(Universitaet für Bodenkultur Wien)

University of Natural Resources and Life Sciences, Vienna

Department of Water, Atmosphere and Environment

Institutes of Hydraulics and Rural Water Management

GIS based Water Resources Assessment and Management of Wujraba Micro-Watershed, North Gondar, Ethiopia

Eneyew Wondifraw AMBERBER

September 2014

Vienna, Austria

GIS based Water Resources Assessment and Management of Wujraba Micro-Watershed, North Gondar, Ethiopia

Thesis Submitted to the University of Natural Resources and Life Sciences, Vienna, Department of Water Atmosphere, Institute of Hydraulics and Rural Water Management, in partial fulfillment of the requirement for the degree of Master of Science in Water Resources Management and Environmental Engineering.

By: Eneyew Wondifraw AMBERBER

Ander the supervisions of:

Univ.Prof. Dipl.-Ing. Dr.nat.techn. Loiskandl, Willibald.

Institute of Hydraulics and Rural Water Management (IHLW)

University of Natural Resources and Life Sciences, Vienna (BOKU)

Vienna, Austria.

Co advisor

Dr. Getachew Alemayehu Damot (Asso.Prof)

College of Agriculture and Environmental Sciences, Bahirdar University

Bahirdar, Ethiopia

Vienna, September 2014

I dedicate this work to my late father Wondifraw Amberber Biresaw

BIOGRAPHICAL SKETCH

Eneyew Wondifraw Amberber was born in Debremarkos, Ethiopia on 12 June 1986. He received his Diploma in Agricultural Engineering and Mechanization from Hawassa University, Ethiopia (2002) and BSc. in Natural Resources Management from Bahirdar University, Ethiopia (2010). He had been working in College of Agriculture and Environmental Sciences, Bahirdar University as technical assistance and graduated assistance (October 2008 to September 2012). Mr. Eneyew as research team member of Strengthening Rural Transformation Competences of Higher Education and Research Institutions in the Amhara Region, Ethiopia (TRANSACT), he won the project grant to be a qualified candidate for MSc. study. He joined University of Natural Resources and Life Sciences, Vienna, to study his MSc. in Water Resources Management and Environmental Engineering (2012). Austrian Government Development Fund (OeAD-APPEAR) financially supported his MSc. study.

ACKNOWLEDGEMENT

Above all, I thank Kidane Mehret St.Mary and almighty God.

I would like to express my deep and intense gratitude for my supervisor Univ.Prof.Dipl.-Ing.Dr.nat.techn Loiskandl Willibald, for his valuable guidance, precious advice and unreserved assistance during all the months of my work, on all issues of concern at any time and place.

I also wish to express my gratitude, for my local supervisor of Dr.Getachew Alemayehu Damot, for his assistance during my participation to TRANSACT project, and for his counseling.

My acknowledgement extended to OeAD for provided funding. I also thanks for ICM: Program Manager Appear / advisor of Ms. Elke Stinnig for voluble cooperation and assistance for logistic and finance during the support of OeAD-APPEAR.

I would like to thank my wife Ms.Seble Dejene, family, relatives and friends who have reinforced my motivation to study.

ABSTRACT

A substantial amount research had conducted in Ethiopia focused on watersheds, which having only abundant water resources. Wujraba-micro-watershed, Chilga Woreda has been examined both lacking of information & inadequate water resources. It characterized by: critical water-shortage, low amount of potable water supply, poor sanitation, and frequent water use conflicts. This work mainly focused on assessment of existing water resources; investigate management practices & watershed characterization. Hence, primary data's have collected about water points & status of water supply infrastructures; NewLocClim and CROPWAT has used for effective rainfall estimation; Runoff has computed by using SCS-CN method. Float method and volumetric measurement were used for river base flow and spring discharge measurement. ArcGIS was used GPS points & DEM satellite image input data for spatial delineation and hydrology analysis. The major existing water supply sources identified are: rivers, protected & unprotected springs, pumped dug wells and traditional hand dug-wells. However, 50% water supply infrastructures are non-functional and 50% are functional with poor management status without satisfying community demand. The survey revealed that high variation of ground water level leads uncertain of the community to use traditional hand dug wells; there are recognized conflicts among watershed users & Aykel town communities; 46% of water supply for the town is from sources within the watershed with inadequate & poor sanitation coverage. The watershed has an area of 840 ha dominated by loam soil with rugged topography ranges [1895m, 2239m]. It has mean annual rainfall 1248.4 mm mono-modal type pattern of 75 % occurring in wet season (i.e. June-September) with effective rainfall of 829 mm. Daily average and annual ETo values 4.42 mm/ day &1716 mm/year respectively with runoff 540.45 mm/year. The main stream Wujraba-River had 209 l/s & 42.4 l/s of estimated peak discharge and measured base flow discharge respectively. Therefore, recommended for long-term solution are: to cluster high yielding on-site traditional wells for water supply system, to construct community-ponds for livestock use, to adopt rainwater harvesting for both domestic & supplementary irrigation, IWRM & CBA for water supply designs.

Keywords: Wujraba Micro Watershed, Aykel, Water Resources Assessment, GIS, DEM

Zusammenfassung

Es wurde eine umfangreiche Menge von Forschung Äthiopien betrieben, die sich auf die Einzugsgebiete konzentrierte, welche eine ausreichende Menge an Wasser zur Verfügung haben. Das Wujraba-Mikroeinzugsgebiet, Chilga Woreda wurde untersucht, in Ermangelung von zweierlei, Information und inadäquate Wasserresourcen. Es ist charakterisiert durch kritische Wasserknappheit, wenig verfügbares Trinkwasser, schlechte Sanitärsituation und stände Wassernutzungsstreitigkeiten. Diese Arbeit bezieht sich hauptsächlich auf der Einschätzung der vorhandenen Wasserresourcen. Daher wurden primäre Daten über die Wasserstellen und den Status der Wasserversorgungsinfrastruktur erhoben. NewLocClim and CROPWAT wurden zur effektiven Niederschlagabschätzung verwendet. Der Abfluss wurde mit der SCS-CN Methode berechnet. Zur Durchflussermittlung wurde die Schwimmkörpermethode bzw. die volumetrische Methode verwendet bzw. auch für die Ermittlung des Quellergiebigkeit. Es wurde ArcGIS mit GPS Punkten & DEM Satellitenfotos verwendet, um die räumliche Lage darzustellen und die Hydrologie des Einzugsgebietes zu analysieren. Die hauptsächlich vorherrschenden Wasserquellen sind Flüsse, beschützte- und unbeschützte Quellen, sowie mit Pumpe gebohrte und traditionellen handgegrabene Brunnen. Allerdings sind 50% der Wasserversorgungsinfrastruktur nicht funktionstüchtig bzw. 50% funktionieren, aber haben eine schlechte Wartung ohne ausreichenden Bedarf der Siedlungen. Die Erhebung zeigte, dass starke Grundwasserspiegelschwankungen zu unvorhersehbarer Nutzung von traditionellen handgegrabene Brunnen durch die Siedlungen führte; es ist bekannt, dass es zu Konflikten von Wasserbenutzern im Einzugsgebiet und der Siedlung Akel kommt; 46% der Wasserversorgung der Siedlung ist aus Quellen im Einzugsgebiet mit unzureichendem sanitärem Zustand. Das Einzugsgebiet hat eine Fläche von 840 ha, Lehmboden und eine ungefähre Schwankungsbreite zwischen 1895m und 2239m Höhe. Es hat einen durchschnittlichen jährlichen Niederschlag von 1248.4 mm, welcher in einer Mono-modal-Art hauptsächlich, d.h. zu 75% in der Regensaison (zwischen Juni und September) fällt, mit einem effektiven Niederschlag von 829mm. Die durchschnittlichen monatlichen und jährlichen ETo Werte sind 4.42 mm pro Tag bzw. 1716 mm pro Jahr, mit einem Abfluss von 540.45 mm pro Jahr. Der Hauptfluss Wujraba hat 209 l/s geschätzten Hochwasserabfluss bzw. 42.4 l/s gemessenen Niederwasserabfluss. Daher empfiehlt es sich langfristig traditionelle Brunnen mit gutem Ertrag in einem Cluster zu betreiben, Siedlungsteiche anzulegen um das Vieh zu tränken, Regenwassersammler zu betreiben, für den Hausgebrauch wie auch zur zusätzlichen Bewässerung, Integriertes Wasserressourcenmangement zu betreiben und eine Gemeinschaftswasserversorgung zu organisieren.

Table of Contents

LIST OF FIGURES

LISTS OF TABLES

Key note / Local Definition/ for this research case:

- ✓ "Aykel Woreda" mean "Chliga Woreda".
- ✓ "Aykel" refer to "Chilga"
- ✓ "Chilga Metrological station" mean "Aykel Metrological station"
- ✓ "Gelegel Antera River" mean "Small Antera River":
- ✓ "North Gondar " mean " Semien Gondar"
- ✓ "Woreda" is a division of administration that administers a population up to 400 thousand.

LISTS OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

ADF: African Development Fund
ARDB/O: Agriculture Rural Development Biro/Office
AWCI: Amhara water construction institute
CBA: Community based approach
CSA: Central Statistical Agency of Ethiopia
DAs: Developmental agents
DEM: Digital Elevation Model
ET: Evapotranspiration
ETa: Actual Evapotranspiration
ETo/PET: Potential Evapotranspiration
FAO: Food and Agriculture Organization
Fig: Figure
GDP: Gross Domestic Product
GPS: Geographic positioning System
GWP: Global Water Partnership
HDW: Hand dug well
INBO: International Network of Basin Organizations
IWMI: International Water Management Institutes
IWRM: Integrated water resources management
LU: Land Use
Masl: meter above sea level
MDGs: Millennium development goals
NewLocClim: Local Climate Estimator
NGOs: Non-Governmental organizations
NWS: North West Sorghum Belt
OWS: Office of water services
RARDB: Regional Agricultural and Rural Development Bureau
RDAB: Rural Development and Agriculture Biro/Bureau
RWASH: Rural Water Supply and Sanitation
SCS-CN: Soil Conservation Service-Curve Number
TDW: Traditional Dug Wells
UNDP: United Nations Development Programme
UNESCO: United Nations Educational, Scientific and Cultural Organization
WHO: World Health Organization
WMO: World metrological organization
WRA: Water Resources Assessment
WS:Watershed

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROAND AND JUSTIFICATION

Ethiopia situated in the "horn of Africa" which lies between 3°30´, 14°50´ North latitudes and 32°42´, 48°12´ East longitudes. It has a surface area of about 1.127 Million km^2, of which 1,119,683-km^2 land, and 7,444-km^2 water area. It covers 12 river basins with an annual runoff volume of 122 billion m^3 of water and an estimated 2.6 billion m^3 of ground water potential. Thus amounts are about 1743 m^3 of water per person per year (Seleshi Bekele et.al.,2006*)*. However, due to an uneven distribution, inaccessibility, lack of water storage infrastructure, spatial and temporal variation of rainfall etc., there is scarcity water for both irrigation & domestic uses in Ethiopia everywhere and in the research area specifically.

Ethiopia is also suffering from various problems concerning sustainable water management. One of the main reasons that suggested by different scholar are, there is no well communication about the ongoing recent and previous research data that indicted water resource availability, particularly at micro-watershed level. One of the major issues concerns the application of hydrological research e.g. surface and ground water resources development and management, surface water harvesting and its effect on ground water recharge with implication to the conjunctive use of water resource. (Loiskandl et.al., 2006). Water management is anthropocentric in its nature but ecological demands have to be treated equally with other demands to their humanly derived benefit (Griffen, 2006).

The past water resources assessment studies by individuals commonly done on the place where there is abundant water resources while at project level are at large scale level. This research conducted at small micro watershed both lacking of information and adequate water resources that focus on the assessment of the existing water resources, investigating the water use and management practice. Wujraba micro watershed is located in Chilga Woreda, North Gondar Administrative Zone, in Amhara Region. Ethiopia.

1.2. STATEMENT OF THE PROBLEM

Even though Wujraba-watershed and Chilga Woreda agro-ecologically is distinct moist (Weyna-dega) with average annual rainfall of 1248mm, which is very abundant. However, still there is a critical water shortage problem in the Woreda, and specifically in Aykel town & Wujrbra watershed. Human conflicts often linked to competition over scarce resources. According to unpublished resources, water resources and irrigation are major source of conflict in the study area. Critical water shortage for domestic water, livestock and irrigation use are highly recognized problems of the watershed for major source of conflicts, both the shortage and conflict of water use is highly recognized during the dry seasons. The trend of Chliga metrological station historical data has revealed an increase of minimum and maximum temperature.

Chliga metrological station data also shows that, the Woreda has a uni-modal rainfall pattern with single growing season. There is decreasing trend in the annual rainfall and change in the seasonal rainfall distribution over time. Like most Ethiopian highland (Rosell, S. and Holmer, B., 2007), the watershed farmers are also dependents on rain feed agriculture depend on rain-fed agriculture. Despite the available irrigation potential for enhancing crop production the irrigation practice is limited in the area, due to lack of water in dry season. Furthermore existing water resources of rivers, springs, pumped dug wells and traditional hand dug-wells do not satisfy dry season demand for domestic use and other demands of the local communities.

On the other hand, water supplies constructed by supporting aid have are prone to non-functionality, non-sustainability of the infrastructure, and overall loss of money. So that, why the system do not continue to run after project funding ends?, is it institutional non-sustainability?, is it a societal problem or operation and maintenance or the design and construction of infrastructures?, is it scarcity of water resources in the area at all? etc.

Given the above-mentioned problems, it is necessary to understand the water resource potential including its management and find out recommendation for unravel human conflicts for scarce water resource in the study area, best adopting water technology by farmers. This research plays great role for indicating a key for sustainable water resources system planning and management.

1.3. GOAL AND OBJECTIVE

The main goal of this research is investigating potential water resources, assessing water conflicts. Understanding aspects of rural water systems supply to develop the sustainability of water facilities for both urban area and rural micro watershed of Wujraba, in Chliga Woreda, North Gondar Administrative.

1.3.1. GENERAL OBJECTIVE

The general purposes of this research are to assess the existing water resource, investigate the water use and management practice in Wujraba-micro watershed.

1.3.2. SPECIFIC OBJECTIVES

- ❖ Investigation of available water resource potential
- ➢ Characterizations of the watershed like watershed delineation, topography and watershed hydrology etc.
- ➢ Analysis of historical hydrological data`s
- ❖ Evaluation of existing water resources management practice
- ➢ Assessment of water uses conflicts and conflict resolution.
- ➢ Assessment of status of existing water supply infrastructures.

1.4. RESEARCH QUESTIONS

Based on these study objectives, the research questions are the following:

- ➢ What water sources are available?
- ➢ What are the major water resources management techniques in the area?
- ➢ What means of storage systems are commonly used?
- ➢ What are sources of irrigation water?
- ➢ What are the current demands?

1.5. SIGNIFICANCE AND SCOPE OF THE STUDY

This study generates and provides relevant information of water use and conflict management, existing water resources, and scarcity of water resources. Such information is expect to be beneficial for government agencies, researchers, development agents (DAs), the community, and for other related stakeholders for proper management and planning water resources in the area. It also enables to select appropriate measures by local people to avoid water use conflicts, to improve their livelihood, and to facilitate community participation and to ensure sustainability of the water projects.

This study includes characterization & watershed delineation, analysis of metrological hydrological data's and water supplies sources for irrigation and domestic use (human & livestock). The demands indicated by partly by basic requirements by the community and partly by developmental activities of infrastructures, those have to be investigated by conducting survey with end users and stakeholders in of the watershed. Limited data availability can be overcome by the application of GIS (Peter .Z; Gilson A. L.; Eliana Beatriz R. L. & Ivairton .M. S., 2008), so hydrological analysis of the watershed using GIS and the result obtained shows spatial distribution of water points which is extremely important for sustainable development of water resources.

Moreover, exploring the community perspective for donors, NGO`s and other similar stakeholders activates and observation of their status of the infrastructure like; prospect the boreholes or pumped ground water well in suitable sites to enhance potable water supply in the communities, and to save plenty of water funds . Therefore, this study enclosed to the assessment available water resources and their management mechanism.

CHAPTER TWO

2. REVIEW OF RELATED LITERATURE

2.1. THE CONCEPT OF WATER SCARCITY

The issue of water scarcity is intensifying by a high dependence on water (Ahmad, 2011). Water scarcity is defined in terms of access to water, and is a critical constraint to agriculture in many areas of the world. According to Molden (2007), more than 1.2 billion world's people live in areas of physical water scarcity; about 1.6 billion people live in water-scarce basins where human capacity or financial resources are likely to be insufficient to develop adequate water supply infrastructures. Symptoms of economic water scarcity include scant infrastructure development, either small or large scale. Especially in a chronic lack of water resources area people have trouble of getting enough water for agriculture or drinking. This holds true for the place where infrastructure exists, if the distribution of water inequitable. Most of Sub-Saharan Africa has characterized by economic scarcity, so further water development could do much to reduce poverty (Moldenet.al., 2007).

Physical scarcity occurs when there is not enough water to meet all demands, including environmental flows. Arid regions are most often associated with physical water scarcity, but water scarcity also appears where water is apparently abundant, when water resources are overcommitted to various users due to overdevelopment of hydraulic infrastructure, most often for irrigation (Moldenet.al., 2007).

Like other most sub-saharan African countries, Ethiopian highland watershed like Wujraba micro watershed characterized as both in physical and economic scarcity. Specially, the drinking water supply and sanitation coverage is extremely very low. The existing water supply infrastructures are unevenly distributed and this end result inequitable water distribution. The topography of Ethiopia characterized as rugged landscapes on which women and children travel long distances by carrying large containers may weigh up to 65 kilograms up and down steep slopes (Meseret et al., 2012).

According to I. D.Moore (2006), topography of a catchment has a major impact on the hydrological, geomorphologic, and biological processes active in the landscape. Furthermore, topography can be used to develop more physically realistic structures for hydrologic and water quality models that directly account for the impact of topography on the hydrology. Additionally, J. Garbrecht and L. W. Martz (1992) also gave strong emphasize that topography playing an important role in the distribution and flux of water and energy within natural landscapes as well. This research also shows that topographic effect is the top most recognized factor in Wujraba watershed water both surface and ground water variation and shortage.

WHO (2012), basic water accessibility can be defined as the availability of drinking water of at least 20 liters per day per person, a distance of not more than 1 km from the source to the house and a maximum time taken to collect (round trip) of 30 minutes. The UNDP (2008), the minimum absolute daily water need per person per day is 50 liters, which include 5 liters for drinking, 20 for sanitation and hygiene, 15 for bathing and 10 for preparing food. However, because of scarcity of drinking water, millions of people try to exist on 10 liters a day (ADF, 2005).

According the research held on rural area, Ethiopia (Degenet.A, Fanaye.T, Tewodaj.M 2010), the major sources of drinking water were identified (table1). Among those multiplicity of sources and primary water source about 58% were from rivers, lakes, and ponds and 1 % were from private standpipe or tap.

Table 1 Principal sources of drinking water (%)

	Wet season	**Dry season**
River, lake, or pond	57.98	58.14
Dug well with pump	24.07	23.75
Public standpipe	4.11	4.31
Unprotected spring	4.11	4.12
Protected spring	3.53	3.74
Water vendor	1.91	0.57
Rain water	1.91	0.10
Water truck	0.67	0.10
Private standpipe or tap	0.57	0.57
Other	0.19	0.57
Dug well without pump	0.00	4.02

(**Source:** *Authors' computation based on EEA/IFPRI 2009IFPRI/ Discussion Paper 01044*)

The major sources of water supply for rural peoples of Wujraba watershed are private traditional dug wells and unprotected springs. On the contrary, river and protected spring were the dominant major source for the urban peoples near to the watershed. Yet rainwater harvesting is not well-adapted technology even though the area is characterized by high rainfall.

2.2. OVERVIEW WATER RESOURCE ASSESSMENT IN THE STUDY AREA

Water resources assessment is difficult to start-up from the scratch mainly on the place where there is lack of information, a social and economical problem and undulated topography like rural area of Ethiopian highlands. On Wujraba micro watershed, the residents and experts have the same argument about that everlasting water shortage problem; they do nothing about to investigate the problem and to find out right solution for mitigation. This is directly or indirectly due to lack of knowledge and experience how to assess the water resource in the high land area, and at small watershed level. The government and non-government organizations along with other stakeholders are spent quite lots of money for water supply construction. However, the problems are continued, and most water infrastructures are non- functional. Except some projects, like irrigation scheme structures, most improved water supply structure in highland rural areas used the same guideline for other projects and different locations without sound water resources potential investigation.

