in selected areas.
Groundwater management plans	• -Non existent.	• Would be required in areas of intensive development.
Monitoring	• See above (knowledge section).	
Basin management	• RBO ordinance promulgation. • One RBO in place (Abay), two under preparation. • Mechanism for allocation. • Groundwater does not figure importantly.	• In future ground water. management plans linked in to river basin management.

6.4 Capacity building – education and training

There is a tendency toward large-scale development of groundwater for agriculture as witnessed from intensified studies and implementation at various areas such as Ada'a and Becho area and Kobo, Raya. Given the little experience in groundwater irrigation and the limited institutional and human resources capacity, there will be enormous requirements in enhancing the knowledge, technical and technological capacity and capability to develop manage and use groundwater resources.

Public universities and training institutions can play pivotal role in building capacity. Some of immediate interventions could be to increase the quantity and quality of geology education: i) public universities offering geology degree such as AAU, Mekelle University can review their curricula to accommodate more hydro-geological courses in their programs; ii) not only for groundwater irrigation but also 85% of the domestic water supply comes from shallow wells, there is substantial capacity requirement in the area, therefore one way of offsetting the shortage of the human resources is through increasing university enrolment in departments of geology. Short term training institutions should either evolve or the existing ones should provide hands on training for technical skills.

Strategically, expansion of the coverage and knowledge of groundwater can be enhanced at three different levels. It is suggested that the first level includes those professionals who attain managerial positions or higher level technical professional skills suitable for

consultancy and contractors, for federal as well as Regional State Bureaus. These group of professionals should be MSc or above in terms of education and skills in the field of hydrogeology. Universities offering masters program should expand into accommodating more hydrogeology education and training tuned to the special needs of the country. The second level of professional studies should be intended to produce large numbers of mid-level professionals at the BSc level. Universities offering geology degrees could mainstream the emerging requirements of hydrogeology by modifying their curricula as a BSc in Geology and Hydrogeology. The geology degree could be modified to mainstream other fields of study such as 'geology and mining and geology and engineering. Graduates from this second level of professionals could fill the gaps up to the level of district offices, NGOs and contractor offices.

Specialized technical and vocational education schools or Water Technology Institutes are emerging in Regional State Bureaus. These institutions are for training technicians in drilling, electricity and mechanical skills. It is important to recognize continuous capacity building for both professionals as well as technicians and advanced short-term training institutions such as currently existing in the Ethiopian Water Technology Centre (EWTEC) under the Ministry of Water and Energy. Such institutes have the capacity to integrate research and development in their training activities to promote innovation and technology in the area of groundwater. The following pyramid shows the role of public institutions and their inputs to various government and private offices.

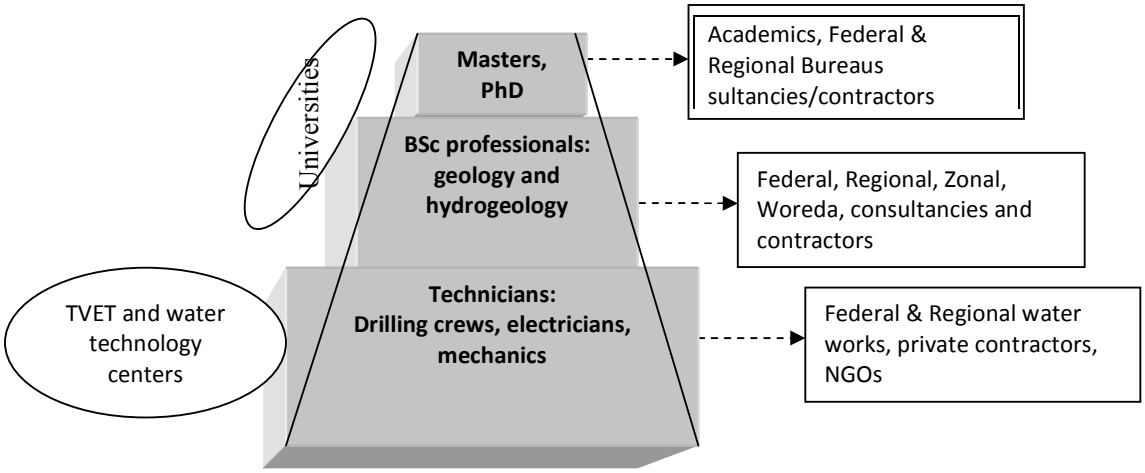


Figure 6.1. Proposed levels of education.

