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SCHOOL OF GRADUATE STUDIES**

DEPARTMENT OF EARTH SCIENCE

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**Groundwater Resources Evaluation and Management in Dugda
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SCHOOL OF GRADUATE STUDIES**

**GROUNDWATER RESOURCES EVALUATION AND MANAGEMENT IN
DUGDA WOREDA, CENTRAL RIFT VALLEY, ETHIOPIA**

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I the undersigned declare that this Thesis is my original work and has not been presented for any degree in any university and all the sources of materials used for the thesis have been duly acknowledged.

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This Thesis has been submitted for examination with my approval as university advisor

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Acronyms

ADF: African Development Fund
AET: Actual Evapotranspiration
CRDA: Christian Relief Development Association
DWS: Domestic water supply
E_t: Evapotranspiration
FAO: Food and Agriculture Organization
GO: Governmental Organization
ITCZ: Inter Tropical Convergence Zone
IWRM: Integrated Water Resource Management
JICA: Japan International Cooperation Agency
LVIA: Lephians Voluntaries International Association
m.a.sl: meters above sea level
MCS: Meki Catholic Secretariat
MER: Main Ethiopian Rift
MoWR: Ministry of Water Resources
NGO: Non-Governmental Organization
NMSA: National Meteorology Service Agency
OSHO: Oromia Self Help Organization
PA: Peasant Association
PET: Potential Evapotranspiration
SAR: Sodium Adsorption Ratio
SDFZ: Silte Debrezeit Fault Zone
SNNPR: Southern Nations, Nationalities and People's Region
UNICEF United Nations Children's Fund
WATSAN: Water Supply and Sanitation
WFB: Wonji Fault Belt
WHO: World Health Organization
WSS: Water supply Schemes
WSSA: Water Supply and Sewerage Authority

Abstract

This study covers two parts where the first part deals with groundwater potential assessment of Meki river catchment and the second part which is the main focus of the study deals with assessment of sustainability problems of developed water supply schemes in Dugda woreda(i.e part of Meki river catchment).

Meki river catchment is found with in the Main Ethiopian Rift in the northern sector of the Lakes region. The average monthly Maximum and minimum temperature of the area are 25.8 °c and 11.4 °c, respectively. Its mean annual aerial depth of precipitation is 992mm. Potential evapotranspiration for the area is calculated using Penman and Thornthwaite gives annual potential evapotranspiration value of 1242.8 mm/year and 827mm/year, respectively. Actual evapotranspiration for the area estimated, from Turc method gives a value of 754mm. While actual evapotranspiration using Soil-water balance (Thornthwaite and Mather) method is 732 mm. The overall water balance of the study area was computed with an aim of estimating the amount of annual recharge to the groundwater. Accordingly; annual recharge to the ground water of the study area is approximated to be 116.7mm. The main aquifer formations of the boreholes are lacustrine deposits, weathered and fractured Basalt, ignimbrite, and welded tuff. The general trend for groundwater flow observed from piezometric heads is from western highlands toward the rift floor in the direction of NW to SE of the study area. Groundwater type of the area evolves from Ca-Na HCO₃ water type in the western highlands and escarpments to Na-HCO₃ water type in the rift floor (i.e. towards lake Ziway) of the study area.

The sustainability challenge of developed water supply schemes is conducted in Dugda woreda. Five representative PA's which can characterize the whole water supply sustainability problem of the woreda were chosen. The main source of drinking water for the woreda is groundwater. Currently there are seventy-five developed water supply schemes; where thirty-eight point eight percent are boreholes, thirty-four point six percent are windmills and twenty-six point seven percent are hand pumps. Twenty-six point six percent of these developed schemes have failed to meet their objectives. Local community in the study area also develop 2162 dug wells individually which could result in depletion of the resource. Findings of the study reveal that Poor quality (high fluoride concentration) of water is the main cause for ninety-one percent failures of developed water supply schemes. Findings of the study reveal that ninety-five percent of the water supply schemes are managed by water committees. Lack of training for the professionals, water managers, community and local operators is other reason for sustainability problem of the woreda. Result of the study shows that ninety-four percent of interviewed technical staffs clarify that the existing training and staff mobility strategy doesn't allow professionals to improve their skills. Eighty-five percent of respondents explain, they didn't obtain any kind of training. In addition there is high shortage of skilled human resource, budget, and logistics in the rural water supply office of Dugda woreda. There is no clear system for monitoring and supervision of schemes by the office. Little role of local communities was seen during water supply development activities; besides Women participation at the time of development of water supply schemes and after development is completed is insignificant. All the above mentioned factors plays significant role for the failure of the developed water supply schemes. A finding of the study also show investing on knowledge of professionals is first priority of beneficiaries to minimize the rate of failure of water supply schemes.

CHAPTER ONE

1. INTRODUCTION

1.1 Background and Justification

Worldwide, the demand for water is growing rapidly, and in many countries the cost of developing new supplies is becoming prohibitive. Simultaneously, increased water pollution is worsening the imbalance between water supply and demand. Water is a vital resource for human survival and economic development; as populations and economies grow; water demand increases while the availability of the resource remains constant (FAO, 1992). For these reasons, water resources development is of critical importance in efforts to improve food security and sustainable agricultural production.

In 2004, about 3.5 billion people worldwide (fifty-four percent of the global population) had access to piped water supply through house connections. Another 1.3 billion (twenty percent) had access to safe water through other means than house connections, including standpipes, "water kiosks", protected springs and protected wells. Finally, more than 1 billion people (sixteen percent) did not have access to safe water, meaning that they have to revert to unprotected wells or springs, canals, lakes or rivers to fetch water (MacDonald 2004).

In many countries, water shortages stem from inefficient use, degradation of the available water by pollution and the unsustainable use of the resource. Ethiopia is one of the countries, which are facing critical problem on the shortage of potable water supply (Rahmato, 1999).

Ethiopia is endowed with a substantial amount of water resources. It has been termed as the "Water tower" of northeast Africa. From the 12 major river/drainage basins the total annual runoff has been estimated at about 110 billion cubic meters. Almost eighty percent of this water actually leaves Ethiopia and flows into the neighboring countries. Groundwater potential in Ethiopia is estimated at approximately 2.6 billion cubic meters. Quite a small portion of this resource is presently developed in the rural areas, the limitation being prohibitively high initial development cost. Already developed groundwater sources are used

primarily for drinking water supply. It offers access to safe water for approximately 40-80 per cent of the water supply provided to the urban and rural population, and it is the largest fresh water source in the country (Getachew Alem, 1998).

Ethiopia has a very low level of water supply coverage, with only 17 and 35% of the rural and urban population having access to safe drinking water respectively, and similarly low levels of sanitation coverage. In addition, Water quality is one of the main factors restricting the development of available water resources. (Kamara *et al*, 2005)

Groundwater is a unique resource, widely available, providing security against droughts and yet closely linked to surface water resources and the hydrological cycle. Its reliable supply, uniform quality and temperature, relative turbidity and pollution free, and minimal evaporation losses are attributes making groundwater more attractive when compared to other sources. Groundwater is considered the prime source of water supply in Ethiopia for both rural and urban communities. (Ethiopia Water Technology Center Project, JICA, 2007).

In order to manage equitable distribution of water in the study area, determination of total available resource is critically important. Identification of factors accountable for depletion of water resources is useful for policy makers to manage the problem with respect to the rising demand. The research is therefore, an important input for water resource management of the area to provide sustainable and equitable supplies for communities.

1.2 Statement of the Problem

Safe and adequate water has multiple benefits which extend into the spheres of health, education, environment, economic production, and cultural and gender matters. The rural population with access to adequate and safe water is very small. More than 50 million people out of 73.8 million total populations have no access to safe and adequate drinking water. Many of the water schemes constructed were poorly designed and had adverse environmental consequences. (Rahmato 1999). ADF (2005) report shows that thirty-three percent of the rural water supply schemes in Ethiopia are non-functional due to lack of funds for operation and maintenance, poor water quality, inadequate community mobilization and commitment, as well as lack of spare parts.

Groundwater is the prime source of domestic water supply schemes in the study woreda. However, Out of the developed schemes many are failed to meet their objectives due to various reasons, resulting in unsustainable utilization of the resource. The community in the study woreda (Dugda) suffers from serious water problems.

Bearing in mind the above issues, this research largely focused on the assessment of causes of sustainability challenges of water supply schemes of Dugda woreda and recommending possible solutions for sustainable utilization and management of the resource which is very important in poverty reduction.

1.3 Objective

1.3.1 General Objective

The main objective of this research is assessment of groundwater resource potential of meki river catchment and assessment of challenges of water supply sustainability in Dugda woreda.

1.3.2 Specific objectives

To assess the ground water resource potential of the study catchment:-

- Characterization of major aquifer systems
- Estimation of Ground water recharge by water balance calculation
- Description of mechanism of recharge of the ground water system
- Description of the hydrochemical nature of the resource from the analysis of water chemistry data

To assess the causes of water supply sustainability problems of the study woreda from:-

- Quality perspective
- Skill perspective
- Institutional/ management failure perspective
- Lack of proper investigation and
- Social perspective

1.4 Methodology

1.4.1 Methods used to assess Groundwater potential

To assess the ground water potential of the catchment; various approaches and methodologies were applied. These are:

- ♣ Literature review, survey and analysis of previous works, topographic and other maps of the study area.
- ♣ Meteorological and River discharge data were collected from Ministry of Water Resources and National Meteorological Service Agency, respectively; and used for the analysis of hydrometeorology of the study area.
- ♣ Collection of well log data, pumping test data, and water scheme inventory reports; and formation of data base under GIS environment to understand the geologic and hydrogeologic system of the catchment was made.
- ♣ Field work accompanied by systematic field methods, geo-referencing water points using GPS is conducted.
- ♣ Interpretation of data in accordance with the field observation, and literature review.
- ♣ The analysis and interpretation of data were carried out by using different Softwares. The softwares used in this research are: Erdas 8.6, Arcgis 9.1, Global mapper 5, surfer 8, Aquachem, Time plot and Microsoft Excel.

1.4.2 Methods used to assess Water supply sustainability problems

The following approaches and methodologies were applied to assess the water supply sustainability problems of the study woreda. These are:

- ♣ Data and information about the beneficiary's perception of water supply sustainability problems were collected using different methods of data collection; like structured questionnaire, interviews and discussions with beneficiaries, members of different water committees, technical staff members, and personal observations were employed to produce primary data.
- ♣ Two types of questionnaires were designed to assess the socio-economic situation of the study area, which were administered to sample households and technical staffs.

- ♣ The survey questionnaires were comprised of both closed and open ended types and cover various issues of water supply sustainability problems.
- ♣ Prior to implementing the survey, the questionnaires were tested after which necessary amendments were incorporated.
- ♣ High school leavers were recruited and trained to conduct the survey. The facts that the house holds in the area are Oromifa speakers, bilingual enumerators from the study area were recruited.
- ♣ In order to conduct the households survey, total number of house holds with in the woreda were collected from Dugda woreda administrative office; then the households were selected using random sampling. Five peasant associations (PA's) were chosen for the house hold survey. These are representative PA's which can characterize the whole water supply sustainability problem of the woreda.
- ♣ Households to be included for the survey were randomly chosen from the lists of households in the selected PA's; when the household was unavailable or unwilling to be interviewed a substitute was selected.
- ♣ An interview was also made with concerned technical persons whom their responses are very important to understand the sustainability problems of the water supply schemes in the Woreda.
- ♣ Informal discussions with key informants about the sustainability problems of existing water-supply schemes and their management have been conducted.
- ♣ The analysis and interpretation of data were carried out by using Soft wares like Microsoft Excel, SPSS etc.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Water Resource Management

Water is a mobile resource: it falls from the clouds, seeps into the soil, flows through aquifers, runs along stream courses, and eventually returns to the clouds. This natural cycle is the basis of all life forms and of the economy of nature. Over 70 percent of the Earth's surface is covered with water, but less than 3 percent of that is freshwater most of it locked up in glaciers, ice caps, atmosphere and deep groundwater reservoirs. Just 13 percent of the globe's total freshwater is readily available to meet human needs. In the meantime, worldwide demand for water is doubling every 21 years according to FAO, (1992). As industrial, agricultural and domestic pollution threatens finite supplies, water is becoming an increasingly precious resource that must be managed with care (Rahmato, 1999).

Water may be "managed" in different ways: it may be harvested, extracted from the ground, diverted, transported, and stored. This makes it different from all other natural resources. However, each form of management that interferes with the natural cycle exacts a price, not just in economic terms but in terms of environmental damage and greater health hazards. Moreover, water does not occur alone, it is rather part of a complex ecosystem consisting of the land, plants, aquatic and other life forms. The improper and unregulated use of water by humans will not only damage the water source but the ecosystem as well.

Access to adequate and clean water will greatly contribute to improved health and better productivity. Secondly, water resources can play a significant role in improving food security and household income. Irrigation is the most common means of ensuring sustainable agriculture and coping with periods of inadequate rainfall and drought. The extent to which water resources will contribute to sustainable livelihoods will depend on availability, the nature of rights of access, the system of management and the technology with which the resources are exploited.

Water Resources Management is the integrating concept for a number of water sub-sectors such as hydropower, water supply and sanitation, irrigation and drainage, and environment.

Integrated Water Resource Management (IWRM) has emerged during the last decade as a response to the ‘water crisis’: the widespread and well-articulated concern that the planet’s freshwater resources are coming under increasingly unsustainable pressure from rising populations, growing demands for water and increasing pollution.

How bad is the water crisis?

- Every 8 seconds, a child dies from a water-related disease
- 50 percent of people in developing countries suffer from one or more water-related diseases
- 80 percent of diseases in the developing world are caused by contaminated water
- 50 percent of people on earth lack adequate sanitation
- 20 percent of freshwater fish species have been pushed to the edge of extinction from contaminated water.

It is increasingly realized that the heart of the water crisis is poor management or governance. IWRM seeks to tackle some of the root causes of the management crisis, namely the inefficiencies and conflicts that arise from Un-coordinated development and use of water resources. (Patrick, 2004)

2.1.1 Water Resource Management in Africa

In sub-Saharan Africa, 300 million people have no access to safe water supplies – approximately 80% live in rural areas. Without safe water near to dwellings, the health and livelihoods of families can be severely affected; children’s education suffers as the daily tasks of survival take precedence over all other concerns. Many water projects in Africa are performing poorly or have failed outright, often with damaging environmental consequences. In many instances, the benefits have gone to a small segment of the urban elite and not to the masses of needy peasants and pastoralists (Bhattarai, 2005).

Over much of Africa, groundwater is the only realistic water supply option for meeting dispersed rural demand. Alternative water resources can be unreliable and difficult or expensive to develop: surface water is prone to contamination, often seasonal, and needs to be piped to the point of need; rainwater harvesting is expensive and requires good rainfall throughout the year (Rahmato, 1999).

The characteristics of groundwater make it well suited for water supply and sanitation are listed below:

- Groundwater resources are often resistant to drought.
- Groundwater can generally be found close to the point of demand (if you look hard enough with appropriate expertise).
- Groundwater is generally of excellent natural quality and requires no prior treatment.
- Groundwater can be developed incrementally, and often accessed cheaply.
- Groundwater is naturally protected from contamination.

Understanding the hydrogeology is the key to identifying how the water point will behave under stress and also the long-term sustainability of groundwater resources under the impact of drought and climate change. A well-planned community supply, that takes into account the nature of the groundwater resources, will be sustainable (MacDonald, 2004).

2.1.2 Water Resource Management in Ethiopia

The overall goals of the national water resources management policy of Ethiopia is to enhance and promote efforts towards an efficient, equitable, and optimum utilization of the available water resources and contribute to the country's socioeconomic development on sustainable basis (MoWR, 2001).

Modern water development schemes are a relatively new phenomenon in the country. The Imperial government took the first initiative in water resource development in the second half of the 1950s. Large-scale water projects for agricultural purposes and power generation were constructed from the end of the 1950s, and were concentrated in the Awash valley as part of the agro-industrial enterprises that were expanding in the area at the time. They subsequently spread to the Rift Valley and the Wabe Shebelli basin. Essentially, the government's interest at the time centred almost entirely on large-scale and high technology water projects: hydro-power dams, irrigation schemes, and water supply projects for Addis Ababa and a few major towns. Since then, all large-scale schemes in the country have been constructed at the initiative of the government (Rahmato, 1999).

2.2 The domestic water supply and sanitation sub-sector

As populations and demands on water resources continue to grow, professionals working in domestic water supply and sanitation (WATSAN) are faced with a range of critical questions. How to develop reliable sources with sufficient water for domestic supplies? How to ensure adequate water quality, and protect sources from pollution? And how to minimize the impacts of water abstraction and water pollution on other water users? Finding answers to these questions, and putting in place processes that lead to sustainable solutions, is of increasing importance as we continue to see more conflicts over access to water affecting domestic supplies, more systems failing due to source problems, and rising infrastructure and treatment costs (Batchelor, 2004).

The limitations of traditional approaches based on supply provision have been recognised in many places, and the principles of integrated water resources management developed (IWRM). It is easier to identify the failings of past approaches, however, than to specify new directions forward. Poverty-focused development projects or programmes cannot continue to ignore WSS in areas with inadequate water supplies and sanitation provision. It is typically the key priority in situations where resources are scarce, supplies irregular and/or water quality is poor. The poor themselves are usually acutely aware of the impact of poor WSS on their health and general well-being, whilst women in particular suffer the burden of fetching water and managing with inadequate supplies (Patrick, 2004).

2.2.3 Water supply and sanitation in Relation to Gender

Women play an important role in water management. They are most often the collectors, users and managers of water in the household. Because of these roles, women have considerable knowledge about water resources, including quality and reliability, restrictions and acceptable storage methods, and are the key to the success of water resources development. Women and children provide nearly all the water for the household in rural areas. Domestic water is used for processing and preparing food, for drinking, bathing and washing, for irrigating home gardens and watering livestock. Women know the location, reliability and quality of local water resources. They collect water, store it and control its use and sanitation (FAO, 1992).

Women spend many hours each day fetching water. Often the sources of their water are unprotected springs, or polluted streams or ponds. By virtue of their household functions they use more of this polluted water than the rest of the household, and therefore they are most vulnerable to water-borne diseases. Thus the development of safe water supply is of particular benefit to women. Access to safe water within easy reach of the household means women can save time, labour and effort, which they can employ in more productive agricultural and income generating activities. Safe water will also mean they and their children will be protected from many water related diseases (Rahaman, 2003).

2.2.4 Defining the Key Challenges

Attempts to improve WSS provision have traditionally focused on increasing supply based around infrastructure development, but the limitations of such approaches are now widely recognized. Infrastructure is important, indeed essential, but so are effective management systems, accountability to consumers and fair and transparent allocation mechanisms. (John et al 2001)

There is a clear need to raise awareness and counter traditions and misconceptions about what will or will not work. There is also a clear need to document cases where innovative approaches have worked so that these can provide models of good practice that can further the case for such approaches and provide exemplars for adaptation and adoption elsewhere.

2.2.5 Why Do Water Supply Systems Fail?

Of the many challenges to the sustainability of water supply projects in developing countries, two stand out. The first is the dependence of community-based approaches on the strength of community spirit. While it is true that in many developing countries, especially in more remote areas, traditional community organizations and loyalties are strong, many ‘modernizing’ influences threaten this strength.

The second challenge lies within Government agencies themselves. Bureaucracies, especially in developing countries, tend to be rigid in their structures, staffing, rules, and procedures, as well as providing inadequate remuneration to their staff (Robert and Zimmerman 1998). The radical change of approach from direct implementation of projects to the enabling of communities to manage their own schemes requires major shifts in attitude, approach, and technique, which have been very slow in emerging. To quote a recent review of the African domestic water and sanitation sector: “(It is generally agreed that) *community engagement and*

empowerment is the solution to the sustainability of water supply and sanitation services. The hallmark of empowerment and capacity building are factors such as transparency, partnership, flexibility, respect, and empathy.

There are many causes of persisting water supply system failures. Some of the most important are identified in Table 2.1.

Table 2-1: some of the principal causes of water supply system failures. (Source: John et al 2001)

Causes of water shortages	Examples
Physical constraints not properly addressed during planning	<ul style="list-style-type: none"> • poor aquifer with limited storage • arsenic/ fluoride risks • potential competition with other uses, especially irrigation, not addressed
Engineering shortcomings	<ul style="list-style-type: none"> • reticulation systems that are too expensive to operate and maintain
Institutional/ management failure	<ul style="list-style-type: none"> • illegal connections to water supply systems and consequent problems in tail-end villages • overexploitation of groundwater under conditions of open access • poor cost recovery leading to lack of investment/maintenance • lack of maintenance e.g. hand pumps • poor institutional organization for the O&M of communal facilities
Rising demands	<ul style="list-style-type: none"> • increasing population • incentives to use water inefficiently especially for irrigation • changing patterns of water use with changes to lifestyles
Social Factors	<ul style="list-style-type: none"> • Social barriers to access to water supply facilities

The causes of non-sustainability are numerous:

- communities or households may never have been convinced of the desirability of new water sources, in the first place;
- the financial costs which communities are expected to raise as a contribution to capital or recurrent expenses may be unacceptable, unaffordable, or impracticable (eg monthly or quarterly cash contributions may be impossible for households which only receive income at harvest);
- communities may never have felt ownership of the new infrastructure, and governments may have been over-stretched and under-resourced, so that repairs and maintenance have not taken place;
- benefits promised at the outset of projects (e.g. dramatically improved health) have failed to materialize;
- Community education (e.g. hygiene education) and the attitudinal and behavioral change expected to be achieved by it, take a long time to produce results, and yet it often ceases prematurely. (Khatri and Vairavamoorthy, 2007).

Even where full community participation or management has been planned in from the start, community-level committees and caretakers have lost interest or trained individuals have moved away. This can be a particular risk if community-level organization is on a voluntary basis (Richard, 1999).

2.3 Water Supply and Sanitation in Ethiopia

Ethiopia has not utilised its water resources adequately or wisely. As we shall see further down, the country lags behind many African countries in the development of safe water supply. Many of the water schemes constructed were poorly designed and had adverse environmental consequences (MoWR, 2001).

Groundwater is considered the prime source of water supply in Ethiopia for both rural and urban communities. (Ethiopia Water Technology Center Project, JICA, 2007). The coverage rate of water supply in Ethiopia remains to be one of the lowest in the world. More than 50

million people out of 73.8 million total populations have no access to safe and adequate drinking water.

Supplying adequate and clean water to the population improves many of the economic and social dimensions of poverty. It improves the health of the population with concomitant advances in the quality of life. Moreover, it releases the labor (particularly that of women and female children) used to carry water, which in turn could be used elsewhere, mainly in education for girls. Access to safe potable water in the year 2000 for urban areas in Ethiopia was 38%. Access to safe potable water for rural Ethiopia is about 24%. The country utilizes only a small proportion of its ground water potential of 2.6 billion cubic meters. Except for Addis Ababa and a few urban centers, sanitation facilities are basically non-existent.

. According to MoWR document (1997b), prepared for the Ministry by the international accounting firm of Ernst and Young, the average water supply coverage for urban settlements excluding Addis Ababa is 31.3 percent. If we disaggregate this by population, the coverage for urban settlements with more than 50,000 people is 58 percent while coverage for those with 5,000 or less is 14 percent. The same document states that the average coverage for rural settlements is 15.2 percent and for the whole country 17.3 percent. Regionally, its findings were 34 percent coverage for Tigray, 14.3 percent for Oromia, 12.5 percent for the Southern Region, and 8.3 percent for Amhara Region. Thus the great majority of Ethiopians uses unsafe and polluted water and as a result is commonly exposed to a large variety of water-borne diseases. *MoWR defines "adequate" water supply to mean 20 litres of water per person per day and accessible within a range of 0.5 to 1.0 km from a dwelling place* . The WHO standard, which was once adopted by WSSA, is 45 litres per person per day. Thus, most households with access to safe water do not get sufficient quantities of it for a healthy life. The current level of per capita water consumption is far below the adequate level set by MoWR. We should also note that in the rural areas safe water does not mean water that has undergone treatment: most households have access to potable water only from wells and protected springs (Rahmato, 1999).

An important impetus for expanding the rural water supply programme in the country was the drought that hit the country in the 1970s and the 1980s. As part of their response to the environmental crises of these years, a considerable number of NGOs and several donor

agencies became actively involved in rural water supply schemes. At present, some 38 NGOs, UNICEFF and number of bilateral organisations are closely involved in rural water supply. It should be noted here that some of the schemes are not functioning due to faulty installation or lack of maintenance (CRDA, 1997).

Among the main reasons given for the slow pace of progress in water supply services the following are noteworthy and are still relevant today: the lack of comprehensive water legislation; inadequate investment resources. Moreover, there has been a strong urban bias in water supply programmes, and the rural areas have suffered as a result. On the other hand, *the main reason for the poor record of sustainability of existing water schemes in the rural areas is the absence of beneficiary participation and community management.* (MoWR, 2001).

From hydrochemical, geological, tectonic and hydrological point of view, many studies have been done in the central rift valley including the study area which directly or indirectly related to this study. All the previous works I have reviewed so far have little or no considerations on the sustainability problems of water supply schemes of the area. In this study the author tries to assess the groundwater resource potential and all possible causes of water supply sustainability problems of the study area.

CHAPTER THREE

3 GENERAL DESCRIPTION OF THE STUDY AREA

3.1 Location

The study was conducted in central Ethiopia and within the Main Ethiopian Rift Valley in the northern sector of the Lakes Region. Located partly in Oromia (East Shewa zone) and partly in Southern Nations and Nationality State. The whole study area is found within Meki River Catchment and it covers five woredas namely:

Meskan, Mareko, Soddo, Siltie and Dugda. The first three Woredas are located in Gurage Zone of Southern Nations Nationalities, and Peoples Region (SNNPR). Siltie is located in Siltie zone of SNNPR. Dugda is located in East Shewa Zone of Oromia Region. The area extends from Gurage highlands in the west to Lake Ziway in the east.

The catchment is accessed by Addis Ababa–Ziway and Addis Ababa–Alem Gena–Butajira asphalt road. Intra catchment is accessed by many gravel and dry weather roads. Meki town which the capital of the study woreda is situated at about 134 kms far from Addis Ababa.

Geographically the study area is bounded within the limits of $7^{\circ} 59' 32''$ to $8^{\circ} 27' 23''$ N latitude and $38^{\circ} 14' 48''$ to $38^{\circ} 49' 35''$ E longitude (Fig 1); with an aerial extent of 1668.5Km^2 and perimeter of 207.8 km.