At the same time, in order to study water resources investigation at Woreda level, the expertise at smaller scale is not well-adopted and somehow difficult as well in terms of knowledge, budgeting and time etc. Most water resources investigation done in past are at large-scale level. The most common stakeholders involved in such investigation are local, domestic-NGO`s and IWMI. This research uses the methodology by downscaling large-scale level of the international and national level approach to a small Keble level and micro-watershed level.

2.3. WATER RESOURCES ASSEMENENT APPROACH

According to global water partnership, a water resources assessment involves taking a holistic view of the water resources in a given country or region related to its use by society. The assessment looks at both the quantity and quality of surface and ground water. It identifies the pertinent parameters of the hydrological cycle, and evaluates the water requirement of different development alternatives. In short, Water resource assessment is a systematic study of the status of water services and resources, and of trends in accessibility and demand within a specific domain of interest (Stefanie Keller, 2014). The assessment pinpoints major water resources issues and potential conflicts, their severity and social implications, as well as risks and hazards such as flood and drought. Water resources assessment is the determination of the sources, extent, dependability and quality for their utilization and control WMO (2012). It is not enough to investigate the potential of resources also to find out the management and appropriate recommendation should be included as well. Any researcher who is interested to do water recourses assessment should know at least those majors components.

Furthermore, WMO (2012) report shows that, water resources is defined as the available or capable of being made available for use in sufficient quantity and quality at a location and over a period appropriate for an identifiable demand. Therefore, the study of water resources should include its hydrological components and the demands imposed by agricultural, human and animal water requirements. The demands are guide partly by basic requirements and partly by developmental activities.

According to INBO (2009) water resources assessment is a part of integrated water resources management approach and a tool to evaluate water resources in relation to a reference frame, or evaluate the dynamics of the water resource in relation to human impacts or demands. This could be applied to a unit such as a catchment; sub-catchment or ground water reservoir depending on the objective of the assessment .It might look at a range of physical, chemical and biological features in assessing the dynamics of the resource WMO (2012).

2.4. MAJOR COMPONENTS OF WATER RESOURCES ASSESSMENT

UNESCO and WHO (1997) indicted by the figure-1 illustrate, the basic element for data collection for conducting a water resources assessment: In order to conduct a comprehensive water resources assessment. It is also recommended by different scholars to use as guideline for conducting water resources assessment research.

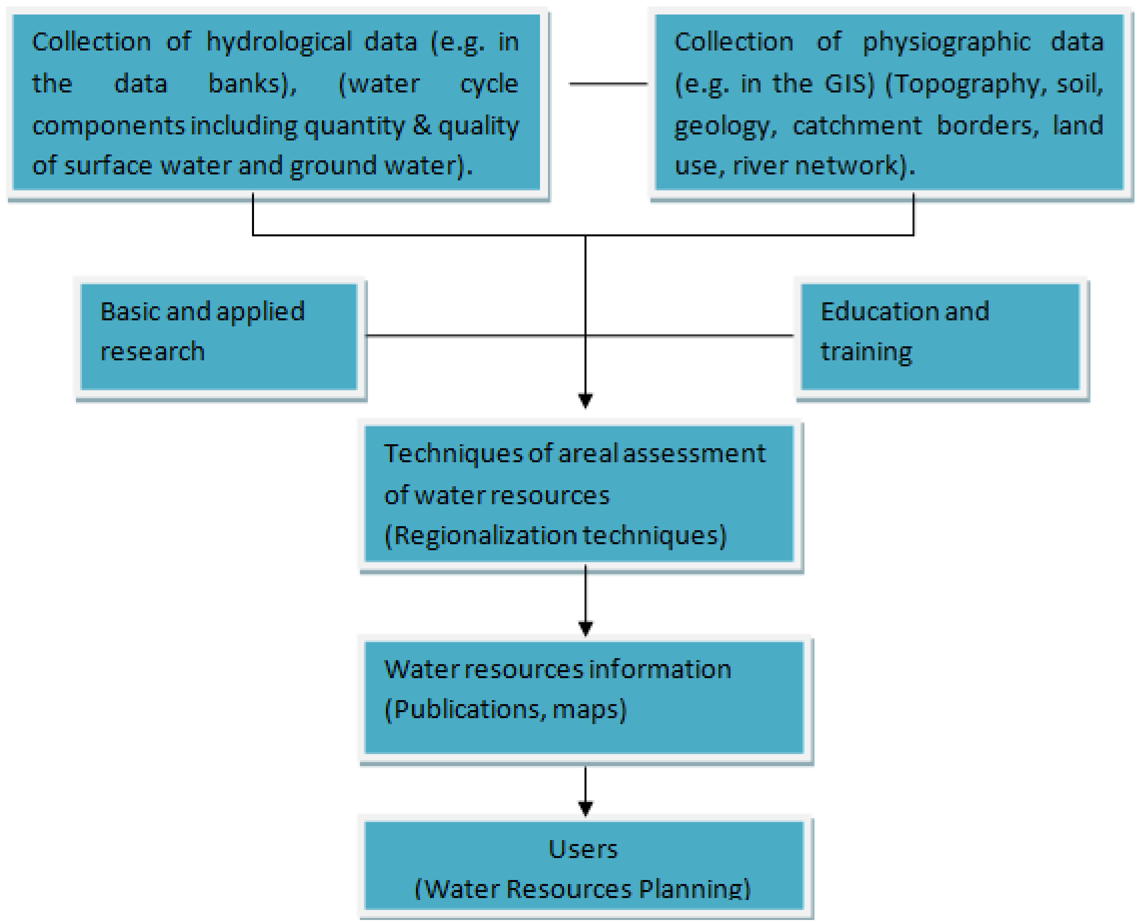


Figure 1: Components of a water resources assessment (WRA) program

(**Source**: *UNESCO and WMO, 1997*)

The guideline shown in the figure-1 recommends a fully integrated approach method. It indicates most important information about what components have to be focused on incorporated during conducting water resources assessment research. Due to this fact, these approaches recommended to conduct individual based research if and only if it is possible to include major data`s. In case of this research, all the elements were included except referring education and training on the recommendation part.

Additionally, priority was given to those elements of water supply resources in the area. Because, the major components water supplies sources are focused on investigation, protection (quantity /quality), management, selection for water supply types (Stefanie Keller: adapted from GWP 2008).

Regarding water management investigation, understating of basic definition of water resource management is prerequisite, and it is the activity of planning, developing, distributing and managing the optimum use of water resources. In an ideal world, water resource management planning has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands. The management system of stakeholders coupled with water quality problems and inaccessible water sources are some of the basic problems (Demeke et al., 2009; Bhandari and Grant, 2007).

In this research not only water recourses potential was investigated, but also the water resource management and water supply infrastructures were investigated. In case of a small watershed at rural area: community participation, bottom-up approach decision-making, and full involvement of water use committee, religion and community elder have played great role for sustainable water resource planning. However, community participation during planning processes and using indigenous knowledge for investigation of water potential and historical data is quite limited. Local experts believe that the role of community is either for labor contribution or water supply infrastructures protection. Community participation as defined in terms of some kind of contribution to small-scale drinking water development was more associated with spring protections than hand dug well protection (Mengesha.A, Abera.K, and Mesganaw.F, 2003).

2.5. NEED OF WATER HARVESTING

Water harvesting arises from many factors such as low rainfall, uneven distribution, high losses due to evaporation, population growth, run off and an increased demand of water for industries. As water harvesting becomes an important strategy to deal with water stress, it is important to consider all factors for selecting the appropriate water harvesting methods. Water harvesting, especiallyrainwater harvesting in Ethiopia has a long history with strong attachment to the ancient Orthodox churches (Habtamu, 1999).

Rainwater harvesting systems can be applicable in all agro-climatic zones and can be more appropriate in arid, semi-arid and sub humid areas; where water demand of crops is higher than the supply because of low and uneven seasonal distribution of rainfall, and high evapotranspiration; in areas where other permanent water sources such as rivers, shallow wells and springs are not available or uneconomical to develop (Gary, 1994).

CHAPTER THREE

3. MATERIALAND METHOD

3.1. DESCRIPTION OF THE STUDY AREA

3.1.1. LOCATION AND TOPOGRAPHY

Chilga Woreda is located at a distance of 60km and 789.2km away from Gondar town and the capital Addis Ababa respectively. Chilga is bordered on the south by Alefa, on the west by Metema, on the north by Sanja, on the northeast by Lay Armachiho, and on the east by Dembiya as shown in figure 2. The research was conducted in a small micro - watershed called Wujraba which is found 5 km away from Chliga Woreda capital (Aykel).

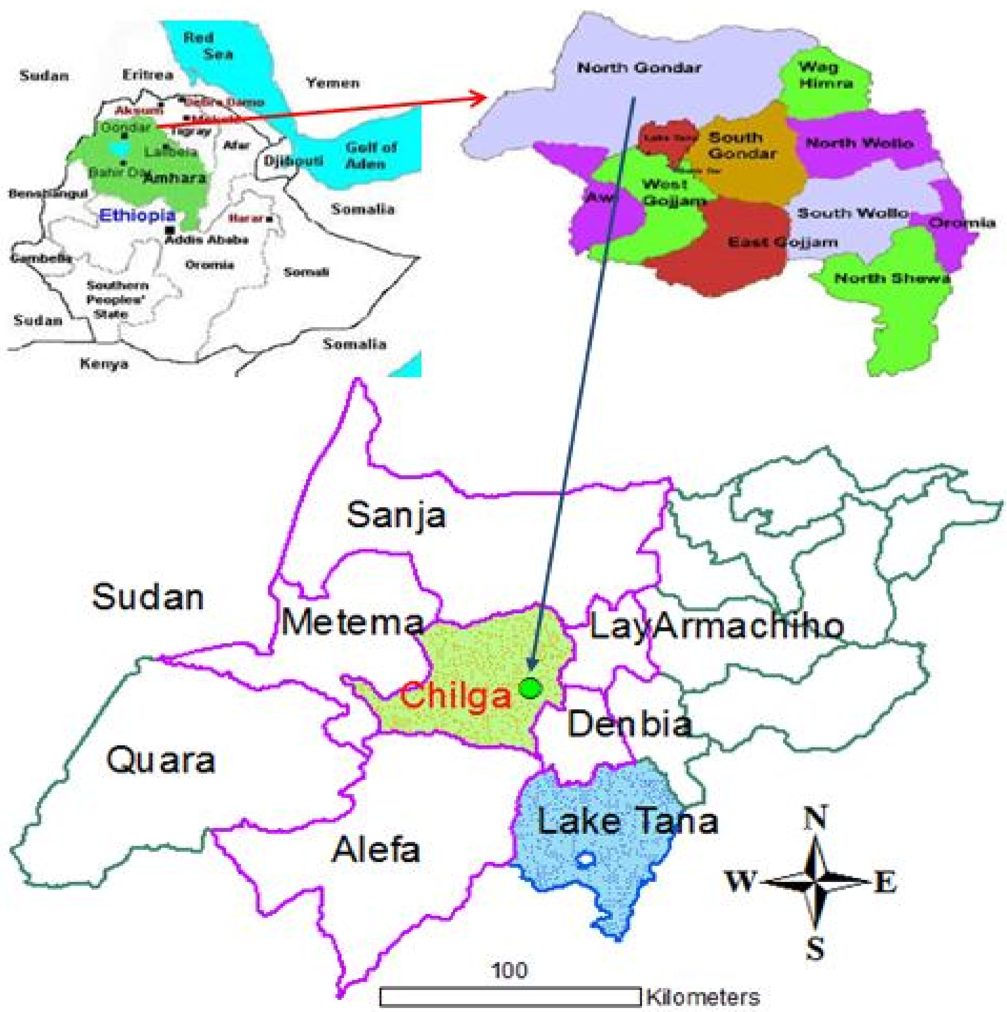


Figure 2: Map of the study area and adjacentWoreda

Both the watershed and the town are accessible by asphalt road from Gondar town to Sudan border. Aykel town and its surrounding area is located in the north western Ethiopia between 12°27′37″ - 12°38′27″ North latitude, and 36°57′30″ - 37°10′06″ East longitude with an elevation range between 1860 - 2240m above sea level. Extremely steep slopes characterize the topography of Wujraba micro watershed and the landscape is mainly mountains and quite rugged hills.

3.1.2. GEOLOGY SOILS OF THE WOREDA

The Blue Nile Basin Survey Project has worked west of Gondar focusing on Oligocene vertebrate paleontology and paleo botany since 1998 and in 2002 investigations at a location in the Chilga district, which is similar to Clark's Gondar Faure smith site and Chilga, suggests that Gondar site may be part of a much more extensive Acheulean record on the Plateau. At Chilga Kernet (Lat 12° 31' 56.33"N, Long 36° 07' 31.83"E) at Gondar, the raw material is predominately fine-grained basalt and surface collected artifacts are so weathered that all evidence of their human origin except their shape has been lost (Lawrence.T, Michelle.G, and John, 2002). Geologically, massive flood basalts as much as 2000 m thick characterize the area, emplaced approximately 30 million years ago, prior to Miocene rifting (Hofmann et al., 1997). Clastic and volcaniclastic sediments occur interbedded with volcanic deposits in a basin formed by faulting of the basalts in the middle to late Oligocene (Bonnie et al., 2005).

The physical assessment of soils of the study area using soil Mensal color chart shows dominated by vertisols soil. At sloppy and medium slope, clay loam is dominant area and while, in flat terrain area dominated by that assumed greater importance with respect to soil water storage. Chilga Woreda Agriculture and Rural Development Office report (2002) shows that average soil depth is about 0.50 to 1.10m with medium infiltration rate and medium water holding capacity.

3.1.3. SOCIO-ECONOMIC INFORMATION

Chilga Woreda has 44 Keble's with a total area of 322,596.00 hectare of land, according to ARDAO report (2001), within the total area of the Woreda only 2000.00 ha of land are selected with potential for irrigation. The present the irrigation coverage is 1,627.29 ha, which is not satisfactory as it compared to the total area. The Central Statistical Authority of Ethiopia (2007) census of the Woreda provides a population number of 221,462.00.

The agro-ecology is predominantly dry or low moist (In Amharic language: Woyina-dega). The natural vegetation consists of acacia trees, gum arabic, and hardwoods such as wild fig (warka) and Cordia africana (wanza) as well as the introduced eucalyptus trees planted by farmers. Agriculture is entirely rain fed and the rainy season lasts from June to September. Farming system is mainly mixed-cropping systems and is dependent on both crop and livestock production where livestock is very important.

Chliga is one of the major Woreda of North Gondar Administrative of the North West Sorghum Belt (NWS) Livelihood Zone. Therefore, modest food and cash crop production and cross-border livestock sales are some of the factors that contribute to relatively high cash income and food self-sufficiency. However, poor physical infrastructure makes trade between the livelihood zone and external markets difficult (North West Sorghum Belt Livelihood Zone (NWS) Amhara Region, Ethiopia 2007).

3.2. RESEARCH METHODS

3.2.1. DATA TYPE

In this study, both primary and secondary data were collected. Major types of data are listed below.

Field Inventory

The onsite field survey was carried out twice during the rainy season 2013 (June – September) and during dry season 2014 (February) to understand the significance difference with in two season of water resource potential assessment and management investigation.

Physical sites observation was conducted extensively along the river continuum to understand about the existing river morphology the base flow condition of the river. The status of both protected and unprotected springs has observed in the watershed. Soil samples were collected and for physical properties analysis as an input of watershed characterization. Primary data by GPS reading were collected for point water sources, existing water supply infrastructures and controlling points for watershed delineation.

Social Survey

Basic survey of key informants from framers, developing agents (DAs), Woreda, and Agriculture Bureau experts were made on investigating of water resources management problem and users' interest. Local farmer's interviews and water use committee members focused on water resources management practice including water scarcity problem, sources of conflict and method conflict resolution.

Secondary Data

Secondary data were collected about water resources uses of the watershed from Water Resources Administrative Office, and ARDB. Hydro metrological data were collected form Chilga Metrological station (Aykel Metrological station). In addition, different professionals like those that DAs, Governmental and NGOs organizations were interviewed.

3.2.2. METHODOLOGY OF DATA COLLECTION AND ANALYSIS

UNESCO & WMO (1997) guide line shown below (figure 3), hydro metrological data is to be collected for water resources assessment research. For this research, 30-year metrological data including temperature, precipitation and wind speed was collected from Chilga Metrological station (Aykel Metrological station). Mean monthly data of that metrological component was computed using excel. Both NewLocClim1.10 and CROPWAT 8.0 were used for effective rainfall estimation.

Based on mean monthly data and land use type of the watershed, the rainfall-runoff was computed using SCS-CN (soil conservation methods) by adopting the concept from Ferguson (1996). The curve number is used determine the amount of precipitation excess that results from a rainfall event over the basin (Mary C. Halley P.E**).**

Nowadays, the advanced technology provided by GIS and the increasing availability and quality of DEMs have greatly expanded for application potential of DEMs to many hydrologic, water resources and environmental investigations (Moore et al., 1991). For this research, field delineation using Arc-GIS 10.2 version was made by using GPS control points in the watershed and 30m by 30mresolution satellite image input was used to analyze the watershed hydrology. Further, Arc-GIS 10.2 based for watershed delineation and watershed hydrology with 30m by 30m resolution satellite image is as input data used for the DEM. This usual technique is to easily understanding Wujraba watershed hydrologic analysis drainage-system, modeling of the water flow.

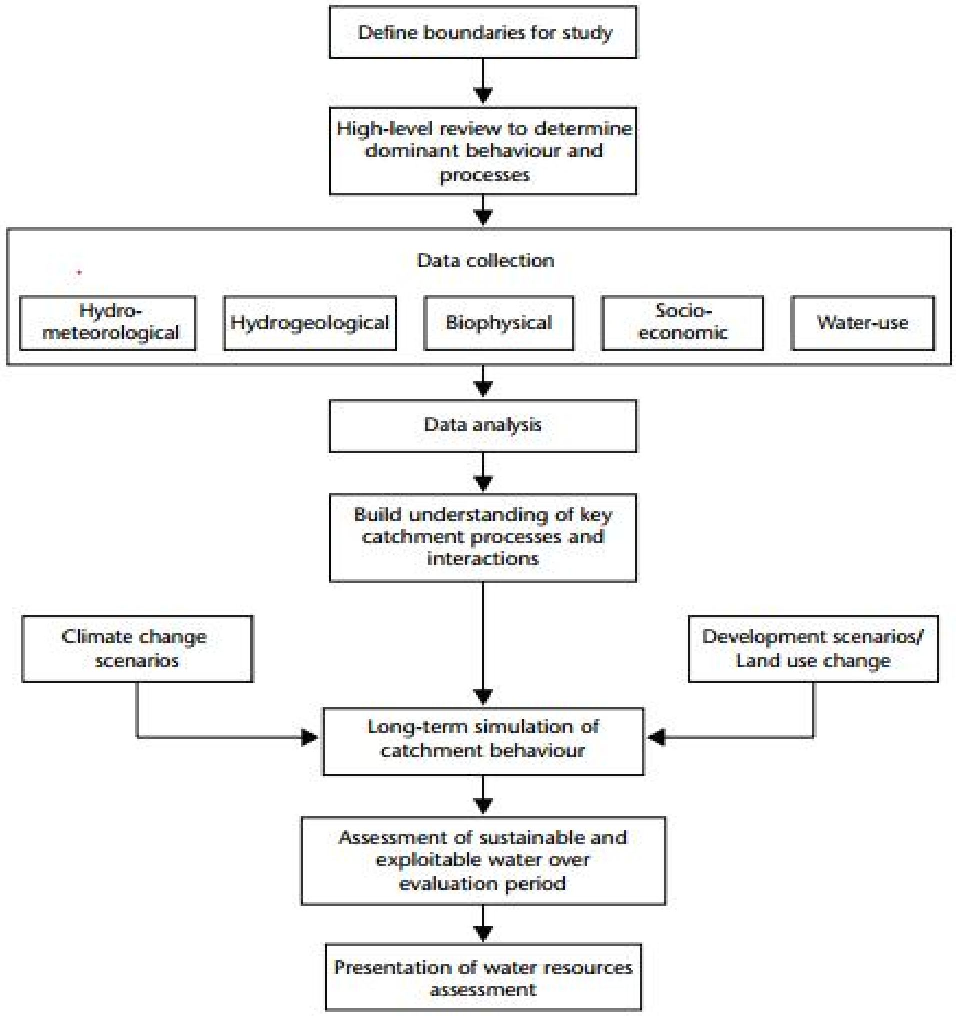


Figure 3: Outline schematic of the water resources assessment development process

(**Source:** *water resources assessment-technical material for water resources assessment, UNESCO &WMO (1997)*)

The characteristics of the watershed broadly categorized into climate, geology and physiography, soils, land cover, hydrology, and socio-economic features. The flow of water through a subset of hydrological cycle includes precipitation, evapotranspiration, and ground water flow. A drainage basin (watershed, basin, catchment, or contributing area) is an area that drains water and other substances to a common outlet (Figure 4). UNESCO & WMO (1997) in the figure-3 also show that define boundaries is prerequisite task for water resources assessment and modeling components of drainage basin is used for understanding the movement of water across a surface, the concepts and key terms regarding drainage systems and surface processes.