7 DRILLING TECHNOLOGY SND COSTS

7.1. Drilling technology and Equipment

According to Hailemichael's review of 2004, there are a total of 103 drilling machines in the country with the largest number of owned by the government (48 machines), private companies (39) and NGOs' 16 (Table 7.1). By any standard, the available number of water well drilling machines, compared to the size of the country is limited.

Hailemichael's review showed drilling in Ethiopia started by providing domestic water supply using percussion type drilling machines and later more modern DTH/rotary type drilling machines. The types of machines usually employed by most private contractors and government enterprises are these modern machines that have a capacity to drill to depths of 350 meters and more. There is some interest among private companies to manufacture or assemble light drilling machines to reduce drilling costs. The effort is not well documented either by Hailemichael or other researchers. Almost all drilling machines in the country are initially meant for water supply, but there is increased use of the machines for drilling wells for agricultural purposes as activities in Raya and Kobo show.

Table 7.1. Drilling Rigs currently engaged in well construction in Ethiopia (private companies)

Private companies	Data collection	DTH/ Rotary with mud	Drilling capacity max depth	Mud rotary	DTH without mud)	Percussion truck mounted	Auger/ bucket	Percussion skud mounted	Total
Hydro Construction & Engineering Co. Ltd.	contacted	1	500		1				2
Yadot Engineering and Trading plc.	contacted	5	120, 400						5
Pile foundation & Water Well drilling Enterprise	contacted	2	150,500	1		1		8	12
Ethio-Drilling and Water engineering Co. Ltd.	contacted	1	500			1			2
Saba Engineering	contacted	3	500						3
Ethio-Libya Drilling Plc.	contacted	1	350						1
China-Geo Engineering company	proxy	2	250-300						2
Wattech	proxy			1		1			2
Aquatech	proxy			1		1			2
CRP (Indian drilling company)	proxy	1	250-300			1			2
Axis	proxy					1			1

engineering									
Daniel Drilling Plc	proxy					1			1
Endale drilling plc?????	proxy		100		1				1
AL Nejah drilling agency	contacted	1	500						1
Rahbah & Sons drilling	contacted					2			2
Total		17		3	2	9	0	8	39

Table 7.2. Drilling Rigs currently engaged in well construction in Ethiopia (Government)

Name of company	Data collection	DTH rotary with mud	Drilling capacity max depth	Mud rotary	DTH w/o mud	Percussion truck mounted	Auger bucket	Percussion skud mounted	Total
Government Organizations									
Afar Regional Water Bureau	Cont'd	1	250-300						1
Amhara Water Works Enterprise	Cont'd	5	350		1				6
SNNPS Water Works Enterprise	Cont'd	5	350				2		7
Oromiya Water Works Enterprise	Cont'd	10	350			1			11
Tigray Water Works Construction Enterprise	Cont'd	7	150,350						7
Somali Water Works Construction enterprise	Cont'd	6	250-354						6
Benninshangul Water Works Construction Enterprise	Cont'd	2	150, 350						2
Water Well drilling Enterprise	Cont'd	4	350	2					6
Ministry of Water Resources	Cont'd	2	350						2
Total		42		2	1	1	2	0	48

Table 7.3. Drilling Rigs currently engaged in well construction in Ethiopia (NGO)

Name of company	Data collection	DTH rotary with mud	Drilling capacity max depth	Mud rotary	DTH w/o mud	Percussion truck mounted	Auger bucket	Percussion skud mounted	Total
NGOs									
Kale Hiwot church	Cont'd	2	150						2
Ethiopian Evangelical Church Mekaneyesus	Cont'd	1	200						1
Norwegian Church Aid	Cont'd	1	250						1
Ethiopian Orthodox Church (DICAC)	proxy	1	150		1				2
World vision/Ethiopia	proxy	2	250						2
Oromo Self Help Organization (OSHO)	Cont'd		300		1	1			2
Ethiopian Catholic secretariat	proxy	1	350						1
Africare/Ethiopia	proxy	1	150						1
Church of Christ	proxy	1	200						1
Relief Society of Tigray	Cont'd	2	350						2
Don Bosco Catholic NGO	proxy	1	350						1
Total		13		0	2	1	0	0	16
Grand Total		72		5	5	11	2	8	103

7.2 Well drilling cost and future trends in Ethiopia

In general, the cost of deep well drilling has decreased from an average cost of Birr 2,000/meter to Birr 1,200/meter. For shallow wells the cost has fallen from the previous Birr 1,500/meter to Birr 900/meter. Well construction quality has deteriorated due to the high competition in that steel casings of poor quality have been used by some contractors. As there are no standardized designs or specifications, price competition has greatly affected quality (Hailemichael, 2004).