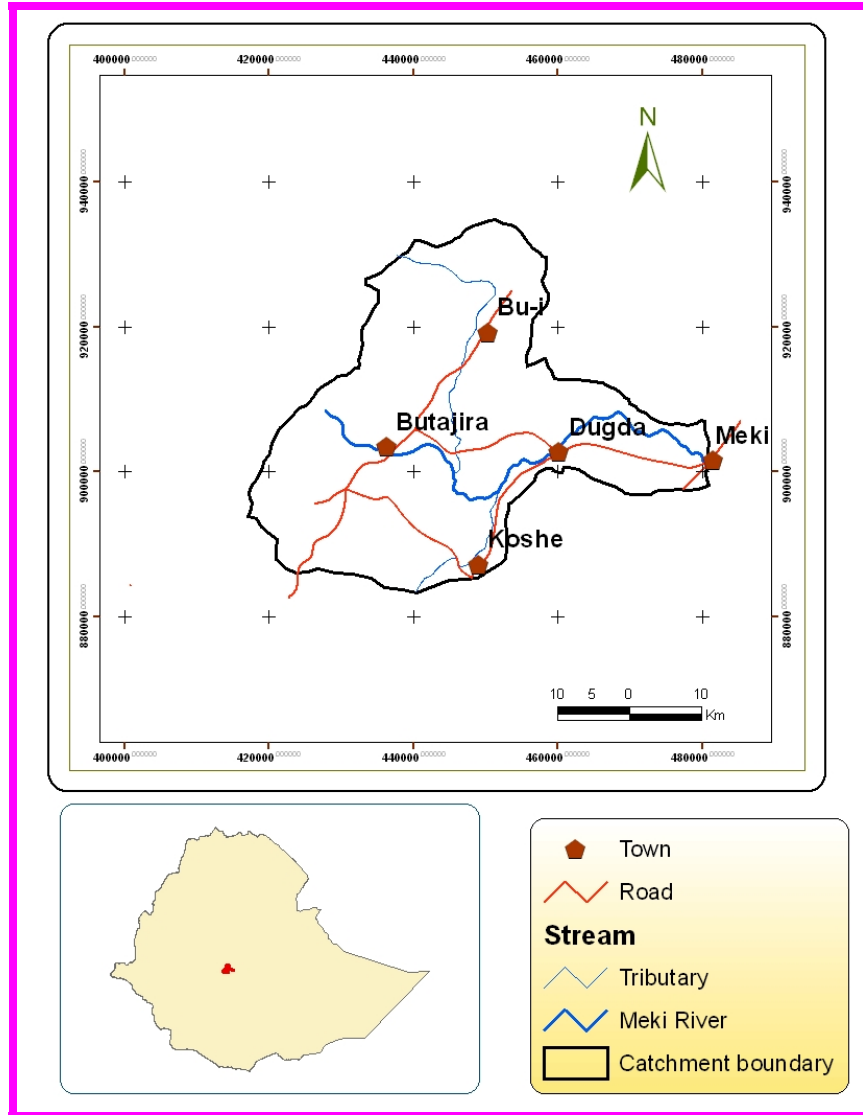


Figure 3-1: Location map of the study Catchment

3.2 Topography

Topography of the area is primarily determined by the rift system faulting. Rift margin faults have undergone a long period of erosion while those of the rift floor are mostly recent (Tesfaye Chernet, 1982). According to Dagnachew Legesse (2003), the catchment can generally be divided into three physiographic areas: the high plateau on the western reach of the study area, the transitional escarpment and the rift floor. The catchment lies within altitudes ranging from 3600a.s.l in the west to 1600 m.a.s.l near to Lake Ziway. The upper reaches of the catchment is steep and mountainous while the lower basin is flat with a broad

valley. Most parts of plateau area are perennial sources of the river while the tributaries in the escarpments and rift floor are almost intermittent sources.

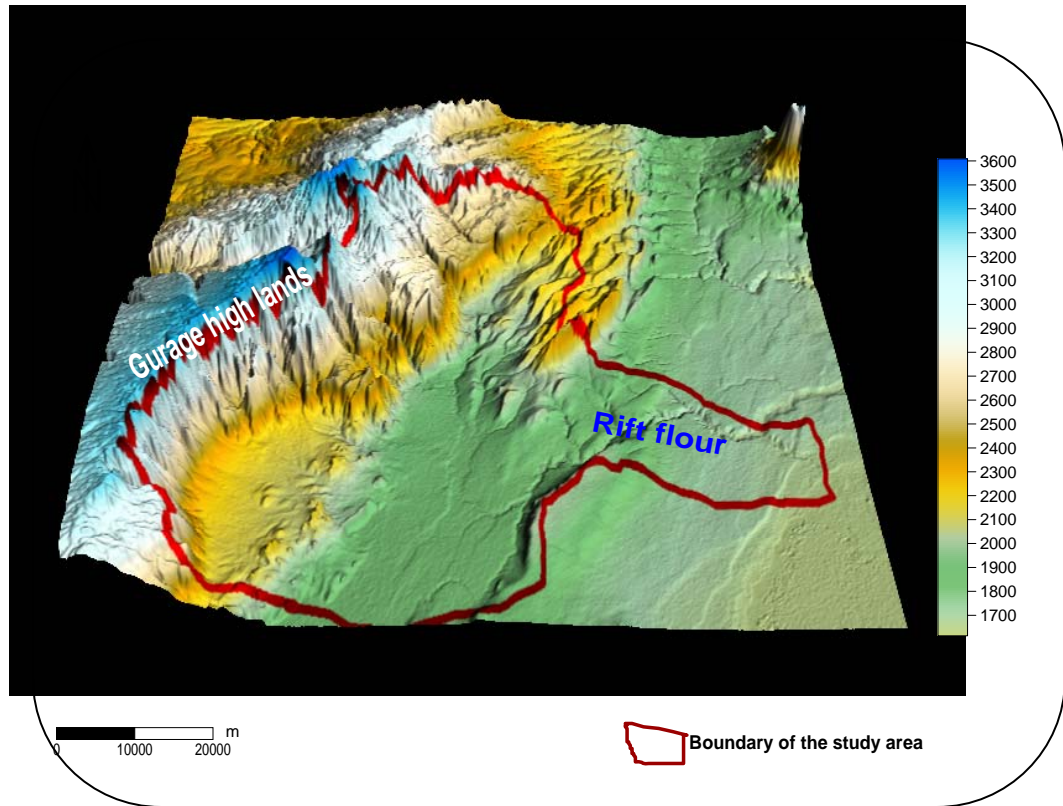


Figure 3-2: Digital elevation model showing Topography of the study catchment

3.3 Drainage

Meki River originates in the highlands of Gurage and travels a distance of about 100 Km from the highlands at altitude of 3,600 m to 1,600 m before draining into Lake Ziway. Moreover, the highland is characterized by higher drainage density than the escarpment due to differences in rock permeability, climate and slope (Chernet, 1982).

Rift faults have affected the drainage of the area both by influencing the river courses and by impounding river water and causing some marshy areas, in the southern part of the study area. (Chernet, 1982).

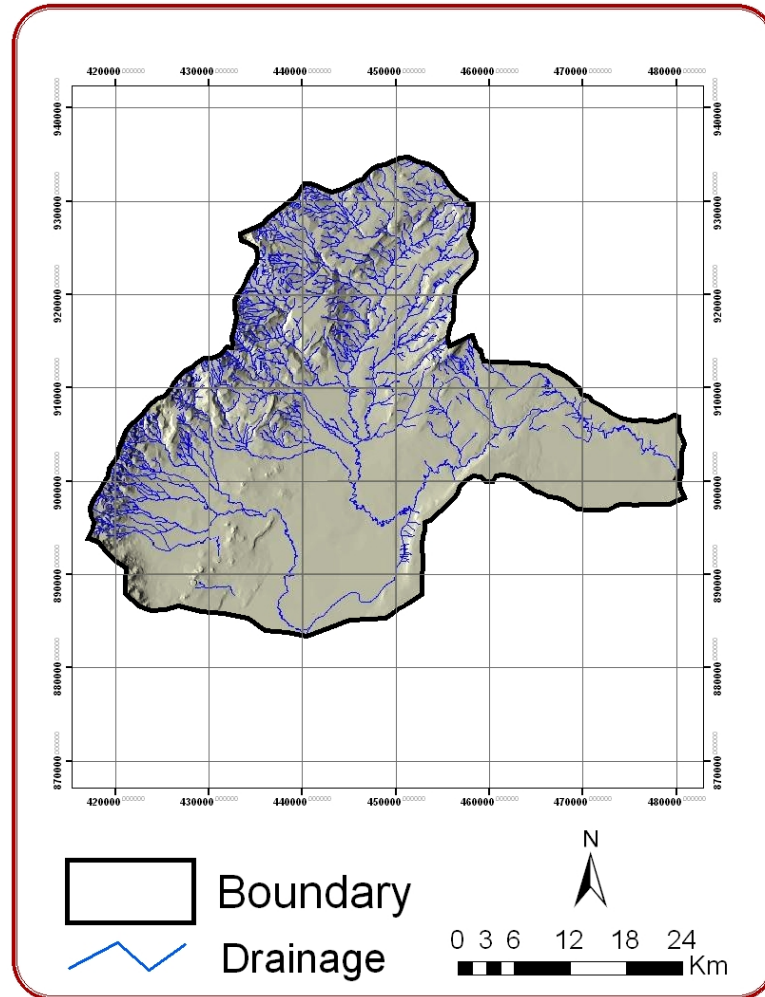


Figure 3-3: Drainage map of the study catchment

3.4 Climate

The study area has a wet season from July to September, dry season from October to January, and a season of highly variable rainfall from February to June. According Makin et al (1975), climate of the study area consists of three ecological zones: humid to dry humid lands, dry sub-humid or semi arid lands and semiarid or arid lands. Accordingly, highland areas west of Butajira are categorized under humid to dry sub-humid land. The areas east of Butajira are dry sub-humid lands. The rest of the area which is around the lake is in semiarid or arid zone.

The average annual rainfall of the study area varies spatially from about 740mm in lowland to 1200mm at extreme highland areas. The wet season winds are generally south-easterly or south-westerly, depending on the location of low pressure convergence zone towards the north of the country. At the beginning of the dry season, the convergence zone moves south

across the study area and thereafter a dry northeasterly air-stream is established with very stable conditions. The climate is characterized by low rainfall and humidity, moderate but persistent winds and by a high rate of evaporation, which averages 5.3 mm/day. Night temperatures commonly fall to less than 10°C and frosts can occur on land above 1800 m a sl. Between February and June, rain-bearing winds are channeled northwards through Rift Valley with the northward movement of low-pressure convergence zones. Rainfall is sporadic and unpredictable. Sometimes the stable dry season conditions persist until March, though there is great variation from year to year.

3.5 Socio-Economic Characteristics of the Study Area

In the study catchment people of Oromo and Gurage are predominantly living, other minority groups such as, Amharas, Afar, Tigray etc. are also living in the area. The sustainability problem of water supply schemes will be conducted in one woreda, i.e. Dugda. A survey of the land in this woreda shows that 36.9% is arable or cultivable, 8.7% pasture, 9.6% forest, 0.4% swampy and the remaining 44.3% is considered degraded or otherwise unusable. Fruits and vegetables are important cash crops. There are 36 Peasant Associations with 18,946 members and 2 Farmers Service Cooperatives with 2226 members. Dugda has 85 kilometers of dry-weather and 122 of all-weather road, for an average road density of 142 kilometers per 1000 square kilometers (www.oromia.org, 2007).

3.5.1 Population

The population in the selected district (i.e Dugda) of the study area was estimated to be 81,687, of whom 41,489 were males and 40,198 were females; 25.53% of its population are urban dwellers, which is less than the Zone average of 32.1% With an estimated area of 1082 square kilometers, Dugda has an estimated population density of 134.5 people per square kilometer, which is less than the Zone average of 181.7 based on the Statistical Abstract, 2005, prepared by Central Statistical Agency.

3.6 Soil

The major soil types in the Rift Valley clearly show the influence of the parent material and extent of weathering. So that Soils of the study area are closely related to the parent material and degree of weathering (Makin et al 1976). The main parent materials are basalt, ignimbrite, acidic lava, volcanic ash and pumice, and riverine and lacustrine alluvium. Tesfaye Cherenet (1982) also found that the geological formation in the upper soil profile has good primary and secondary porosity and permeability characteristics, which enable continuous recharge to the groundwater.

According to Makin et al, 1976, there are three soil types in the area

Type I: covers predominantly the rift floor formed on pyroclastic deposits. Generally, the soils are dark grayish free draining friable silty loam to sandy loam with moderate structure and good moisture storing properties. This soil covers 9.6% of the total area of the study Catchment.

Type II: is found on steep faulted undulating and rolling low plateau escarpments of the rift zone. The soil is well drained, brown, friable silty loam to sandy loam with moderate structure and good moisture storing properties. This soil covers 53.3% of the total area of the study Catchment.

Type III: is well drained deep reddish brown to red, friable clays to clay loams.

This soil type is found on flat to undulating plateau of western margin and it covers 37.1% of the total area of the study Catchment.

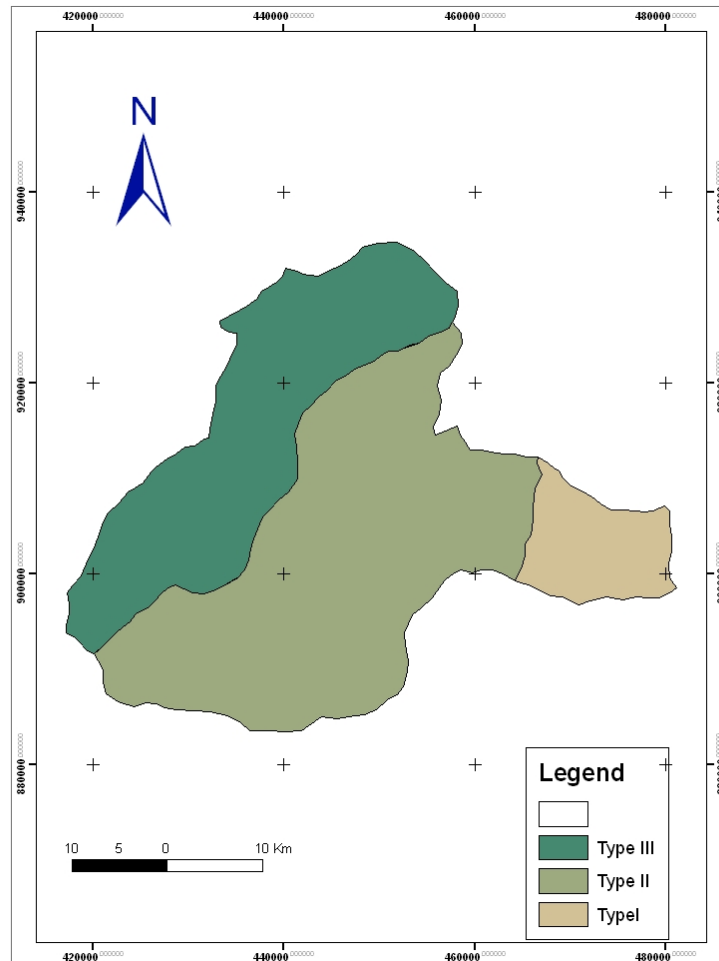


Figure 3-4: Generalized soil map of Meki catchment (Modified after Alemu Dribssa, 2006)

Table 3-2: Aerial distributions of Soil types.

Class	Soil type	Area%	Area(km) ²
2	Type I	9.6	161
3	Type II	53.3	888.5
4	Type III	37.1	161

3.7 Land use and land cover

The different topographic and climatic conditions determine the ground ecological groups in the catchment; each of which is characterized by particular associations of vegetation (Alemu Dribssa, 2006). The vegetation in the Rift Valley is mainly characterized by wooded grass land with various species of acacia. Around the lakes the dominant species are *Acacia tortilis*. These species are extensively used by the local people for charcoal production. To date, much of the Acacia Woodland is converted into agricultural and grazing land. This conversion results in ecological

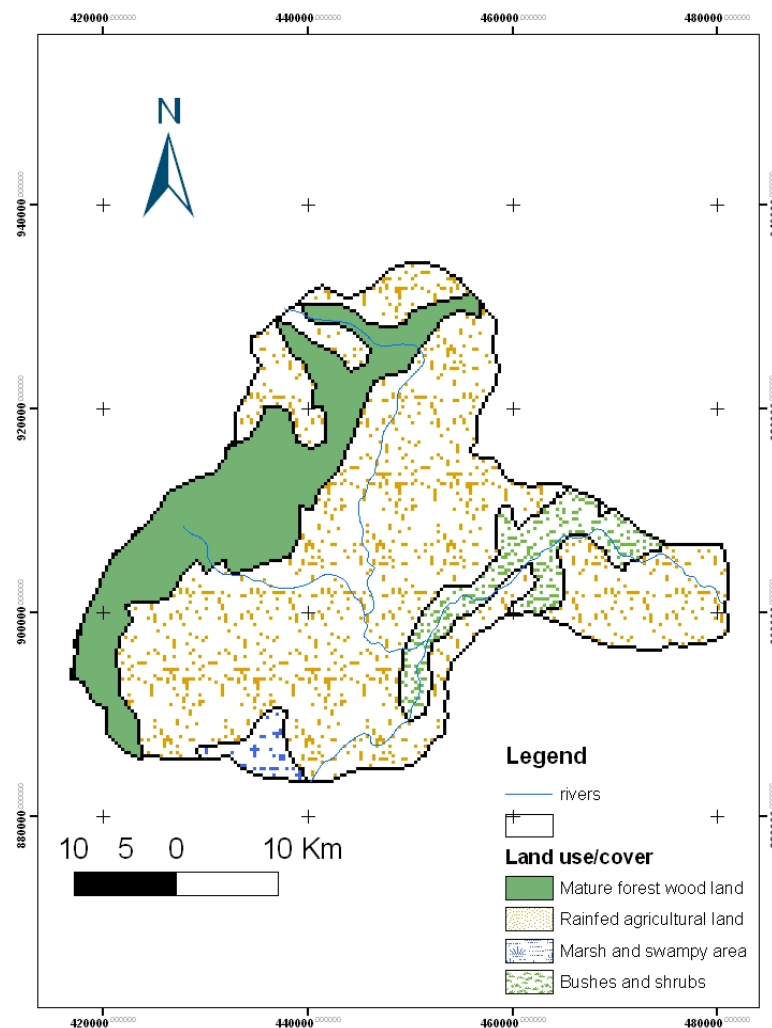


Figure 3-5: Land use/land cover map of Meki river catchment (Modified after Alemu Dribssa, 2006)

imbalance and leads the whole region into desertification, which is accelerated by high wind and storm erosion. The detail land cover comprises of numerous groups. However, for its relevance to the objective of study, like estimation of actual evapotranspiration and direct groundwater recharge, the catchment is classified as listed in the table below (Alemu Dribssa, 2006).

Table 3-3: Arial distributions of land cover units

Class	Cover type	Area%	Area(km) ²
1	Marshy and swampy areas	2.2	36
2	Rain fed cultivated land	70.9	1182.5
3	Bushes and shrubs	7.5	125
4	Woodland and afro-alpine vegetation	19.4	325

CHAPTER FOUR

4. GEOLOGICAL SETTING

4.1 Regional Geology

The geological and tectonic processes operated by the internal forces in the rift system generally govern the geology and geomorphology of the area. magmatism and extensional processes, which resulted in the MER and sea floor Spreading in the red and Gulf of Aden, is related to Afar Plume. Uplifting, magmatism and extensions in Ethiopia and East Africa is attributed to a single plume activity beneath Ethiopian plateau (Afar Plume). Extensional processes commenced after volcanic activities in Ethiopian plume activities.

The Ethiopian rift system is subdivided in to the South-west Rift, which includes the Lake Turkana and the Lake Chamo Rift in the south; the Main Ethiopian Rift (MER), in which the study area is located, in the center; and the Afar, which is a triple junction between the MER, the Red Sea Rift and the Gulf of Aden. According to (Mohr, 1967), subsequent volcanic activity has been largely confined to the Wonji Fault Belt (WFB), a 5 – 15 km wide, NNE to SSW – trending zone of intense quaternary faulting which tends to be axial to the rift floor. In association with this fault belt several important clusters of hot springs have been originated.

Both the eastern and western escarpments are mainly composed of ignimbrite and, particularly along the western escarpment, lacustrine sediments with some scoria cones. The rift floor is fully occupied by lacustrine sediments and acidic rocks (welded and un-welded tuff, ash flow tuff, and pumice and obsidian rich lava. Tesfaye Chernet (1982) indicated that the geology of the large part of the rift valley areas is characterized by Lacustrine Sediments and Volcano-Sedimentary Rocks.

The MER development is related to volcanism. They believed that the initial rifting began in the Oligocene-early Miocene. In the late Oligocene nearly Miocene the first Tertiary Volcanism dominated by basaltic rock occurred, which forms a Series of half graben with opposed border faults of greater than 60° dip. In middle Miocene an important volcanic event

occurred which is associated with the edification of the main Ethiopian Rift and it is dominated by Rhyolitic rocks. In Late Miocene- Early Pliocene another very large volume basaltic eruption occurred, which was associated with the full development of the MER by forming or evolved into symmetrical grabens. Finally in the Pleistocene Volcanism dominated by Rhyolitic rocks occur which is the youngest and associated with the rift reorientation and the formation of the Wonji Fault Belt which is the active axis of the Main Ethiopian Rift (Giday Woidegebriel et al.1990).

4.2 Geology of the Study Area

The geologic and geomorphic features observed in the study area are the results of Cenozoic volcano-tectonic and sedimentary processes.

4.2.1 Nazareth group and Dino Formation Undifferentiated

This volcanic rock occupies the western escarpment. It includes what was mapped by Di Paola (1972) as basalts and ignimbrites of the Plateaux Trap series. The Nazareth group includes ash flow tuffs, pantellritic ignimbrites and un-welded tuffs while the Dino formation is made up of Dino ignimbrites. These rocks outcrop at the NW part of the plateau in the study area.

The rift ignimbrites are highly faulted and outcrop in most parts of the rift. This formation covers mainly the Tora- Koshe- Dugda Ridge. It is made up of lithic and pumaceous tuff alternating with highly weathered reddish brown ash.

4.2.2 Basalts and associated flows of the rift floor

This unit consists of recent basalts which is located close to the western escarpment, in the Butajira-Siltie area. The formation of this group is from Pleistocene to Holocene and includes basaltic hyaloclastics and recent basalts outcropping in the rift floor. The hyaloclastics consist of fine glassy material; generally yellowish to brown in color containing small boulders of basaltic lava. This flow consists of a lot of scoria. This lava field (Cinder cones and lava flows) are aligned from Siltie in the south to Shershera in the north of Butajira. They look to have come out along a regional fault.

4.2.3 The Central Rift volcanic complexes

This portion consists of several individual volcanoes and volcanic complexes. The groups are characterized by rhyolytic lava flows and domes associated with the rift floor ignimbrites with age ranging from 0.24 to 0.02 million years. The ignimbrites and pumice are the result of gas rich silicic magma. The alkaline and peralkaline silicics are the last volcanic products and are located in the slopes of Bericho, Bora, O-Itu koshe, Alluto volcanoes, and Gadamotta Volcanoes northeast, of Lake Ziway. The pyroclastics are unwelded pumice and tuff, obsidian, pitchstone and rhyolytic lava flows.

The group is divided in to two units and described as follows:

- i. *Bora-Bericho*: The volcanics are formed in late Pleistocene - Holocene and consists of two large volcanic centers (Bora and Bericho) associated with a great number of smaller volcanic foci and with sub historical limited fissure eruptions. Most of the products found in this area are silicic pyroclastics. Bora volcano is located on the northeast of the study area and it consists of alternates of pumice and ash layers.
- ii. Poorly welded or completely unwelded Bericho volcanics are located just northeast of Bora and comprises completely of unwelded pumice flows. (Abiyu kebede, 2007)

4.2.4 Volcano-sedimentary rocks and lacustrine sediments

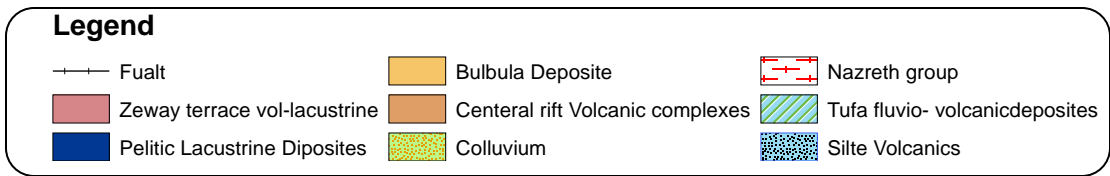
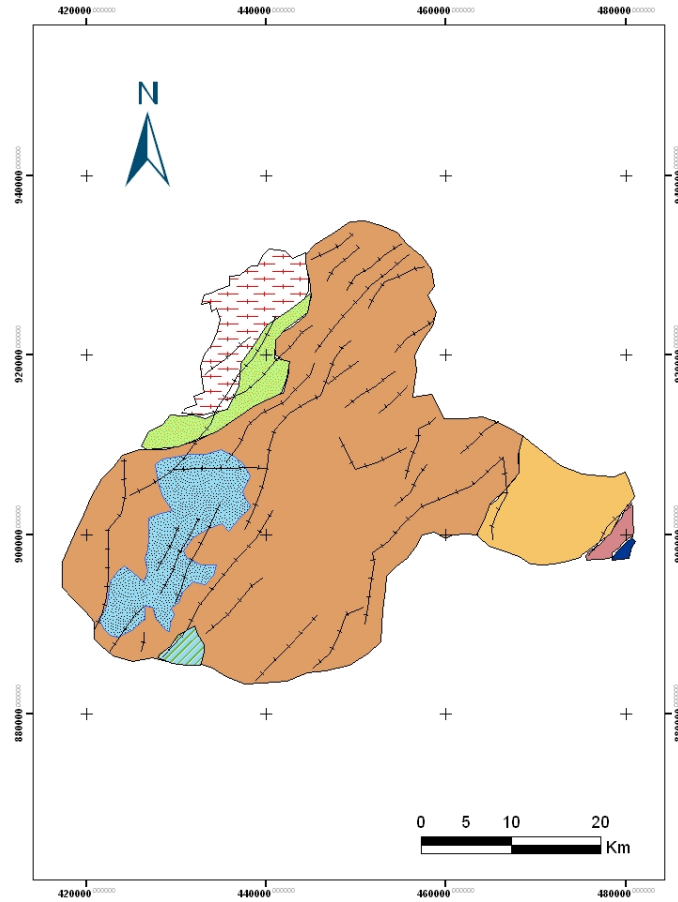
These sediments predominantly comprise volcanoclastic sediments, tuff and associated lacustrine sediments.

It consists of layers of alternating silt and clay with volcanoclastic sediments, sands, ashes, transported pumice, silt, clay and diatomite. According to Caroline et al. (1999), sedimentation initiated in the Ziway basin before 0.3 to 0.2 million years which is the age for the initiation of the Ziway Basin and continued until present.

The sediments have been deposited during a wide time interval from the end of Pliocene until recent, which is suggested by their considerable thickness and by the fact that in many places they underlie young volcanic products and are often deeply affected by regional faults. Besides volcano-sedimentary and lacustrine deposits alluvium is widely observed in valleys.