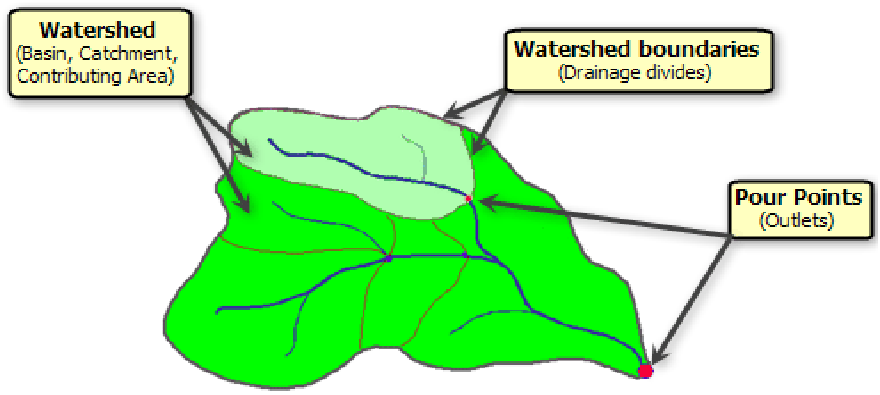


Figure 4: Components of drainage basin ***(source:** ARC-GIS 10.2)*

ArcGIS was used for point water supply infrastructure mapping using Garmin-GPS coordinated reading as input data. Reading of coordinate was made for 22 traditional ground water wells, randomly selected in the Woreda. Most are in the sub-Keble near to Aykel Town and Wujraba watershed. Hand dug wells equipped with hand pumps and status of those water points was observed physically about status functionality or not. An interview of well owners using a structured questioner was done as well. This observation survey of water sources was conducted in places where water sources existed and water pints maps of the watershed developed too. Data collected from the area was organized and composed in an Excel data sheet. The outputs are presented through tables, charts, figures and maps using Arc.GIS 10.2.

Protected and unprotected springs coordinate readings were collected, and for spring discharge very simple techniques called volumetric measurement was used. Float method was used for their base flow discharge estimation. This method is very easy, usual and recommendable techniques that provide good estimated value when there is lack of discharge measurement. It used for measuring the discharge (m^3/s or l/s): Velocity calculated as the distance traveled divided by the time it takes to travel that distance. Float method computation, Where: Surface velocity =Distance /Time, Average Velocity=0.8*surface velocity and Discharge (m^3/s) = Velocity of flow (m/s)* cross-sectional area (m^2) according to M. Kay (1986).

CHAPTER FOUR

4 .RESULT AND DISCUSSIONS

4.1. HYDRO-METEOROLOGICAL DATA ANALYSIS

Hydro meteorological information is important for planning and management of natural resources and assessments of potentials of water resources in a watershed. It is the pre-requisite for all activities like future planning, integrated water management, and sustainable water use. The National Metrological Survey of Ethiopia classifies the metrological stations according to recorded measurements in to three types: Class-1 (Rainfall, temperature (maximum and minimum), sunshine, radiation, humidity, and wind speed), Class-2 (Rainfall and temperature) and Class-3 (Rainfall). Therefore, Chilga/Aykel metrological station is class -l and found in the town of Chilga near to the main road to Sudan. The exact location is: Latitude 12.53 ^{o}, Longitude 37.05 ^{o}, Elevation of 2150 masl, 5km away from the study watershed. Due this, the metrological data obtained is reliable and representative for Aykel town and its surrounding including, the Wujraba watershed.

4.1.1. RAINFALL

The north-western part of Ethiopia from June to September is the main rainy season (Dawit Abebe, 2010). The study area is also reflecting similar characteristics with mono-modal rainfall with single peak 299.5mm on July (figure 5). The mean monthly rainfall is about 1248mm.

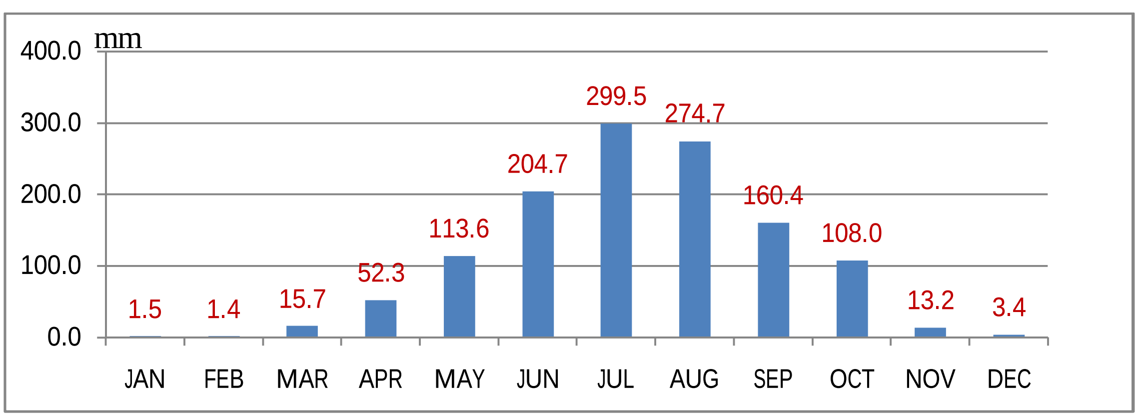


Figure 5: Mean Monthly rainfall of Chilga/Aykel metrological station

Generally, the highest amount with 75% of the rainfall occurring in wet season (i.e. June-September). The rest of 25 % occurs in the dry season from October to May. The mean annual coefficient of variation and standard deviation data is shown (appendix 2).

4.1.2. TEMPERATURE

From three decades Chilga/Aykel metrological data analysis, the hottest season is January, February, March, April and May. The maximum temperature was recorded in March and April. While, the coldest months are: July, August and September. The mean monthly maximum temperature and minimum temperature are 27.7^{o}C and 12.2 ^{o}C respectively (figure 6).

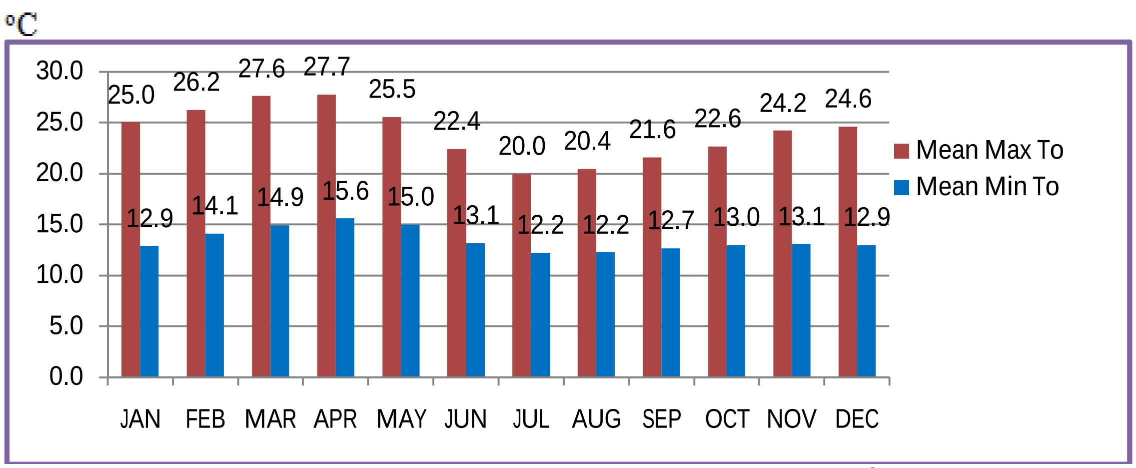


Figure 6: Mean monthly average temperatures (^{o}C)

4.1.3. SUNSHINE HOURS

The mean annual sunshine hour is obtained from the monthly data on the base of 12 years of record at Chilga/Aykel meteorological station gauge, the maximum being 9.8 (December) and the minimum 5.5 hours in the month of July (figure 7)**.**

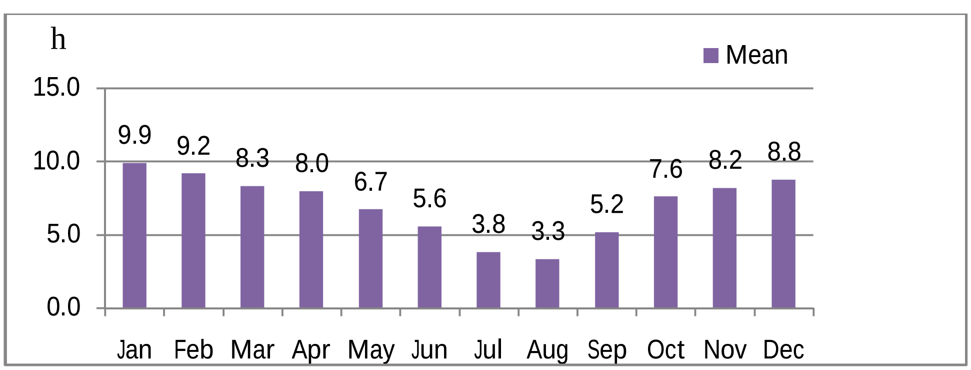


Figure 7: Mean monthly sunshine hours

4.1.4. RELATIVE HUMIDITY

The mean annual relative humidity obtained from records at Aykel meteorological station gauge is about 50.8%. The most humid month is July (82.6%) and the least humid is April (32.6%) (figure 8).

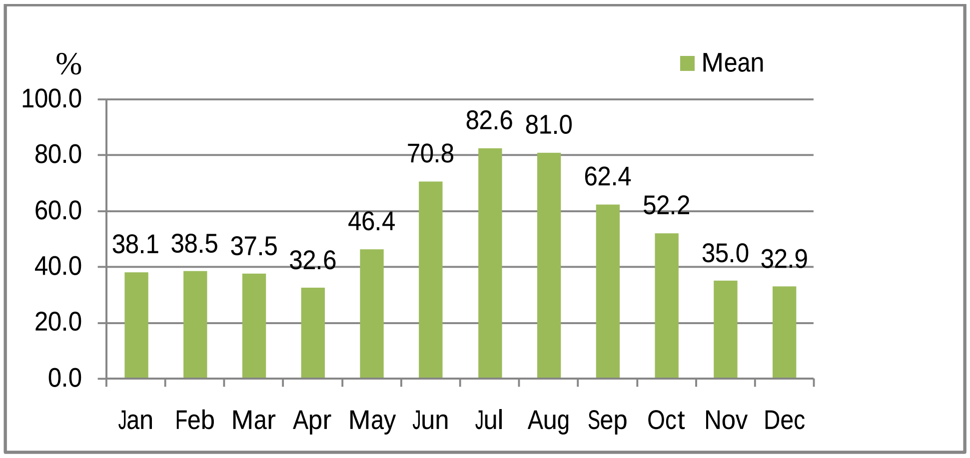


Figure 8: Mean monthly relative humidity

4.1.5. WIND SPEED

The mean annual wind speed obtained from the monthly data base on12 years of record at Chilga/Aykel meteorological station gauge is mean monthly 2.5 m/s. The highest wind speed occurring between February and May and decreased between June and September. The highest wind speed is 2.9m/s (March) and the lowest wind 1.9m/s speed occurred is October (figure 9).

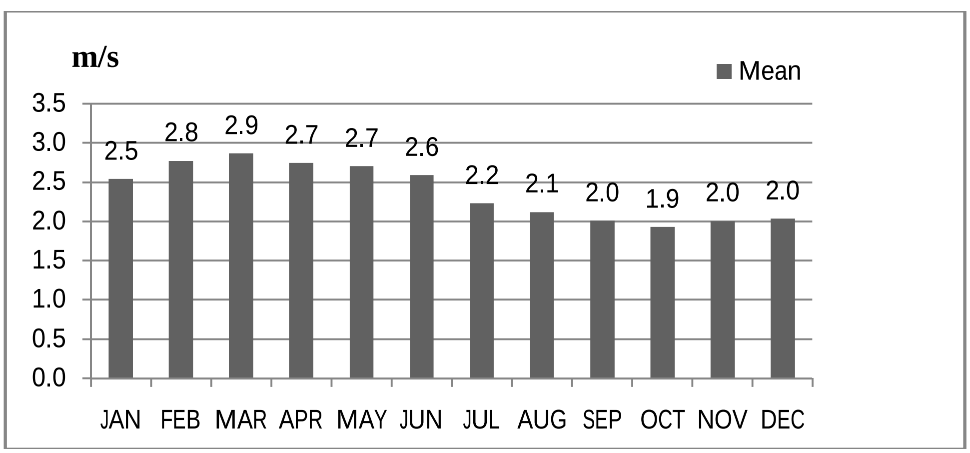


Figure 9: Mean monthly wind speed in m/s

4.2. CHARACTERISTIZTION OF WUJRABA WATERSHED

Based on field observations and data obtained from secondary sources, the major components for characterization of the Wujraba watershed include: Agro-climatology, land use type, soil, hydrology and water bodies (springs, streamlines and the rivers) and water supply infrastructures and management. In result and discussion parts, the hydro metrological data analyses referred in (4.1) are used for Wujraba watershed adaptations since it is located only 5km away from the metrological station. Likewise, some of the results below are also uses for the large scale of the Chilga Woreda.

4.2.1. AGRO-METEOROLOGY CHARACTERISTIC OF WUJRABA

4.2.1.1 GROWING SEASONCHARACTERISTICS

Graphical climate information (figure10) shows the growing season characteristics derived by the FAO local Climate Estimator (NewLocClim version 1.10) using specific location of latitude and longitude reading of the study area as input. This result is accordance with the metrological data analysis shown in figure 5, the rainfall pattern of the watershed is mono-modal type with 75% of the rainfall occurring in wet season (i.e. June-September). The rest of 25 % occurs in the dry season from October to May.

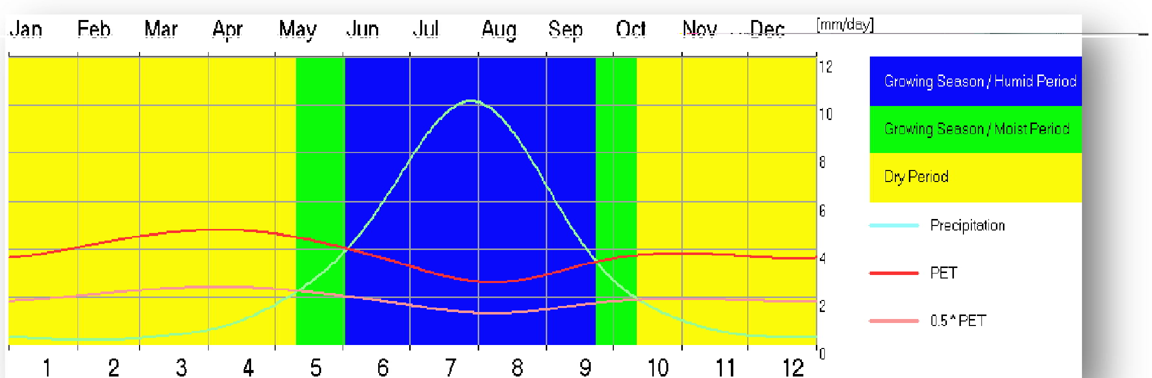


Figure10: Annual climatic information of Wujraba Watershed
(FAO, NewLOcClim-Climate Estimator, Penman-Monteith-Method 2014)

Therefore, the green color is show growing season -moist period (on May except the first week, last week of September, and first week of October), the blue color is show growing season-humid period (from June to last week of September), and yellow color show the dry period (from second week of October to beginning May). The blue precipitation curve line is showing mono-modal type pattern with single pick on end of August (figure10).

4.2.1.2. POTENTIAL EVAPOTRANSPIRATION

The daily average potential evapotranspiration (ETo) is about 4.42 mm/ day. The minimum ETo is in 2.84 mm/day (August) and the maximum values 6.11mm/day (April) (table 2).

Table 2: Monthly climate and Penman-Monteith estimated ETo data

Country: Ethiopia　　Station: Chilga

Altitude: 2150 m.　　Latitude: 12.51 °N　　Longitude: 37.05 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	Rad MJ/m²/day	ETo mm/day
January	12.9	25.0	38	2.5	9.9	21.1	5.02
February	14.1	16.2	39	2.8	9.2	21.7	4.56
March	14.9	27.6	38	2.9	8.3	21.8	5.83
April	15.6	27.7	33	2.7	8.0	21.9	6.11
May	15.0	25.5	46	2.7	6.7	19.6	5.26
June	13.1	22.4	71	2.6	5.6	17.7	3.84
July	12.2	20.0	83	2.2	3.8	15.1	2.88
August	12.2	20.4	81	2.1	3.3	14.5	2.84
September	12.7	21.6	62	2.0	5.2	17.1	3.68
October	13.0	22.6	52	1.9	7.6	19.7	4.14
November	13.1	24.2	35	2.0	8.2	19.1	4.46
December	12.9	24.6	33	2.0	8.8	19.1	4.44
Average	13.5	23.1	51	2.4	7.0	19.0	4.42

(FAO, CROPWAT 8.0 software, Penman-Monteith-Method -2014)

Hydrological study of the Tana-Beles sub-basins surface water investigation held by SMEC (2008), the spatial variation ETo-values of different metrological stations (figure 11). Annual ETo of Chilga/Aykel meteorological station is 1716 mm, and is higher value as compared with others nearby metrological station.

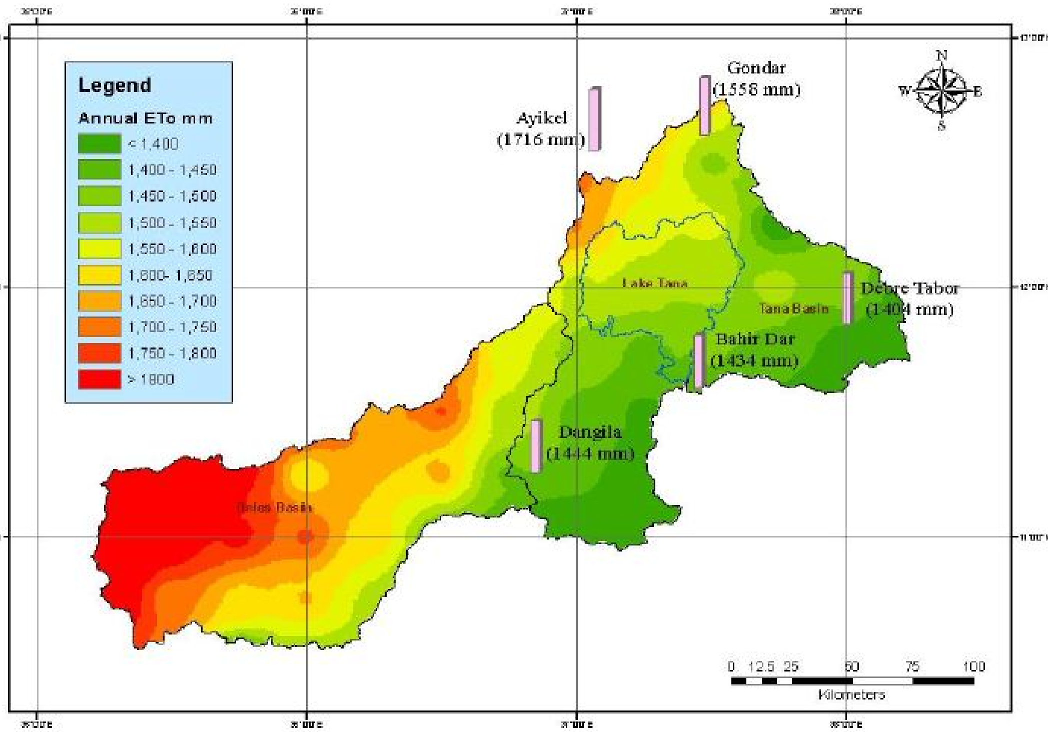


Figure11: Spatial variation ETo-values different metrological station
(**Source:** *SMEC International Pty Ltd 2008, Project Number: 5089018*)

4.2.1.3 .RAINFALL-EFFECTIVE RAINFALL RELATIONSHIP

Computed effective rainfall computed is using USDA-Soil Conservation Service method with CROPWAT 8.0. From the mean annual rainfall of 1248.4 mm, about 829 mm is effective rainfall (table 3). The relationship of rainfall and effective rainfall is shown in the form of chart (figure 12). Annual cycles of the derived variables with CROPWAT 8.0 are show (appendix-3).