Drilling costs are dependent on:

- The distance of sites from the Addis (usually where the drilling companies are located);
- The accessibility situation and the availability of water for drilling;
- The climatic condition where drilling is conducted;
- The expected hydrogeologic situation of the area (massive rocks, possible loss of circulation and/or collapse, etc); and
- Cost of drilling machine accessories.

The government of Ethiopia provides incentives to private and public well drilling companies to import drilling rigs free of tax. However, the initial capital cost of the machines is up to 800,000 USD (T3W rigs). This discourages the expansion of the private drilling companies.

Government may encourage private companies either through long-term loan schemes or forming public private partnership schemes. The latter may be appealing for the government to improve performance and reduce loses usually seen in public institutions.

8. Summary and Conclusion

Ethiopia is a country of great geographical diversity and geological complexity. High rugged mountains, flat-topped plateaus, deep gorges, incised rivers and rolling plains are the pre-dominant physiographical features. Since the country is located in the tropics, the physical conditions and variations in altitude have resulted in a great diversity of climate, soil and vegetation. The highlands on each side give way to vast semi-arid lowland areas in the east, west and south. The ground water potential is shaped by the two complex phenomena of complex geological formations in the one hand and the diversity of the topography, climate and soil in the other.

Several assessments of ground water potential and studies indicate the rechargeable ground water potential of the country is in the order of 2.6 BCM. This magnitude is believed by many hydro-geologists and academics as a gross underestimation of the actual potential. Indications are that the regional ground water aquifers of the country are deeper and larger than previously thought. For instance, recent studies for irrigated agriculture at Kobo, Raya, and Adaa Bechoo indicate the regional ground water aquifers are deeper; water movement crosses surface basin boundaries (basin transfer) and there are large reserves of groundwater. It is estimated that the ground water reserve of the Kobo Girana Valley is in the order of 2.5 BCM (WAPCOS, 2009) while the reserve of Raya is 7.2 BCM. The estimated annual recharge at Adda Bechoo is in the order of 965 MCM, of which the majority contribution comes from Abbay Basin. This emphasizes the importance of understanding the regional groundwater aquifers and movement when considering ground water assessment and development for highly water consuming agricultural use.

The use of groundwater for agricultural is very low. Assessment of the borehole data from Federal and Regional Water Bureaus indicates over 80% of the groundwater use is for domestic water supply. The depth range of assessed wells indicates most wells are shallow (83%) and have low yield in the order of less than 10 lps (>60%). However, groundwater use for agriculture is emerging as a mainstay of irrigated agriculture development, particularly in rainfall deficit areas. The five year plans from the Directorate of Groundwater Development Studies and Management of the Ministry of water resources shows several ground water irrigation projects will be implemented. Over 8,000 ha of land will be developed as a pilot scheme using groundwater during the five-year period from 2010/11 to 2014/15.

The planning and implementation of irrigated agriculture using ground water is highly encouraging. There are robust planning documents and ongoing studies at federal and regional state government level. There are, however, valid concerns that may impede the development efforts of the government. The most important concern is the limitation of knowledge and information available on the extent of the potential ground. Second, the available human and institutional capacity to plan, develop and manage is limited in quantity and quality. Third, drilling equipment and spare parts are so hard to obtain.

Therefore, it suggested that the government of Ethiopia should invest in developing institutional and human capacity if the current activity of ground water development is to be sustained. The most important areas of human capacity development are hydrogeology, water supply engineers, geologists and drilling technologies and associated technician skill development.

The initial capital cost of the drilling rigs and spare parts are discouraging private companies to expand. It is important to provide some kind long-term loan schemes for private companies for importing deep drilling rigs and establish spare parts distribution within the country. This enhances the coverage of ground water drilling activity and guarantees sustainable availability of spare parts, contributing to ongoing efforts towards irrigated agriculture development.

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