Seven lithostratigraphic units of this group were identified in the study area:

- i. *Pelite dominated lacustrine deposits*: deposits of pelite and peat (early Pleistocene - Present)
- ii. *Colluvium*: gravels, sands, silts and volcanic pyroclastics (mid Pleistocene-Recent)
- iii. *Deltaic and fluvio-deltaic deposits*: deposits of sand, silt, and clay (Holocene).
- iv. *Meki deltaic deposits*: Pumaceous volcanic fall deposits are evident along Meki river bank. sand, silt and clay (Holocene).
- v. *Tufa fluvo-lacustrine deposits*: This plain has two main distinct features. The area between Lake Abaya (Tuffa) and Dobena River. These areas have very flat plain fed by flood and seasonal streams from west of Butajira area. Mainly consists gravel, sand, pelite, and peat (Holocene).
- vi. *Ziway terrace and volcano-lacustrine deposits*: pyroclastics derived from ash and tuff. Also included are pelite, diatomite, silt, and clay with occasional shore sand and shell beds (Holocene).
- vii. *Bulbula deposits*: volcano-lacustrine deposits, mainly pyroclastics derived from ash and tuff, and subordinate shell beds and sand.



4-1: Geological map of the study area (modified after Alemu Dribissa, 2006)

4.3 Geological Structures in the study area

The study area has been confined to a NNE-SSW trending structures formed by a line of hundreds of young faults and volcanic centers along the rift floor close to the eastern escarpment. This volcano-tectonic axis, named the Wonji Fault Belt (WFB), is considered to be the current axis of crustal extension (Morton et al., 1979 and WoldeGabriel et al., 1990).

Wonji Fault is the most active part of the MER. Faults along this active zone form numerous minor horst and graben structures or “rift-in –rift” structures.

The western escarpment is primarily characterized by one major fault scrap. It shows a high throw in its north-eastern part, which progressively decreases and dies out to the southwest where it has been covered by volcanic products. However, in the western escarpment along the Guraghe Mountains, more than 1.5km thick flood basalt is displaced by several step faults that strike NNE. These faults are cut by north-west and west striking transverse fault. The Silte Debrezeit Fault Zone (SDFZ) of the western marginal graben is more than 100km long and 2-5km wide and converges at its southern end with the WFB. The SDFZ contains lacustrine sediments and tuff on which rest several nested scoria cones aligned parallel to the west escarpment (Alemu Drbisa, 2006)

The central part of the basin is characterized by fresh faulting with variable displacements along the strike of the boundary faults .These margins are marked by high angle normal faults with large throws that comprise several step–faulted blocks. The faulted margins show right angle spurs. In places, the rift escarpment adjacent to the Quaternary silicic centres located aligning the rift axis (for example, Aluto, Shala and Corbetti) are generally subdued, in part due to pyroclastic accumulation along the rift margins.

The tectonic development and associated volcanism have resulted in the following morphologically distinct areas.

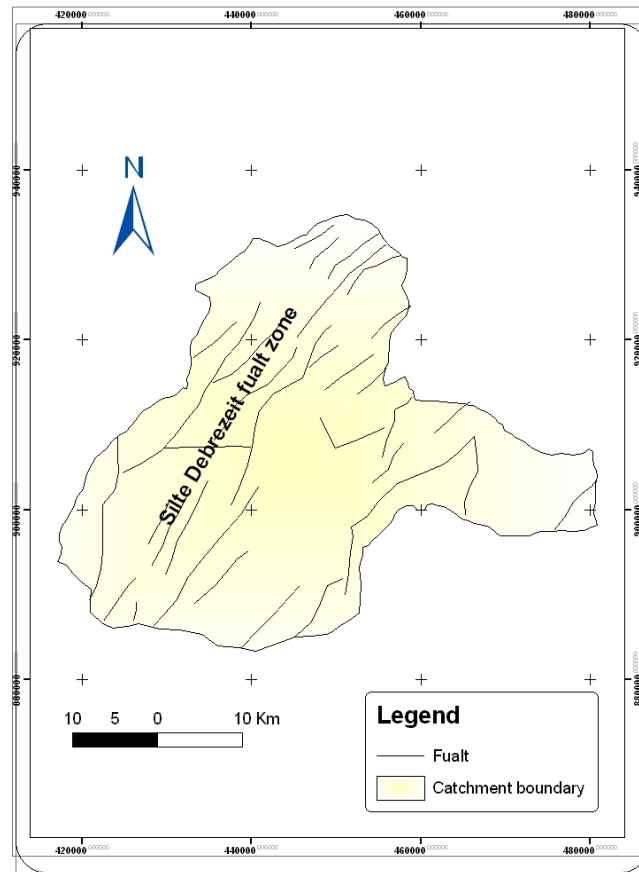


Figure 4-2: Structural map of the study area (Modified after Tamiru alemayehu et al, 2006)

4.3.1 Recent Tectonic Structures

Earth fissures are roughly aligned in the direction of local fault pattern indicating a possible relation between surface collapse, underground drainage and tectonic trend. The role of faults is established as a focus for fissure development and related subsidence.



Figure 4-3: Ground crack around zaway area (Adopted from: Tamiru alemayehu et al, 2006)

In the Main Ethiopian Rift, ground fissuring is a basic hydrologic and geomorphic process which occurs in association with high intensity rains. In the study area, during unusual heavy rains, both new failures and renewed displacement on older ones occur. The formation and propagation of fractures in this basin are determined by its rainfall, pre-existing structures and heterogeneous materials consisting of layers of clays and silts, sand, pumice and volcanic ash and hardpan calcrete. The contrasting physical and mechanical properties (such as permeability and compressibility) of this sequence evidence their different potential of deformation (Bekele et al., 2004).

All areas affected by subsidence and fissure development are characterized by very low drainage density. The flat topography does not allow the development of integrated surface drainage network which suggests the importance of underground drainage of intense storm water.



Figure 4.5 Re-collapsing of filled road crack ,Ziway-Butajira (Adopted from: Kebede Mideksa, 2007)

CHAPTER FIVE

5. HYDROMETEOROLOGY

General

In this study, attempt is made to analyze the mean monthly and annual precipitation, runoff and evapotranspiration using hydrometeorological and hydrological data.

5.1 Meteorological parameters

There are seven meteorological stations within and around the study area. The overall meteorological parameters available in the study area are; rainfall, temperature, relative humidity, wind speed, and sunshine hours.

The meteorological data together with Meki River, gauging near Meki town are the basis to determine the water balance of the catchment.

Table 5-1: Meteorological Stations within and around Meki river catchment

No	Station name	XUTM	YUTM	Altitude
1	Bui	460267	919803	2027
2	Butajira	431353	897207	2088
3	Ejersalele	465763	912116	1779
4	Koshe	448183	884908	1873
5	Meki	481640	900802	1663
6	Torra	436647	868906	2012
7	Ziway	468771	876858	1646

5.2 Precipitation

The seasonal distribution of rainfall over the country is governed by the position of Inter Tropical Convergence Zone, ITCZ (Dagnachew Legesse, 2003).

Accordingly: the rainy season from June to September is controlled by ITCZ which lies to north of Ethiopia. Hence, the study area intercepts most of the monsoon rainfall from Atlantic and Indian oceans. The dry period, from October to February is when the ITCZ lies to the southern of the country. In these months, the north easterly trade wind traversing

Arabia dominates the region and therefore, produces very little or no rainfall in the area. During March, the ITCZ is located in south of Ethiopia moving northwards. At that time low pressure is developed in Sudan and Arabia while high pressure develops over Gulf of Aden and Indian Ocean. The high pressure generates a moist easterly air current over southeast Ethiopia producing spring (Bulg) rain from March to May.

Precipitation of the study area was analyzed based on the seven stations found in and around the catchment. Precipitation in the catchment varies with altitude. High altitude areas of Guraghe Mountains receive higher mean annual rainfall while the rift floor area gets lesser amount.

5.2.1 Seasonality of Rainfall

In this study, long-term (more than 30 years) monthly total rainfall records of seven stations are used to analyze monthly mean rainfall and mean annual rainfall. The study area experiences bi modal rainfall distribution. These are belg rains (march to April) and kiremt rains (June to September).

According to the data obtained from National meteorology service agency (NMSA), mean annual rainfall of the catchment is 903mm. The area obtains the highest rainfall in the months of July and August, there is also small rain in the months of March and April this can be easily recognized in table 5.1 and Figure 5.1.

Table 5-2: Mean Monthly Rainfall of seven Stations in and around Meki River Catchment (mm)

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	Name													
1	Bui	26	45	84	85	76	111	213	204	111	35	8	6	1004
2	Butajira	36	65	137	135	118	125	180	173	127	48	11	13	1169
3	Ejersalele	16	38	61	77	67	81	196	162	85	23	4	4	816
4	Koshe	25	46	78	92	91	99	173	170	109	50	5	5	945
5	Meki	14	35	58	64	49	76	171	147	89	33	7	4	747
6	Torra	23	43	85	116	100	88	133	122	114	50	8	6	863
7	Ziway	17	30	55	79	75	84	145	120	87	37	2	4	736
	Mean Monthly RF of catchment	22	43	79	89	79	96	180	163	101	38	6	6	903

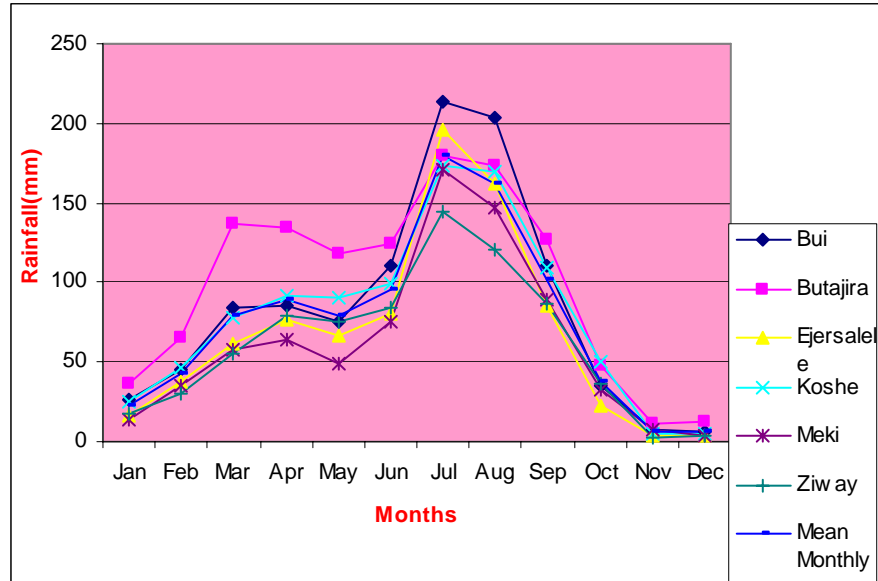


Figure 5-1: Mean Monthly Rainfall of seven Stations in and around Meki River Catchment (mm)

5.2.2 Arial Depth of Rainfall

Arial depth of rainfall of the area was computed using three approaches:

- i. Arithmetic mean method ii. Thiessen polygon method iii. Isohytal method

i. Arithmetic mean method: - Arithmetic mean method is the mean of all the rain gauges that are located on relatively flat topography and closely and evenly distributed. Since the study area consist various physiographic features ranging from 3600-1600 m.a.sl and widely spaced gauges, the value obtained by this method is unreliable.

Table 5-3: Annual rainfalls at each station

Station name	XUTM	YUTM	Altitude	Annual Rain fall
Bui	460267	919803	2027	1004
Butajira	431353	897207	2088	1169
Ejersalele	465763	912116	1779	816
Koshe	448183	884908	1873	942
Meki	481640	900802	1663	747
Torra	436647	868906	2012	863
Ziway	468771	876858	1646	736
Mean				896.7

$$PA = \sum_{i=1} P_i / n = \mathbf{896.7mm}$$

Where PA = average rain fall of the total area

P_i = Measured precipitation at a given station and time

n = Number of rain gauges.

Therefore, an annual aerial depth of precipitation computed from Arithmetic mean method is **896.7mm**.

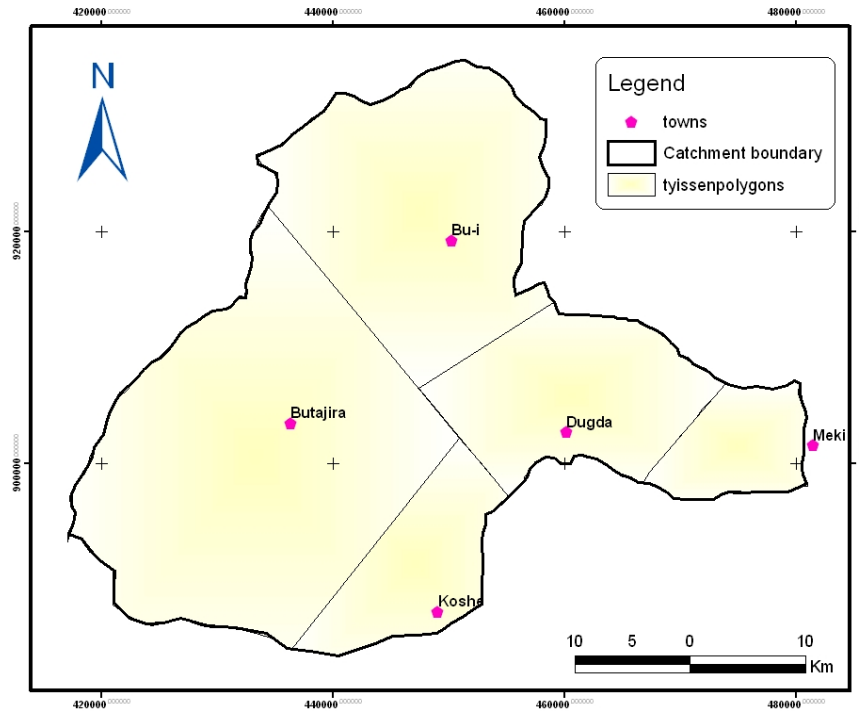
ii. Thiessen polygon method: - This approach provides a good result for non-uniformly distributed rain gauges over the area for both flat and hilly terrains. The method assumes that the recorded rainfall in a gauge is representative for the area half way to the adjacent gauges, and involves the connection of the stations on the map by lines and drawing the perpendicular bisector of the lines joining the adjacent stations. And the observed precipitation (P_i) is weighted according to the area (a_i) of the polygon associated with it. All the seven stations namely, (Bui, Butajira Ejersalele, Koshe, Meki, torra and Ziway) are used for computing weighted annual rainfall (Figure5.2).

Using this method, aerial depth of rainfall of the study area is **993 mm**.

Table 5-4: Annual weighted rainfall depth using Thiessen polygon

Meteorological station	Area of influence (Km ²)	Mean RF (mm)	Weighted area %	Weighted RF (mm)
Bui	435.2	1004	26.1	262
Butajira	552	1169	33.1	387
Ejersalele	357.7	816	21.4	174.6
Koshe	167.8	942	10.6	99.8
Meki	155.8	747	9.3	69.5
Total	1668.5		100%	993

Figure 5-2: Thiessen polygon map of the study area



iii. Isohytal method

This approach provides good results, because it allows the influence of physiographic parameters to be taken into account. These factors include elevation, slope and exposure to rain bearing winds. (shaw, 1988)

The area between successive isohyets is calculated and multiplied by the average rainfall on that area. The average rainfall is the average value of the two adjacent isohyets.

$$Pa = \frac{P_{12}a_{12} + P_{23}a_{23} + \dots + P_{n-1,n}a_{n-1,n}}{A_T}$$

Where P_{12} - Rainfall depth between isohyets1 and 2

a_{12} - Area enclosed by successive isohyets1 and 2

A_T - total Area

Using this method, aerial depth of rainfall of the study area is **990.8 mm**.

Table 5-5: Annual weighted rainfall depth using isohyetal method

Isohyte (mm)	Average	Net Area (km ²)	Percent of the area (%)	Weighted precipitation(mm)
816-873	844.5	183	11	92.9
873-922	897.5	233	14	125.7
922-965	943.5	205.7	12.2	116.1
965-1008	986.5	438	26.3	259.3
1008-1067	1037.5	219.9	12.7	131.7
1067-1121	1094	206.5	12.1	131.2
1121-1169	1145	202.4	11.7	133.9
			100%	990.8

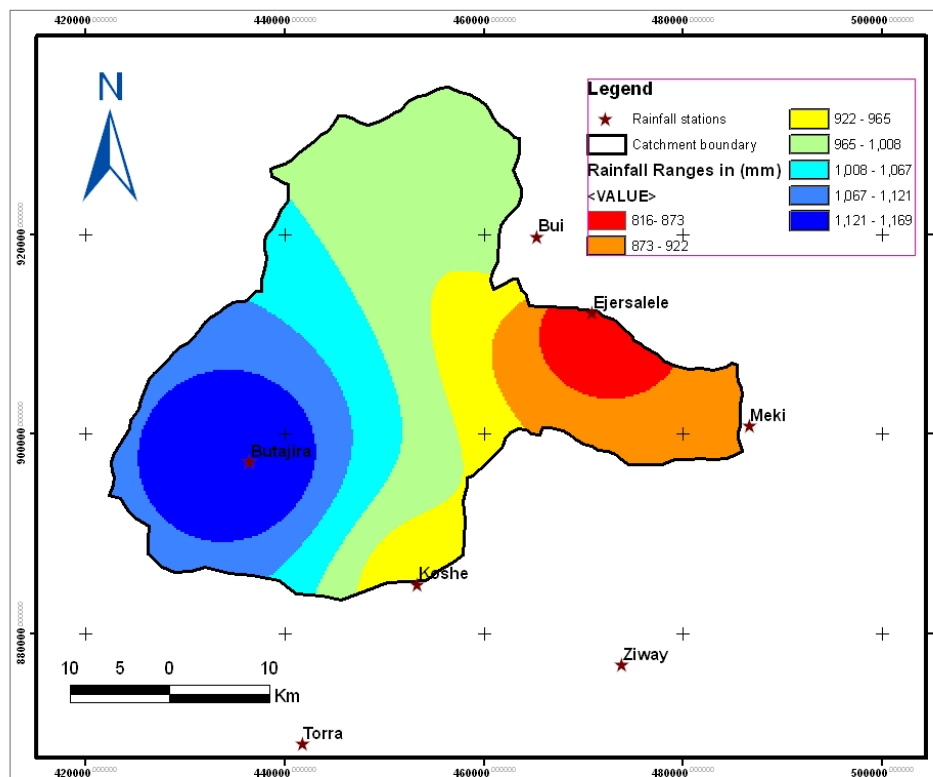


Figure 5-3: Isohyetal map of the study area

Using the above three approaches the representative aerial depth of rain fall over the study area is analyzed. Considering the variation in topographic features and uneven distribution of

gauging stations the average value of the two methods (Isohytal and Thiessen polygone) has been used as a representative value of aerial depth of precipitation. Therefore,the annual aerial depth of precipitation computed from the average of these methods is **992mm**.

5.3 Hydrometeorological factors affecting evapotranspiration

5.3.1 Temperature

Temperature data are the major factor in computing potential evapotranspiration of an area. The higher the air temperature, the more vapor it can hold, and similarly if temperature of evaporating water is high, it can more readily vaporize (Shaw, 1994).

In the study area, there are three stations recording maximum and minimum daily temperatures. One station i.e. Bui is found at highland area while Burajira, is situated at the escarpment; and Ziway at rift floor. These stations are used to calculate representative monthly and annual average temperature of the area. Accordingly the average monthly and annual maximum and minimum temperatures of the catchment are shown in Table5.6and Figure5.4.

The mean annual minimum temperature of the study area is 11.4 °C and the mean annual maximum temperature is 25.8°C. The mean annual air temperature of the study area is 18.6°C. Maximum temperature value was recorded in the month of May while minimum temperature record was obtained in December.

Table 5-6 Mean Monthly Temperature of Meki River catchment(0c)

No	Temperature in (°c)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual airTemp
1	Mean Max	25.7	26.6	27.2	26.9	27.3	26.1	24	24	25.2	25.7	25.7	25.6	25.8
2	Mean Min	10.5	11.1	12.3	12.7	12.6	12.1	12	12	11.7	10.7	9.8	9.4	11.4
	Mean Monthly air temperature	18.1	18.8	19.7	19.8	20	19.1	18	18	18.5	18.2	17.8	17.5	18.6

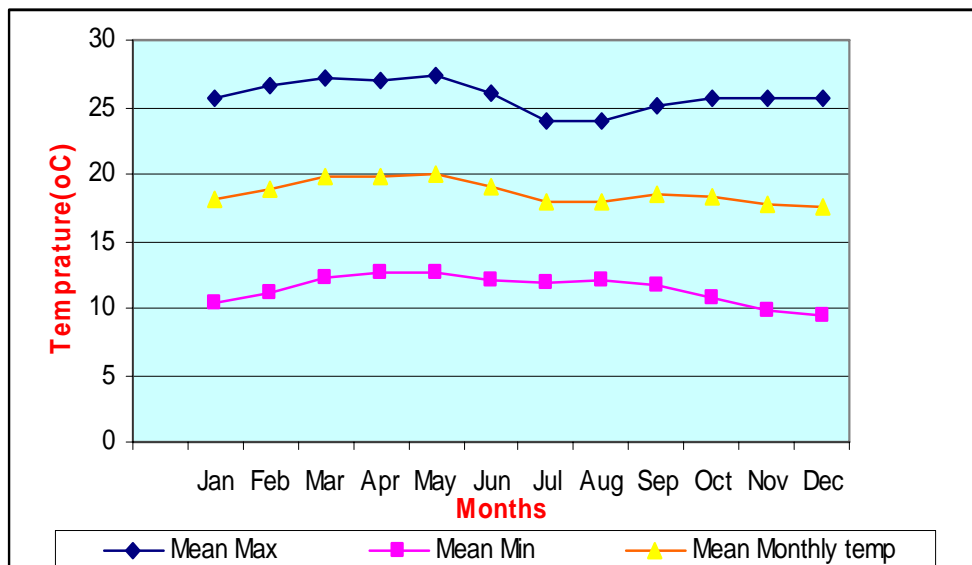


Figure 5-4: Mean Monthly Temperature of Meki River catchment(°C)

5.3.2 Wind speed

The movement of air and moisture transfer depends on wind speed and turbulence. Presence of wind speed and atmospheric turbulence can greatly increase the rate of evaporation by removing vapor from evaporating surface and giving space for fresh air capable of holding additional vapor in the atmosphere. Two stations, namely Bui and Zeway, located in the study area have records of wind speed at 2m above the ground surface.

The mean monthly wind speed of the area varies from 1.2m/s to 1.8 m/s with average value of 1.6 m/s.

Table 5-7: Mean Monthly and mean annual Wind speed (m/s) of Meki catchment

No	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean AnnWs
1	Bui	2.1	2.1	2.1	1.9	2	1.6	1.5	1.4	1.4	1.9	2	2	1.8
2	Ziway	1.4	1.4	1.3	1.3	1.5	2	1.9	1.6	1.1	1.3	1.5	1.5	1.5
	Mean Monthly Ws	1.75	1.8	1.7	1.6	1.7	1.8	1.7	1.5	1.2	1.6	1.7	1.8	1.6

Where Ws is wind speed, and Ann is annual

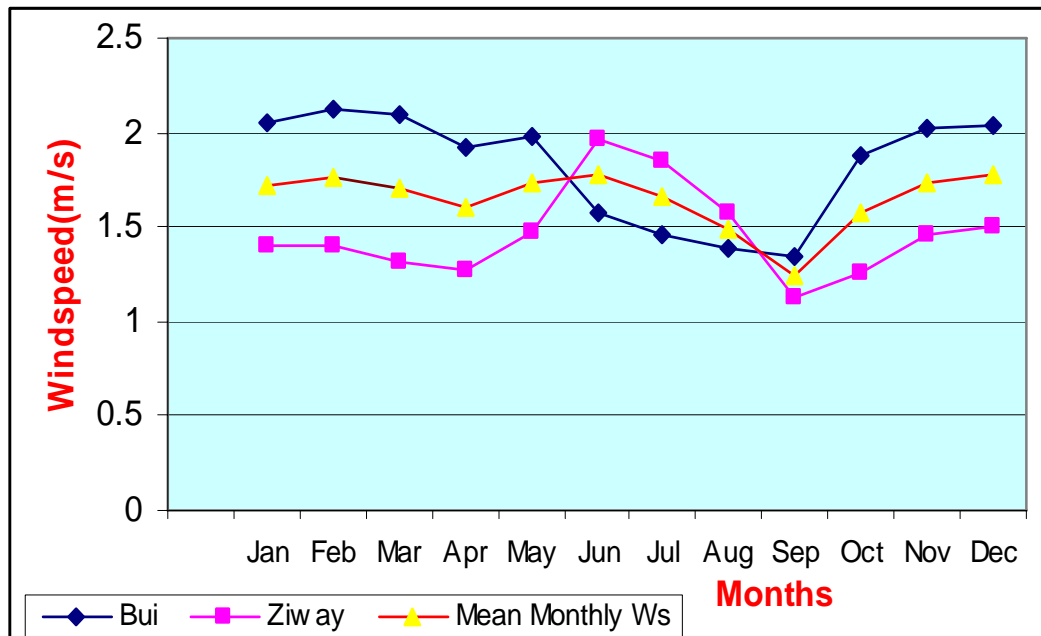


Figure 5-5: Mean Monthly Wind speed (m/s) of Meki catchment

5.3.3 Sunshine hours

Since evaporation requires continuous supply of energy, which is derived mainly from solar radiation, the radiation will play greater role in affecting its rate. Two stations, namely Bui and Zeway, located in the study area have records of sunshine hours.

The mean monthly sunshine hours of the area are given in the table5.8. The maximum sunshine hour is recorded in November (10 hours) whereas the minimum one is in July (5.7 hours).

Table 5-8: Mean monthly sunshine hours(hrs)

No	Station	Recording-period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual
1	Bui	1990-2005	8.8	8.6	8.3	8.1	8.1	6.7	5	5.26	6.8	8.8	9.8	9.1	7.8
2	Ziway	1980-2005	9.5	9.4	8.4	8.4	9.1	8.4	6.4	6.67	7.1	9.1	10	10	8.6
	Mean Monthly		9.2	9	8.3	8.2	8.6	7.5	5.7	5.97	6.9	8.9	10	9.6	8.2

Where, SShrs is sunshine hours

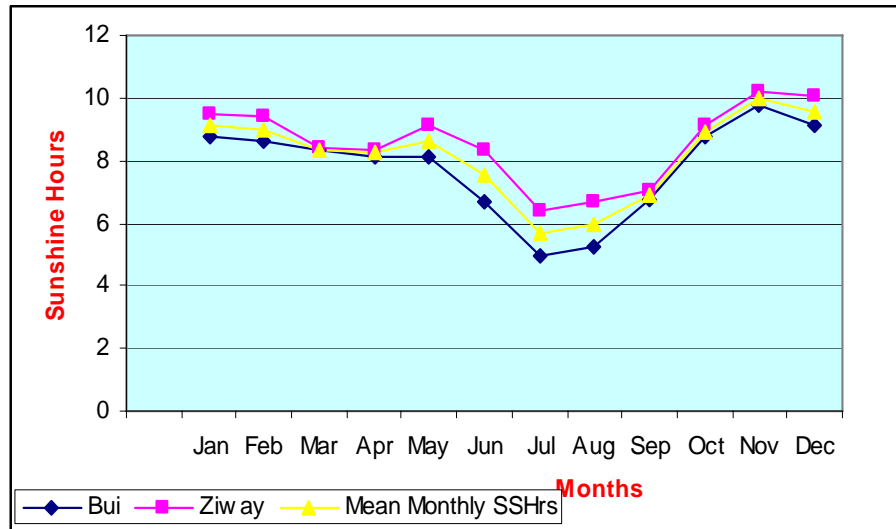


Figure 5-6: Mean monthly sunshine hours(hrs)

5.3.4 Relative humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature. The higher the relative humidity the lower will be the rate of evaporation. (Shaw, 1985).