Table3: Climate data rainfall versus effective rainfall

Eff. rain method: USDA Soil Conservation Service formula: Peff = Pmon * (125 - 0.2 * Pmon) / 125...for Pmon<= 250 mm Peff = 125 + 0.1 * Pmon ……for Pmon> 250 mm		
	Rain-mm	Eff rain-mm
January	1.5	1.5
February	1.4	1.4
March	15.7	15.3
April	52.3	47.9
May	113.6	93.0
June	204.7	137.7
July	299.5	154.9
August	274.7	152.5
September	160.4	119.2
October	108.0	89.3
November	13.2	12.9
December	3.4	3.4
Total	**1248.4**	**829.0**

(USDA-Soil Conservation Service method with CROPWAT 8.0 /3014)

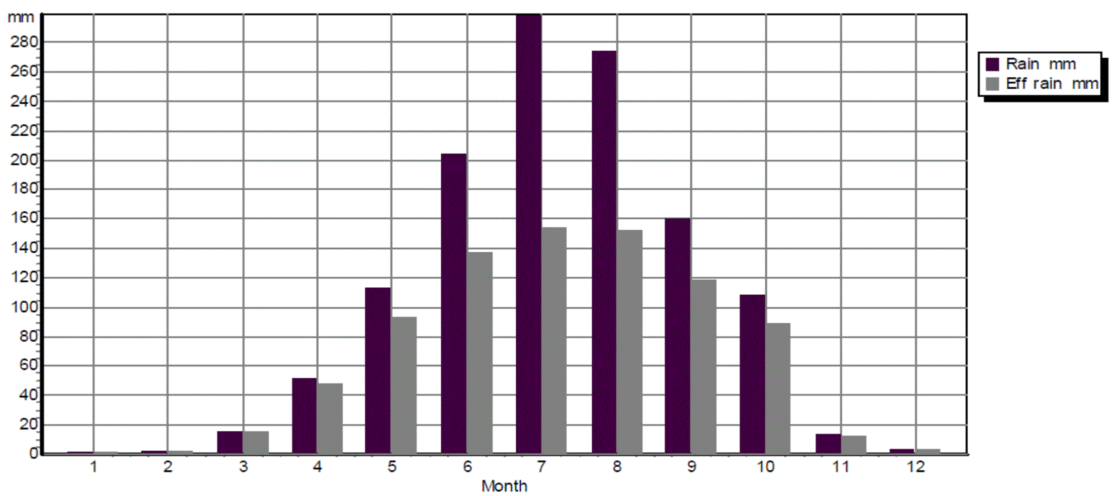


Figure 12: Chart of rainfall and effective rainfall relationship

4.2.2. LANDUSE LAND COVERS OF THE WATERSHED

Survey data obtained from Chilga Woreda, ARDB and DA`s report (2001), the total area of the Wujraba watershed is roughly estimated to 552 ha. The land use and land cover of watershed is classified in to major classes of agriculture, forest, grazing land, residential and other. After delineations of the watershed using ArcGIS, there is additional 288ha of land. Therefore, the total watershed area is about 840 ha, and the different land use types are shown (figure13). The largest proportion of Wujraba micro watershed areas has not covered by vegetation instead it curved with cultivation and farmstead areas. The forest coverage of watershed is about 50ha (6%) which is very small. The major land use types include cultivated land about 480 ha and grazing land 100ha.

Land use	Soil type	Area (ha)	Slope (%)	(%)
Agriculture	Sandy loam	480	1-8	57
Grazing	Sandy loam	180	1-15	21
Forest	Clay	50	15-30	6
Settlement (Residential)	Clay/ Sandy loam	100	1-8	12
Others(bare, gully, river)	Clay /Sandy loam	30	1-30	4
Total		**840**		**100**

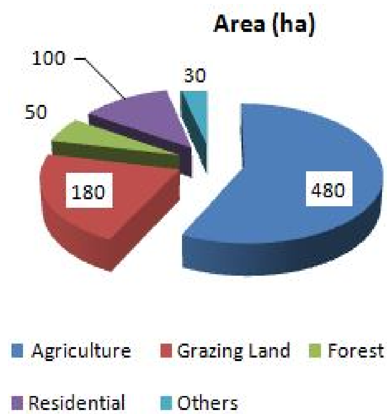


Figure13: Wujraba Watershed Land Use / Area (840 Ha)

The total inhabitants of the Wujrbra watershed are reported as 1575, and the watershed is divided in three Keble’s. About 90% of the watershed and almost all cultivated land were found in the so-called Nara-Awerarda Keble. Total numbers of households having landowners certificate of this Keble are about 1338 (173 male-household head, 318 female-household head, 847 both male and female-household head).From 840 ha of the watershed (figure13), only79 ha of land are potential for irrigation. 75.6 ha is found in one Keble called Nara-Awerarda, 2.9ha is found in the so-called Tebor-Serko, and below 0.5 ha is found in Anguba-Bularge Keble (table 4). For future irrigation schemes planning, Nara-Awerarda Kebele is recommended.

Table 4: Irrigation potential in the Wujraba-watershed (ha)

	Keble's Distribution in the watershed	Irrigation Potential/Area/-Ha
1	Nara-Awerarda	75.85
2	Teber-Serako	0.31
3	Anegewuaba-Buladege	2.88
Total		78.99

The result obtained by questioner survey (appendix-1), the most common irrigation water sources in Woreda are: River, spring development, open hand dug wells, and others but limited (eg. pond water harvesting using geo-membrane in the so-called Walideba-Kebel, roof water harvesting in the so-called Serba-Kebele & Eyaho-Serba-Kebele). Furthermore, the most common water abstraction and supply technologies are motor pump, pedal pump and river diversion. All most in all Kebele, the most common irrigation methods for irrigation practice is river diversion. Likewise, in Wujraba-micro watershed, river diversion from the main Wujraba-Antera River is used as a source for nursery site irrigation, on farm and home garden irrigation. Even though, almost all the inhabitants of the watershed corrugated roof type house, they never used roof water harvesting technology for domestic use and home garden irrigation sources.

Generally, the most common sources of water use conflicts related to irrigation are: by the diverted river water during day or night irrigation, and due to lack of willingness of some farmers to construct irrigation canals and furrows across their own farmland. The most common methods for conflict resolution for the problem are traditional by-law, by decision of water use & management committee, and by land use administration at Woreda level.

4.2.3. SOIL CHARACTERIZATION WATERSHED

Before soil sample collected from the watershed by reconnaissance surveys was held using in to three homogenous lands especially considering the topography and land use type. The watershed (840ha) is divided in three parts: 25 ha (3% of the total watershed) is top WS, 739ha (88% of the total watershed) is middle WS, and 76 ha (9% of the total watershed) is in the bottom (figure 20).

The soil texture was analyzed in soil testing laboratory using hydrometer method. Result of USDA (United States Department of Agriculture)-soil textural triangle classifications are: clay loam, loam and clay respectively to top, medium and bottom of the watershed (table 5).

Table 5: Soil textural classification the watershed

S.No	Soil type	Watershed Location	Wujraba Watershed in %	840ha Area
1	Clay Loam (reddish)	Top	3.0	25
2	Loam (brown)	Medium	88.0	739
3	Clay (black)	Bottom	9.0	76

The color and texture of the soil slightly varies based on slope variation. The dominant soil color and texture is brown loam soil at the middle of the watershed (88%), about 9 % of the watershed (at the bottom) is clay type that is back color, and the remaining 3% at the top of the watershed is clay loam, reddish color (table 5). The soil depth in the dominantly cultivated land is around 1m to 1.5 m with stoniness percentage of 15-30%. Therefore, the soil type of the Wujraba-watersheds is very good for water conservation and recommendable for agriculture use as well. Other physical properties of soil analysis result are shown in the appendix-4.

4.2.4. WATERSHED HYDROLOGY

4.2.4.1. RUNOFF-ESTIMATION-COMPUTATION

The main weaknesses of SCS-CN method reported in literature are: it does not consider the impact of rainfall intensity, not addresses the effects of spatial scale, is highly sensitive to changes in values of its single parameter-CN and is ambiguous considering the effect of antecedent moisture conditions (Hawkins, 1993; McCuen, 2002; Michel et al., 2005; Ponce and Hawkins, 1996). Heyin (2013) states the hydrologic changes in a watershed occurred with influence of interactive multiple factors include climate, land cover, soil, and terrain. The advantage of runoff estimation using curve number method for a drainage basin are accounted by those interactive factors in combination of land use, soil, and antecedent soil moisture condition (AMC).

Thornthwaite and Mather (1957) established the procedures, and SCS-CN method (Mishra and Singh, 2003, S. K. Mishra, M. K. Jain, P. K. Bhunya and V. P. Singh, 2005). J.P. Patil, A. Sarangi, A.K. Singh, T. Ahmad (2008) are recommended of the several methods for runoff estimation from ungauged watersheds, the soil conservation service curve number (SCS-CN) method along with its derivatives has been widely applied to ungauged watershed systems, and has proved to be a rapid and accurate estimator of surface runoff (Mishra et al., 2003).

The original SCS-CN method uses daily data to estimate the daily direct runoff. However, in this research to mean monthly precipitation data was used as input for runoff computation by adopting the concept from Ferguson (1996). In his study, he uses the following equations to estimate the monthly direct runoff *(Equation 3)*.

The potential retention (S) is expressed in terms of the dimensionless curve number (CN) through the relationship.

Equation (1)…. $S = \frac{1000}{\mathrm{CN}} - 10$

Where, S-The potential retention

CN- curve number values from [0,100], when S ∞ and S = 0 respectively.

Most of the time CN has a range from 30 to 100; larger numbers are indictor for increasing runoff potential and vice-versa. The curve number equation, runoff cannot begin until the initial abstraction is met. *Equation (1)* is applied to the English metric system (with S in inches). If the SI units of potential retention (S) are in unit -mm instead of unit-inches, *equation (2)* is used:

Equation (2)………. $S = \frac{25400}{CN} - 254$

Fergusson (1996) presents a refinement, again explored the SCS method, such that monthly direct runoff can be estimated using the equation-3:

Equation (3)………… $Q = \frac{0.208*P}{0.66*S} - 0.095 \leq 0 \dots\dots.. Q = 0$

Where: Q = Average monthly Runoff (Precipitation excess)………..[Inches/ mm]

P = Average monthly rainfall (Cumulative Precipitation)….[Inches / mm]

S = Potential maximum retention…for *(Equation.1)*…………….[Inches]

For curve number of each drainage basin, area weighting is used by considering the land use-soil group polygons within the drainage basin boundaries. The basic equation for curve number calculation is as follows (Mary C. Halley P.E., Suzanne O. White, and Edwin W. Watkins P.E.).

$$CN_{aw} = \frac{\sum_{i=1}^{n}(CN_i * A_i)}{\sum_{i=1}^{n} A_i}$$

Where:

CN_{aw} = the area-weighted curve number for the drainage basin;

CN_i = the curve number for each land use-soil group polygon;

A_i = the area for each land use-soil group polygon;

n = the number of land use-soil polygons in each drainage basin.

For this research, different land use types are considered instead of different drainage basin for computing the area–weighted curve number. Generally, the SCS runoff equations deliver how much of the precipitation appears as runoff and the presented explored SCS method by Fergusson (1996) is appropriated, because for this study:

- The watershed is ungauged.
- The watershed is interlinked with urban area.
- The available data is mean monthly rainfall data (Mean monthly data easily accessible when there is lack of daily rainfall data).

Land use land cover of Wujraba watershed and there corresponding curve number values are shows in the table 6.

Table 6: List of Curve Number Values versus land use type

Land Use Type	Area(Ha)	CN
Agriculture	480	80
Forest	50	69
Grazing land	180	61
Residential	100	80
Others	30	82
Total	840	

Land uses (Area), CN, S and soil type relations are show in (appendix-6). Those values of CN for the watershed are selected land use type description based on soil class with refereed of Westenbroek (2010), the land-use lookup table is shown in (appendix-5).

From the total annual rainfall 1248.4 mm, about 540.45mm is runoff .There is high values of rainfall and runoff in July 300 mm & 142 mm respectively (table 7) and/or (figure14).There is no runoff at all for five months consecutively (November –March). Summary of rainfall- runoff relationship using SCS-method is show in the (appendix-7).

Table 7: Rainfall and runoff estimation from metrological rainfall data and Fergusson's equation respectively

Month	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall mm	1.5	1.4	15.7	52.3	113.6	204.7	299.5	27.7	160.4	108	13.2	3.4	1248.4
Runoff mm	0	0	0	14.88	46.45	93.38	142.22	129.44	70.56	43.57	0	0	540.45

(Rainfall runoff relationship using SCS method / 2014/)

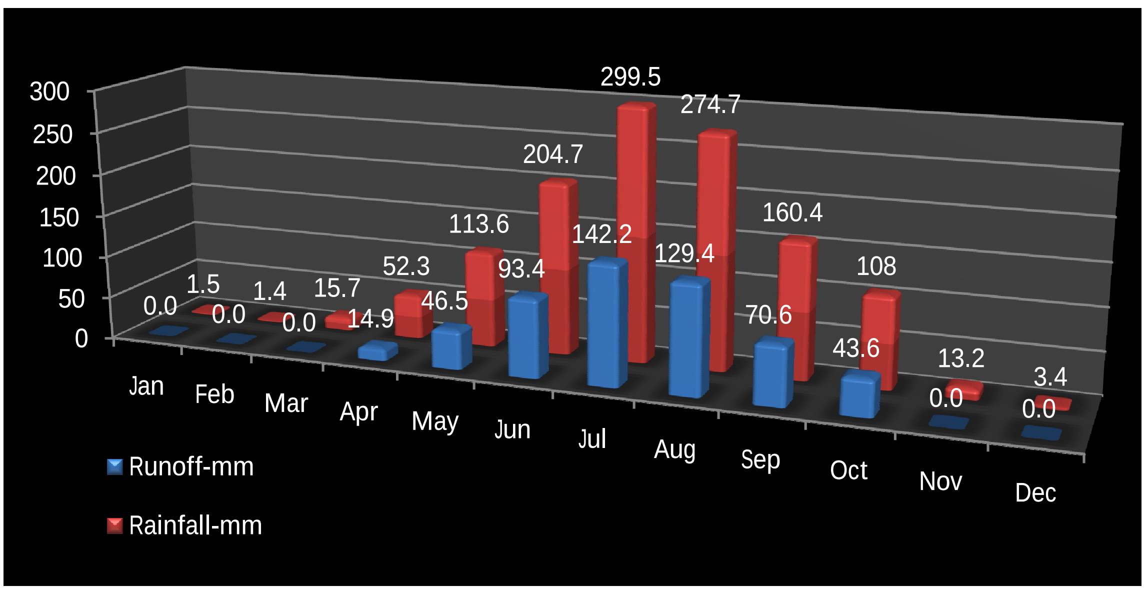


Figure 14: Monthly run off data

The values of rainfall & effective rainfall of the watershed are shown (table 3), and the difference of the total rainfall1248.7mm and effective rainfall 839mm is **419.4mm** [1248.7mm-839mm](figure15). Total runoff value is about 540.5mm (table 7), those two values (419.4mm & 540.5mm) more or less similar. Figure 15 also show all values have almost the same trend except on July (runoff is lower than the difference rainfall and effective rainfall). Therefore, the computed runoff value of Wujrbra watershed using SCS method is show soundness.

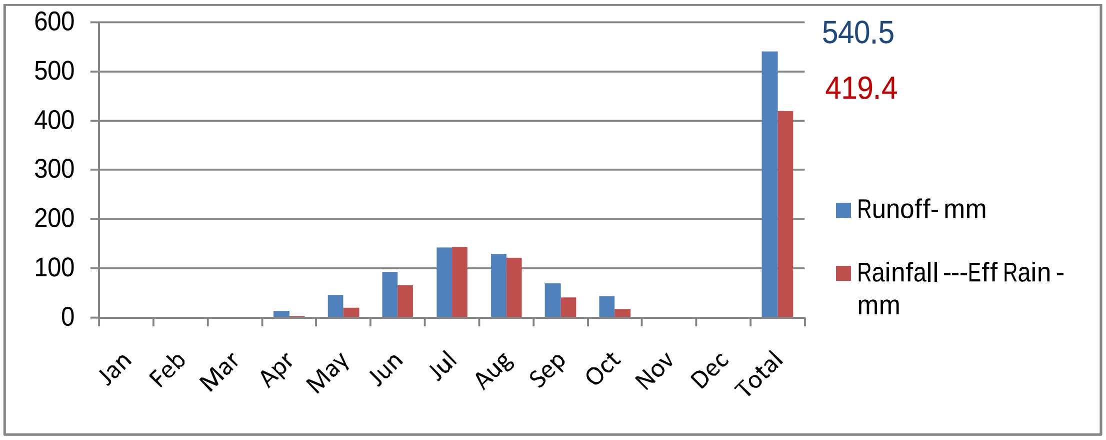


Figure15 :(Run-off) versus (Rainfall - Effective Rainfall) relationship

Generally, runoff generated in the watershed is usually very high increasing the flow regime highly during the rainy season. Runoff, effective rain and rainfall values are increases and/or decrease proportionally as shown in the figure 16.

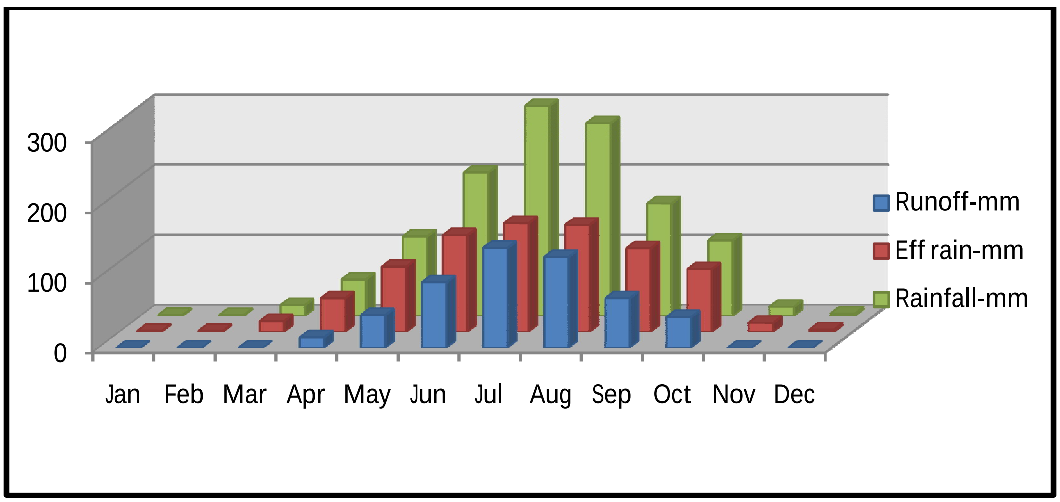


Figure 16: Rainfall, effective rainfall and runoff relationship

Furthermore, according to SMEC (2008) surface water Investigation in Tana-beles sub-basin**,** The average annual water balance terms of the Abbay basin (Nile basin) , Ethiopia are: Rainfall [1197mm/year], **Runoff** [**243mm/year]**, and Potential Evapotranspiration: [954 mm/year]. Shimelis Gebriye Setegn (2008) study shows the Lake Tana basin including the lake area comprises an area of 15,096 km^2, and mean annual rainfall of the catchment area is about [1280 mm]. The mean annual actual-evapotranspiration [773 mm] and **water yield** of the catchment area is estimated [**392 mm]**.