Two stations in the study area (Ziway and Bui), have monthly records of mean relative humidity. The mean monthly values were computed and are given in table 5.9 below. The

maximum relative humidity is found in August (78.2%) and the minimum in November and February (63.3%).

Table 5-9: Mean monthly Relative humidity (%) of Meki catchment

No	Station	Recording period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual RH
1	Bui	1990-2005	62.7	60.2	63.2	62.9	63.5	70.1	79.1	79.5	73.1	64.1	62.1	61.4	66.8
2	Ziway	1970-2005	67.3	66.4	66.1	67.8	67.9	69.8	75.8	76.9	74.4	66.3	64.4	66.8	69.2
	Mean Monthly RH		65	63.3	64.6	65.4	65.7	69.9	77.5	78.2	73.8	65.2	63.3	64.1	68

Where RH is Relative Humidity

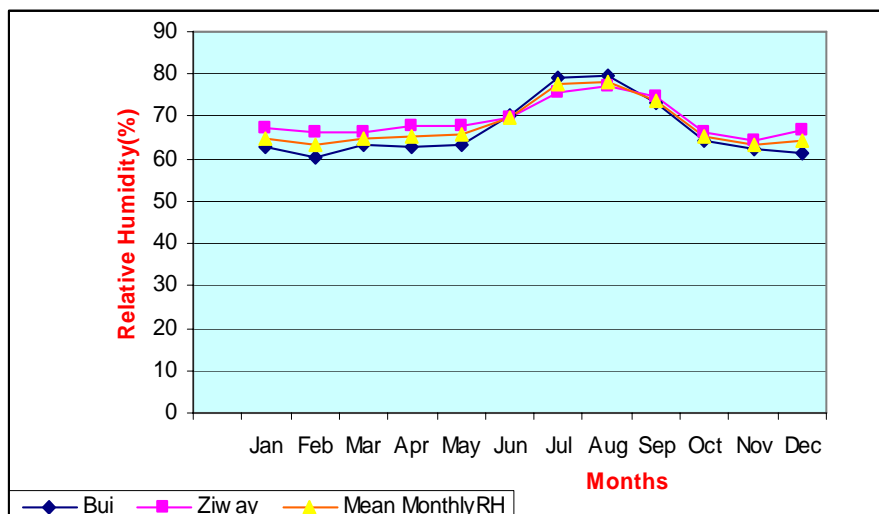


Figure 5-7: Mean monthly Relative humidity (%) of Meki catchment

5.4. Estimation of Evapotranspiration

Evapotranspiration E_t is the process of water loss from a vegetated land surface by evaporation plus transpiration (Shaw, 1988). The evaporation from a vegetated surface is a function of available energy, net radiation, the temperature of the surface and air, the saturation deficit, the wind speed, and the available soil moisture.

5.4.1. Potential Evapotranspiration (PET).

PET is defined as the evapotranspiration which would occur under unrestricted availability of water to a fully vegetated surface (Shaw, 1988). PET of the study area is computed as follows:

i. Thornthwaite method

Thornthwaite method is based upon the assumption that Potential evapotranspiration is dependent only on meteorological conditions and ignores the effect of vegetation density and maturity. The only necessary factors to compute potential evapotranspiration using this method is mean monthly air temperature (T), Latitude and month (Thornthwaite and Mather 1944). The last two factors yield average monthly sunlight.

PET_m, calculated on a monthly basis is given by:

$$PET_m = 16N_m (10t/I)^a \text{ mm}$$

Where:

m: months

N_m: is monthly adjustment factor depending on latitude and season

t: mean monthly temperature

I: annual heat index obtained by adding monthly heat index (i_m) of 12 months.

$$i_m = (t/5)^{1.514}$$

$$a = 6.7 \times 10^{-7} I^3 = 7.7 \times 10^{-5} I^2 + 1.8 \times 10^{-2} I + 0.49$$

The mean annual Potential evapotranspiration of the study area using the above mentioned method is **827 mm/year**.

Table 5-10: Potential evapotranspiration of Meki river Catchment (mm) using Thornthwaite method

Element	Months												Annual	
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
T _m (°C)	18.1	18.8	19.7	19.8	20	19.1	18	18	18.5	18.2	17.8	17.5		
N	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5		
N _m	0.97	0.98	1	1.03	1.05	1.06	1.05	1.03	1.01	0.98	0.97	0.96		
i _m	6.9	7.3	7.8	7.9	11.2	7.5	6.8	6.8	7.1	6.9	6.7	6.5		
I	89.4													
a	2.00													
PET _m	63.3	69.4	70.4	72	84.2	77.9	67.9	66.8	69.1	65.5	61.3	58.9	827	

ii. Penman method or combination method

The most general and widely used equation for computing PET is the penman equation. The penman monteith variation is recommended by the Food and Agriculture Organization (FAO). This equation uses climatic data such as vapor pressure, sunshine hours, net radiation, wind speed and mean temperature. The basic equation of penman to compute potential evapotranspiration, PET_m is

$$\text{PET}_m = \frac{(\Delta/\gamma)H_T + E_{at}}{\Delta/\gamma + 1}$$

The procedures followed during calculation are given below:

H_T is the available heat and is calculated from the formula given by;

$$H_T = R_I(1-r) - R_0,$$

Where r is the average albedo of the area based on land cover type. R_I and R_0 are incoming and out going radiation, respectively and their empirical formulas take the form:

$$R_I(1-r) = 0.76 R_a f_a (n/N)$$

R_I is a function of R_a , the solar radiation (fixed by latitude and season) modulated by a function of the ratio, n/N , of measured to maximum possible sunshine duration. And “ n ” is bright sunshine hours over the same period.

$f_a(n/N)$ is calculated as:

$$f_a(n/N) = (0.16 + 0.62 n/N).$$

The empirical formula of the out going radiation takes the formula,

$$R_0 = ET^4 (0.47 - 0.75ed)^{1/2} (0.17 + 0.83n/N)$$

Where: T^4 is the theoretical black body radiation at T_a , which is then modified by functions of the humidity of the air (ed) and the cloudiness (n/N), temperature in °C.

The parameters e_a saturated vapor pressure at air temperature.

T_a is obtained from standard table of air temperature and saturation as:

$$e_a(T_a) = 6.11 \exp(17.3 T_a / T_a + 273.3)$$

Relative humidity (RH) in % used to calculate the value of actual Vapor pressure(e_d) as :

$$ed = ea \text{ RH}\%.$$

Wind speed (u_2) in m/s was converted to mile/ day

The energy for evaporation E_{at} is given by

$$E_{at} = 0.35 (0.5 + u_2 / 100) (ea - ed)$$

The value Δ/γ is found from weighing factor Δ/γ versus temperature from (FAO, 1967) given in (Shaw, 1996) where Δ is the slope of saturated vapor pressure versus temperature and γ is the hydrometric constant.

The annual Potential evapotranspiration of the study area computed using the above mentioned method is **1242.8** mm/year.

Table 5-11: Potential evapotranspiration of Meki river Catchment (mm) using Penman combination method

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
P_m	26	49	88	96	87	111	190	177	108	44	8	8	992
PET(mm/day)	3.22	3.55	3.75	3.79	3.76	3.05	3.04	3.21	3.42	3.56	3.37	3.13	
PET(mm/month)	100.4	99.4	116.3	113.7	116.6	91.5	94.2	99.5	102.6	110.4	101.1	97.1	1242.8

From the above results, the PET obtained from Penman combination method gives higher value relative to thornthwaite method; the reason for this variation could be competition using penman method uses many variables such as climatic data (vapor pressure, sunshine hours, net radiation, wind speed and mean temperature) while thornthwaite method uses only one variable i.e. temperature.

5.4.2. Actual Evapotranspiration (AET)

Actual evapotranspiration is used to describe the amount of evapotranspiration that occurs under field conditions (Thornthwaite, 1944).

5.4.2.1 Empirical formula

i. Turc:

A widely used formula to estimate annual values of AET for a catchment area was published by Turc (1954, 1955) as follows:

$$AET = P/[0.9 + (P/L)^2]^{1/2} \text{ mm per annum}$$

Where: p = mean annual precipitation (mm)

$$l = 300 + 25T + 0.05T^3$$

T = mean temperature ($^{\circ}$ C)

Actual evapotranspiration of the study area using this method is equal to **754** mm/year.

5.4.2.2 Thornthwaite& Mather (Soil-water balance) method

This method calculates actual evapotranspiration using precipitation and soil moisture deficit values. Shaw introduced the concept of 'root constant' that defines the amount of soil moisture (mm depth) that can be extracted from a soil without difficulty by given vegetation. A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constants (Dunne and Leopold, 1978). Therefore, to

evaluate actual evapotranspiration over a catchment area, the proportions of different types of vegetation covering the basin must be known. The values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation (Shaw, 1994).

In the model, accumulated potential water loss, which indicates the severity of water shortage, is obtained by cumulating of the negative values of the differences between monthly precipitation and potential evapotranspiration for dry season only; and the summation begins with the first month of dry season.

The soil moisture during the dry months is then obtained from the following formula:

$$S_m = W \exp\left[-\frac{(La_m)}{W}\right]$$

Where, S_m : Soil moisture during the month M (mm)

La_m : Accumulated potential water loss at month M (mm).

W : Available water capacity of the root zone (mm)

The soil moisture for each wet month is obtained by adding the excess of rain of the current month to the soil moisture of the month before. However, this sum may not exceed the water capacity and excess is booked as moisture surplus. PET value computed using thornthwaite method is taken up in the calculation of AET; because, it is important to use the same method.

The monthly actual evapotranspiration, AET_m , is then found as:

$$AET = PET \text{ if } P_m > PET_m$$

Otherwise,

$$AET_m = P_m - DS_m$$

Where, AET is actual evapotranspiration, PET , Potential evapotranspiration, P is aerial precipitation, DS_m are soil moisture during the month $m-1$ and m respectively.

Accordingly, the annual actual evapotranspiration of meki river catchment using Soil-Water balance (Thornthwaite & Mather. 1957) method is **732mm**.

Table 5-12: Soil-Water balance method of estimating AET, (Thornthwaite & Mather. 1957)

mm	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
P_m	26	49	88	96	87	111	190	177	108	44	8	8	992
PET _m	63.3	69.4	70.4	72.	84.2	77.9	67.9	66.8	69.1	65.5	61.3	58.9	827
$P_m - PET_m$	-37.3	-20.4	17.6	24	2.8	33.1	122.1	110.2	38.9	-21.5	-53.3	-50.9	
Acc. Pot. W l($\bar{L}a_m$)	-163	-183.4								-21.5	-74.8	-125.7	
S_m	88.5	79.9	200	200	200	200	200	200	200	179.6	137.6	106.7	
DS _m	18.2	-8.6	120.1	0	0	0	0	0	0	-20.4	-42	-30.9	
AET _m	8.8	59.6	70.4	72.	84.2	77.9	67.9	66.8	69.1	62.4	52	40.9	732
D	55.5	11.8	0	0	0	0	0	0	0	5.1	11.3	20	104
S	0	0	102.5	24	2.8	33.1	122.1	110.2	38.9	0	0	0	433.6
AWCR(W)	200mm												

AWCR = ACCUMULATED WATER CAPACITY OF ROOT ZONE :

71% Moderately deep rooted, 19% Matured forest woodland and 10% Deep rooted plants grown on a silty loam, sandy loam and Clay loam soils respectively

From Table developed by Thornthwaite and Mather, 1957, the total Available Water Capacity of the Root zone (AWCR) for the above mentioned land covers and soil is calculated to be □

71% (150mm) + 19% (400mm) + 10% (200mm) = 200mm

P_m = Mean Monthly Precipitation, mm

PET_m = Potential Evapotranspiration, mm

AET_m = Actual Evapotranspiration, mm

Acc. Pot. Wl = Accumulated Potential Water Loss, mm

S_m = Soil Moisture, mm

DS_m = Change in Soil Moisture, mm

D = Soil Moisture Deficit, mm

S = Soil Moisture Surplus, mm

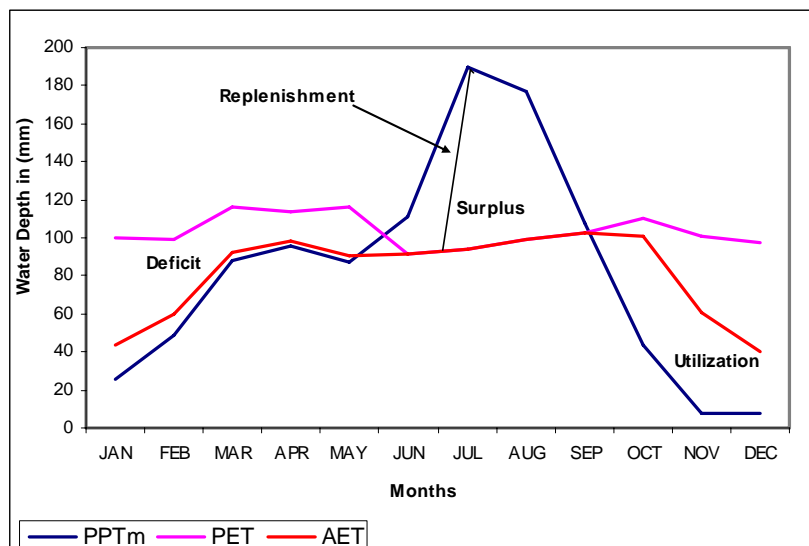


Figure 5-8: Monthly water balance plot for Meki River catchment

AET competed using Thornthwaite& Mather method is used for water balance calculation of the study area; because this method uses many variables relative to Turc method.

5.5. Runoff

5.5.1 Mean monthly and annual flows.

Meki River is the feeding river to the Lake Ziway that radiated from the guraige highlands and travels a distance of about 100km at altitude of 3600m a.s.l to about 1630m a.s.l before draining in to the Lake. Its discharge is highly affected by amount of precipitation around Butajira area; Based on discharge data of the past 30 years (1975 -2005) recorded at Meki town, the mean annual discharge of the river is 161.8mm. Peak discharge occurs at the month of August; and often dries during extreme dry season from December to February.

Table 5-13: Mean monthly discharge of Meki River.

No	River	Recording. Period	Discharge (m3/s)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Meki	1970-2005	0.96	1.9	4.81	6.58	5.87	5.63	18.4	29.3	19.2	8.23	2.63	0.77	104.2

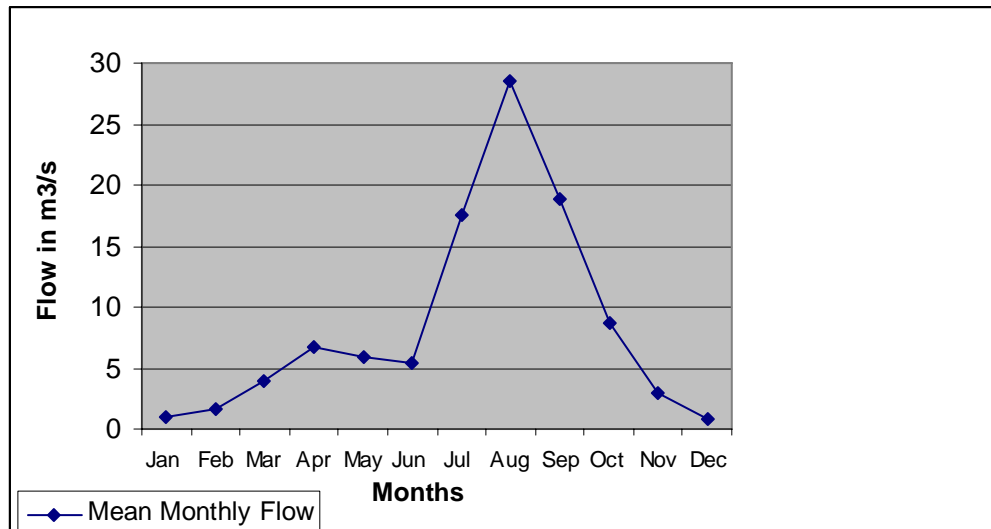


Figure 5-9: Mean monthly discharge of Meki River.

The figure below shows the monthly rainfall-runoff relationship. Runoff is concentrated from July to September. This runoff represents more than 50% of the annual runoff.

Table 5-14: Rainfall-Runoff relationships at Meki river catchment

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly RF(mm)	22.4	43.1	79.7	92.6	82.3	94.9	173	156.9	103.1	39.4	6	6
Mean Monthly Ro(mm)	1.0	1.6	4.6	6.9	6.2	5.9	20.0	32.1	20.3	9.2	2.9	0.9

Where RF is rainfall and RO is run off

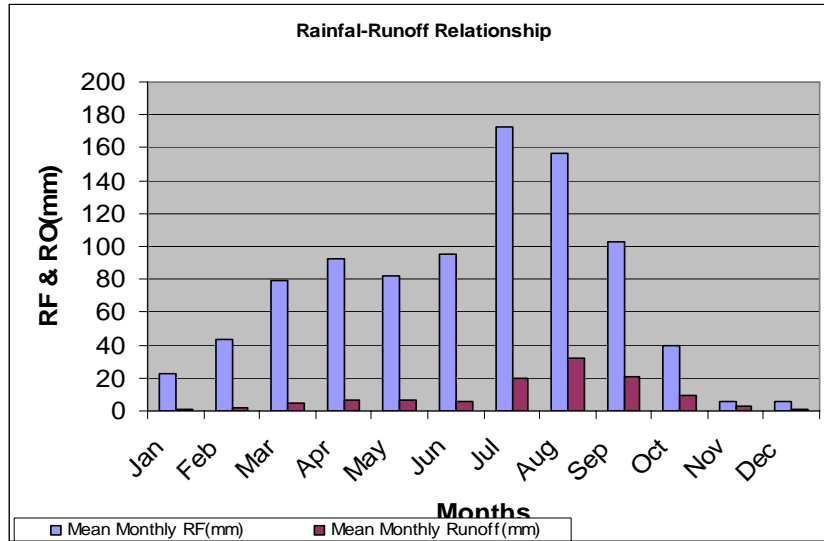


Figure 5-10: Rainfall-Runoff relationships at Meki river catchment.

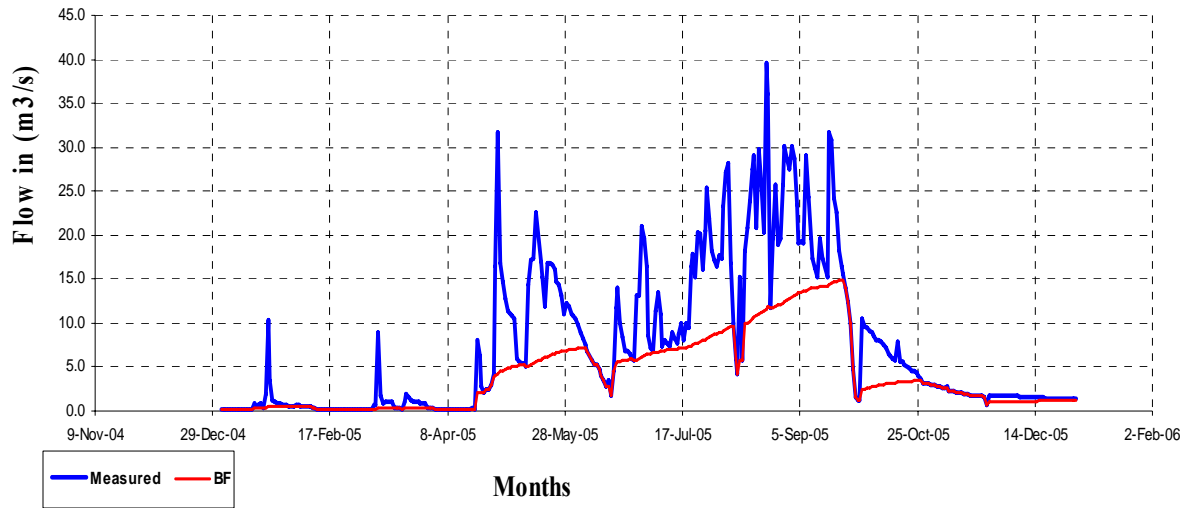
5.5.2 Hydrograph separation

Hydrograph is an aggregate of surface runoff, interflow, channel precipitation and base flow. However, for practical application it is customary to divide the hydrograph in to surface runoff and base flow.

In this study, TIMEPLOT software was used for hydrograph separation. One year (2005) Daily average discharges have been used to construct hydrograph before separating baseflow. Accordingly, the annual base flow components of Meki river gauged at Meki town is 54 % (77.5 mm) of its total annual flow of 143.3mm.

Table 5-15: Base flow separation of meki river Catchment

Unit	Total flow	Base flow	Runoff
m ³ /s	7.6	4.1	3.5

**Figure 5-11: Base flow separation of meki river Catchment**

5.6 Water balance

The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc) over a specified period (Tenalem Ayenew and Tamiru Alemayhu, 2001). The water balance of the study area was computed using the following methods:

5.6.1 Base flow separation method

Ground water recharge can be defined as the entry of water into the saturated zone made available at the water table surface together with the associated flow away from the water table within the saturated zone (Freez and cheery, 1979).

The best method of separating base flow from the total flow of Meki River is soft ware separation method (i.e. Time plot method). This method considers the in put data of daily flow of the river. Accordingly, the amount of base flow to Meki River is 77.5mm.

5.6.2. Groundwater balance of the basin

For natural catchment, measurement of the precipitation and river discharge may be made satisfactorily with some degree of precision. However, estimation of the rate of groundwater recharge is one of the most difficult components to measure. It is a fundamental precondition for efficient groundwater resource management.

Generally water balance has the following form:

$$\text{Inflow} = \text{out flow} \pm \text{change in storage}$$

The following assumptions made to derive the water balance equation of the study area:

- i. Change in storage in annual basis is almost negligible and is assumed to be zero.
- ii. From the topographical and groundwater elevation contour maps, it is observed that surface water flow direction is the same as ground water flow direction (i.e. surface water divide coincides with ground water divide). Hence the groundwater in the basin is in a closed system.

Therefore water balance of the catchment is represented by the general equation.

$$P = AET + RO + R \pm \Delta S, \quad RO = SRO + BF \quad \text{where, } SRO \text{ is over land flow and } BF \text{ is base flow}$$

$$\Delta S = 0$$

Here, the inflow component is precipitation where as the out flow components include Run off, Evapotranspiration and Groundwater recharge.

Finally, the study area will have a water balance equation of the form:

$$P = AET + RO + R$$

P=precipitation (992 mm) annually

AET=annual actual evapotranspiration (732mm)

RO=annual runoff (143.3mm)

$$R = P - AET - RO$$

The main purpose of this computation is to estimate the amount of water that percolates in to the ground to recharge the groundwater of the study area. From the above equation, the amount of recharge to Meki river catchment annually is 116.7mm.

Water balance is the best method to estimate the groundwater recharge of a catchment. Because Some of the meteorological elements that are inputs for the balance have been obtained by adopting different empirical and physical approaches and are integrated to yield sound and reliable results. The remaining hydrological elements, such as surface runoff, are computed from stream hydrograph analyses. Based on the above calculation, therefore, it is possible to say that the total amount of water which is actually available to recharge the groundwater circulation with in the study area is 116.7mm.

CHAPTER SIX

6. HYDROGEOLOGY

General

The existing hydrogeologic units in the study area are volcanic rocks that are subjected to varying degrees of secondary activities like weathering, fracturing and faulting which intensively divided the area by a number of minor and major normal Faults. Comparing to the primary structure, secondary one has a significant role in the circulation and distribution of groundwater in the study area.

Existing data, indirect and direct approach was used in order to characterize the different aquifer units in the area. The characterization involves the use of existing pumping test data, lithology obtained from well logs, water table depth, structures and topography so as to see the vertical and lateral distribution and the nature of the aquifers.

6.1 Hydrostratigraphic units in the study area

Classification of lithostratigraphic units into hydrostratigraphic units requires information on the hydraulic characteristics of rocks. Lithological description of the existing data has been used as a basis for classifying Hydrostratigraphic units. The rocks in the study area possess different permeabilities due to variation in lithology, primary and secondary structure, fragment size of pyroclastic dusts, and weathering grades. Pumping test data analysis method was the primary approach to assign the permeability group.

According to Alemu Dribissa, 2006, the catchment is classified in to four ranges of permeability groups. These are:

High to very high permeability zone where $K: 10 - 20\text{m/day}$

Medium to high permeability zone where $K: 5 - 10\text{m/day}$

Medium permeability zone where $K: 1 - 5\text{m/day}$

Low to medium permeability zone where $K: 0.1 - 1\text{m/day}$

Where: k is permeability of the aquifer

i. scoraceous and fractured basalt aquifers:

(High to very high permeability zone, K: 10 - 20m/day)

These are situated to the east of Butajira pediment and dominantly composed of scoria cones and associated vesicular basalts.

Groundwater occurs in these areas are at a relatively deeper level with respect to surface topography. Permeability is largely related to joints, faults, vesicles and fragment size of scoria. The existing borehole data indicates the aquifer is composed of scoria, vesicular basalt and at some places sand and gravel deposit underlying thin layer of basaltic flows. The thickness of the basaltic flow is highly variable in areas, such as Shershera Ele Dirama Shershera, Shershera Jole areas the underlying sand and gravel deposits contribute to the aquifer. The existing data shows it has transmissivity varying between 16m²/day to 242m²/day and hydraulic conductivity 0.9m/day to 20 m/day. The aquifer varies from unconfined to semi confined. The aquifer within the basaltic formation is unconfined and the one in the underlying sediment is semi-confined.

Table 6-16: showing lithological log of ShersheraEle Borehole

Thickness Range (m)	Aquifer Zone	Geologic Description
0 to 10		Black Clay
10 to 20		Vesicular Basalt
20 to 37		Sand
37 to 41		Basalt
41 to 60		Highly weathered basalt
60 to 62		Vesicular Basalt
62 to 68		Brown clay
68 to 74		Clayey Sand
74 to 85		Sand Gravel

ii. Fractured Ignimbrite and Welded Tuff Units

(Medium to high permeability, K: 5 - 10m/day)

This area is mainly composed of pyroclastic fall, pyroclastic deposits such as tuff and Ignimbrite. These are less welded ignimbrites intercalated with pumice fragments, alluvial and colluvial deposits located at the foot of volcanic mountains. This permeability zone covers large area. Based on the characteristics of ignimbrite, fracturing and weathering grade, the units possess medium to high permeability. The groundwater in this part of the study area is deep. The groundwater level in this region suddenly gets deeper probably as a result of the major fault. Existing borehole data indicates the aquifer is composed of ignimbrites and tuffs. Transmissivity varies from 6m²/day to 171 m²/day and hydraulic conductivity 0.25m/day to 4.75 m/day. The aquifer is a confined aquifer.

Table 6-17: showing lithological log of inseno deep test well

Thickness Range (m)	Aquifer Zone	Geologic Description
0 to 4		Brown weathred pumaceous payroclastic fall
4 to 20		Brown weathred pumaceous payroclastic fall deposit
20 to 40		Brownish grey pyroclastic deposit with pumice, ash, and secondary infilling of white hard fine grained material
40 to 56		Grey pyroclastic deposit with pumice and some lithic materials
56 to 72		Greyish brown pyroclastic material with pumice.
72 to 74		Grey pyroclastic deposit with pumice
74 to 78		Pumaceous, lithic pyroclastic deposit (tuff).
78 to 110		Relatively hard tuff, brown grey color
110 to 116		Pumaceous lithic pyroclastic deposit.
116 to 168		Pumaceous, lithic pyroclastic deposit. Loose probably fall deposit

iii. Lacustrine sediments:

(Medium permeability zone, K: 1 - 5m/day)

This area is characterized by a complex mixture of sediments composed of unsorted to poorly sorted alluvial, talus or fan deposits, debris flow and volcano-clastic deposits. The sediment is mainly made up of gravels, sands and boulders with interfingering of some clay deposits. This permeability zone covers the area near Lake Ziway. The lithologic groups found in this

area are ignimbrites overlain by lacustrine sediments such as: clay, diatomite, shale beds and reworked pumice. Groundwater is fairly shallow. It is close to the surface at the lake’s shore area and deeper further away from the lake. The sediment thickness varies from 80 m to about 120m. The depth to water level varies from surface to about 20 m meters below the ground. Because of this there are a number of family owned dug wells and community wells in the area. The aquifer type is unconfined aquifer. This plain has generally poor aquifer property. The existing data shows it has Transmissivity varying between 1 m²/day to 137m²/day and hydraulic conductivity 0.02m/day to 3.8 m/day.

iv. Welded ignimbrites:

(Low to medium permeability Zone, K: 0.1 - 1m/day)

These rocks are situated at western highlands of Guraghe Mountains. The rocks comprising this zone are highly welded ignimbrites, tuff, rhyolite and trachaytes without visible large faults. The upper weathered rock and soils are permeable; however, the underlying volcanic sequences are massive. The sediment is mainly made up of gravels, sands and boulders with interfingering of some clay deposits. It has generally poor aquifer property.

Table 6-18: showing lithological log of Dobo Bedeno borehole (BH-32)

Thickness Range (m)	Aquifer Zone	Geologic Description
0 to 2		Clay
2 to 3		Highly Weathered Basalt
3 to 8		Gravel
8 to 16		Clay
16 to 32		Weathered Rhyolite
32 to 44		Gravel with Clay
44 to 56		Pumice
56 to 68		Tuff
68 to 71		Pumice
71 to 74		Ignimbrite
74 to 80		Weathered Rhyolite

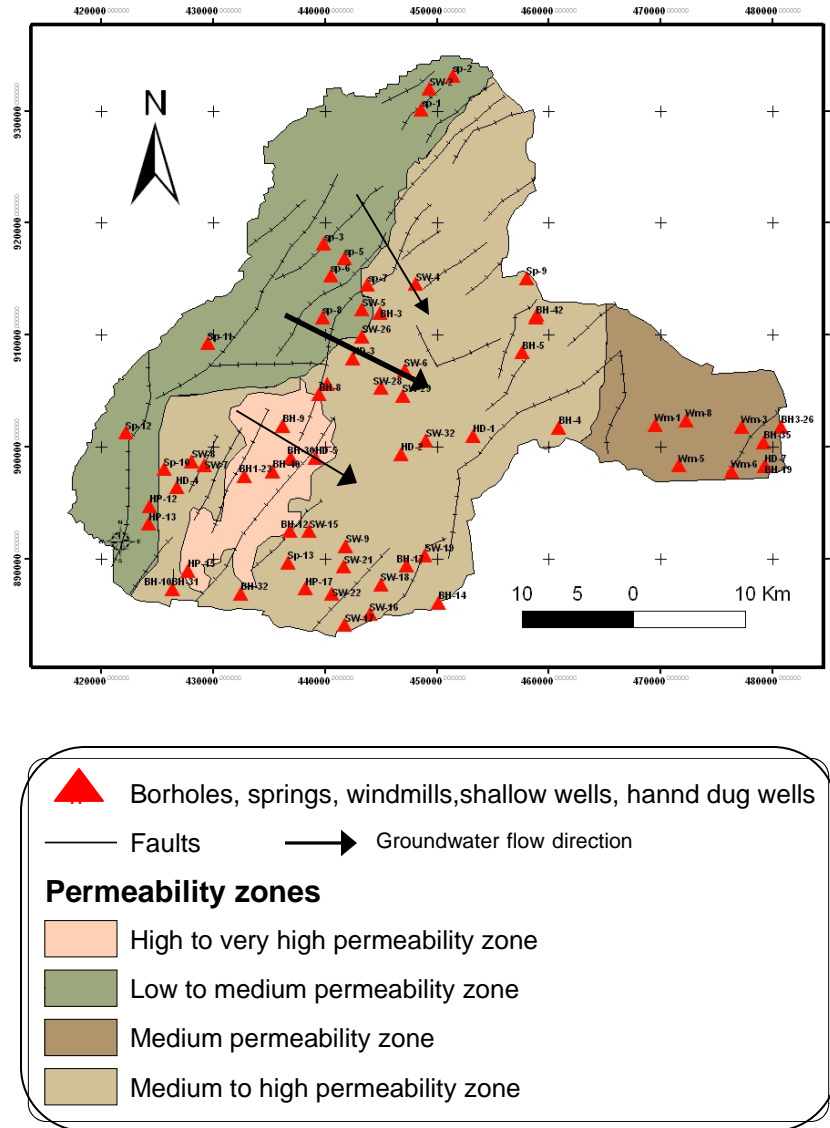


Figure 6-1: Hydrogeological map of the study area(modified after Alemu Dribisa)

6.2 Aquifer characterization

Major Aquifer system classifications have been made from the hydrogeologic patterns of the area from the depth of groundwater level in wells and aquifer units. This is based on the observation and analysis of all the compiled well log data and pumping test data from the existing wells in the study area.

Regarding to the nature of the aquifers in the study area, there are two types, shallow unconfined and deep confined aquifer systems.

Shallow unconfined type: - its lateral extent is not regionally extended relative to the confined one. On the average, their depth is not greater than 80m with different aquifer formations including weathered volcanic rocks, lacustrine sediments, sandy volcanic ash, quartz sand and welded ignimbrites. All of these aquifer formations have variable lateral extent.

Deep confined type: - it has regional lateral extension; its depth start running from 80m to deeper with variable aquifer formation including weathered and fractured ignimbrite and weathered scoriaceous basalt.

Generally, the main aquifer formations are lacustrine deposit, weathered and fractured basalt, ignimbrite, and welded tuff having a variable thickness and variable weathering and fracturing intensity.

6.2.1 Groundwater Recharge and discharge areas

Recharge mechanism in the study area has been explained based on lithology, topography and structures in the area. The main recharge areas of the study catchment are the western Guraghie highlands which are located at higher elevation. These areas get high rain fall as compared to its surrounding low lying area. Ground water recharge can take place due to rain fall at the mentioned recharge area, through direct infiltration of the precipitation in to the aquifer system, localized recharge through tectonic discontinuities(such as faults, joints, fractures etc) and through infiltration of river water into the aquifer. The other possible recharge is direct infiltration of the precipitation on the rift floor (i.e. discharge area). However, due to the relatively higher annual potential evapotranspiration over the total annual precipitation in the rift floor, direct recharge from precipitation for this lower valley part is unusual. The discharge areas of the catchment lie in the low lying part of the study area. That is almost all parts of the flat plain of the catchment. The catchment has recharge area in the Guraghie highland and the discharge area at the valley floor.

6.3 Groundwater Flow

Groundwater contour map has been generated based on the available secondary well log data from appropriate offices. This map has been constructed to show the groundwater flow direction. Topography, geology and structures are the primary controlling factors on the flow system of the groundwater. Groundwater flow is generally towards the east and southeast from the western and northwestern high lands. The groundwater level is generally flat to gentle slope except at Tora-Koshe-Dugda ridge. In these areas the groundwater contour shows steep slope showing lower permeability, probably due to the nature of the rocks or the fault systems separating these zones. The groundwater level drops from about 2000 m in Butajira Crescent to 1800 m amsl in Kuntane Inseno area.

From groundwater flow direction map, several parameters like regional groundwater flow divergent and convergent zone, and local ground water divide are observed. Accordingly, ground water flow directions radiate from the Guraghe highland and its escarpment to wards eastern and south-eastern part of the catchment. The flow direction converts to wards west and northwest in the vicinity of Lake Ziway.

As shown in the figure below, there is local groundwater divide west-east direction around koshe; groundwater divide is imaginary and vertical impermeable boundary across which there is no flow. The divide is generated from vector map where vector lines shows opposite direction. There is a divergent zone at the western escarpment around mareko; which may probably because of recharging of water from the highlands. Divergent zone is a specific area where the water starts to flow to any other area of different direction and considered as recharging zone. In addition there is also a convergent zone in the rift floor around dugda woreda in the vicinity of Lake Ziway; which might be considered as discharging zone. Convergent zone is specific area where the water flows toward specific zones that comes from its surrounding of any direction.

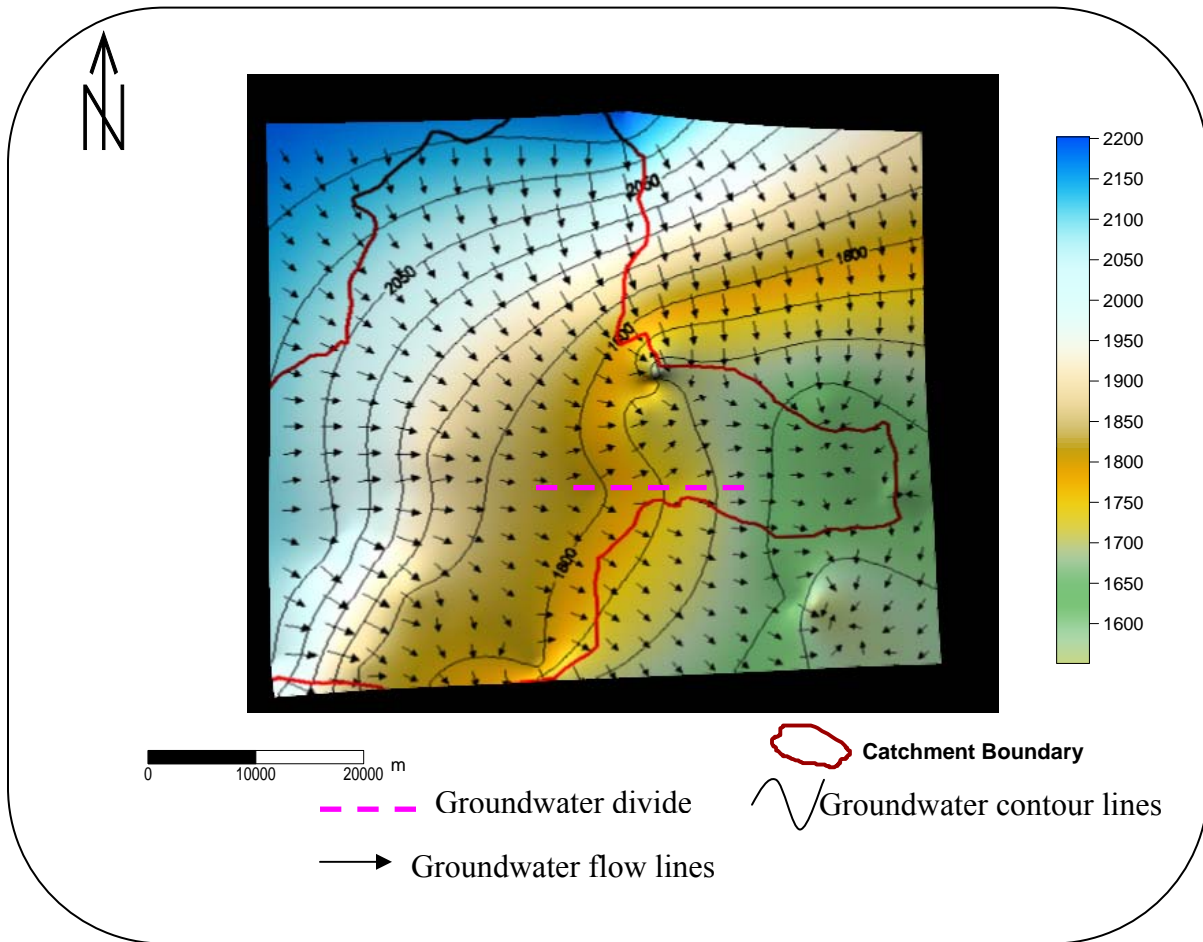


Figure 6-2: groundwater flow direction map of the study area

CHAPTER SEVEN

7. HYDROCHEMISTRY

General

To realize the general chemistry variation and the possible sources for variation (natural or anthropogenic); existing well log data (mostly from deep wells, shallow wells and springs) have been used.

7.1 Evaluation of Hydrochemical parameters

7.1.1 Physical Parameters

i. pH

The waters in Western high lands show acidic characteristics where their pH ranges from 6-7. pH value increases towards the rift floor indicating higher rock-water interaction. The highest value is found in Silty Ashute (Kontane Marsh) for SW-12 which is about 9.5. This could be the input of mineralized Ashute thermal spring.

Most of the deep wells display pH values between 7.0 and 8.5 indicating the alkaline condition. The range indicates that the carbonate equilibrium conditions of the study area favor the dissociation of bicarbonate into carbonate ions.

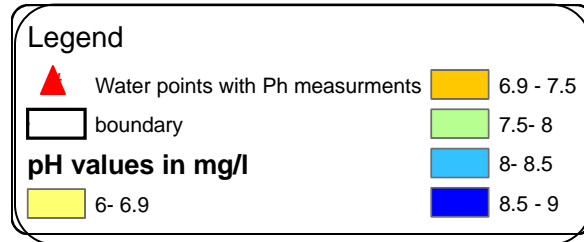
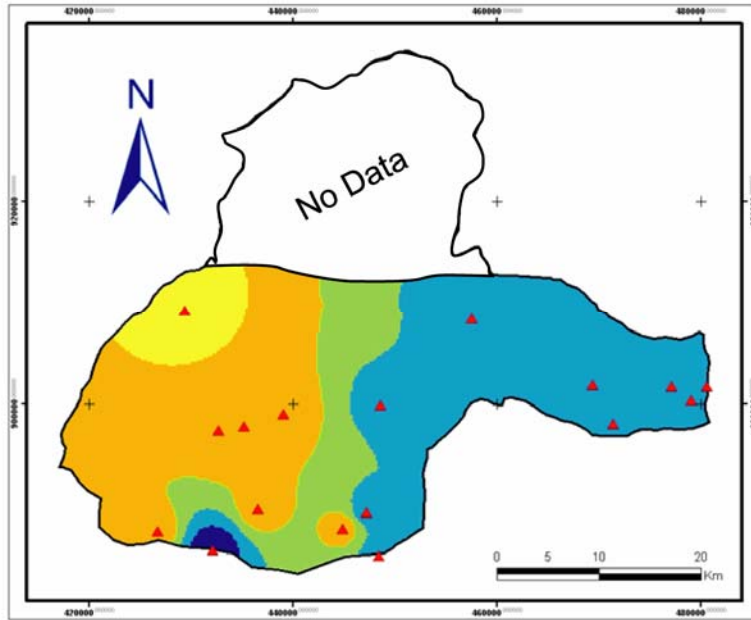


Figure 7-1: pH map of the study area

ii. Total Dissolved Solids (TDS)

TDS of natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000ppm for some brine.

The TDS values in the western highlands and escarpments at Sodo, Meskan and Mareko show lower values ranging from 40-540mg/l; indicating the low rock-water interaction or recharge zone. The Value increases towards the rift floor where it ranges from 1000-6000. TDS value is also higher in south western part of the study area. The water chemistry from Silty Ashute (Kontane Marsh) shows highly mineralized water with TDS value of 6502 mg/l. This high concentration could probably be the result of the input from the mineralized Ashute thermal spring.

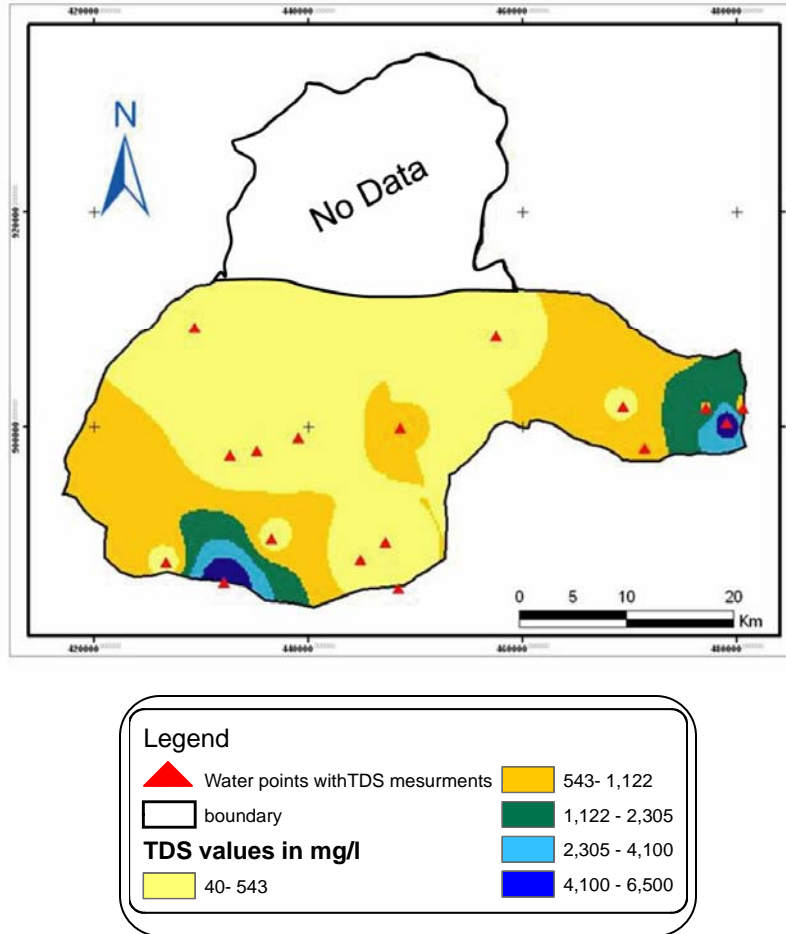


Figure 7-2: TDS map of the study area

The TDS values of the study area ranges from 40mg /l for spring (Sp-11) at Meskan Meserte Wogera to 6000mg/l for borehole (BH-35) at Meki town. Groundwater samples from Dugda: Abeno 01, Graba philla and Meki town are brackish water; with TDS Values greater than1000 mg/l).

7.1.2. Major cations and anions

The major cations and anions that have been considered are sodium, calcium, magnesium, potassium, bicarbonate, carbonate, sulfate, and chloride.

Sodium is the dominant cation followed by calcium and magnesium, and bicarbonate is the dominant anions which also followed by Cl and SO4. Sodium shows significant variation whose values range between 3 to 720 mg/L. The (Na+) concentration ranges from minimum values in the high land and rift escarpments to maximum values in the rift floor close to Lake Ziway. The dominance of Sodium in the study area is likely to be attributed to the dominance

of the acidic volcanic rocks, mainly ignimbrite, rhyolite and pumice. In addition this Na dominance could be attributed because of long time of water-rock interactions. On the Other hand, the concentrations of calcium and magnesium are very low, which was reflected the low hardness of water.

Bicarbonate is the dominant anion in the catchment and its proportion to carbonate was being controlled by the PH values of respective groundwater samples. For PH value less than 8.00, the carbonate concentration of the ground water samples are negligible. Chloride is another anion known by its conservative nature in the chemical evolution process and good indicator of the relative age of ground water compare to other major ions. Even though, more important source of Cl is association with sedimentary rocks, volcanic gases from geothermal fields may also introduce in the ground water system and in some rift lakes (Tenalem Ayenew, 2005). The chloride value of the study area ranges from 1mg /l at Sodo (BH-5) to 122mg/l at Dugda(BH-36).Generally, Cl concentration increase from western highlands and rift escarpment to wards the floor of the rift. sulphate concentrations in the study area are found to be in trace amounts.

7.1.3 Minor cations and anions

All the ions other than those mentioned under the major ions, such as fluoride, Nitrate, iron, and manganese are considered as minor ions.

The most essential minor chemical constituents for consideration in the study area are Nitrate and Fluoride concentrations as they are causes of anthropogenic pollution and natural contamination respectively. Excessive presences of these ions in drinking water are very serious public health concern.

i.Fluoride

Most of the fluoride in groundwater comes from acidic volcanic rocks such as pumice, obsidian, pyroclastic deposits, ignimbrite and rhyolite. The natural concentration of fluoride depends on the geological, chemical and physical characteristics of the aquifer, the porosity, the acidity of the soil and rocks and the temperature and the action of other chemical elements. The high permeability and large rock water interaction makes the leaching process more effective in pumice. As pumice fall deposits are wide spread in the study area, these rocks represent first order potential reservoir of fluoride. Groundwater with high fluoride content is found mostly in calcium-deficient groundwaters. (Tamiru, 2006).

The fluoride guideline values for World Health Organization and Ethiopian drinking water quality guidelines are 1.5 and 3.0 mg/l respectively. It has to be noted that fluoride concentrations above 1.5- mg/l causes dental fluorosis, concentrations ranging from 1.5-10 mg/l results in skeletal fluorosis and concentration greater than 10 mg/l results in crippling fluorosis with nerve disorder. Fluoride toxicity may be acute or chronic, with effects ranging from superficial damage, to disability and even death. Fluoride values over 3 mg/l commonly occur in the Ziway Plain and Tora-Koshe-Dugda ridge. The fluoride concentration in boreholes of the study area ranges from 0.15 for (BH-40) at Meskan to 8 mg/l For (BH-36) at Abono1. And some boreholes and hand pumps near Lake Zeway have concentrations above 3mg/l. One hand pump at Meki Bole elementary school has fluoride concentration of 40 mg/l.

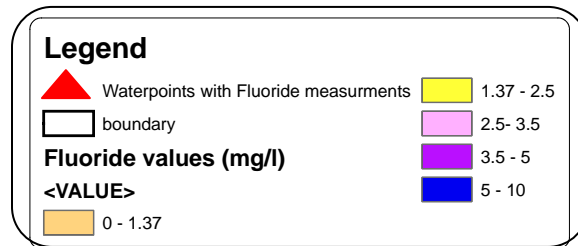
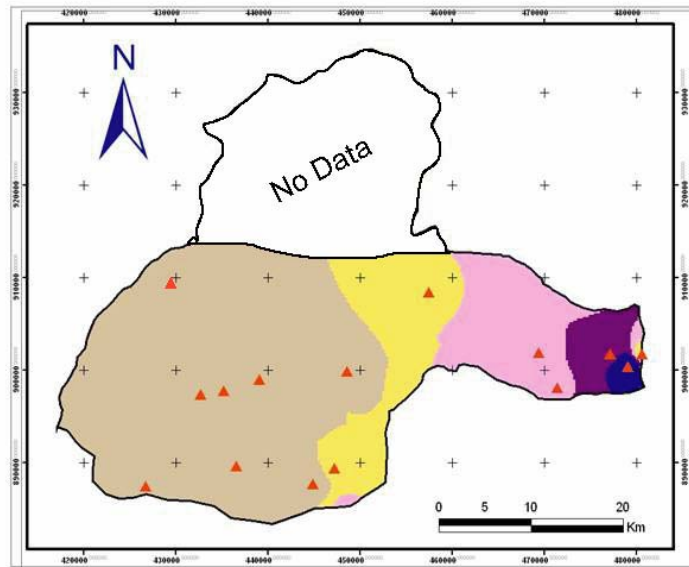


Figure 7-3: fluoride map of the study area

ii. Nitrate

The Nitrate concentrations in the boreholes of the study area ranges from trace amount to 12.5 mg/l. All the waters are well below the Nitrate guideline values of World Health Organization and Ethiopian drinking water quality guidelines. The relatively lower concentration of Nitrate is related to the absence of deep aquifers affected by anthropogenic source related to agricultural fertilizers (inorganic) and animal manures (organic sources).

7.2. Water Types

Water type classification of deep bore holes, shallow wells and springs is made to observe the major water groups, their relationship and evolution along the flow path by using a piper diagram graphical presentation method. The majority of the cold springs, dug wells and boreholes from the highlands and escarpments are Ca-Mg-HCO₃ type and Ca-Na-HCO₃ type. These types of waters are often regarded as recharge area waters which are at their early stage of geochemical evolution.

In the majority of waters from the rift floor boreholes, shallow wells and windmills; sodium dominate their cation species and bicarbonate dominate their anions. These groundwaters fall in the Na-Ca-HCO₃ and Na-HCO₃ type, indicating long duration of rock-water interaction.

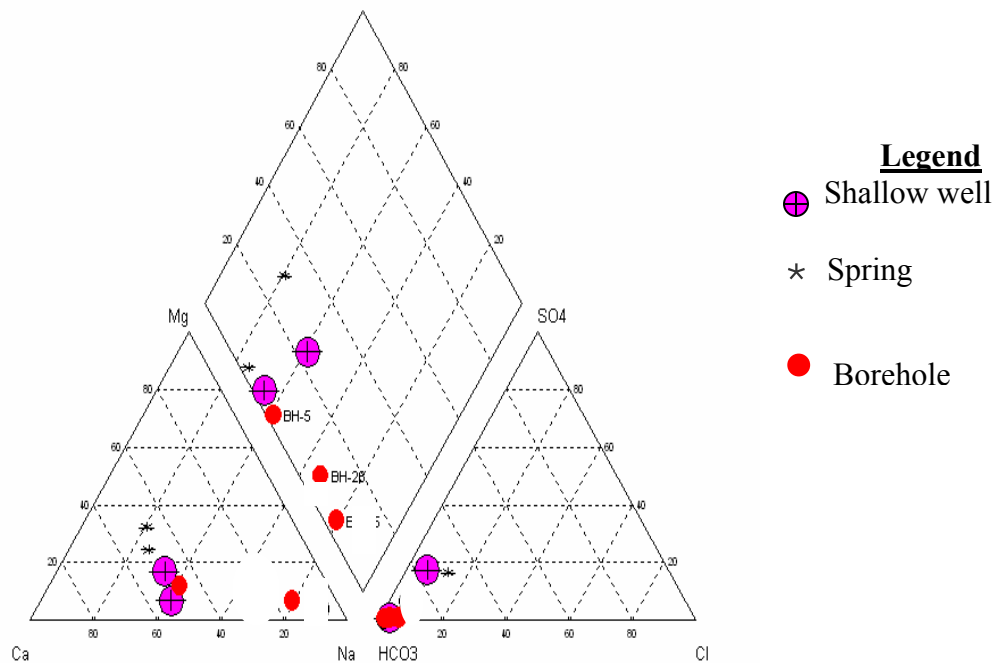


Figure 7-4 Piper plot for all water sources (Boreholes, Shallow wells, Springs)

7.3 Water Quality

7.3.1 Drinking Water Quality

The chemical constituents of water in the study area have been evaluated and compared with WHO and Ethiopian guide line values for water quality standards to observe the level of potability of the water with respect to some ionic constituents like Fluoride, sodium, chloride, sulfate etc that are the major threat in relation to health problem. The major drinking water quality problem in the study area is excessive fluoride. Excessive Fluoride in drinking water poses serious public health concern. Forty-five percent of the water samples in the study area, from various groundwater sources contain fluoride concentrations greater than the Ethiopian drinking water quality guideline value.