Fitsum Merid also referred in (Executive Summery, BCEOM, 1998) on his National Nile Basin Water Quality Monitoring Baseline Report; Lake Tana Gross Runoff is about [**514mm/year]**.

Therefore, Wujraba watershed has Rainfall [1248.4 mm/year], Runoff [**540.5 mm/year**], and Potential evapotranspiration [1716 mm/year]. Furthermore, the project area (Wujraba watershed) is located in Tekeze river basin, in Goang river sub-basin but very close and adjacent to uppermost Nile of Tana basin (figure 17). The gross annul run off Wujraba watershed [540.5mm/year] nearly similar to the value studied by Fitsum Merid [**514mm/year]**, and approximately similar with the values given by others studies too.

4.2.4.2. TOPOGRAPHY AND WATERSHED DELINEATION

Topography defines a watershed that is fundamentally the most basic hydrologic landscape element and be represented by digital presentation or a Digital Elevation Model (DEM). The automated derivation of topographic watershed data from DEM is faster, less subjective and provides more reproducible measurements than traditional manual techniques applied by topographic maps (J. Garbrecht and L. W. Martz et.al, Tribe et.al., 1992). First hand control points recorded by Garmin-GPS along with the river stream points and the outlet point were used to develop Wujraba watershed shape file (delineated by Arc Hydro extension tool of ArcGIS 10.2). Additionally, 30m by 30m resolution satellite image also used as input data.

The boundaries Wujraba micro watershed are located on specific points at the top North [0291090.32 m, 1392527.61 m] E [2256 m], bottom of the WS to South [0294885.23 m, 1386891.75 m] E [1899 m], and adjacent to Aykle town to West [0290017.97m, 1388701.70 m] E [2252 m], to East [0293016.94 m, 1389517.62 m] E [2084 m].

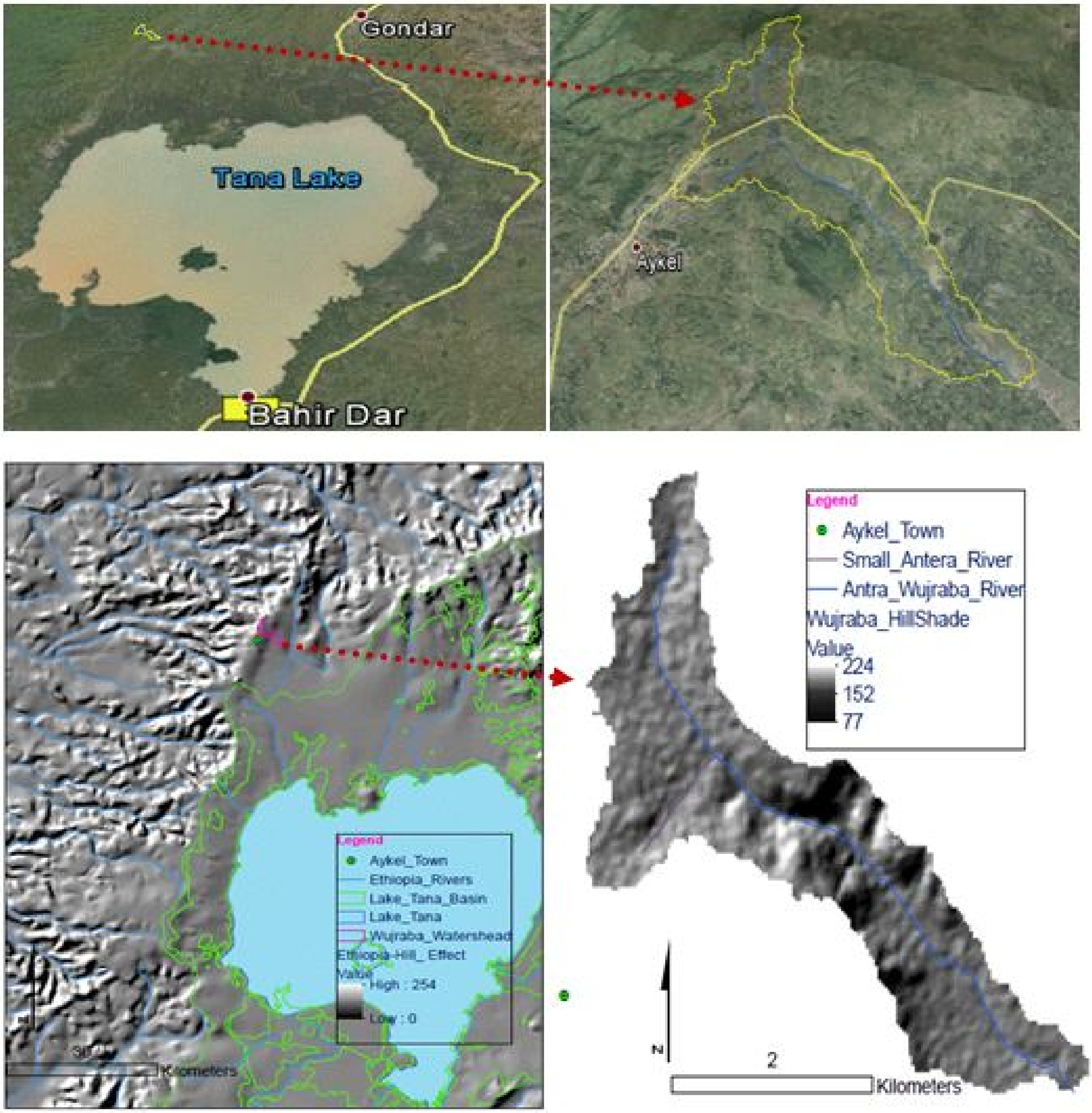


Figure 17: Wujraba Micro Watershed

On figure 17, upper left corner show Wujraba watersheds versus adjacent uppermost Nile of Tana basin Lake Tana Basin, upper right corner show of Aykel town and Wujraba watershed. Hill shading is a 3D model of the surface, with the sun's relative position taken into account for shading the image and powerful for visualizing a DEM. Therefore, hill shade effect of study area adjacent basin and Wujraba Watershed are show in the bottom left and right corner respectively (figure17). The hill shade raster has an integer value range of [0,255] (source: ArcGIS Help 10.1), and hill hade of Wujraba watershed values ranges [77,224] minimum and maximum respectively.

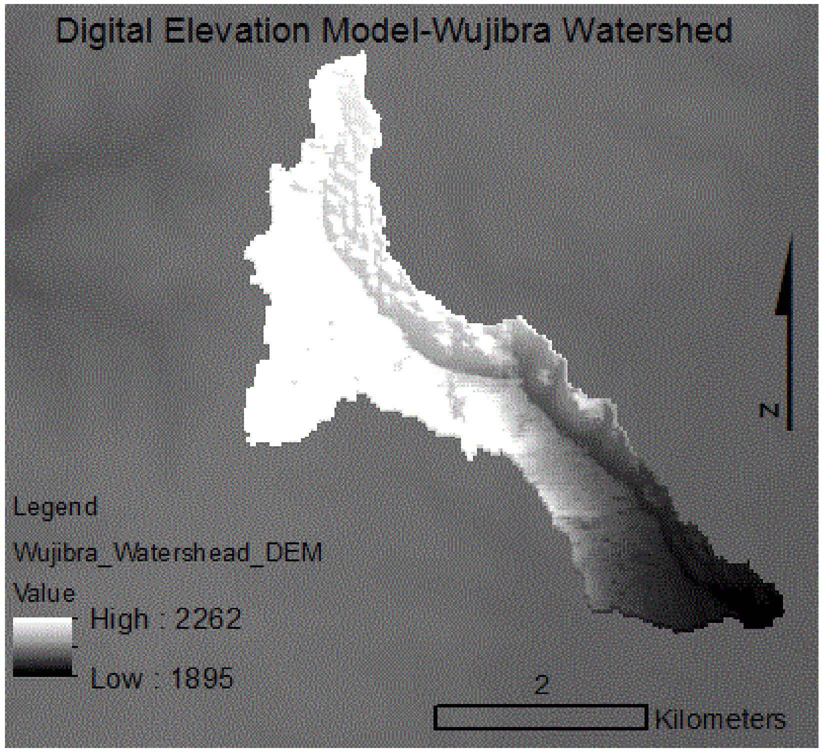


Figure 18: Digital Elevation Model of Wujraba-Watershed

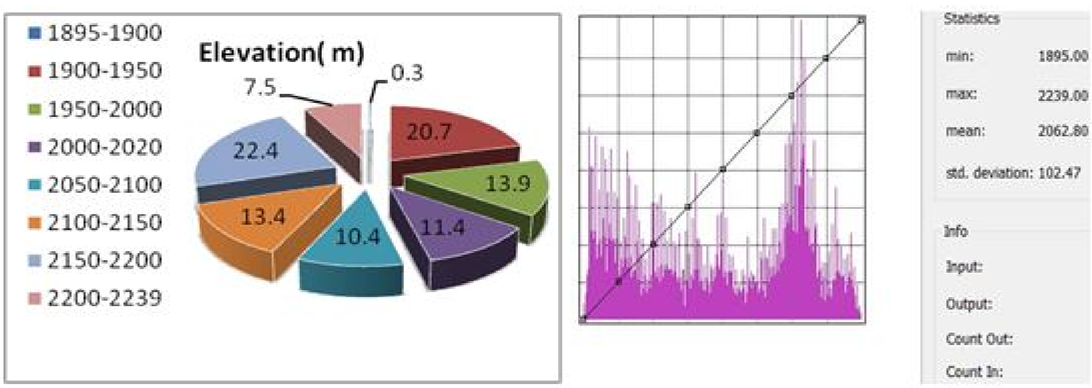


Figure 19: Statically Data of Digital Elevation Model of Wujraba Watershed

From DEM (figure 18), the Wujraba Watershed ranges from the maximum elevation 2239m and the minimum1895m with mean value 2062.8 m, and standard deviation 102.47m (figure 19). The watershed has an area 848ha, and has to be considered as micro watershed, but difference in range of elevation is 344m [1895m-2060m]. The watershed is very small, rugged, undulated, along with high variation of topography. The topography has significant effects on availability of water resources in the watershed, and critical water shortage was observed during this research survey.

In fact, watershed scale hydrological processes are also being affected by climate and land use change/variability, even if these challenges are felt at varying levels by different watersheds (Xu, 1999).

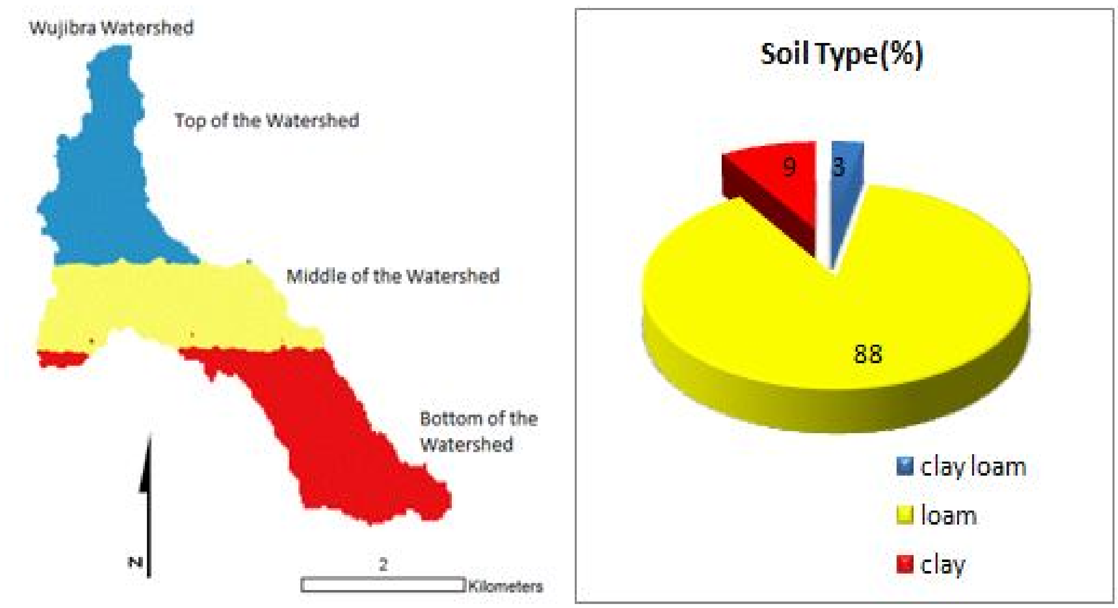


Figure 20: Topography and Soil Map of Wujraba Watershed

Furthermore, the effect of topography on soil characteristics of the watershed is clearly showed in (figure 20). As a result, the top of the watershed [3%] is characterized by clay loam, at the middle of the watershed [88%] is loam soil, while the bottom of the watershed [9%] with the lowest elevation is about clay soil (figure20).

There is no pervious study about those factors affecting the water resource potential in Aykel Woreda and Wujraba watershed. I concluded that, among all other factors topography has the most significant factors affecting the watershed hydrology, and its hydrological processes in the Wujraba watershed.

4.2.5. HYDROLOGICAL MODELING OF WATERSHED

For first time investigation, lack of recent and historical hydrological data for Wujraba Micro watershed, a DEM is very powerful for watershed characterization. DEM is used to subdivide the watershed into upland and channel model elements, each of which is parameterized according to their soil, topographic, and land cover characteristics. It is the primary data used in the analysis of catchment topography (D.Moore, B. Grayson and R.Ladson, 2006). Hydrologic analysis or modeling of the flow of water are used to know about where the water came from and where it is going, the movement of water across a surface, to understand the general concepts regarding drainage systems and surface processes.

For this research of extracting hydrologic information, a digital elevation model (DEM) was used as input. The hydrology tools in sequence were used to create and extraction of Wujraba watershed hydrological information from the DEM such as: a stream network, watershed boundaries, flow accumulation and delineate watersheds deriving runoff characteristics by following Hydrological-modeling flowchart (figure 21). The results are show in figure 22&23.

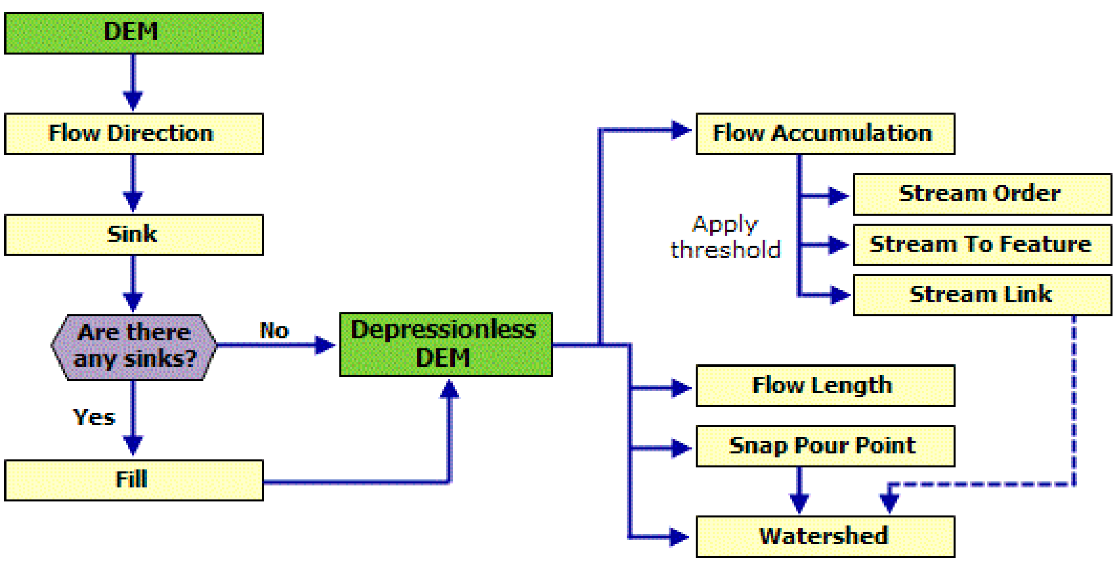


Figure 21: Chart of Hydrological modeling flowchart
(**Source:** ARC-GIS 10.2 the process of extracting hydrologic information from DEM)

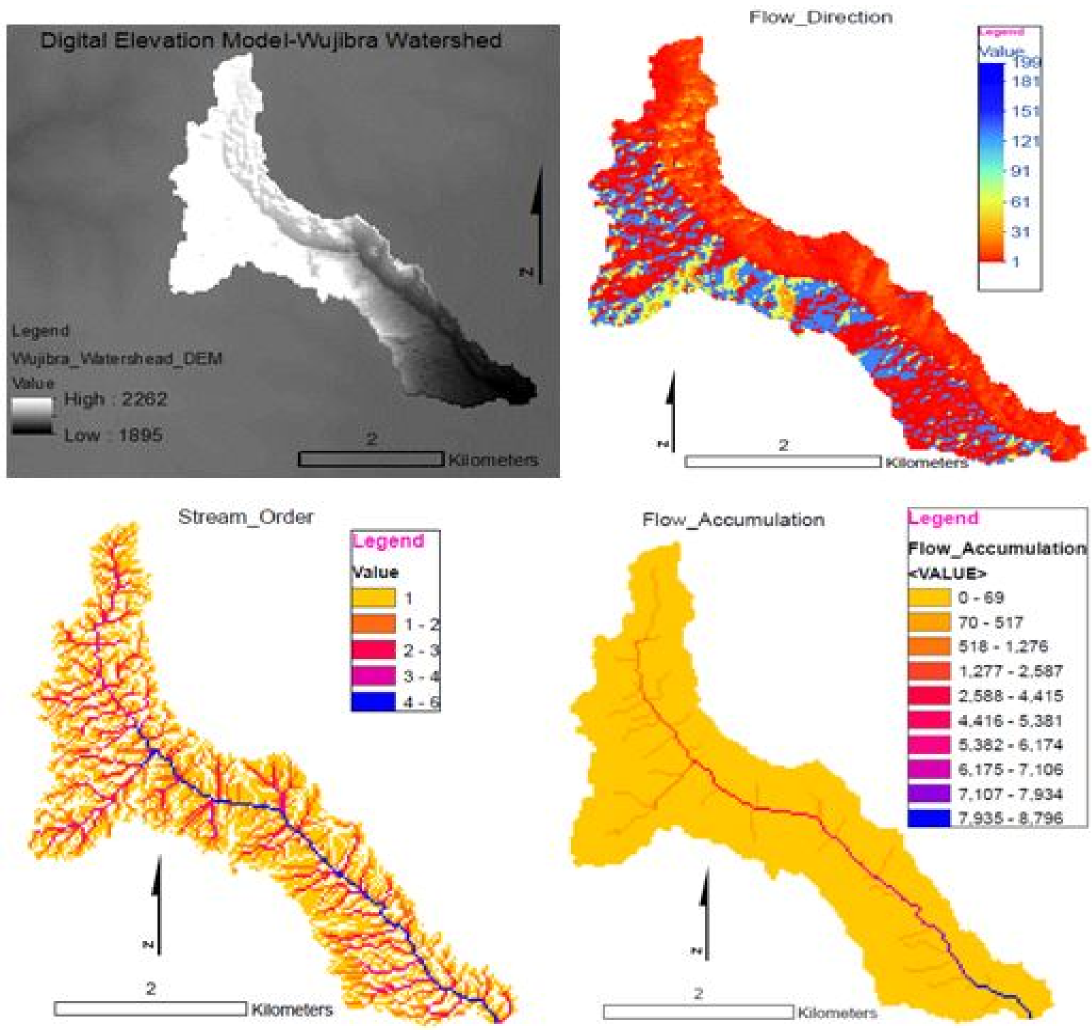


Figure22:DEM-Flow Driection-Stream Order-Flow Accumulation

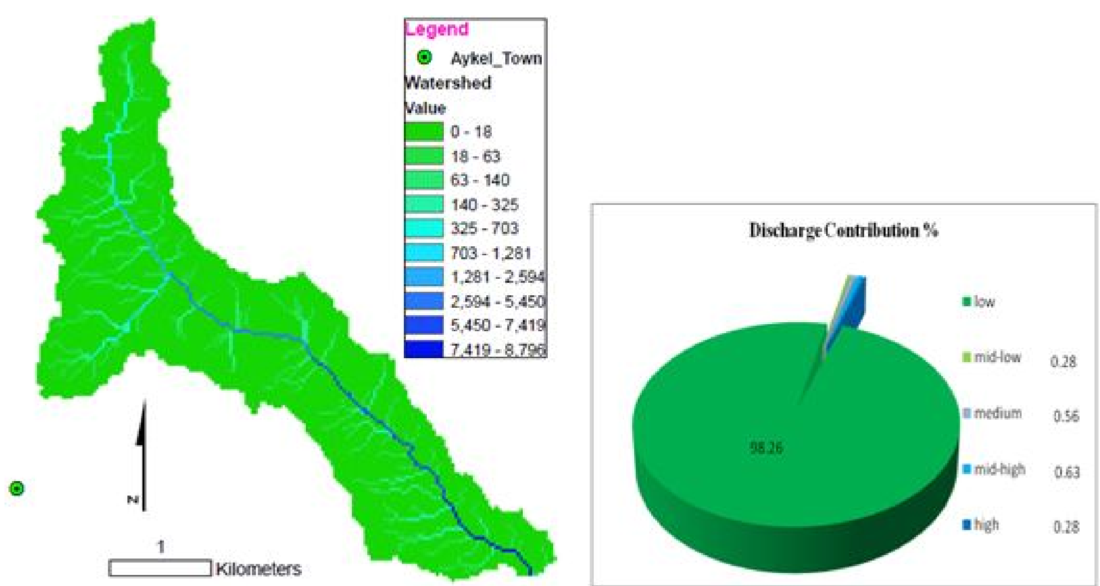


Figure23: Wujraba Watershed Discharge Contrbuting Area

The total number of columns and rows are 167, 185 respectively, with cell size by 30 X 30 m. The largest parts of the watershed about 98.3% (green in color, fig.23) is very low for discharge contrubtion. Each streams network, which are clearly visible contribute from medium (0.28%) to high (0.63%).The second most visible channel of small Antera River is 1.3 km has medium contribution (0.28%). The high discharge contribution is by the main stream Wujraba-Antera River (blue in color, fig. 23) is 7.5 km channel length, and is covered 0.28% below 1%. More or less, most of the water point sources are located in short distance to those major visible streams (small-Antera River and Wujraba River) (figure23).