Next to fluoride, sodium (Na) is also another major element that exhibits higher values above WHO guideline. The World Health Organization drinking water quality guideline value for sodium is 200 mg/l. It is reported that, excessive sodium in drinking water causes the increase of blood pressure. Around 28.6% of the water samples show sodium concentration above the guideline (>200 mg/L).

High concentration of these two chemical constituents mainly occurs in the tora-Koshe-Dugda ridge, Ziway plain and Ashute/Kuntane plain. Except these two parameters all other water quality parameters are within the acceptable range of both national and WHO drinking water quality guidelines.

Table 7-19: comparison of water Quality standards for drinking water

Element	WHO guide Line mg/L	Total % of samples Above WHO guide line	Ethiopian guide line mg/L	Total % of samples Above Ethiopian guide line
Fluoride	1.5	55	3	45
Sodium	200	28.6	358	19
TDS	1000	19	1776	14.3
Chloride	250	0	533	0
Sulfate	250	0	483	0
Nitrate	50	0	50	0

7.3.2 Irrigation Water Quality

Good quality of water permits maximum crop yields consistent with proper soil and water management. Water quality requirement for irrigation is related to several factors including salinity (which can be expressed in TDS), specific toxicity (which can be expressed by sodium, magnesium, chloride and boron) and infiltration (which can be expressed by Sodium Adsorption Ratio).

Sodium Adsorption Ratio

When sodium rich water is used for irrigation, some of the sodium is taken up by clay and the clay releases calcium and magnesium in exchange in the reaction known as base-exchange reaction. Clays of montmorillonites group can expand and contract in response to changes in the composition of the adsorbed cation between the clay plates resulting in decreasing in permeability of soils. Since large part of the study area is covered with lacustrine sediments of which the top layer is dominated with clay soils, effect of sodium on soils during irrigation should greatly be taken into consideration.

The United States salinity laboratory proposed the following relation to calculate the sodium hazard.

$$\text{SAR} = \text{Na} / (\sqrt{(\text{Ca} + \text{Mg})/2})$$

Where SAR is defined as Sodium Adsorption ratio expressed in mill equivalents per liter.

The United States Development of Agriculture has developed a widely accepted classification of irrigation waters based on the sodium adsorption ratio as an index for sodium hazard.

Table 7-20: Suitability of natural waters for irrigation based on SAR

Water class	Alkali hazard (SAR)
Excellent	<10
Good	10-18
Medium	18-26
Bad	>26

Groundwater samples from the guragie highlands, the escarpment and the rift floor have been taken to evaluate its suitability for irrigation.

Table 7-211: SAR values of various water samples in the catchment

No.	Woreda	Scheme ID	SAR(meq/l)
1	Sodo	SW-2	5.00
2	Silty	SW-11	21.7
3	Mareko	BH-15	8.2
4	Mareko	SW-23	10.2
5	Dugda Bora	BH-37	15.2
6	Dugda Bora	Wm-3	4.1
7	Dugda Bora	Wm-10	19.5
8	Dugda Bora	Wm-1	4.2

Accordingly, most of the SAR values in the study area lie in the range between 5 and 26; they are classified from medium to excellent for their suitability for irrigation purpose.

CHAPTER EIGHT

8. SUSTAINABILITY CHALLENGES OF THE WATER SUPPLY SCHEME IN DUGDA WOREDA General

Water-supply programs consist of three essential components: technology, people, and institutions. The interface of these facets determines whether a particular scheme is sustainable (Betman & Miriam, 2007). The goal of the water supply and sanitation sector is to improve the social well being of the populace, enhance the performance of the national economy and ensure equitable provision of adequate quantity and quality of water services to all competing user groups on a sustainable basis (Republic of Kenya water Authority project appraisal report, 2004).

Project-evaluation reports from developing countries indicate that poor construction of Drinking Water Supply (DWS) schemes, lack of rewards for good operation and maintenance, and widespread corruption in supporting organizations are the major causes of failed systems (Howe & Dixon, 1993; Singh et al. 1993).

The major cause of poor utilization of water resources is attributed to the absence of a well defined water resources management policy and finance. Besides, there was no well delegated institution with clear mission and vision. As far as conditions permit, every citizen shall have access to sufficient water with acceptable quality, meeting basic needs.

Supplying water projects alone would not contribute for communities especially in rural areas to reduce the problem of sustainability of schemes. Rather the issue of functionality, utilization by intended beneficiaries and continuity of water projects to serve for longer period are very important to be considered and integrated to scale up intended impacts. Hence, integration between beneficiaries and project suppliers in all phases needs to be addressed to come up with sustainable utilization of the resource

8.1 Description of the study Woreda

Dugda is one of the woredas found in the North eastern part of Meki river catchment. Dugda woreda is located in the Oromia Regional state of Ethiopia; Part of the Misraq Shewa (or "East Shewa") Zone, in the Great Rift Valley. The woreda is bordered to the southeast by Lake Ziway on the south by Adami Tullu and Jido Kombolcha, to the west by the Southern Nations, Nationalities and Peoples Region, to the northwest by the Mirab Shewa Zone, to the north by Bora Woreda, and to the east by the Arsi Zone. The capital of Dugda is Meki. Geographically this Woreda is bounded within the limits of $8^{\circ} 01' 56''$ N to $8^{\circ} 23' 54''$ N latitude and $38^{\circ} 32' 47''$ E to $38^{\circ} 59' 38''$ E longitude (Fig 8.1); with an aerial extent of 1089km^2 . The altitude of this woreda ranges from 1500 to 2300 meters above sea level.

Based on figures published by the Central Statistical Agency in 2005, the population of the study Woreda was estimated to be 81,687, of whom 41,489 were males and 40,198 were females; 25.53% of its population is urban dwellers, which is less than the Zone average of 32.1%. Dugda Woreda has been divided into 36 peasant associations for administrative purpose. Water supply coverage in the study woreda has been estimated at 64% of rural residents.

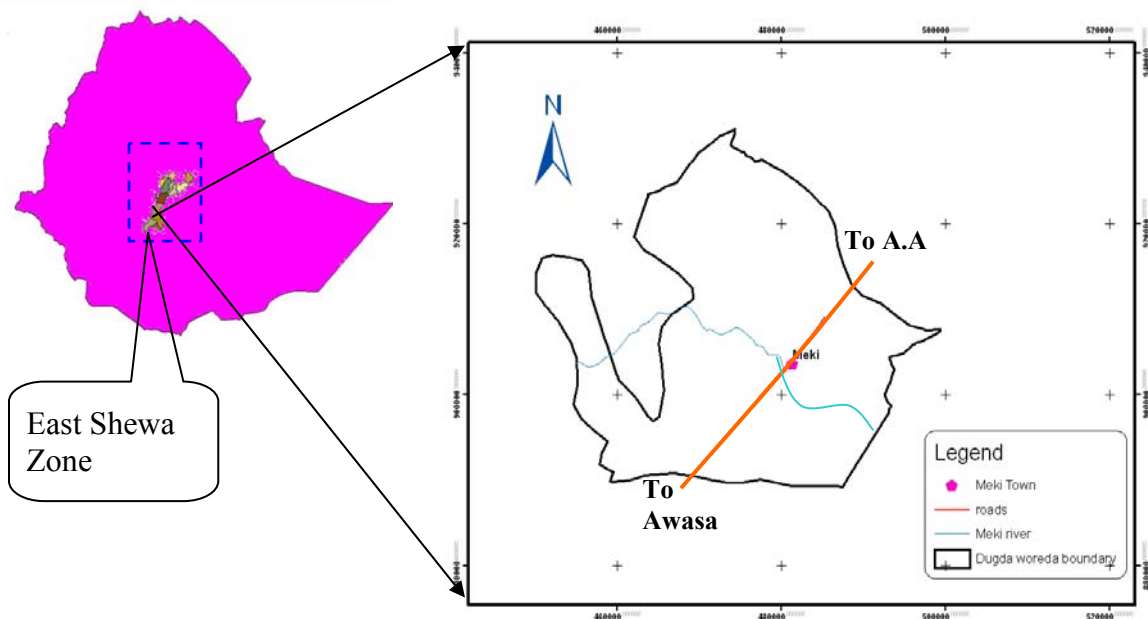


Figure 8-1: Location map of Dugda woreda

8.2 Characteristics of the Sample population

Prior to data collection, the author held a meeting with selected community leaders, officials from the district water-supply offices, representatives from concerned NGOs, and members of the water committees. During the session the PA's to be included in the survey were identified and this determination ensured the cooperation of relevant individuals from the respective PA's and communities throughout the field-survey period.

Accordingly, from the existing 36 Peasant associations (PA's) of the woreda, Five representative PA's which can characterize the whole water supply sustainability problem of the woreda were studied in this research work. The PA's are namely, Woyo Gebriel, Abono Gebriel, Dodota Denbel, Tepo Choreke, and Bekele Grisa. Numbers of Households to be interviewed from each PA's was made proportionally with the total number of households in the respective PA's as shown in the table below.

Table 8-222: numbers of Households interviewed from each PA's

Name of peasant association	Total Number of households	Total Number of households interviewed
Abono Gebriel	236	16
Bekele Grisa	616	41
Dodota Denbel	333	22
Tepo Choreke	508	34
Woyo Gebriel	401	27
Total	2094	140

More than 50% of the respondents were females because, it was women who suffer the burden of fetching water and seriously affected by the problem.

8.3 Major findings of the study

The study reveals that groundwater is the main source of water supply; eighty-two percent of the respondents use groundwater as the main source of domestic water supply. Rivers and Lake Ziway are also sources of drinking water in addition to the safe one. Only eight percent use surface water for drinking purpose. The rest ten percent uses surface water and groundwater sources for drinking purpose.

In this part, main causes that affect sustainability of the water supply scheme of the woreda are discussed based on findings obtained from the survey.

Water quality problems, lack of enough budgets, lack of proper investigation and lack of trained workers are commonly cited reasons for the failure of most water supply schemes in the study area. Mobilisation and community participation, with able organizers and appropriate information support, may offer a great opportunity for sustainability of the schemes.

All development activities are for the beneficiaries and exclusion of these communities from pre-development aspect means losing information for identification of problems and solutions too. Other wise what is happening in the ground may mismatch with needs of community.

8.3.1 Technology used for rural water supply

Two technology types namely Boreholes, and shallow wells are most widely used. These technologies are unevenly distributed through out the woreda. According to the data obtained from rural water supply office of Dugda Woreda, there are 29 boreholes, 26 windmills and 20 handpumps total of 75 water supply schemes.

Three PA's namely Orgo Gadilala, Welda kelina, Mengiso Woji in the study woreda has no any developed water supply schemes. The people there use unsafe water from community pond, river and lake for drinking purpose. In addition, some of the people fetch water from adjacent PA's which are very far from their settlements. One reason mentioned by the rural water supply head officer as to why this PAs did not have water supply development activities is road inaccessibility. But currently all are under investigation.

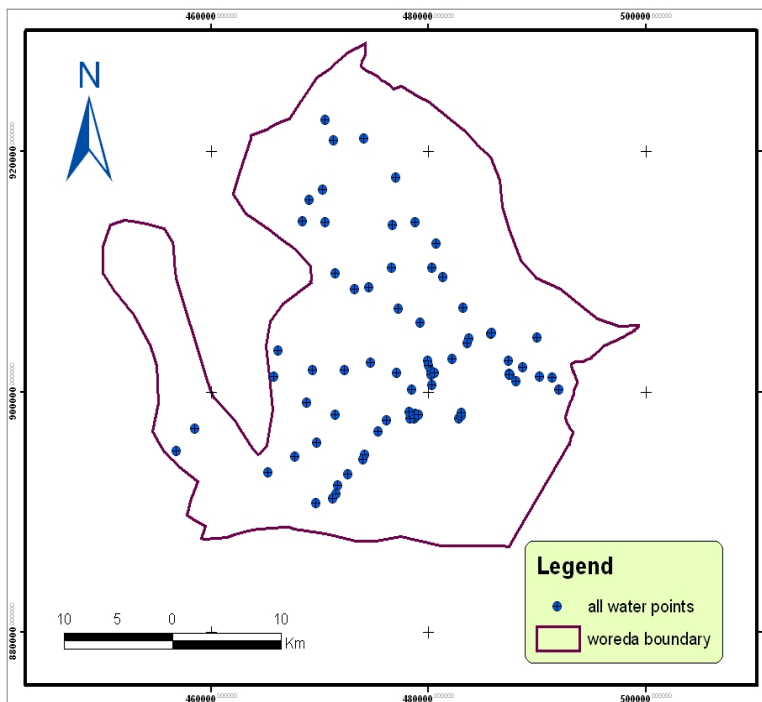


Figure 8-2: Distribution of water points in Dugda woreda

Twenty-six point six percent of the water points in the study woreda are non-functional. Accordingly, 7 hand pumps, 8 boreholes, 2 windmills are failed to meet their objectives. The causes of failure are; pump defect, looting, burial due to flooding, and abandoned due to high fluoride content. More over, 3 water points; 1 hand pump and 2 boreholes are delayed to provide service at the expected time. Major cause for the delay of projects is financial problem in which beneficiaries lag to cover their share. Result of the survey reveals also that technical staffs of the woreda justify imbalance between supply and demand of water is another problem which affects Sustainability of developed water supply schemes.

Table 8-233: Non-functional water supply schemes in Dugda Woreda

PA's Name	Easting(X)	Northing(Y)	Status of WS schemes
<i>Koto Biliti</i>	<i>456820</i>	<i>895084</i>	<i>BH nonfunctional</i>
<i>Tepo choreke</i>	<i>474226</i>	<i>894751</i>	<i>BH nonfunctional</i>
<i>Tepo choreke</i>	<i>474038</i>	<i>894422</i>	<i>BH nonfunctional</i>
<i>Birbirs Guda Sabole</i>	<i>470565</i>	<i>914133</i>	<i>BH nonfunctional</i>
<i>Graba korke</i>	<i>475417</i>	<i>896738</i>	<i>BH under constraction</i>
<i>Korke Adama</i>	<i>471295</i>	<i>920931</i>	<i>BH under constraction</i>
<i>Walda Hafa</i>	<i>480404</i>	<i>910358</i>	<i>HP under constraction</i>
<i>Darara Dalacha</i>	<i>490315</i>	<i>901264</i>	<i>HP nonfunctional</i>
<i>Oda Boqota</i>	<i>482266</i>	<i>902758</i>	<i>HP nonfunctional</i>
<i>Sera Wakele</i>	<i>477313</i>	<i>906916</i>	<i>Wm nonfunctional</i>
<i>Oda Bokota</i>	<i>480034</i>	<i>902598</i>	<i>Wm nonfunctional</i>
<i>Bekelei Girisa</i>	<i>478766</i>	<i>897805</i>	<i>HP nonfunctional I</i>
<i>Bekele Girisa</i>	<i>478942</i>	<i>897992</i>	<i>HP nonfunctional</i>
<i>Bekele Girisa</i>	<i>478816</i>	<i>898150</i>	<i>HP nonfunctional</i>
<i>Bekele Girisa</i>	<i>483119</i>	<i>898014</i>	<i>HP nonfunctional</i>
<i>Bekele Girisa</i>	<i>483129</i>	<i>898268</i>	<i>HP nonfunctional</i>
<i>Mukiye Leman</i>	<i>465716</i>	<i>905691</i>	<i>BH nonfunctional</i>
<i>Weyo Gebriel</i>	<i>471209</i>	<i>891140</i>	<i>BH nonfunctional</i>
<i>Dongorota Gusa</i>	<i>473249</i>	<i>908545</i>	<i>BH nonfunctional</i>
<i>Weyo Gebriel</i>	<i>465299</i>	<i>893316</i>	<i>BH nonfunctional</i>

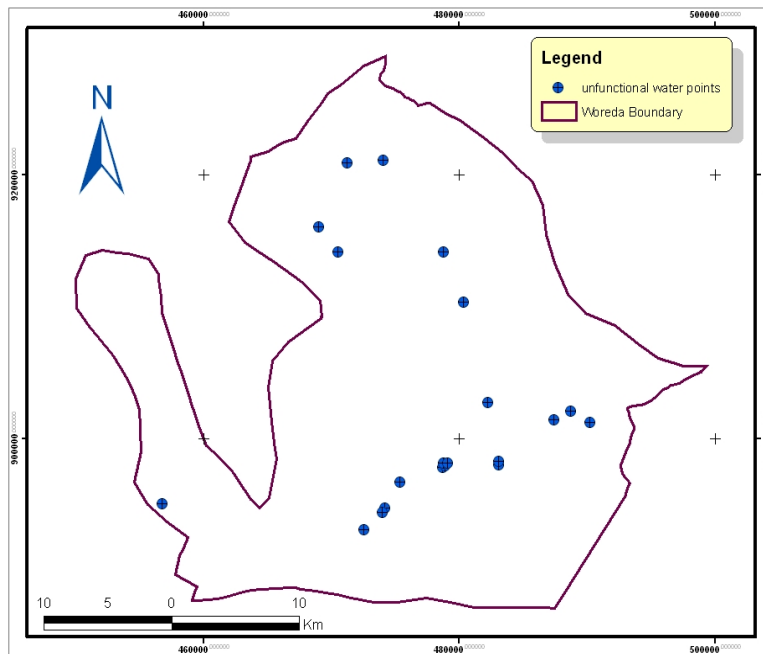


Figure 8-3: Distribution of non-functional water points in the Woreda

Findings of the survey show that rate of failure for boreholes is higher than that of windmills and hand pumps.

In addition local communities in the study woreda develop 2162 dug wells for individual consumption without permission. This may result in depletion of the resource. The study tells forty-eight percent of the beneficiaries put boreholes at their first priority of water supply sources, thirty percent of the respondents give priority to wind mills and the rest twenty-two percent give priority to hand pumps.



Figure 8-4: traditionally developed Hund dug well by local people at Bekele Girisa

In the study woreda, Bekele Girisa PA, most of the community develops groundwater by digging up to a depth of 30 meters. There are 253 hand dug wells within this PA developed by individuals which may result in depletion of the resource. Nearly fifty percent of the households in the described PA use water schemes developed by their own, they do not care about the public water supply schemes.



Figure 8-5: water supply schemes in Dugda Woreda

8.3.2 Water quality

Water quality is the main cause for the failure of majority of water supply schemes in the study area. Many of the developed schemes are failed to meet their objectives before the expected time due to water quality problem.

The main source of water quality problem of the study woreda is high concentration of fluoride. Most groundwater sources have fluoride values above WHO standards, i.e. 1.5mg/l. Results of this survey show that 83% of the respondents explained the water in which they are using currently is not healthy potable due to higher concentration of fluoride.



Figure 8-6: water schemes failed due to high fluoride concentration

90% of the beneficiaries are victims of dental or/and skeletal fluorosis. (In the broadest sense, the term "Fluorosis" describes a state of toxicity of the trace element, Fluorine within an organism. Fluorosis is not limited to humans, and can affect any aspect of the ecosystem. Humans appear to vary considerably with respect to their susceptibility to Fluorosis. As a general guideline, prolonged total Fluoride intake exceeding 1.0 mg/day can produce clinical signs of Fluorosis in adults). According to Teklehaimanot reda *et al.* 1987, over exposure to fluoride results in accumulation of the element in the mineralizing tissues of human body. In young people fluoride accumulates in teeth (dental fluorosis) and bones (skeletal fluorosis). While in older people over exposure of fluoride causes skeletal fluorosis only.

Table 8-244: Number of victims of fluorosis in a family

Members of a family (victims of fluorosis)	Frequency	
	No.	Percentage
0	14	10
1-3	48	34
4-6	78	56

Many people from Woyo Gebriel, Abono Gebriel and tepo Choreke are faced with severe crippling form fluorosis characterized by complete physical incapacity. The higher water consumption rate of the people due to its higher temperature (25-30 °c) contributes to higher exposure risk. People living in the above mentioned areas explained that the water is not suitable even for cooking it changes its taste and color. So that they prefer to use unprotected surface water (i.e., Lake Ziway), which is more than five kilometers far from their settlements.



Figure 8-7: Skeletal fluorosis due to high fluoride concentration, right from woyo Gebriel left from Abono Gebriel.

Ninty-one percent of the respondents reveals water quality problem (i.e. the presence of higher concentration of fluoride $>3\text{mg/l}$) is the main cause for failure of developed water supply schemes.

Table 8-255: Respondent's prioritization for Causes of developed water supply scheme failures

Causes of developed water supply scheme failures	Rank
Water quality	1
Lack of proper investigation	3
Management problem	5
Institutional problem	4
Finance	2

There are several methods to remove fluoride from drinking water; even though the methods differ from each other in technique and performance. The process of removal of fluoride from water is generally termed as *defluoridation or defluorination*. Activated Alumina is one of the methods most successful and the most often used absorbent for fluoride removal. This method uses Al_2O_3 for defluoridation. In many cases it appears to be technically feasible and economically viable. The main advantages are the simplicity of normal operation and the efficiency; fluoride can be reduced to practically any desired levels. Very recently, beneficiaries in abono Gebreil are using this method at a household level; with some sort of follow up regarding the usage by the trained water committee members of the PA.

The head of rural water supply office explains also that OSHO (Oromia Self Help Organization) is on the way to disseminate bone char gravels for defluoridation purpose at household level. Bone char gravels are bones, which have been heated to high temperature above 400 degree Celsius, and crushed. In the process, all organic materials are removed and only the mineral content apatite is left. Due to its porous structure this material is able to absorb high amount of fluoride.

8.3.3 Community participation

Community participation should be oriented towards making the communities have sense of ownership and responsibility. Involvement of the community in water supply projects and the training of grassroots-level technicians could be the most important option to enhance sustainability of water supply schemes in the woreda. Forty-six percent of the respondents did not have any kind of contribution during water supply scheme development activities.

Their reasons for not participating are:

- 1 Some people did not see the project at work, but the scheme completed and delivering service.
2. Some people did not have the idea how to participate.
3. Some of them did not understand even the importance of their participation.

The table below illustrates that there was higher level of participation during implementation. Survey of technical staff also reveals greater number of beneficiaries participate during implementation of projects. Community contribution takes different forms during implementation of water supply projects; labour gets the largest part followed by providing local materials and food to project workers.

Table 8-266: Significance of community participation in water supply scheme development activities

Community participation	Frequency	
	No.	Percentage
Site selection	8	6
Planning	-	-
Implementation	60	43
Management	-	-
Site selection and implementation	7	5
Not participate	64	46

Bringing together the beneficiary communities to participate in development activities can develop them. Lack of greater attention of community participation in the study woreda greatly affects the sustainability of developed schemes since they do not feel sense of ownership and become casual when schemes are failed.

Monitoring works seem weak, since failures have been ignored for more than a year. Once huge capital is invested to tackle the problems of local communities, failures are common due to many reasons. However, monitoring status of water services and making repairs is easy and do not require as much resource as the initial requires.

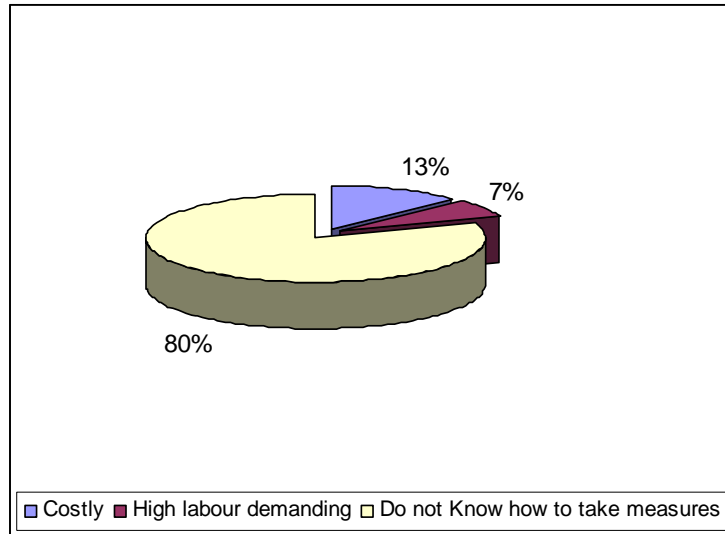
Fifty-five percent of the respondents know the presence of failed water supply schemes in their respective areas as illustrated in the table below. In addition, sixty-eight percent of the beneficiaries discuss with their neighbours and concerned bodies about the water supply problems occurred in their schemes and have also been claiming for the repair of failed schemes.

Table8-27 Beneficiaries perception to wards failed water supply schemes.

Is there any failed water supply scheme?	Frequency in (%)
Yes	55
No	24
I do not know	21

Ninety percent of the respondents did not try to take measures to the failed schemes due to various reasons; where eighty percent of them did not know how to take measures.

Figure 8-8: Reasons of beneficiaries for not taking measures to the failed water supply schemes.



As sustainability of rural water supply requires active concern and involvement of beneficiaries, it is crucial to consider it against their satisfaction. Whilst users get satisfied, they will be highly concerned and involved in any water supply development activities. However, in the case of the study woreda beneficiaries are not satisfied with the quality of water which severely harmed their health. They rather seek development of other sources which are friendly to their health (example development of surface waters).

Community participation helps water supply development activities to be efficient in resource allocation, effective in implementation, equitable, sustainable and increase accountability among stake holders. To keep the people participating in resource provision, their satisfaction has to be considered. When satisfaction is addressed, sustainability of the water supply system would also be addressed. Result of the survey shows that 68% of the Beneficiaries discuss with their neighbours and concerned bodies about the water supply problems occurred in their scheme. Community satisfaction is a tool for the overall sustainability of water supply schemes.

8.3.4 Role of Women's participation in sustainability of water supply schemes

Water supply scheme failures largely affect women, because they are most often collectors, users and managers of water in the household. In such cases, participation of women in both development and management activities is crucial for sustainability of the scheme. Access to sustainable water supply within easy reach of the household means women can save time, labour and effort, which they can employ in more productive and income generating activities. Thus the sustainability of water supply scheme is of particular benefit to women.

Although there is a rule that encourages equal participation of both men and women in water committees, some people in the study area interpret this equal share in management seats negatively. Because they thought that women can not carry equal responsibilities as men do. Therefore, enormous effort has to be done in awareness creation of the society to enhance their understanding towards participation of women in keeping the service working for a longer period.

Result of the survey shows that, women participation in planning, site selection, management and implementation of a project have not been given the necessary focus.

According to Results of the survey sixty-five percent of respondents describe that women contribution in the scheme is fetching water.

Table 8-278: respondent's perception towards women's role in water supply schemes

Women participation	Frequency in (%)
Main fetchers	65
Water committee and fetching water	45

On the contrary, some respondents clarify that involvement of women have greater influence in sustainability of the scheme. Accordingly, 58% of the beneficiaries reveals

participation of women have greater role in sustainability of the scheme. The rest does not consider their involvement have as such greater value.

Generally, the involvement of women in every aspect of water supply development activities enhances sustainability and performance of the schemes. Therefore they should participate at the time of formulation, implementation and maintenance of the schemes.

8.3.5 Organizational and human resource aspects

The office of rural water supply of Dugda woreda is the only responsible body for activities related to water supply development activities. Local and international NGOs help community of the woreda through the channel of this office. MCS (Meki catholic secretariate), self help, OSHO (Oromia self help organization), LVIA (Lephians Voluntaries International Association), UNICEF, World Vision are NGOs working in rural water supply development of the study woreda. Currently, MCS is playing the leading role in water supply and sanitation development activities in the woreda.

Table 8-289: beneficiaries' perception to wards stakeholders participation in WS development activities

Who develop the water supply scheme?	Frequency	
	No.	%
GO's	22	16
NGO's	17	12
Both	76	54
Do not know	25	18

Currently, the rural water supply office of the woreda has only two staff members; where head of the office is diploma holder in plant science which has no direct relevance to the unit. This may result in lack of proper knowledge about the resource as a consequence it could be one reason for failure of the schemes. The other staff member is diploma holder in rural water supply and sanitation and he works as a technician. The head of the water

supply of Meki town is manufacturing graduate in which he has no relevance with the department. There is greater shortage of skilled human power in the woreda. The Head of rural water supply office explains that, the staff greatly suffers in covering all problems of the schemes found in the woreda. The office does not have enough budget and facility (such as vehicle, equipments, etc) as well as spare parts to solve failings at the right time. According to the rural water supply officer of the woreda, they have only one motor cycle to serve the staff members in all areas of the woreda. This all have negative impact on the sustainability of the scheme.

Findings of the survey show that, the respondents give first priority to invest on the knowledge of professionals to minimize failure rate of developed water supply schemes.

Table 8-30: technical staffs' perception towards measures that must be taken to minimize rate of failure of developed water supply schemes.

Measures taken to minimize rate of failure	Rank
Improving institutional structure	3
investing on knowledge of professionals	1
Improving awareness about the resource utilization to all concerned bodies at all levels	2

One of the key informants from MCS, Miss Yetnayet, explains that special care must have been given to windmills; because spare parts are not easily available at the market. In addition maintenance of these schemes needs skilled personnel. Therefore, much effort has to be done in capacity building of beneficiaries by arranging various training programs and workshops at the grass root level.

Repair time depends on the time interval of failures and report of beneficiaries. Whenever report reached the staff; the technician will reach the area and give support. However, this does not work consistently because there are schemes that did not get repair even if frequent reports were made. For example a borehole at tepo Choreke is failed due to pump defect before a year but it is nonfunctional till know.

Lack of enough budgets, trained workers and logistics were frequently cited reasons for the low sustainability of water supply schemes. Decisions on capital budget exacerbate the weakness. The woreda has usually not made budget decisions at one time in a year. When some leftover budgets found from the treasury of sector offices, relocating it to capital projects like water development is common. Due to these factors, supervision works of the office usually get insufficient budget and hence ineffective.

Discussion with the technician of the office approves that repair and maintenance of schemes has been given as soon as the PA's report to the office. Although the office has said this, the reality seems to be different. It makes no sense for water supply schemes to stop functioning for more than a year. It seems that less attention is given to take action. Monitoring seems to be weak when failures of projects to give service have been ignored for more than a year.

Generally, as far as beneficiaries are not able to report problems, the office does not have clear system for supervision and monitoring works.

8.3.6 Accessibility to water supply points: distance to water points

Results of the survey show that technical staff gives first priority for hydrogeological feasibility of the area as main criteria considered for site selection in water supply development activities following by settlement as shown in the table below.

Table 8-31 Criteria considered when planning sites for water supply schemes

criteria	rank
settlement	2
hydrogeological feasibility	1
Transport accessibility	3

The study notifies sixty-two percent of the developed water schemes are located in areas 2-5 kms far from settlements. In this case, the schemes lack closer eye contact from beneficiaries resulting in exposure to danger.

Findings of the survey show that forty percent of the water points are 3-5kms far from beneficiary's settlements. The graph below illustrates the average distances to water points.

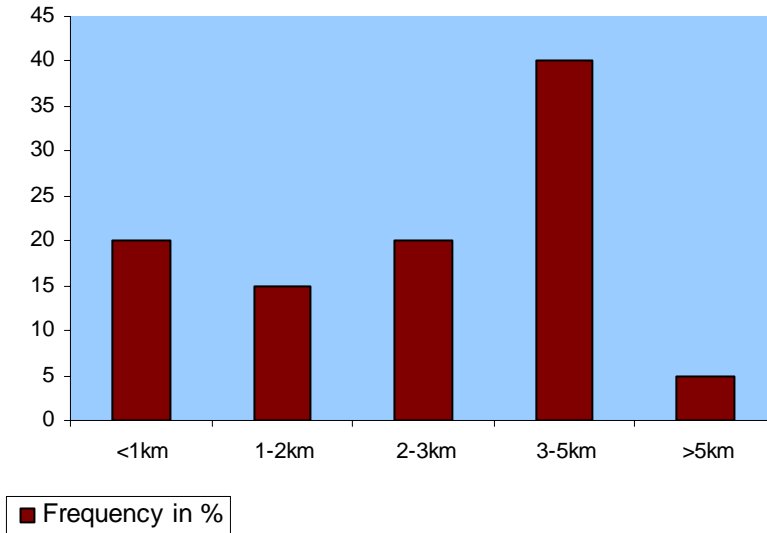


Figure 8-9: average distance from settlements to water supply schemes

8.3.7 Management of rural water supply

The rural water supply management is organized by the water committee; where members of the committee are elected by the community. Result of the survey reveals that 82% of the beneficiaries know the water supply scheme is managed by water committee. These water committees have been given little training related to financial management, minor repair, and maintenance works, environmental sanitation and hygiene education. Water committees together with the beneficiaries set service charges to support operational and expected repair costs. In the study area, almost all the water supply schemes are managed by water committees

The water committee members are not paid for the service they provide. As a result, the majority does not seriously carry the responsibility given by the community. This thoroughly affects the management of the scheme which later affects its sustainability. One of my key informants from MCS explains that, water supply scheme is better to be managed by board than water committee; so as to attain better sustainability of the developed schemes.

8.3.8 Training to technical staffs, water committee and Households

Training is one important factor for sustainability rural water supply schemes. The government as well as other concerned bodies of this sector gives greater stress to the infrastructural development of water supply schemes. However, better attention should also be given to train personnel which is important for the developed infrastructures to achieve their goals.

Sustainability of water supply schemes depends on good technical training and staff motivation. In addition to educating and training water management committee at all levels, ensuring that women participate equally in education and training programs, needs especial emphasis.

The technical staff of the woreda requests to obtain some objective oriented training concerning the technical and managerial aspect of water supply development activities which are very crucial to develop their skills. But little attention has been given at zonal and even regional level, although it is basic to attain sustainability of the schemes.

Findings of the survey reveal 94% of the interviewed technical staffs forward their idea that the existing training and staff mobility strategy does not allow professionals to improve skills.

Water committee training is weak because of inadequate support from the woreda. The reason for this drawback set by the woreda officials was shortage of budget and logistics. In addition, there are no trained technicians at community level except some sort of exposure given with regard to maintenance of schemes when they face simple failures. All repair and maintenance works are taken care of by technician from the woreda office.

Training includes not only the professionals and management bodies but also that of the household level. The survey result shows, more than 85% of the beneficiaries did not take any kind of training related to water use and proper utilization of the resource. This shows there is lack of education and awareness creation practices in the woreda.

Therefore special consideration should be given by all concerned bodies to disseminate objective oriented trainings at all levels; since it is essential to sustain the developed water supply schemes for a longer period.

CHAPTER NINE

9. Conclusions and Recommendations

9.1 Conclusion

- ➡ In the study catchment, there are four hydrostratigraphic units
- ➡ The main recharge area of the study catchment are western Guraghie highlands, and the recharge amount is 116.7 mm/yr
- ➡ The general geochemical trend for the groundwater flow path evolving from calcium-sodium bicarbonate and calcium-magnesium bicarbonate type to sodium- calcium bicarbonate and sodium bicarbonate type.
- ➡ The concentration of fluoride increases towards the rift.

Main determinant of sustainability problem of water supply schemes in the woreda is Poor quality of water in addition:

- ➡ Communities involvement is weak
- ➡ Women participation of low focus.
- ➡ No clear system for supervision and monitoring of water supply schemes.
- ➡ Special attention is not given to train a personnel
- ➡ There is lack of enough budget, skilled and trained workers and logistics

9.2 Recommendation

- ➡ Investigation with management can bring a significant leverage towards enhancing the use of groundwater in poverty reduction, water supply and sanitation improvements.
- ➡ Well compilation report should be properly documented to obtain adequate data on borehole history of the studied area
- ➡ Detail hydrochemical study with respect to origin of high fluoride concentration in the groundwater should be conducted.
- ➡ Community awareness and training about the effect of their activities on the hydrogeologic environment as well as efficient and sustainable use of their water resources should be made

- ➡ Inventory of available groundwater abstraction sources and estimation of actual groundwater utilization must be made, to carry out optimum utilization of the resource.
- ➡ Various defluoridation techniques must be implemented in the study area so as to minimize the effect of high fluoride concentration of the water.
- ➡ Dugda woreda rural water supply office needs to be equipped with adequate trained and skilled professionals. In addition concerned bodies must allocate sufficient budget to the office to carry out tasks appropriately.
- ➡ It is recommended to have strong involvement of local communities especially women in water supply development and management activities from start to end.
- ➡ More works are expected from the office to persuade the administrators to have budget support for training of technical staff, water committees, local operators and beneficiaries.
- ➡ Promotion of awareness-creation programs, including community mobilization works at all levels need to be strengthened.
- ➡ Strong monitoring and supervision mechanism should be established to ensure that water supply schemes are sustained for the intended period of time.
- ➡ Community level operators facilitate service recovery from failures. Therefore, a lot has to be done in this regard.
- ➡ Designing new strategies of water supply scheme management (for example managing water supply schemes by Board) have to be implemented to attain sustainability of the water supply schemes.

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Annexes

Annex 1. Monthly Sunshine hours at Bui station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	9.5	5.1	7.5	7.4	8.5	7.9	5.5	5.3	6.8	9.6	10	10
1991												8.6
1992				7.4	8.4	7.2	4.8	3.1	6.3	8.1	8.4	8.5
1993	7.1	6.7	10.2	6.2	8.1	7	5.5	6.5	5.9	7.4	10.3	9.8
1994	10.1	9.7	7.6	8.1	8.9	6.1	4.8		7.2	10.1	9	
1998			7.8	8.8	7.9	7.8	4.8	4.1		6.4	10.6	8.3
1999	9	10.7	7.7	10.3	6.4	8.8	4.5	6.1	7.3		10	9.7
2000	10.2		7.1	9.3	7.3							
2002	8.3	8.6		8.4		4.2	6.3	5.6	6.7	9.7	10.4	7.5
2003	8.5	9.4	9.6	7.2	9.4	6.8	3.9	4.2	6.6	10.2	9.7	
2004	8.2		8.3		9.3	5.1	4.9	5.4	7.4	8.2	10.3	9.2
2005	8.4	9.9	9	8.1	7	6.1	4.8	7.1	6.9	9.1	9.3	10.7

Annex 2. Monthly Sunshine hours at ziway station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980			6.5	9.5	10.3	8.6	6.6	7.5			10.3	10
1981	9.5		6.6		10.2	9.2	5.5	6.8	4.7		11.1	10.5
1986	10.4	8.8	9.5	7.4	9.6	7	7.5					
1987	9.3	8.6	7	8.5	7.1	8.3	8.5	7.2	7.7	8.8	10	10.4
1988			9.5	7.4	9.9	8.3	4.3	6.6	6.6	9.5	11.1	10.5
1989	9.4	9.6	8	7.5			6.5	6.9	7	9.8	10.4	8.8
1990	10.4	7.4	8.4	8.6	9.4	9.4	6.4	6.7	6.8	9.7	10.5	10.4
1991	10.1	8.2	8.2	9.1	8.7	8.8	6.5	5.8	7.7	9.3	10	
1992	7.8	8	8.9	8.6	8.9	8.3	6.3	5.4	7.2	9	10.1	9.5
1993	8.9	8.3	10.1	7.7	8.8	8.5	6	7.5	6.8	8.3	10.8	10.6
1994	10.7	10	8.2	8.4	9	7.8	5.9	6.7	7	9.7	9.9	10.7
1995	10.7	9.4	8.4	7.7	10	9.7	6.1	6.1	6.9	10.1	10.1	10.7
1996	9.1	10.3	8.5	7.9	8.3	7	6.3	6.1	6.9	10.1	10.1	10.7
1997	8.5	10.9	8.9	7.7	9.4	8.3	7	7.5	8.3	8	8.4	10
1998	9.1	8.4	8.3	9	8.9	8.8	5.8	6	6.9	7.7	10.8	10.7
1999	9.8	10.6	8.5	9.5	8.8	8.6	5.4	6.1	7.3	7.3	9.9	9.7
2000	9.7	10.4	9.5	8	8.8				6	7.8	9.7	9.9
2001	9.5	9.6	7	9.6	8.6	7.8	7.5		8.4	9.3	10.3	10.1
2002	9	10.1	7.5	9.6	8.9	8.4	8.1	7.1	7.6	9.7	10.5	8.6
2003	9.6	10.2	9	7.5	10.2	8.3	5.4	5.7	7	10.3	10	9.3
2004	8.8	9.7	8.8	7.8	9.9	8.3	6.7	7.1	6.9	8.9	10.2	10
2005	9.6	10.4	9.2	8.8	7.5	8.1	6	7.9	7.8	9.4	9.6	10.6

Annex 3. Monthly wind speed at Bui station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	2.3	2	2	2.9	3	1.7	1.9	1.6	1.7	2.1	2.1	2.2
1992	2.2	2.1	2.3	2.2	2.4	1.6	1.6	1.5	1.6	1.9	2.1	2.3
1993	2.2	2.2	2.5	2	1.9	1.5	1.5	1.7	1.3	1.7	2.1	2
1994	2.3	2.1	2.1	0.1	2.1	1.7	1.5	1.5	1.5	2.2	2.1	2.2
1995	2.2	2.1	2.3	1.9	1.9	1.6	1.5	1.5	1.3	2	2.1	2.1
1996	2	2.3	2.2	2.2	1.9	2.1	1.4	1.4	1.4	2.2	2.1	2.2
2000	2.2	2.5	2.5	2.3	2.2	1.7	1.5	1.5	1.2	1.6	1.7	1.8
2001	1.8	2	1.7	2.1	1.5	1.4	1.4	1.2	1.5	1.9	2.1	2
2002	2.1	2.1	1.8	2.2	2	1.5	1.4	1.2	1.3	2	2.2	2
2003	2	2.1	2.2	1.8	1.7	1.5	1.4	1.2	1.1	1.8	1.9	
2004	1.7	2.1	1.9	1.6	1.8	1.4	1.3	1.2	1.2	1.6	1.9	1.9
2005	1.6	1.9	1.7	1.8	1.4	1.2	1.2	1.2	1.1	1.6	1.8	1.7

Annex 4. Monthly wind speed at Ziway station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979	0.17	0.16	0.14	0.17	0.14	0.21	0.21	0.17	0.14	0.16	0.19	0.19
1980	0.18	0.18	0.16	0.17	0.19	0.25	0.23	0.19	0.17	0.15	0.2	0.19
1981	0.19	0.21	0.16	0.16	0.18	0.24	0.22	0.2	0.14	0.16	0.19	0.18
1982	0.18	0.17	0.19	0.15	0.16	0.23	0.23	0.17	0.13	0.17	0.18	0.2
1983	0.2	0.18	0.17	0.14	0.14	0.17	0.22	0.19	0.14	0.13	0.15	0.18
1985	0.19	0.21	0.19	0.19	0.16	0.22	0.2	0.22	0.15	0.13	0.15	0.18
1986	0.13	0.16	0.18	0.15	0.16	0.22	0.22	0.18	0.12	0.35	2.24	2.51
1987	2.43	2	1.85	1.85	1.92	2.69	3.02	2.4	1.83	1.91	2.12	2.29
1988	2.34	2.05	2.35	1.95	2.69	3.16	2.97	2.3	1.73	1.49	1.8	2.11
1989	2.1	2.1	1.7	1.4	2	2.6	2.8	2.1	1.5	1.5	2.1	1.8
1990	2.1	1.5	1.9	1.7	2.4	3.2	2.6	2.4	1.6	1.8	2	2.3
1991	2.1	1.8	1.6	1.9	1.9	2.6	2.6	1.9	1.5	1.7	1.9	1.9
1992	1.8	1.9	2	1.9	1.7	2.5	2.2	2	1.4	1.5	1.9	2.1
1993	2.1	1.9	1.7	1.7	1.7	2.4	2.3	2.1	1.5	1.6	1.8	1.9
1994	1.8	2.1	1.8	1.9	2.1	2.6	2.2	2.1	1.5	2.1	2.3	2.2
1995	1.8	1.8	1.8	1.4	1.8	2.4	2.4	2.2	1.4	2.2	1.9	2
1996	1.8	1.9	1.7	1.6	1.6	2.4	2.2	1.9	1.4	1.6	1.8	1.7
1997	1.6	2.4	1.8	1.5	1.8	2.1	2.2	1.7	1.4	1.8	1.9	1.9
1998	1.8	1.6	1.6	1.6	1.9	2.7	2.6	2.3	1.5	1.2	1.6	1.7
1999	1.8	2	1.7	1.8	2.4	2.7	2.3	1.9	1.6	1.3	1.7	1.7
2000	1.8	2.1	1.9	1.7	1.8	2.9	2.5	2.2	1.3	1.4	1.5	1.5
2001	1.4	1.5	1.4	1.7	1.9	2.5	2.4	2	1.2	1.5	1.6	1.7
2002	1.8	1.7	1.5	1.9	2.2	2.6	2.6	2.2	1.5	1.7	1.8	1.9
2003	1.7	1.7	1.8	1.6	1.8	2.5	2.2	1.9	1.4	1.5	1.7	1.6
2004	1.3	1.8	1.5	1.4	2.1	2.6	2.2	2	1.4	1.6	1.8	1.7
2005	1.5	1.5	1.5	1.5	1.4	2.5	2.3	2.1	1.5	2	1.5	1.6

Annex 5. Monthly Relative Humidity at Bui station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	87	95	91	93	90		91	90	94	86	84	75
1991	81	85	84	79	74	93	90	90	88	78	80	81
1992	87	88	80	79	75	84	87	91	86	82	81	81
1993	81	83	72	79	80	79	85	83	84	81	78	74
1994	48	46	50	52	62	x	x	x	x	x	x	x
1995	x	x	x	x	54	60	80	78	69	50	x	x
1996	60	52	62	60	71	75	78	77	65	48	48	48
1997	49		51	59	54	65	75	72	61	61	62	x
1998	65	63	57	49	56	63	77	81	71	64	50	38
1999	44	38	60	47	46	59	75	74	66	.	49	54
2000	51	41	x	x	x	x	x	x	x	x	74	x
2001	x	x	x	58	68	70	76	76	67	53	49	x
2002	60	46	55	53	60	64	68	73	64	x	x	58
2003	50	47	51	57	48	64	77	79	71	54	52	x
2004	60	52	51	62	49	66	75	75	70	60	51	55
2005	55	46	57	53	65	69	73	74	68	52	49	50

Annex 6. Monthly Relative Humidity at Zeway station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1970	57	56	55	72	61	69	79	75	67	64	56
1971	76	60	64	64	77		83	82	83		71
1972	62	69	59	69	68	67	73	79	78	77	74
1973	77	73	73	74	72	72	81	81	78	79	77
1974	80	79	76	78	73	78	80	79	80	73	54
1975	66	66	67	61	62	75	83	85	81	73	71
1976	69	80	82	80	87	79	86	87	85	79	84
1977	93	87	86	84	86	83	87	87	86	88	89
1978	86	87	83	84	83	84	88	89	89	83	87
1979	93	90	90	86	91	77	74	74	74	71	62
1980	69	62	62	64	63		62	66	66	58	53
1981	53	59	68	65	60	65	73	73	69	61	63
1982	71	75	70	76	70	71	76	77	73	71	69
1983	84	85	84	86	86	86	87	87	89	84	86
1984	87	87	89		90	86	81	84	84	84	85
1985	78	77	78	79	80	76	85	86	87	81	86
1986	76	85	84	82	79	80	80	83	82	69	
1987	61	59	68	64	72	71	70	72	68	61	53
1988	63	62	49	63	59	65	77	77	78	69	59
1989	63	65	62	74	62	66	77	72	75	62	57
1990	55	71	67	64	57	59	70	74	71	52	53
1991	56	64	66	61	58	64	75	76	71	50	49
1992	64	66	53	55	57	63	74	77	74	65	61
1993	66	69	50	66	64						
1994						71	77	76	72	54	61
1995	51	56	63	67	60	61	71	73	68	53	53
1996	65	48	62	67	70	74	75	76	75	56	62
1997	64	49	55	67	58	65	72	70	64	66	66
1998	67	62	62	55	62	64	72	76	71	68	52
1999	54	43	55	49	55	60	73	75	67	69	50
2000	51	42	46	53	62	65	69	71	68	64	57
2001	53	51	62	55	62	66	70	71	66	64	60
2002	63	60	62	55	61	56	63	74	65	38	53
2003	45	54	45	51	38	47	65	64	56	39	46
2004	65	52	46	64	52	58	69	68	67	56	52
2005	73	74	72	72	81	81	78	79	77	71	80

Annex 7. Mean Monthly Maximum and Minimum temperature of stations present in the study area

No.	Station	Recording. period		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Minimum	12.41	13.32	14.47	14.73	15.05	14.77	14.66	14.51	13.88	12.74	12.00	11.49
1	Ziway	1970-2006	Maximum	26.18	27.40	28.22	28.22	28.58	27.32	25.06	24.94	25.83	26.62	26.32	25.91
			Mean	19.29	20.4	21.4	21.48	21.81	21.04	19.86	19.73	19.85	19.69	18.9	18.7
			Minimum	10.95	11.27	12.09	12.51	12.23	11.83	11.65	11.72	11.75	11.30	10.66	10.08
2	Butajira	1972-2006	Maximum	25.51	26.01	26.34	25.97	26.01	25.07	23.64	23.71	24.95	25.56	25.61	25.60
			Mean	18.23	18.6	19.2	19.24	19.12	18.45	17.64	17.71	18.35	18.43	18.1	17.84
			Minimum	8	8.7	10.3	10.8	10.6	9.6	9.6	9.8	9.5	8.2	6.7	6.5
3	Bui	1990-2006	Maximum	25.4	26.4	26.9	26.7	27.3	25.8	23.3	23.4	24.7	25	25.3	25.3
			Mean	16.7	17.6	18.6	18.75	18.95	17.7	16.45	16.6	17.1	16.6	16	15.9

Annex 8. Mean Monthly rainfall of stations present in the study area

No.	Station	Recording. period	Location			Mean monthly precipitation(mm)											
			XUTM	YUTM	Altitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Bui	1969-2006	460267	919803	2027	26	45	84	85	76	111	213	204	111	35	8	6
2	Butajira	1970-2006	431353	897207	2088	36	65	137	135	118	125	180	173	127	48	11	13
3	Ejersalele	1968-2006	465763	912116	1779	16	38	61	77	67	81	196	162	85	23	4	4
4	Koshe	1974-2006	448183	884908	1873	25	46	78	92	91	99	173	170	109	50	5	5
5	Meki	1966-2006	481640	900802	1663	14	35	58	64	49	76	171	147	89	33	7	4
6	Torra	1974-2006	436647	868906	2012	23	43	85	116	100	88	133	122	114	50	8	6
7	Ziway	1970-2006	468771	876858	1646	17	30	55	79	75	84	145	120	87	37	2	4

Annex 9. Hydrochemistry data used in this work

Woreda	Kebele	Scheme ID	TDS (mg/l)	P ^H	Na (mg/l)	Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)	Fluoride (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Alkalinity (mg/l)	HCO ₃ (mg/l)	SO ₄ (mg/l)	PO ₄ (mg/l)
Sodo	Refenso	BH-5	144.0	8.04	20.5	64.4	20.5	3.2	1.68	1.0	7.5	113.4	138.3	1.05	0.041
Mareko	Koshe 01	BH-15	494	7.84	139	79.9	21.4	6.48	3.16	8.7	7	411	502	4.22	0.185
Mareko	Dida Halibo	BH-17	412	7.68	48	253.1	82.8	11.3	1.92	5.8					
Meskan	Butajira Town	BH-23	64	7.27	3.1	39.96	9.8	3.8	0.15						
Dugda Bora	Meki Town	BH-26	374	8.37	96	15.5	26.3	9.72	1.24	12.6	12.5	306.6	359.6	3.16	0.267
Dugda Bora	Cheleleke 2	BH-34	480	8.31	170		13.4	2.7	3.3	7.7			443.5		
Dugda Bora	Meki Town	BH-35	6000	7.88	2020		102.4	19.4	8	13.4			1332.2		
Dugda Bora	Graba phila	BH-36	1184	8	420		31.2	6.5	8	121.9			1017.1		
Dugda Bora	Abono 1	BH-37	1840	8.26	720		8	5.4	8	60.5			1819		
Dugda Bora	Choro ke	BH-38	872	8.25	288		8.9	1.6	3.3	63.4			650.99		
Dugda Bora	Gusa 2	BH-39	280	8.04	33.8		0.05	5.9	3.3	5.8			274.1		
Meskan	DehubShershera	BH-40	230	7.01	18.5		46.1	14.6	0.15	5.8			238.9		
Silty	SiltyBoze	BH-41	235	7.1	90.8				0.63	1.5					
Silty	Ashute Burako	SW-12	6502.0	9.5	2150.0	39.96	8.9	4.32		36.7		3570			
Mareko	Waja Jare Dembeka	SW-18	168	7.17	29.5	71.0	16.0	7.6	0.36	5.82	23				
Sodo	Adele Cheleleke	SW-30	628.0	7.54	93.0	290.8	103.2	8.1	1.1	26.2	10.7	426.3	520.1	93.63	0.226
Meskan	Ile	HDW-5	264.0	7.6	32.5	159.8	40.9	14.0	0.5	4.8	Trace	226.8	276.7	1.58	0.103
Dugda Bora	Laluna Dero	Wm-1	360	8.01	94.0	95.5	28.5	5.9	3.3	2.9	7.0	315.0	384.3	1.58	0.226
Dugda Bora	Giraba Jarso	Wm-3	972	7.8	300	73.3	17.8	7.02	3.7	109.6	8.5	577.5	704.6	42.19	0.303
Meskan	Meserete Wogeram	sp-11	40.0	6.8	2.7	22.2	5.34	2.2	Trace	2.91	4.0	21	25.62	4.75	0.103
Silty	Dobo Sabola	sp-13	278	7.3	28.5	184.3	49.8	14.6	0.96	2.9	12.5	231	281.8	2.37	0.185