4.2.6. SURFACE WATER RESOURCES INVESTIGATIONS

4.2.6.1. RIVERS

One of the longest rivers crossing the watershed is called Wujraba- Antera- River and a small river called of Small-Antera River (Gelegele-Antera) is a tributary to the main river. Both rivers are ungauged. Due to this, the only means of estimating base flow of this river was by local people's information and measuring the river flow in many seasons using float method. The measurement was conducted at least for three float tests, and an average velocity was calculated to avoid errors. The average travel time was taken for float to travel through the reach length [s]. Discharge [m^3/s] = cross-sectional area [m^2] x velocity of flow [m/s]. With an estimate of the cross-sectional area, the discharge was can be computed as Q = Av, where v is average velocity. The discharge measurements made on August 3013 and February 2014.

For the main river, the designed base flow measured in dry season on (February 2014) was 42 l/s and the estimated peak flow discharge measured during rainy season on (August 2013) was 209.0 l/s (table 8). In both cases, thus flow was the remnant water from the upstream. While, measuring peak discharge of rivers during in the rainy seasons in such way is not enough and accurate method for recommendation for the design of an infrastructure but it provides estimated value without gauging station.

Table 8: Recording of flow measurement data and calculations for Wujraba-Antera-River

Date	August 2013			August 2013			February 2014
Purpose of measurement /Hydrometric Parameter	**Peak Flow Estimation**			**Peak Flow Estimation**			**Base Flow Estimation**
Location	Head of Antréa			Outlet of Wujraba			Outlet of Wujra.
Lengths of channel reaches (L)[m]	20			20			10
Depth of water level [m]	0.15			0.123			0.12
Mean of depth of water level	(0.1+0.1+0.15+0.15+0.17+0.19+0.20+0.15)/8=1.21/8=0.15125=0.15			(0.08+0.12+0.15+0.13+0.10+0.13+0.15) /7=0.863/7=0.123			(0.05+0.15+0.2+0.15+0.05)=0.6/5=0.12
Width of water level, [m]	3.50			9			1.5
Area (m^2)	0.525 (0.15*3.5)			1.107			0.18
Float travel time through the reach length[s]	T1	T2	T3	T1	T2	T3	
	60	53	60	70	60	65	
Average time T=(T1+T2+T3)/3)	57.67			65			34
Surface flow velocity (Vs=L/T)	0.3468			0.3078			0.2941
Average flow velocity(V=0.8Vs)	0.27744			0.2463			0.2352
Discharge (Q= VA) [m^3/s]	**0.145656**			**0.2726541**			**0.042354**
Q (Liter /Second)	0.145656/0.001= **145.656** l/s			0.2726541/0.001= **272.6541** l/s			0.042354/0.001 =42.354 l/s
	Average Result=(0.145656+0.2726541)/2 =0.20915 m^3/s =209.15 l /s						

Table 9: Recording of flow measurement data for Gelgel-Antera and small-Antera-River

Date and Purpose of the measurement	August 2013, Estimation of peak flow					
Location and local name of the river	Small-Antera -1			Small-Antera-2 (Gelegel-Antera)		
Lengths of canal reaches (L), m	10			6		
Depth of water level, (m)	0.1			0.15		
Width of water level, (m)	1			0.6		
Area (m^2)	0.1 (0.1*1)			0.09		
Time taken for float to travel through the reach length(sec.)	T1	T2	T3	T1	T2	T3
	19	20	21	18	20	19
Average time (T=(T1+T2+T3)/3)	20			19		
Surface flow velocity (Vs=L/T)	0.5			0.31579		
Average flow velocity(V=0.8Vs) V:Mean River velocity	0.4			0.2526		
Discharge (Q= VA), m^3/s	0.04			0.0227		
Q (Liter/second)	**Q= 0.04 m^3/second =40 liter/second**			**Q= 0.0227m^3/second =22.7 liter/second**		

Small Antera-1 and Small Antera-2 are tributary rivers to the main Wujraba-Antera River located at the head of the watershed with an estimated peak flow discharge of about 40 l /s and 22.7 l /s respectively (table 9). Those small Antera Rivers are intermittent and dry during dry season. Thus, the seasonal fluctuation of the river flow has occurred. However, the local people ensure that base flow of the main Antera River at driest period does not vary.

Wujraba-Antera-River and those tributary small Antera rivers are the major source of water for human and livestock consumption in the area. Mainly the framers are dependent on rain feed agriculture and there are no modern irrigation practices upstream and downstream in the river basin. However, farmers used traditional irrigation practice during dry season (October to April). For this, the framers in the dawn stream of the watershed used tradition diversion canal to irrigation filed along from Wujraba- Antera River (measured base flow 42 l/s).

During focus group discussion held with farmers and experts, the watershed is potential for growing different type of crops, accessible with asphalt road and availability of market of Aykel town, there is high demand of irrigation by the framers. Nevertheless, there is shortage of irrigation water source in the watershed.

4.2.6.2. SPRING CAPPING

Spring discharge measurement using volumetric techniques work on very low flows, collects a known volume of water for a known period of time with Volume/time: Discharge (Q)[l/s] = Volume of bucket [l] / Time taken to fill [s].

Table 10: Spring Discharge measurement – Volumetric measurement

Code	Volume [L]	Time 1	Time 2	Average's [S]	Q [L/S]	Remark
Spring -1	10	36	38	37	0.27	Connected to collection chamber for Aykel Town water supply
Spring -2	1	9	7	8	0.13	Unprotected springs at head of Wujraba-watershed
Spring -3	3			27	0.11	

As shown in the table 10, Spring-1 is located at GPS Location of (UTM E 291073, N1389726; E 2171m), somehow protected and has a measured discharge 0.27 l/s. This spring is capped separately, and is collected in one collecting chamber together with the

Small Antera River. The spring is abstracted by pipe, connected to collection chamber by gravity system for community water supply for Aykel Town during dry season. It is used direct domestic use for watershed inhabitants in wet season (figure 33).

Spring -2 and spring-3 are amongst others unprotected small springs located at the head of the watershed located (GPS Location UTM E 291062, N1390297, E 2172 m) with very weak average measurable discharge of 0.11 l/s and 0.13 l/s (table 10). Those springs are uses for drinking water source and for livestock. They are considered as spring eyes of the watershed. Even if their discharge was measured during rainy season (August 2013), they had very low discharge, are not recommended for design as well, and area affected by covering of soil-sediments (appendix-11, a, b). Summary of GPS location of those springs are show (appendix-8).

4.3. WATER SUPPLY SOURCES AND MANAGEMENT PRACTICE

4.3.1. WATER SUPPLY INFRASTRUCTURES AND THEIR STATUS

Until 2013, all types of water points including the current status of the Aykel town and surrounding Keble's using GPS coordinate reading were recorded in the excel file by ARDB report/2014/ (appendix 9-a). While detail data of Wujraba micro watershed, and Aykel town were collected on July 2013 (appendix 8 & appendix 9-b). Results, figures and maps are developed by using ArcGIS.

The major types of both improved and unimproved water supply sources identified during the survey in Aykle surrounding province area were hand pump dug well, spring development, traditional dug well, unprotected springs and river (figure30).

Likewise, the most common types water supply sources in the Wujraba watershed are river, protected spring development, traditional hand dug well and hand pump dug well (fig.25 B, fig.27 B, fig.28). The way of management is either public water supply or self-supply (local well). Commonly, the river and unprotected springs are major sources for domestic use (livestock, washing cloth and bathing).

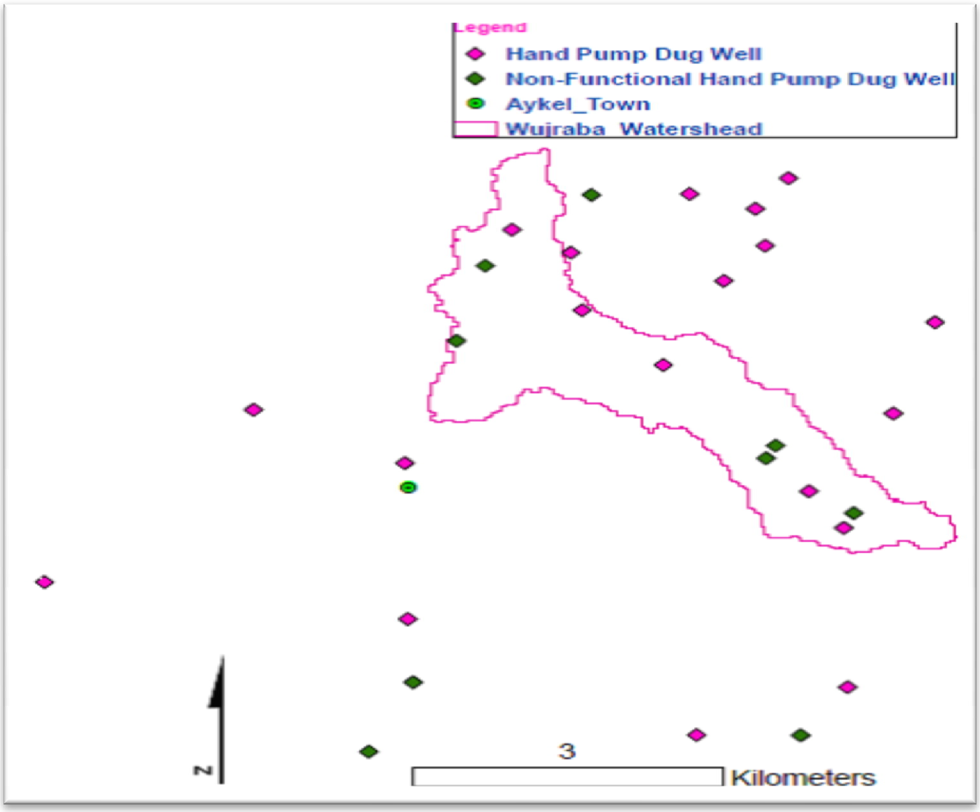


Figure 24: Maps of Aykel Town Province Ground Water Wells

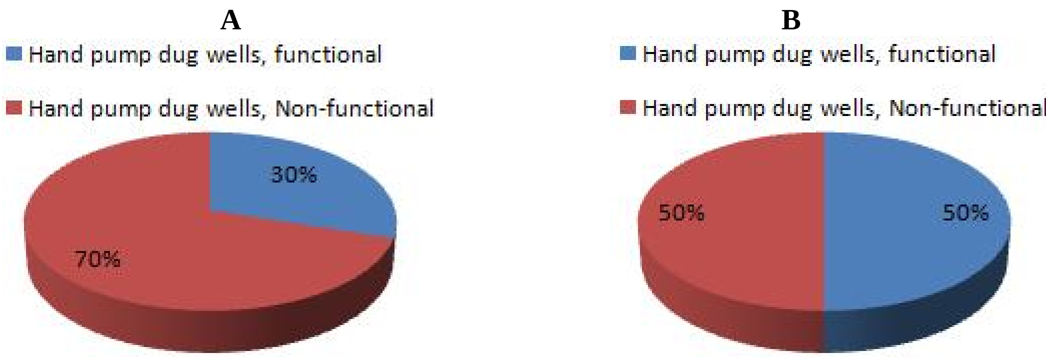


Figure 25: A-Aykel Town Province hand dug wells, **B**-Wujraba Watershed HPD Wells

About 30% of the hand pumped dug wells are still functional, while 70% were not functional at all. Within Wujraba watershed 50 % were functional and 50% of were not functional at all (figure 25). From this, the hand pump dug wells could not be promising for future planning; it need advance investigation to know about whether it is due to ground water depletion or improper infrastructure constructions. However, during surveying, the problem indicted both planning and low ground water potential. The functional and non-functional hand pump dug wells are show (appendix-11, d, e).

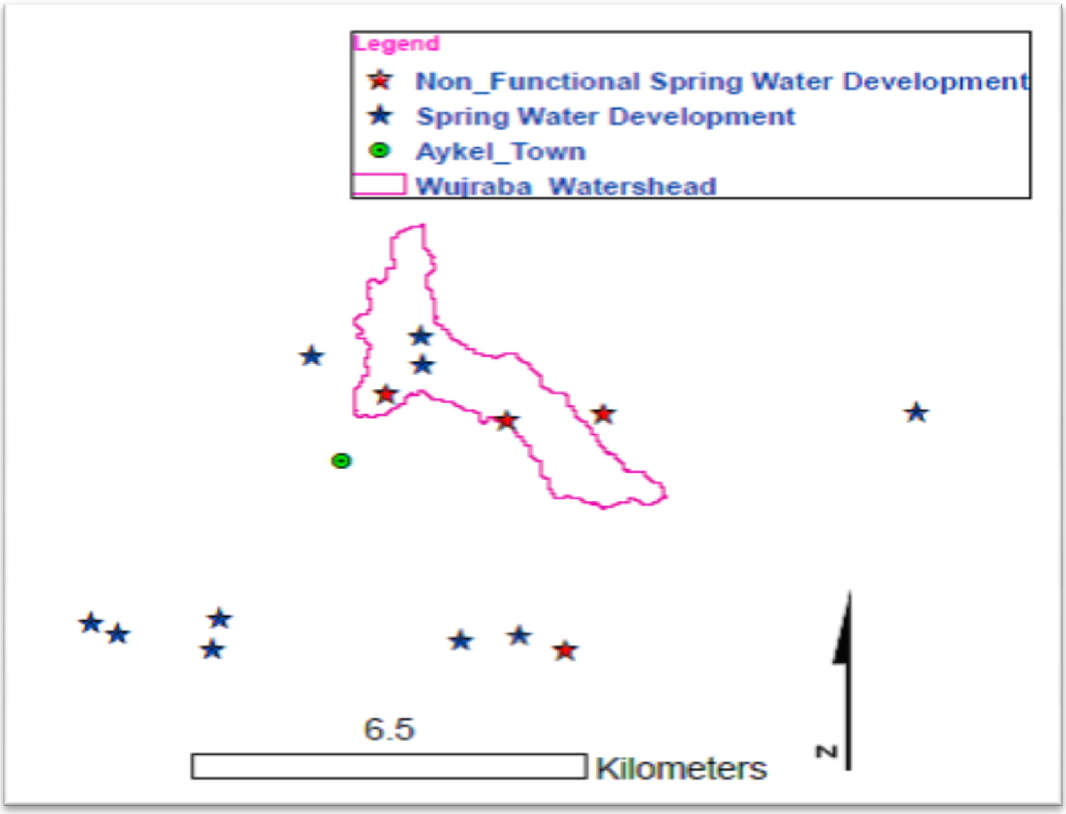


Figure 26: Map of Aykel Town Province Developed Spring Water

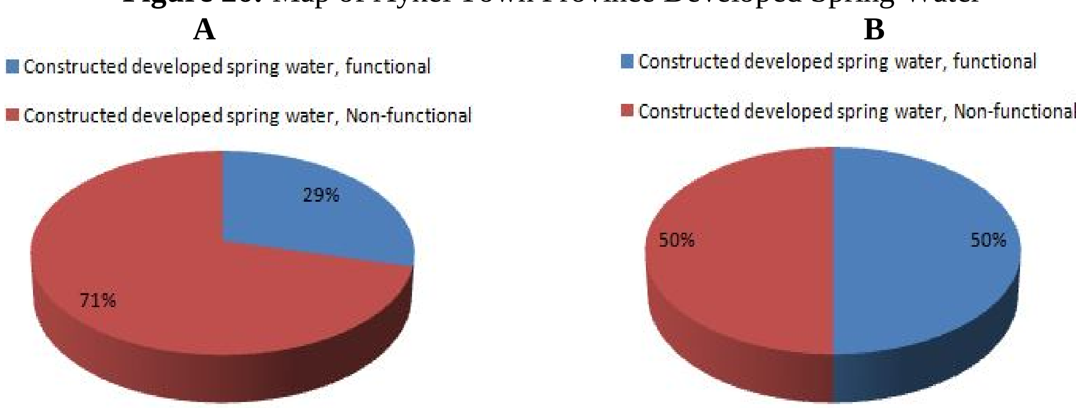


Figure 27: A-Aykle Town Province spring water, B-Wujraba Watershed WS

About 29% of spring water developments were still functional, while 71% were not functional at all. Within Wujraba watershed 50 % were functional and 50% of were not functional at all (figure 27). The distribution of the status of both spring water development and ground water well were equivalent. This is good indicator of ground water depletion in the area. Functional and non-functional constructed spring water are show in respectively (appendix-11, f & g).

Almost 75% of the watershed resident's use traditional ground water-wells as alternative sources of water supply. In Ethiopian highland commonly traditional ground water wells near to their home garden are used. Nevertheless, in Wujraba watershed, all most all traditional ground water wells are located on grazing land and farmland, far away from their home. Figure 28 show map of 22 ground water points data collected (appendix-9,b) during the research survey, and all most all located along with the stream of the watershed that is tributary to the main Wujraba-Antera- River (figure 30).

A B

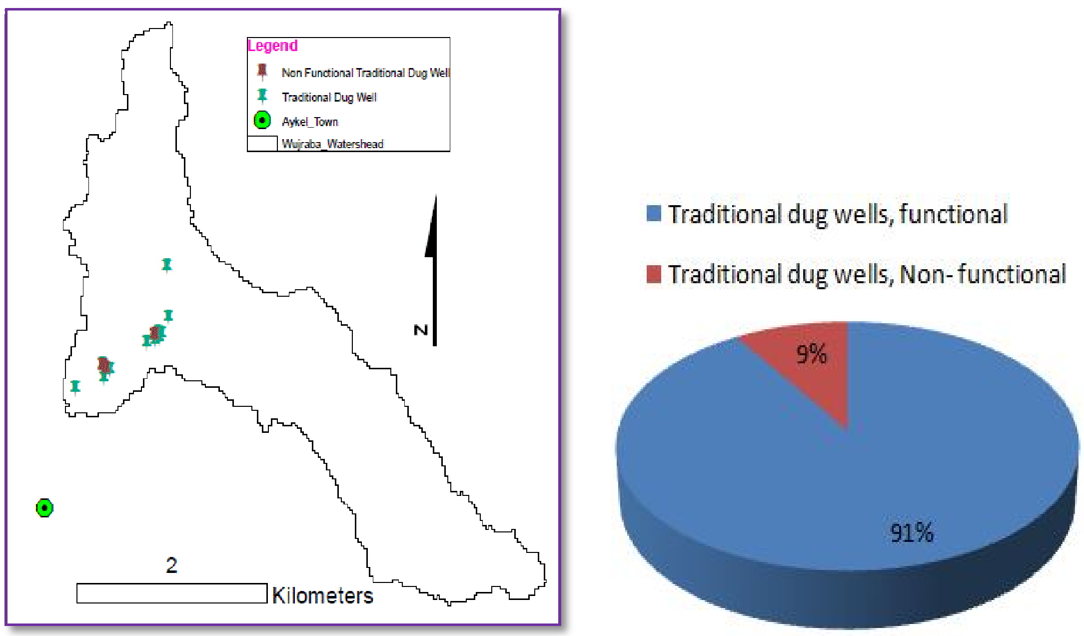


Figure 28: A, Map of Wujraba-Watershed Traditional Dug Well, fig. 28. B, TDW *(Figure 28-A, show 18 functional and 4 non-functional traditional dug wells along with a stream, fig.28-B, shows total percentage of functional and non-functional traditional ground water wells in the watershed).*

In Wujraba watershed, about 91% of the traditional dug wells are functional, but all those ground water well had very low yield during critical dry month in February and March, and about 9% traditional dug wells are non- functional at all (figure 28-B). Functional and non-functional traditional dug well are shown (appendix-11, h, i).

In general, the watershed having an area of 840 ha has 66 functional, 12 non-functional water supply facilities (table 11). About 76.9% water supply sources for watershed inhabitants are from functional traditional dug well, 5.1% is from functional hand pump dug wells, and 2.6% is from constructed developed functional spring water (figure 29).

Table 11: Summery of water supply facilities in Wujraba Watershed

Facility	Functional	Non-Functional	Total
1 .Hand Pump dug wells	4	4	8
2 .Traditional dug wells	60	6	66
3. Spring Development	2	2	4
Total	**66**	**12**	**78**

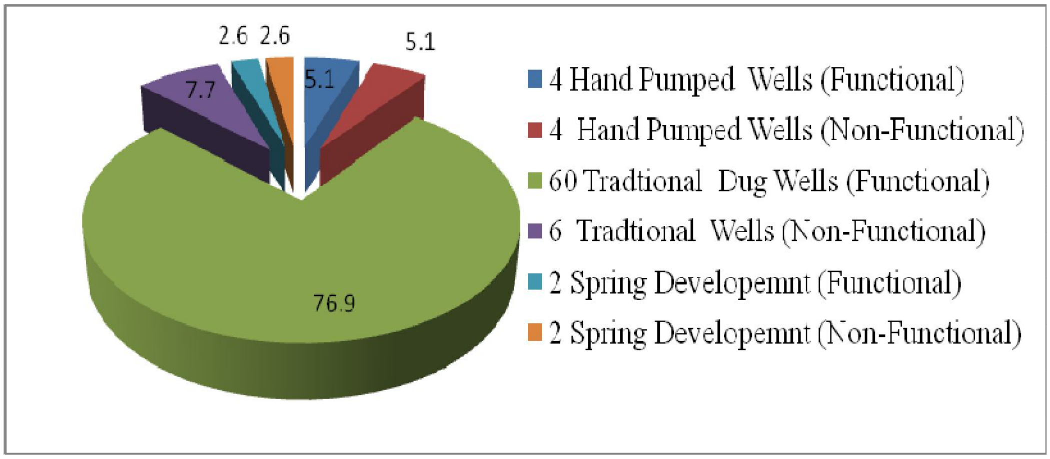


Figure 29: Ratios and types of community water supply facilities in Wujraba watershed

The majority of users withdraw water from traditional ground water wells manually with jars (jerican) that is tedious and tiresome. Some farmers are interested to use the technology like pedal pumps and wing pump mechanisms. However, there is limitation of adopting new technology due to: lack of the extension for adaptation, the cost of the pumps, and lack of skill in operation and maintenance.

Even if, water shortage is the recognized problem in Aykel province, the available water resources in Wujraba watershed relatively better as it compared to the others, and all types of functional water supply infrastructures are available within the watershed. Most of the water point sources located along with streams of small-Antera River and Wujraba Antera Rivers (figure 30). The town peoples are use water from the watershed, and this is main causes for conflicts among the town and watershed inhabitants.

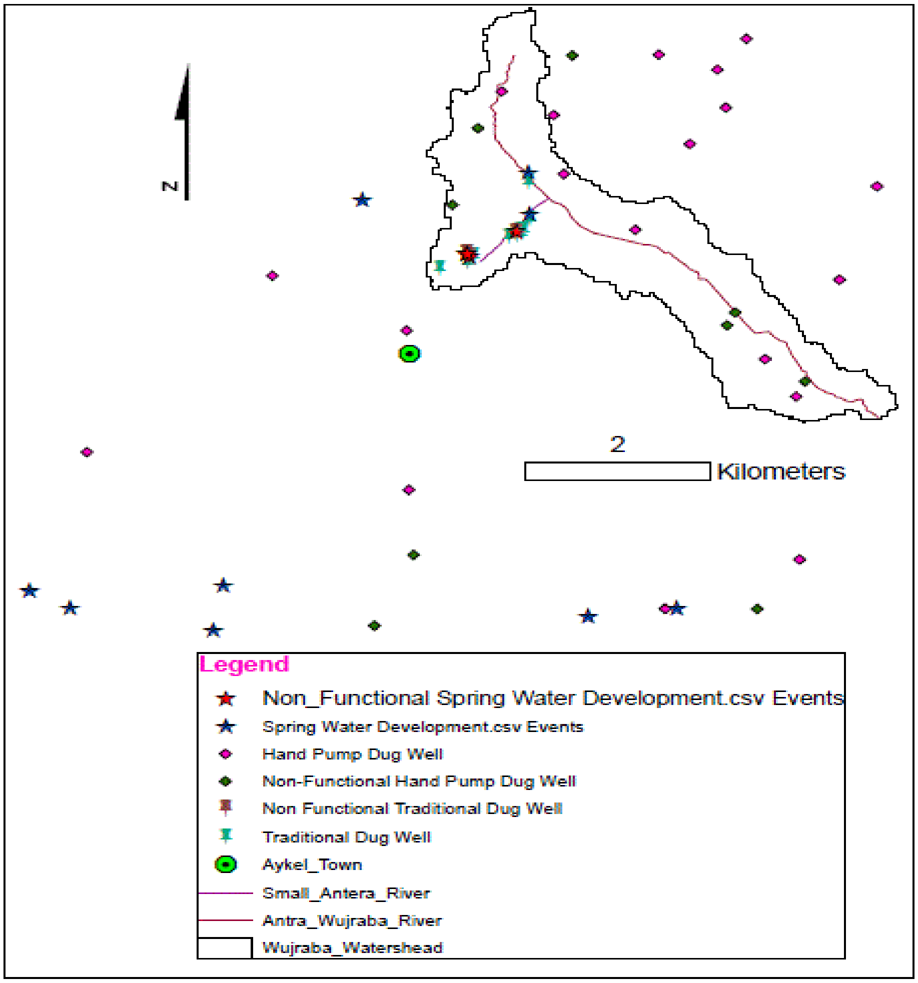


Figure 30: Map of Aykel Province and Wujraba Watershed Water Points

4.3.2. URBAN AND RURAL WATER SUPPLY AND SURVEILLANCE

According to WHO (2012), a number of definitions of water access (coverage) refer to qualifications regarding safety or adequacy of water. Access to safe drinking water measured by the proxy that assesses the use of improved drinking-water sources by households. Based on this, unit quantity of service level is the proportion of the population with access to different levels of drinking-water supply example [no access, basic access, intermediate access and optimal access]. A surrogate for health impacts in relation to quantity of water has taking in to account as well. Therefore, Accessibility is the percentage of the population that has reasonable access to an improved drinking water supply. WHO (2012), the daily per capita consumption of drinking water are: If water service infrastructure is more than 1 km away to users /round-trip travel time more than 30 min / and lower than 5 l /capita /day called No Access. While, if it is within 1 km / round-trip travel time below 30 min /and on average of 20 l /capita /day on average called Basic Access.

Using WHO (2012) guide, Ethiopian Ministry of Water and Energy developed common guideline for all regional and Woreda level used to computing urban and rural water supply accesses and actual coverage.

- ***Accesses coverage -Urban and rural water supply***

A water supply infrastructure in rural area within 1.5km distance is providing 15 liters/capita/day. Accesses coverage is the ratio of sum expected users benefitted by the constructed infrastructure and total population as whole. On the other hand,

- ✓ A dug well is assumed for providing 270 capita / 15 l / day, with in 1.5km distance. No. of constructed wells *270= expected no. wells users= W.
- ✓ A developed spring is assumed for providing =340 capita /15 l /day, with in 1.5 km distance. No. of constructed springs*370= expected no. springs users=S

$$Access\ Coverage = \frac{W+S}{Total\ Number\ of\ Population} * 100\%$$

- ***Actual coverage -Urban and rural water supply***

While, Actual coverage is the ratio of sum expected number of users benefited by the constructed infrastructure versus the sum of actual users by the water supply infrastructures. $Actual\ Coverage = \frac{W+S}{Total\ Number\ Current\ Users} * 100\%$

ARDB, Chilga-report (2014) shown in (appendix-9.a), Aykel town and surrounding Keble’s water supply in terms of quantitative unit by accesses coverage is 63% and the actual coverage is about 47%. Therefore, the actual coverage (47%), which is below 50%, and 53% of the rural water supply users doesn’t have actual coverage of rural water supply. 37% of the population doesn’t have access of rural water supply at all. This is an indicator for uneven distribution of water supply infrastructures, an equitable use of resources and insufficient water supply infrastructure and /or shortage of water resources for design**.**

4.3.3. WUJRABA MICRO-WATERSHED SURVEILLANCE

Common household domestic water sources are from traditional open hand dug wells, developed spring water, unprotected springs hand pump dug wells. Domestic use of water consumption is about 10 litters/day/ $\leq$ 2-5 people / household, an average 20 l / day / $\geq$ 6-7 person/ household, and nearly 4 l/day/capita. So the area is characterized as no-access/intermediate access according to WHO (2012). In general, the price of 20 liters of water is 4-5 Ethiopian birr.

The surveillance Wujraba micro-watershed is more or less similar to the research conducted by Mengesha.A, Abera.K, Mesganaw.F (2002) (table 12). It was held on 11 randomly selected Peasant Associations of 768 households, about 442 households (57.6%) were using protected water sources, and there average frequency of water collection was 2 times per day with the mean per capita water consumption of 6.68 liters /day. While, the duration of waiting time needed to collect water at the water points is 15 to 30 minutes for 65 % of households due to the non-functionality of water points. Similarly, the management of the existing functional infrastructures is not promising. About 77% of the protected springs and 52% of the hand-dug wells are non-functional at least once from the time when their service was commissioned. More or less, 30% of the water supply structures had good management status: had guards, fences, cloth washing stands, and animal water troughs, which is highly recommended and for maximizing community services and for sustainable use of the infrastructure.

Table 12: Characterstisc of water utilization in North Gondar/2002/
(n=442), Where n is number of respondants

Variables	Number	Percent	Mean ± SD
Time for collecting water (minutes)			
15 and less	83	18.8	
16 – 30	287	64.9	
30 and above	72	16.3	20.51 ± **7.89**
Water collection frequency per day			
Once	83.	18.8	
Twice	273	61.8	
3 times and above	86	19.4	2.04 ± **0.69**
Per capita consumption (liters)			
8 and less	357	80.8	
9 –19	75	16.9	
20 and above	10	2.3	6.68 ± **4.36**

Source: *Sustainability of Drinking Water Supply Projects in Rural of North Gondar, Ethiopia (Mengesha.A, Abera.K, and Mesganaw.F: Januray2002)*

4.3.4. AYKEL TOWN WATER SUPPLY SOURCES

Based on the CSA (2007) national census conducted), total inhabitants in Aykle town are about 27,061. The town is located 5km away and adjacent to the study Wujraba micro watershed (figure 31).

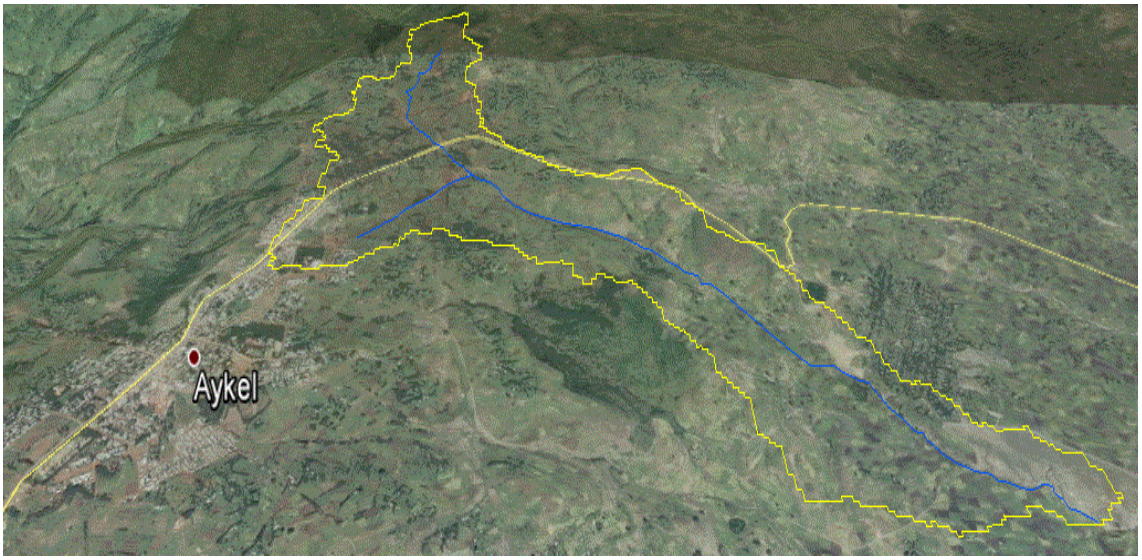


Figure 31: Map of Aykle Town and Wujraba Micro Watershed

Drinking water shortage is the recognized problem in the town for the last decades, outcome of key informant focus group discussion and source of Water district of Chilga Woreda, the problem is going to from worse to worst. The sources of water supply were from both spring and deep dug well. As shown below (figure 32) about a 150 m^3 reservoir found in Aykel town is used for storage of water supply service via distribution pipe network.

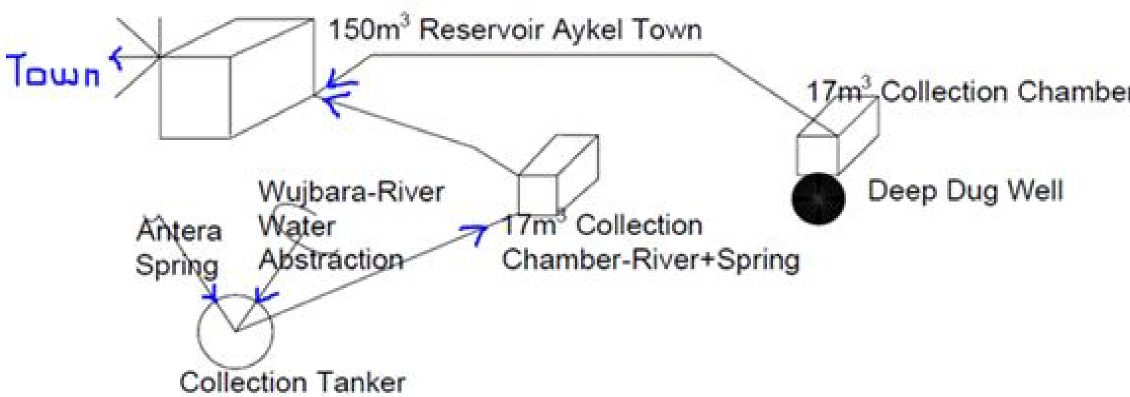


Figure 32: Map of Schematic Sketched of water supply of Aykel Town

Until this research done, the reservoir of Aykel town (150 m^3) has two supply sources (figure 33). From150m^3 reservoir of Aykel town (sources from I & II below), 140 m^3 /day is released to the pipe network for yard connection for an average 1 -1/2 h /day.

I. 17m^3 collection chambers and power house is from deep dug well-located 7 km away from Aykel town and out of Wujraba watershed in the so-called Nara-Awerarda Keble, which covers 56%.

II. While, the rest 44% of the Aykel town community water supply is covered by 17 m^3 collection chamber from:

A. Spring water

B. Wujraba Antera River in the watershed

A. The source from the main Wujraba-Antera-River is connected to collection tanker by pipe, abstracted from a very small dam constructed by soil, and is worked on dry season of each year. The water do not well protected at all and the people use the water near the source for domestic use such as bathing, washing cloth and feces disposal (figure 33).

B. The collection chamber source is partially from the spring. The same spring use for town community waters supply during dry-season via pipe connection, and for watershed residents during rainy season.

Therefore, the quality of water is not provided the minimum quality requirement of improved drinking-water source according to the law of WHO (2012). The nature of its construction and design adequately protects the source from outside contamination, in particular by fecal matter. For this reason, Water borne diseases due are common in the area due to inadequate sanitation. Moreover, Aykel and its province categorized among those towns that high nitrate concentrations are detected in polluted wells refereed by Fitsum Merid with (NEDCO, 1998) on his National Water Quality Monitoring Baseline Report. Generally, both Aykel town and Wujrbra micro-watershed are characterized as a more difficult area to provide basic water and sanitation service.

Figure 33: Water Supplies of Aykel Town and Point Source at Wujraba Watershed *(Blue line is show Small Antera River and main Wujraba Antera River, green line show boundary of the watershed)*

Additionally, in the town many public fountains (wells) were also constructed and used by some people, but for unknown reason almost no public fountains, private traditional dug wells, and spring developments were working. The household consumption per capita is extremely low (below 20 l/capita), there is hygienic problem, and water borne diseases as well. As a result, the town people are enforced to fetch water from open hand dug wells and unprotected springs located in Wujraba watershed. Users commonly and easily use various water-fetching types like Jerican and barrel. On one hand, this was the main recognized conflict among watershed users and urban community.

On the other hand, thus were good sources of income for watershed households by providing and selling water to the people of Aykel town especially during dry season from January to end of May. For few inhabitants, they are lucky enough for having a good yield of well during the dry period, and they get high finical income by selling the water for their neighbors and town peoples (eg.fig.34), a 20 liter container (traditionally called Jerican) water sold 0.26$ / 4 to 5 Ethiopian birr.

Figure 34: Locked Traditional Dug Wells User

(Figure 34 shows locked and well protected private traditional dug wells of Mr. Hgoes Nure Hussenin Wujraba watershed. He earn money 1548$ or 30,000.00 birr (Gross annual income) by selling an average100 Jerican (20-liter container) per day from his own three private traditional dug wells).

According to the sources of ongoing form Aykel Water Biro district, The ongoing project and that expected to be alleviate the current water shortage of Aykel-Town are Urban Water Supply project is 33km away from Aykel town in Dembya Woreda so celled Aiemba. By the project use, five bore hole type wells are constructed, is expected to be functional in the beginning of September 2015.There is also other ongoing project, it is piping system water supply from the so-called Gownage River (Perennial River) and Awega River (Perennial River).

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

Major existing water supply resources identified in watershed are from rivers, protected and unprotected springs, pumped dug well and traditional hand dug-well. Even if the total numbers of all types of water supply infrastructures are more, but nearly 50 % from the total are non-functional, and the rest of 50 % are functional but they cannot satisfied the demand for domestic use.

The main watershed Wujraba Antera River is 209 l/s and 42.4 l/s of estimated peak discharge and measured base flow discharge respectively. This is not recommendable for further small irrigation and water supply structures and small-scale irrigation development. However, residents from the middle of the watershed used small-scale traditional irrigation by diverting the Wujraba Antera-river, but the river do not full-fill the requirement either supplementary or full irrigation.