Annex 10. Borehole data used in this work

Woreda	Kebele	Scheme ID	Elevation, AMSL	Depth (m)	SWL (m)	Altitude of SWL (m) mamsl
Sodo	Tiya Town	BH-1	2318	136	114	2204
Sodo	Adele Kobo	BH-2	1850		40	1810
Sodo	Kela	BH-3	1886	50	1.86	1884.14
Sodo	Dugda Goro	BH-4	1925	301	185	1740
Sodo	Refenso	BH-5	1891	200	170	1721
Meskan	Inseno	BH-6	1832	63	15.2	1816.8
Meskan	Inseno Ousme	BH-7	1833	66	8.7	1824.3
Meskan	Shershera Mechmena	BH-8	1914	75	33.9	1880.1
Meskan	Dirama Shershera	BH-9	2008	128.55	43.9	1964.1
Silty	Kibet town	BH-10	2095	118	50	2045
Silty	Kibet town	BH-11	2094	174	50	2044
Silty	Dobo Sabola	BH-12	1845	65	8.25	1836.75
Mareko	Argo Wollati	BH-13	1928	267	182	1746
Mareko	Semen Koshe	BH-14	1884	210	158	1726
Mareko	Koshe 01	BH-15	1884	220	180	1704
Mareko	Koshe Zuria	BH-16	1834	56	18	1816
Mareko	Dida Halibo	BH-17	1830	106	20	1810
Adame Tulu	Abosa 01	BH-18	1654	80.7	31	1623
Dugda Bora	Bekele & Girisa	BH-19	1647		14.5	1632.5
Dugda Bora	Bekele & Girisa	BH-20	1648		9	1639
Dugda Bora	Weyo	BH-21	1556	90	8	1548
Sodo	Suluke	BH-22	1934	295	270	1664
Meskan	Butajira Town	BH1-23	2058	154	54.7	2003.3
Dugda Bora	Meki Town	BH1-24	1662	84	49	1613
Meskan	Butajira Town	BH2-25	2056	65	13.4	2042.6
Dugda Bora	Meki Town	BH3-26	1661	82.5	29	1632
Meskan	Butajira Town	BH-28	2070	86	22	2048
Mareko	Weja	BH-29				1788.4
Meskan	Semen Shershera	BH-30				1932.45
Silty	Kibet town	BH-31				2021.7
Silty	Dobo Bedeno	BH-32				1847.74
Silty	Kibet town	BH-33				2021.7
Dugda Bora	Cheleleke 2	BH-34			79	1637
Dugda Bora	Meki Town	BH-35			31.1	1637.9
Dugda Bora	Graba phila	BH-36			33.6	1643.4
Dugda Bora	Abono 1	BH-37			33.2	1643.8
Dugda Bora	Chorokeye	BH-38			78	1628

Dugda Bora	Gusa 2	BH-39			96	1625
Meskan	DebubShershera	BH-40			40.7	1965.3
Silty	SiltyBoze	BH-41			72.32	2029.68
Sodo	Soloke	BH-42			151.87	1784.13
Sodo	Gere	SW-1	2573	85	53	2520
Sodo	Amawte Gufutige	SW-2	2565	61	25	2540
Sodo	Semero Michaelaele	SW-3	2156	85	58	2098
Sodo	Negesa	SW-4	1950	70	50	1900
Sodo	Delelesa	SW-5	1917	46	16	1901
Sodo	Gose Salen	SW-6	1873	54	18	1855
Meskan	Mekicho	SW-7	2093	32	3	2090
Meskan	Mekicho	SW-8	2107	50	3.65	2103.35
Meskan	Inseno	SW-9	1832	17	14.5	1817.5
Meskan	Jole	SW-10	1901	60	15	1886
Silty	Ashute Burako	SW-11	1825	17	3	1822
Silty	Ashute Burako	SW-12	1823	18	3	1820
Silty	Shele Washo	SW-13	1837	30	4	1833
Silty	Shele Washo	SW-14	1833		4.5	1828.5
Silty	Dobena Inseno	SW-15	1836	32	4	1832
Mareko	Mekak Jare Dembeka	SW-16	1828	46	25	1803
Mareko	Gola Jare Dembeka	SW-17	1844	56	30	1814
Mareko	Waja Jare Dembeka	SW-18	1820	32	16	1804
Mareko	Dida Halibo	SW-19	1827	60	19.3	1807.7
Mareko	Dida Halibo	SW-20	1820	35	16	1804
Mareko	Hobe Jare Dembeka	SW-21	1844	54	22	1822
Mareko	Kuno Alemena	SW-22	1831	23	8	1823
Mareko	Kuno Kertefa	SW-23	1839	40	18	1821
Dugda Bora	Bekele & Girisa	SW-24	1648		18	1630
Dugda Bora	Bekele & Girisa	SW-25	1666		12	1654
Sodo	Gogeti	SW-26	1908	48	33	1875
Sodo	Gogeti	SW-27	1893	25	15	1878
Sodo	Gogeti	SW-28	1878	27	10	1868
Sodo	Adele Gose	SW-29	1864	36	14	1850
Sodo	Adele Cheleleke	SW-30	1855	81	37	1818
Sodo	Negesa	SW-31	1924	22	5	1919
Sodo	Adele Cheleleke	SW-32	1856	92	44	1812
Sodo	Adele Kobo	HD-1	1854	40	39	1815
Sodo	Adele Silasie	HD-2	1849	22	20.5	1828.5
Sodo	Gogeti	HD-3	1914	29	26.15	1887.85
Meskan	Mirab Embor	HD-4	2144	20	15	2129
Meskan	Ile	HD-5	1890	30	22.93	1867.07
Dugda Bora	Giraba Korke Adi	HD-6	1665	35	33.35	1631.65
Dugda Bora	Bekele & Girisa	HD-7	1647	17	14.5	1632.5
Sodo	Amawte Morege	HP-8	2784	15	0	2784

Sodo	Atene Endebuyo	HP-9	2743	10	0	2743
Meskan	Misrak Embor	HP-10	2117	40	25	2092
Meskan	Bidara	HP-11	2244	16	13.2	2230.8
Meskan	Mirab Meskan	HP-12	2186	27.2	15	2171
Meskan	Odo	HP-13	2169	22	8.5	2160.5
Meskan	Odo	HP-14	2150	22	10	2140
Silty	Agode	HP-15	2091	16	10	2081
Mareko	Hobe Jare Dembeka	HP-16	1840	30	15	1825
Mareko	Kuno Kertefa	HP-17	1824	6.5	4.6	1819.4
Dugda Bora	Laluna Dero	Wm-1	1721	100	85	1636
Dugda Bora	Ate Meti	Wm-2	1709	80	65	1644
Dugda Bora	Giraba Jarso	Wm-3	1688	75	60	1628
Dugda Bora	Cheleleke 2 (Germeji)	Wm-4	1705	110	79	1626
Dugda Bora	Chorokeye	Wm-5	1722	93	78	1644
Dugda Bora	Korke Adi	Wm-6	1664	51	30	1634
Dugda Bora	Weyo	Wm-7	1675	60.5	33.2	1641.8
Dugda Bora	Alem Tena	Wm-8	1660	90	57	1603
Dugda Bora	Birbirsu Guda Sabole	Wm-9	1747	62	54	1693
Dugda Bora	Tuchi Sumeyan	Wm-10	1677	50	26	1651
Dugda Bora	Sera Wekele	Wm-11	1721	92	81	1640
Dugda Bora	Oda Bokata	Wm-12	1685	41	34	1651
Sodo	Gerein Betons	sp-1	2646			2646
Sodo	Gerino Enset tekil	sp-2	2580			2580
Sodo	Atene Endebuyo	sp-3	2724			2724
Sodo	Dega Nurena	sp-4	2669			2669
Sodo	Dega Nurena	sp-5	2667			2667
Sodo	Dega Nurena	sp-6	2655			2655
Sodo	Kola Nurena	sp-7	2149			2149
Sodo	Boke Bishan Jilba	sp-8	2150			2150
Sodo	Suluke	Sp-9	1935			1935
Meskan	Yetebon	Sp-10	2164			2164
Meskan	Meserete Wogeram	Sp-11	2635			2635
Meskan	Goiba	Sp-12	2565			2565
Silty	Dobo Sabola	Sp-13	1832			1820

Annex 11. Mean monthly Flow of Meki River gauged at meki town

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1969	0.753	9.822	19.334	10.272	12.714	7.932	23.599	33.716	22.049	3.683	0.592	0.208
1970	4.032	2.188	17.205	2.345	2.497	1.745	25.988	41.618	20.28	6.039	1.608	0.871
1971	0.742	0.459	0.549	2.148	5.09	17.657	30.947	38.882	20.898	2.935	0.968	0.396
1972	0.399	4.849	10.126	12.749	9.301	3.951	13.807	25.955	13.952	3.331	0.606	0
1973	0.075	0.001	0	0.007	0.619	1.033	17.502	24.411	25.424	12.185	0.972	0.094
1974	0.193	0	1.78	1.077	1.224	2.597	21.802	25.626	28.105	7.36	0.89	0.185
1975	0.111	0.239	0.007	0.601	0.437	4.469	27.194	28.109	44.886	12.07	1.964	0.492
1976	0.263	0.089	2.388	2.041	5.865	2.079	14.829	18.857	13.942	2.041	5.43	0.743
1977	2.497	3.941	0.66	3.521	9.952	6.445	31.521	28.75	18.783	17.916	24.474	2.838
1978	0.457	1.303	5.265	1.204	0.743	3.856	13.214	29.338	16.006	14.268	-	-
1979	2.969	5.864	7.913	20.888	13.187	2.979	23.361	30.567	13.963	12.853	3.532	1.157
1980	0.805	0.962	1.269	2.186	1.536	4.953	16.657	21.071	9.534	4.352	0.818	0.527
1981	0.401	0.487	13.689	20.031	-	-	-	30.135	22.225	5.11	0.62	1.139
1982	0.917	1.774	1.49	7.026	7.115	2.529	8.255	30.07	9.635	16.617	2.581	1.736
1983	0.529	2.758	4.618	11.871	17.961	13.965	9.919	33.418	21.385	7.531	1.614	0.89
1984	0.623	0.485	0.451	0.318	2.599	4.583	9.808	9.818	12.969	1.083	0.354	0.29
1985	-	-	-	-	-	-	-	-	-	-	-	-
1986	0.094	0.523	0.868	4.894	2.555	-	-	-	-	1.896	0.197	0.042
1987	0.007	0.282	7.697	18.25	17.262	14.626	7.518	6.256	7.309	-	0.407	0.041
1988	0.035	0.409	0.148	3.066	2.216	2.853	15.805	23.259	22.475	12.622	2.914	0.918
1989	0.141	2.432	3.301	9.65	2.933	3.903	15.169	15.765	17.616	9.722	1.646	0.888
1990	0.313	11.347	20.203	21.691	5.282	5.816	17.077	19.805	15.172	6.423	1.855	0.874
1991	0.502	2.598	7.17	2.84	0.891	3.76	24.49	34.9	20.137	3.483	0.872	0.664
1992	-	-	-	-	-	-	-	-	-	-	-	-
1993	4.919	0.977	0.978	13.436	17.518	12.305	25.185	57.523	19.897	11.61	4.454	0.89
1994	0.8	-	0.603	-	-	-	-	60.027	47.132	4.388	0.981	0.619
1995	-	-	-	-	-	-	-	-	-	-	-	-
1996	-	-	-	-	-	-	-	-	24.512	5.549	1.987	1.21
1997	0.315	0.268	0.988	9.947	2.894	4.363	16.595	16.597	5.398	-	6.184	0.922
1998	1.599	0.741	12.119	3.272	11.768	5.227	27.62	70.112	29.236	23.117	2.553	0.417
1999	0.088	0.074	2.841	0.115	0.508	2.835	20.644	22.42	10.155	23.554	4.732	0.277
2000	0.016	0.002	0	0.045	0.831	0.643	6.308	14.019	11.005	8.245	2.96	0.938
2001	0.009	0.176	3.062	1.908	4.614	10.892	-	-	-	2.554	0.938	0.517
2002	4.076	3.117	1.581	-	-	-	-	-	12.462	2.462	1.946	1.633
2003	0.998	0.584	-	-	2.197	4.923	-	-	-	3.993	0.365	0.81
2004	0.928	0.286	0.7	-	0.736	2.176	-	-	-	-	-	-
2005	-	-	-	3.329	12.906	8.06	12.988	-	-	6.139	2.012	1.532
2006	1.237	-	-	-	-	-	-	-	-	-	-	-

Annex 12. Water points found in dugda woreda both functional and nonfunctional

PA	Easting(X)	Northing(Y)	Remark
<i>Hate Leman</i>	472345	901797	<i>Wind Functional</i>
<i>Maja lulu</i>	469360	901800	<i>Wind Functional</i>
<i>Biliti Bale-waldi</i>	458539	896948	<i>BH functional</i>
<i>Koto Biliti</i>	456820	895084	<i>BH Nonfunctional</i>
<i>Mukiye Laman</i>	465716	905691	<i>BH Nonfunctional</i>
<i>Lamaan</i>	474696	902443	<i>Wind functional</i>
<i>Tuchi Dambel</i>	469434	8896123	<i>Wind functional</i>
<i>Tuchi Dambel I</i>	469716	890725	<i>Wind functional</i>
<i>Weyo Gabriel</i>	465299	893316	<i>BH Nonfunctional</i>
<i>AbonoGabrel</i>	467751	894659	<i>Wind functional</i>
<i>Dodota Dambel</i>	469742	895824	<i>Wind functional</i>
<i>Abono Gabrel</i>	471690	892252	<i>Wind functional</i>
<i>Weyo Gebriel</i>	471595	891503	<i>Wind functional</i>
<i>Weyo Gebriel</i>	471209	891140	<i>BH Nonfunctional</i>
<i>Dodota Dambel</i>	472626	893137	<i>Wind functional</i>
<i>tepoChoroke</i>	474226	894751	<i>BH Nonfunctional</i>
<i>tepoChoroke</i>	474038	894422	<i>BH Nonfunctional</i>
<i>tepoChoroke</i>	471470	898142	<i>Wind functional</i>
<i>Maja lulu</i>	468854	899139	<i>BH functional</i>
<i>Graba Qorke</i>	476204	897667	<i>Wind functional</i>
<i>Graba Qorke</i>	475417	896738	<i>BH under construction</i>
<i>Baymo Gusa</i>	474552	908751	<i>Wind functional</i>
<i>Baymo Gusa</i>	476658	910366	<i>BH functional</i>
<i>Dongorota Gusa</i>	473249	908545	<i>BH Nonfunctional</i>
<i>Gusa</i>	471486	909842	<i>BH functional</i>
<i>Birbisa Gale</i>	467589	911305	<i>BH functional</i>
<i>Kure</i>	468481	914236	<i>BH functional</i>
<i>Birbirsa Gusa Sabole</i>	470565	914133	<i>BH functional</i>
<i>Ela Garba</i>	469074	916035	<i>BH functional</i>
<i>Birbirsa Gusa Sabolee</i>	470304	916860	<i>BH Nonfunctional</i>
<i>Qiltubilbila</i>	470573	922628	<i>BH functional</i>
<i>Qorke Adama</i>	471295	920931	<i>BH under construction</i>
<i>QorkeAdama</i>	474115	921072	<i>Wind functional</i>
<i>Koye Jajaba</i>	477019	917886	<i>Wind functional</i>
<i>Hafa Qamale</i>	476734	913941	<i>BH functional</i>
<i>Walda Hafa</i>	480784	912323	<i>BH functional</i>
<i>Hafa Qamale</i>	478835	914130	<i>BH functional</i>
<i>Walda Hafa</i>	480404	910358	<i>HP under construction</i>
<i>Walda Hafa</i>	481416	909593	<i>Wind functional</i>
<i>Jawe Bofa</i>	483250	907025	<i>BH functional</i>
<i>Oda Boqotaa</i>	483828	904423	<i>Wind functional</i>
<i>Jawe Bofa</i>	485832	904861	<i>Wind functional</i>
<i>Jawe Bofa</i>	485901	904913	<i>Hp functional</i>
<i>Oda Boqota</i>	483655	904105	<i>BH functional</i>
<i>Tuchi Sumeyan</i>	490081	904511	<i>BH functional</i>
<i>Tuchi Sumeyan</i>	487438	902563	<i>Wind functional</i>

<i>Tuchi Sumeyan</i>	<i>487540</i>	<i>901550</i>	<i>HP functional</i>
<i>Tuchi Sumeyan</i>	<i>487606</i>	<i>901455</i>	<i>HP functional</i>
<i>Tuchi Sumeyan</i>	<i>487479</i>	<i>901415</i>	<i>HP functional</i>
<i>Tuchi Sumeyan</i>	<i>488122</i>	<i>900935</i>	<i>HP functional</i>
<i>Tuchi Sumeyan</i>	<i>488753</i>	<i>902097</i>	<i>HP functional</i>
<i>Darar Dalacha</i>	<i>490315</i>	<i>901264</i>	<i>HP Nonfunctional</i>
<i>Darar Dalacha</i>	<i>491447</i>	<i>901208</i>	<i>HP functional</i>
<i>Burqa Debrebeg</i>	<i>492117</i>	<i>900220</i>	<i>BH functional</i>
<i>Oda Boqota</i>	<i>482266</i>	<i>902758</i>	<i>BH functional</i>
<i>Sera Wakale</i>	<i>479313</i>	<i>905768</i>	<i>Wind functional</i>
<i>Sera Wakale</i>	<i>477313</i>	<i>906916</i>	<i>Wind Nonfunctional</i>
<i>Oda Boqota</i>	<i>480034</i>	<i>902598</i>	<i>Wind Nonfunctional</i>
<i>Oda Boqota</i>	<i>480103</i>	<i>902191</i>	<i>HP Nonfunctional</i>
<i>Mki Town</i>	<i>480346</i>	<i>901714</i>	<i>HP functional</i>
<i>Mki Town</i>	<i>480305</i>	<i>901414</i>	<i>HP functional</i>
<i>Mki Town</i>	<i>480599</i>	<i>901616</i>	<i>BH functional</i>
<i>Mki Town</i>	<i>480403</i>	<i>900580</i>	<i>BH functional</i>
<i>Giraba Qorke Adi</i>	<i>477133</i>	<i>901616</i>	<i>Wind functional</i>
<i>Meki Town</i>	<i>478507</i>	<i>900181</i>	<i>BH Functional</i>
<i>Bekele Girisa</i>	<i>478766</i>	<i>897805</i>	<i>HP Nonfunctional</i>
<i>Bekele Girisa</i>	<i>478942</i>	<i>897992</i>	<i>HP Nonfunctional</i>
<i>Bekele Girisa</i>	<i>478816</i>	<i>898150</i>	<i>HP Nonfunctional</i>
<i>Bekele Girisa</i>	<i>478622</i>	<i>898041</i>	<i>HP functional</i>
<i>Bekele Girisa</i>	<i>482846</i>	<i>897802</i>	<i>HP functional</i>
<i>Bekele Girisa</i>	<i>483119</i>	<i>898014</i>	<i>HP Nonfunctional</i>
<i>Bekele Girisa</i>	<i>483129</i>	<i>898268</i>	<i>HP Nonfunctional</i>
<i>Bekele Girisa</i>	<i>479124</i>	<i>898130</i>	<i>HP functional</i>
<i>Bekele Girisa</i>	<i>478364</i>	<i>897796</i>	<i>HP functional</i>
<i>Bekele Girisa</i>	<i>478272</i>	<i>898345</i>	<i>HP functional</i>

Annex 13. House hold survey questionnaire prepared to understand water supply sustainability problems of Dugda Woreda

Water -Supply Sustainability Problems of Dugda woreda , East Shewa Zone

House hold survey questionnaire

Surveyarea: Region _____ Zone _____ Woreda: _____

Date of interview: _____ **Name of interviewer:** _____

Name of head of house hold _____ **Age** _____ **Sex** _____

Respondent's Name (if different from the head): _____ **Age:** __ **Sex** ____

1. What type of source do you use for domestic water supply?

- a. Surface water source
- b. Groundwater source
- c. Both sources

2. If your answer is surface water, what type of surface water?

- a. River
- b. Lake
- c. Ponds
- d. Dams
- e. All
- f. Other, specify _____

3. If your answer is groundwater, what type of groundwater?

- a. Hand dug well
- b. Spring
- c. Bore hole
- d. Wind mill
- e. Other, specify _____
- Purpose specify _____

4. Is the source you are using at present healthy potable? Yes _____ No _____

5. If it is not healthy, what are specific problems?

- a. Physical contaminants
- b. Chemical contaminants
- c. Biological contaminants
- d. a&b
- e. b&c
- f. a&c
- g. all

6. Are there members of the family who are victims of dental fluorosis?

- a. Yes
- b. No

16. What type of participation did you have during the water supply scheme development?
a. Cash b. Labor c. local materials d. idea e. Other _____
17. Do you get training at a household level?
a. Yes b. No
18. Do you need new water points?
a. Yes b. No
19. Who organizes the water supply scheme management?
a. water committee b. professionals c. community d. administrators
e. others, specify _____
20. How can you justify the acceptance of the water management committee by the community?
a. not accepted b. accepted c. well accepted d. extremely accepted
e. other, specify _____
21. What is the participation of women in water supply scheme management and development?
a. water committee and water use management
b. main fetchers c. guards d. technical workers
e. Other specify _____
22. Do you think representation of more women in the water committee is good for the society?
a. Yes b. No
23. Do you discuss about water supply problems with your neighbors, Local authorities, or other community members? a. Yes b. No
-
-

24. What major natural disasters occurred in your Woreda that affects sustainability of the water supply scheme?

- a. drought
- b. flooding
- c. conflict over water resources
- d. water born diseases
- e. presence of hazardous chemical constituents
- f. other, specify _____

25. What are the causes of groundwater development failures?

- a. Quality problem
- b. Quantity problem
- c. Financial problem
- d. Conflict
- e. Institutional problem
- f. Lack of proper investigation
- g. Management problem
- h. Others specify _____

26. What are the causes for the delay of water supply scheme projects?

- a. Financial problem
- b. Conflict
- c. Management problem
- d. Policy
- e. Political instability
- f. Institutional structure problem
- g. Lack of proper investigation
- h. others specify _____

27. What kind of measures should be taken to minimize the current water supply development failures?

- a. improving institutional structure
- b. prevention of the resource from contamination

- c. investing on knowledge of professionals
- d. revisiting policy
- e. improving awareness about the resource to the water management committees and administrators
- g. Other specify _____

28. Are there any conflicts that arise from competition over water resources? Yes ___ No ___
If there are any, when? _____ With whom? _____
What types of damages occurred? (In number)
a. deaths _____ b. injuries _____ c. property damage _____
d. others, specify _____

29. Do you believe that the sustainability of developed water supply schemes have the potential to improve productivity. a. Yes b. No

30. What are the major benefits of water supply scheme development for the community?
a. improves health b. reduces conflict over resources
c. improves productivity d. safe, adequate and clean water for domestic supply
e. other, specify _____

31. What are your Main recommendations regarding water supply Sustainability problems?

Annex 14. Technical expert's questionnaire prepared to understand water supply sustainability problems of Dugda Woreda

Water -Supply Sustainability Problems of Dugda Woreda in East Shewa zone

Questionnaire survey

A. Experts and technical persons survey questionnaire

Survey area: Region _____ Zone _____ Woreda: _____

Date of interview: _____ **Name of interviewer:** _____

Respondent's Name: _____ **Age:** _____ **Sex** _____

1. Describe the most important water supply development activities carried out in the past till to date through government /or other organizations support, Discuss what is working well and what not, including suggestion for improvement and change: _____

2. What are the major water supply sustainability problems in order of importance?

i. Quality ii. Quantity iii. Skill iv. Policy v. institutional structure

vi. Hydrogeological knowledge vii water use management

vii. Others, specify _____

3. What is the role of women on domestic water supply development activities?

a. water committee and water use management

b. main fetchers

c. guards

d. technical workers

e. Other specify _____

4. How can Water supply sustainability problems be minimized?

a. improving institutional structure

b. prevention of the resource from contamination

- c. investing on knowledge of professionals
 - d. revisiting policy
 - e. improving awareness of the resource to the water management committees and administrators
 - f. understanding the resource
 - g. Other specify _____
5. What major natural disasters have occurred in your Woreda that affects sustainability of the water supply scheme?
- a. drought b. flooding c. conflict over water resources
 - d. water born diseases e. presence of hazardous chemical constituents
 - f. other, specify _____
6. What prevalent problems encountered in the developed water supply schemes?
- a. imbalance between supply and demand b. poor administration
 - c. conflict over water resources d. failure of developed schemes
 - e. No problem
 - f. other, specify _____
7. Do you have legal frameworks for promoting participation of various stakeholders?
- Yes _____ No _____
8. What are the major benefits of sustainable water supply schemes for your community?
- a. improved health b. reduced conflict over resources
 - c. improved productivity d. safe, adequate and clean water for domestic supply
 - e. other, specify _____
9. What criteria's are considered when planning sites for water supply development schemes?
- a. Settlement
 - b. transport accessibility.
 - c. hydrogeological feasibility
 - d. policy makers decision
 - e. others, specify _____
10. Is there continuous supervision during water supply scheme development?

- a. Yes b. No c. intermittent supervision
11. Is there any monitoring system after development of water supply schemes?
a. Yes b. No
12. What is the extent of community participation in deciding the site and design of the water supply scheme projects?
a. involved in site selection b. involved in planning
c. involved in implementation d. involved in administration and management
e. others, specify _____
13. What is the average distance to the water point?
a. <1km b. 1km-2km c. 2km-3km d. 3km-5km e. >5km
14. Out of the developed groundwater sources, how many are failed to meet their objectives? (In percent)
Bore holes _____
Shallow wells _____
Springs _____
Wind mills _____
15. How many water supply development scheme projects are delayed than the planned time? (In percent)
Ground water development scheme projects _____
Surface water development scheme projects _____
16. What are the causes of ground water development failures? (Put in order of importance)
a. Quality problem
b. Quantity problem
c. Financial problem
d. Conflict
e. Institutional structure problem
g Lack of proper investigation
h. Management problem
i. policy

j. Others specify _____

17. What are the causes for the delay of water supply project schemes?

- a. Financial problem
- b. Conflict
- c. Management problem
- d. Policy
- e. others specify _____

18. Who organizes the water supply scheme management?

- a. water committee b. professionals c. community d. administrators
- e. others, specify _____

19. Are there any conflicts that arise from competition over water resources?

- a. Yes b. No

If there are any, when? _____, with whom? _____

What types of damages occurred? (In number)

- a. deaths _____ b. injuries _____ c. property damage _____
- d. others, specify _____

20. Does the existing education and staff mobility policies allow professionals to improve their skills? Yes _____ No _____

21. Do you think staff is enough and capable?

- a. Yes b. No

22. Do you train village level operators?

- a. Yes b. No

23. Do you give training to house holds and water committee?

- a. yes b. No

24. Do you have Zone-level/Woreda level organization(s) for management of multiple water resources? a. Yes b. No

25. What are the possible solutions to improve water supply sustainability in your woreda?

26. What are your Main recommendations regarding water supply Sustainability problems?