The past historical data and the current study indicated about hand pump wells and developed springs above 50% are not functional, yield of the existing functional spring source infrastructures are not satisfactory for the demand of the peoples. The potential of the ground water wells are not promising for constructing water supply infrastructure, depleted and high variation of ground water level. This is recognized easily by traditional ground water wells in the watershed.

Awareness of the people to use traditional wells, and finding mitigation measures for the water shortage problem, and using their own indigenous knowledge had been highly appreciated. The numbers of traditional dug wells are working; most of the wells at dry season period have very low yield of recharge or does not give at all. Nevertheless, due to limited support of experts for site selection, and there past experience faced by low potential for ground water recharge of wells, it leads to uncertainty by the community for future use.

Most small-unprotected springs are commonly located at the head of the watershed had weak average measurable discharge of 0.11 l/s during wet season, the protected spring water sources used water supply source for Aykel Town during dry season are 0.27l/s. Therefore, both the protected and unprotected springs have very low discharge below 0.5 l/s.

There is also poor management of existing functional pumped dug wells. Both Aykel–town and the watershed peoples lack adequate and quality water.In general, there is low potable water supply and sanitation coverage in the area. Most public fountains, private traditional dug wells, and spring developments were not working. Frequently water use conflicts recognized were between the Aykel and watershed user increase form past to the present. Both the shortage and conflict of water use is highly recognized during the dry seasons.

In Aykel Province this watershed, even if lots of money invested for water resource planning by government and non-governmental organizations, the entire water infrastructures are not yet functional. The functional water supply infrastructures are not enough for the demand by the community. Still the areas are characterized by very critical water shortage.

The watershed is generally characterized by rugged topography along with intense nature of rainfall, conduct proper watershed management practices for rehabilitation, for decreasing infiltration excess runoff and this used for increasing ground water potential of the watershed benefit of both beneficiaries (upland and lowland).

5.2. RECOMMENDATION

At large scale level of hydrology and hydrological analysis beside micro watershed level, further investigation and detail study with using appropriate models has been recommend. The most determinate factors that significantly affecting the area to be a water stress like: topography, evapotranspiration, orographic lifting, and rain shadows etc. be investigated at larger scale.

Adoptions of alternative ways of water harvesting infrastructures should be tried as pilot projects and future water resources planning should been considered the interaction of the local community, regional government, concerned institutions and stakeholders.

Local and international NGOs and government organizations to use all the available resources efficiently take an action for sustainable water resource planning in the area. The future project should conceive as part of an effort to guarantee, ensuring farmers to full benefit from water resource, and to enhance improve the living standard of community through full participation starting from the planning processes and creating sense of ownership for the infrastructures. Before the implementation of water resource planning, a hydrological analysis and understanding the drainage system of the watershed is prerequisite for sustainable planning of water use infrastructure.

Moreover, water supply projects should not only focus at increasing coverage targets simply looking at the hydrological, financial, and technological possibilities, but also on the sustainability of the systems to help contribute to long-term and comprehensive development objectives (Aschalew, 2009). This would have significant contribution to sustainability of rural water sources in developing countries. John Kwose (2011) and Gleitsmann (2005) suggested that the functionality of water supply systems is dependent upon the degree to which the technology corresponds to the needs of users, their ability and willingness to maintain and protect it over time.

IWRM, community based approach for water supply designs, and watershed rehabilitation especially at the top of the watershed is highly recommended. John Kwose (2011) suggested that community participation and community-based management, accompanying administrative decentralization processes, have become the dominant strategy for reforming inefficient rural water allocation in developing countries. Moreover, community based management, are preferentially used for donor organizations and implementing agencies to improve the management of rural water resources.

Even though the framers indigenous knowledge for using irrigation was highly appreciated, especially at middle and dawn stream of the watershed had potential irrigable land. However, the recognized water shortage problem should give priority for the future planning on improved watershed supply structures than irrigation schemes.

Generally, based on the identified types of available water resources, evaluation there management with refereed to social competence: Proper water management options and alternative water supply sources for sustainable use are recommended.

Therefore, recommended for long-term solution of the watershed problems are:

- To cluster on-site traditional wells having good potential for ground water recharge (high yielding wells) for community water supply system (eg. public fountain).
- To collect run off from catchment/ sub-catchment: to construct community ponds /cattle through for livestock use, to construct farm pond (eg. not-cemented, low cost micro-ponds) are use full during rainy season as supplementary irrigation during dry spells and recharge ground water.
- To use rainwater harvesting technology, more suitable in high rainfall areas of Wujrbra watershed by frequent filling of storage reservoirs, and useful for both domestic and home garden supplementary irrigation as well.
- To education and training (UNESCO, WMO, 1997) of experts and Wujraba watershed residents, for sustainable use the scarce resource, for watershed rehabilitation, and for sustainable water system planning by considering population growth.

REFERENCES

ADF (African Development Fund) (2005).Ethiopian rural water supply and sanitation appraisal report. Infrastructure department north, east and south, Onin.

A Handbook for Integrated Water Resources Management in Basins (INBO, GWP, 2009) ENGLISH (1). Published 2009 by the Global Water Partnership (GWP) and the International Network of Basin Organizations (INBO).

Ahmad Reza Ommani (2011). Water Scarcity and Need for Sustainable Water Use. Journal of American Science 2011; 7(5):98-105]. (ISSN: 1545-1003). *http://www.americanscience.org.*

Aschalew Demeke (2009). Determinants of Household Participation in Water Source Management: Achefer, Amhara Region, Ethiopia.

Awulachew, S. B.; Yilma, A. D.; Loulseged, M.; Loiskandl, W., Ayana, M.; Alamirew, T. (2007). Water Resources and Irrigation Development in Ethiopia. Colombo, SriLanka: International Water Management Institute. 78p. (Working Paper 123).

Bonnie,F., Jacobs, Neil,T., Mulugeta Feseha, Aaron,Pan., John, K., Tab ,R., William ,S., Michael ,W., J., and Juan, L,.(2005).Oligocene terrestrial strata of northwestern Ethiopia: a preliminary report on paleo environments and paleontology.

Central Statistical Agency of Ethiopia (CSA) (2005). Censes Report, Addis Ababa, Eth.

Dawit Abebe (2010). Future climate of Ethiopia from PRECIS Regional Climate Model Experimental Design, Ethiopia.

Degnet Abebaw, Fanaye Tadesse and Tewodaj Mogues (2010). Access to Improved Water Source and Satisfaction with Services Evidence from Rural Ethiopia. Development Strategy and Governance Division, IFPRI Discussion Paper 01044.

Degnet Abebaw, Fanaye Tadesse and Tewodaj Mogues (2011). Access to Improved Water Source and Satisfaction with Services Evidence from Rural Ethiopia. Ethiopia Strategy Support Program II (ESSP II): ESSP II Working Paper 32.

Demeke Demeke (2009). Determinants of household participation in water resource management; Achefer Woreda, Amhara region, Ethiopia. Master's thesis Integrated Agriculture and Rural Development. Cornell University, USA.

Fergusson, B.K., (1996). Estimation of Direct Runoff in the Thornthwaite Water Balance, professional vol, 48, no 3, pp. 263-271.

Ferguson, B. K., (1996). Preventing the Problems of Urban Runoff, Renewable Resources Journal vol. 13, no. 4, pages 14-18. 4Selection of Urban Runoff Model, pp.51.http://www.geog.leeds.ac.uk/projects/nps/reports/npsch4.pdf [25/08/2014].

Empowers Partnership (Editor) (2014): Day 4 –Water Resources Assessment. Introduction Jubeiha: Empowers Partnership. Url [Accessed: 12.09.2010]. Pdf. (Av. online, http//:http://www.sswm.info/content/water-resources-assessment).

Fitsum Merid (2010) National Nile Basin Water Quality Monitoring Baseline Report for Ethiopia. Sanitary Engineer and National Consultant, Nile Basin Initiative Transboundary Environmental Action Project. [Table-1. 2, Page 11].

Garbrecht, J., and Martz, L.W.(1992).Digital Elevation Model Issues In Water Resources modeling.

Griffen, R.C. (2006). Water Resource Economics. The Analysis of Scarcity Policies and Projects.MIT Press, Cambridge, MA.

Heyin Chen, I. (2013). Simulating the hydrological impacts of land cover and climate change under semi-arid environment. University of Cincinnati.

John, K. (2011).Local Participation in Project Planning and Implementation of Boreholes in Ghana *(http://johnkwose.blogspot.co.at/2011/09/local-participation-in-project-planning.html).*

Kay, M. (1986). Float measurement techniques for measuring river discharge.

Lawrence, T., Michelle, G., and John, K.(2002). Chilga Kernet - 1, an acheulean landscape on Ethiopia's western plateau. *(http://www.humanpaleo.org/AmAnth/Chilga%20Kernet.pdf).*

Loiskandl, W., (2006). Hydrogeology and Water Utilization in Ethiopia, Departments für Bautechnik und Naturgefahren Nr. 11 - Nov. 2006. Fiebig, M. (Ed.) (2006)

Mary C. Haley P.E, Suzanne O. White and Edwin W. Watkins P.E, 2014. ArcView GIS Extension for estimating curve number. [available online http:/gis.esri.com/ library/ userconf/proc0/professional/papers/ PAP657/p657.html].

Mengesha Admassu, Abera Kumie, Mesganaw Fantahun (2003). Sustainability of Drinking Water Supply Projects in Rural of North Gondar, Ethiopia. Ethiop.J. Health Dev. 3:221-229.

Meseret Belachew (2012). Assessment of drinking water quality and determinants of household potable water consumption in simada district, Ethiopia.

Mishra.K.S.,Jain.K.M., Bhunya.K.P., and Singh.P.V (2005). Field Applicability of the SCS-CN-Based Mishra–Singh General Model and its Variants. Water Resources Management (2005) 19: 37–62.

Molden, D. (2007). A Comprehensive Assessment of Water Management in Agriculture. Summary Water for food water for life, International Water Management Institutes Standalone Summary 02/14/07.

Moore, I.D., Grayson, R.B., and A.R. (2006). Digital terrain modeling: A review of hydrological, geomorphologic, and biological applications.

North West Sorghum Belt Livelihood Zone (NWS) (2007). Livelihood Profile Amhara Region, Ethiopia, Augusts 2007.(file:///C:/Users/mediamarkt/Downloads/ NWS%20-%20North%20West%20Sorghum%20Belt.pdf).

Nurul Nadrah Aqilah Tukimat, Sobri Harun, Shamsuddin Shahid (2012). Comparison of different methods in estimating potential evapotranspiration at Muda Irrigation Scheme of Malaysia. Journal of Agriculture and Rural Development in the Tropics and Subtropics, Volume 113:77-85.

Patil, J.P., Sarangi. A., Singh A.K., Ahmad .T (2008). Evaluation of modified CN methods for watershed runoff estimation using a GIS-based interface.

Peter .Z., Gilson A .L., Eliana .B., Rondon, L. & Ivairton, M.S (2008) Development of A GIS-Based Information System for watershed Monitoring In Mato Grosso, Central Brazil.

Rosell, S. and Holmer, B., (2007). Rainfall change and its implications for Belg harvest in South Wollo, Ethiopia. Physical Geography, Earth Sciences Centre, Göteborg University, Sweden, Geogr. Ann., 89 A (4): 287–299.

Seleshi Bekele and Dueglas J. M. (2004).Assessment of Small Scale Irrigation and Water Harvesting in Ethiopian Agricultural Development, International Water Management Institute (IWMI).

Seleshi Bekele (2006). Assessment of water resources and recommendation to improve water resources management, Ref. Adaa Pilot Learning Site of the project Improving Productivity and Market Success of Ethiopian Farmers, Oromia, Ethiopia. Final Draft Report, 2006, (IWMI).

Setegn Shimelis, Srinivasan,R. and Dargahi,B. (2008). Hydrological Modeling in the Lake Tana Basin, Ethiopia Using SWAT Model, the Open Hydrology Journal.

Shimelis Gebriye Setegn (2008). Hydrological and Sediment Yield Modeling In Lake Tana Basin, Blue Nile Ethiopia.

SMEC International Pty Ltd (2008) .Hydrological study of the tana-beles sub-basins surface water investigation2008, Project Number: 5089018.

Soulis, K. X. and Valiantzas, J. D. (2012), SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds – the two-CN system approach. Hydrol. Earth Syst. Sci., 16, 1001-1015, 2012.

Stefanie, K. (2014), Water Resources Assessment,(seecon international gmbh) Published on SSWM (http://www.sswm.info/) [Accessed: 04.08.2014*]*.

Tribe, A. 1992. Automated Recognition of Valley Heads from Digital Elevation Models. Earth Surface Processes & Landforms, 16(1):33-49

UNDP (United Nations Development Program) (2008). Millennium development goal report.

Water Resources Assessment (2014). Understanding resources and needs (C1), Global WaterPartnership,(http://www.gwptoolbox.org/index.php?option=com_tool&id= 24, [Posted: 2013-08-05, Accessed 04.08.2014].

Water Resources Assessment Global Water Partnership (2014) -Toolbox for Integrated Water Resources Management -Management Instruments -C1, Understanding resources and needs (available online http://www.gwp.org/en/ToolBox/TOOLS/ Management- Instruments/Water Resources-Assessment/.

Westenbroek, S. M. (2010). SWB-A modified Thornthwaite-Mather Soil-Water-Balance code for estimating ground water recharge. U.S. Geological Survey Techniques and Methods 6-A31, 72.

WMO (World meteorological organization) (2012). Technical material for water resources assessment, technical report series number 2. 14th session from 6-14 November 2012, Geneva, Switzerland.

APPENDICES

Appendix1: Questioner for Water Users

Name of the Enumerator: ____
Date of the Interview: ____

Part I: Biography Data and Site Description:

1. Location:
Région ___________________________
Zone ___________________________
Woreda ____________________________
Name of Kebeleadmin.____________________Village/Gote __________________

2. Household head characteristics
Farmer Number _____________
Farmer's Name ____
Sex of the household head ------- (male =1, female =2)
Age of the household head-------Years
Marital status 1. Married 2. Single 3. Widowed 4. Abandoned
Can you read and write? ------ 1. Yes: 2. No
Completed formal education grade level ------
Total family size (including the household head) male ___ Female ____ and Total _
Children less than 15 years of age male_____, Female___ , and Total _____
Men 15-60 years of age________
Women 15-60 years of age______
Persons over 60 years of age male ____ and Female____ Total _______

3. Residential and water abstraction/use location referred to Wujraba Watershed?
A. At head-end of the watershed B. Middle of the watershed
C.Tail-end of the watershed D. Out of the watershed.

4. Resources ownership, Type of houses:
A.Corrugated roof: B.Thatched roof: C.Both

5. What is your source of income and how it has been changed for the last ten year?
A. On farm activities
Crops produced using irrigation ___________
Crops produced using rain-fed ____________
Livestock _______________, If yes, how many livestock you have_____________?
B. Off-farm activities ____

6. Land holding size in 'timed' in 2005 E.C.
A. Own Irrigable _______ B. Share cropped-in irrigable ______
C. Own non-irrigable _______ D. Share cropped-in non-irrigable _________
E. Grazing land ________

7. Your level of living condition (household income level)? (Note: Wealth>=2-3ha land, 2 oxen, 1 caw, 1 donkey /Medium=1-1.5ha, 2 oxen,1caw/poor=0.25ha-0.5ha with insufficient tillage equipments /Very poor<=0.25ha, dependent peoples, having not tillage materials. (Source: AykelWoreda Agriculture and Rural Development Office)
A. Wealth B. Medium C.Poor D.Very Poor

Part-II Irrigation practices and development

1. Are you using irrigation agriculture or not? Yes/No.
If yes, I. For how long have you practiced irrigation agriculture: ____________?
II .How many hectares did you cultivate per year___________________?
III. How many cropping season do you use irrigation in a year ____________?

2.Do you irrigate your farmland entirely and the whole crop production season? Yes / NoIf 'no' for the above question, what is the reason?
A.Shortage of water for irrigation B. lack of working capital and family labor
C. lack of oxen D. shortage of seed and shortage of hired labor
E. others (specify) ____
3. What kind of irrigation method currently you used_______________________?
Does the water developed for irrigation is also used for other purpose?
A.Used for irrigation purpose only: B.Used for animals drinking:
C.Used for human drinking: D.Fishing is take place:
E.Other (Specify)____
4. What is the source of irrigation water for your scheme and what kind of water abstraction &supply method do you used for?
A. River(s):____
B. Well(s)____
C. Individual water harvesting____
D. Common water harvesting____
E. Small holders' traditional irrigation schemes_______________________________
F. Other Modern irrigation schemes____
G. Other (specify)____
5. In relation to the demand availability of water, is it __________?
A. B. Sufficient C. Periodically scarce D. Other
6. What are the major problems regarding accessibility, availability and reliability of water?
7. Do you plan to produce using other alternatives irrigation means in addition to the existing scheme? A. Yes B. No
8. What major crops do you grow using irrigation?
A. Vegetables: B. Cereal crops: C. pulses D. Oil crops E. Perennials
F.Others____
9. How frequent do you irrigate/week________________?
10. Do you irrigate on holidays and night times? Yes/NO.If no, why________________
11. Do you face any performance challenge/damage on irrigation system?
A. Yes: B. NoIf yes, what kind of challenge and what are the reasons?

- A. No responsible body for the scheme:
- B. Unfair distribution of water:
- C.Shortage of water:
- D.Other (specify)____

12.Do you have a water use schedule for equal distribution of water among head-end, middle and tail-end users? Yes/No. Who is in charge of it?
A. Keble administration: B. Irrigation users cooperative
C. Traditional water users association D. YewhaAbat E. other (specify
13. Do you participate in management of existing irrigation the scheme? Yes/No
If yes, what is your role?____

Part III, Domestic Water Supply (Drinking Water supply and Livestock Water Supply):

1. What are the main sources of drinking water for your family?
A River: B: Protected springs: C: Non-protected springs: D. hand-dung: E. Pond: F. Rain water:
G. Deep well: H Lake: I. Piped water: J. Other (specify)______________________
2. In relation to the demand availability of water, is it
A. AboundentB.Sufficient C. Periodically scarce D. OtherIf others,
What other alternative source do you use to fulfill your domestic water shortage?____
3. Does the existing water supply scheme used for other purpose? Yes/No
If yes, why for?

A.:Used for livestock drinking B. Used for irrigation purpose:
C. Used for domestic use only: D. Fishing is take place:
E. Other (Specify)
4. What are the major problems regarding accessibility, reliability and availability of water?
❖ If there is accessibility problem
Who is responsible within the family for fetching water for domestic use?
____
How long do you travel to fetch water from the major sources? (Round trip in meter)____
❖ If there is reliability problem
At what month and season of the critical domestic water shortage occurred?
____
❖ If there is availability problem,
Did you face any problem related to the quality of water? Yes/No.
Do you have a water use schedule for equal distribution of water among head-end, middle and tail-end users? Yes/No. Who is in charge of it?
A. Keble administration:
B. Irrigation users cooperative
C. Traditional water users association
D. YewhaAbat
E. other (specify)____
5. What kind of support you need and recommended to solve domestic water shortage?
Part IV, Water Use conflict and Conflict Resolutions:
1. Is there downstream and upstream water use conflicts in the scheme? 1. Yes: 2. No
If yes, what are the main reasons for the conflict?
A. The existence of another upstream diversion on the source of the scheme water:
B. Seasonal water shortage:
C. Competition among different uses (livestock, water supply, irrigation...)
D. Plantation of different types of crop, which require different watering frequency:
F. Other (specify)____
2.What are the most common causes for water use conflicts?
A.Due to lack of willingness of some farmers to construct irrigation canals and furrows across their own farmlands.B. Due to conflicts of interest to use either for domestic use and irrigation use. C. Among irrigated landowner and land less peoples due to common pool resources of water. D. Due to damaging water supply canal and water supply structures.
E.Others____
3. Is there any water use conflict between among irrigation users? Yes/No.
If yes, how the problem is resolved?
____
4.Are there any water use conflicts between among irrigation users and non-irrigation users?
If yes, why and how the problem is resolved?______________________________
5. Is there any water use conflicts between farmers having accessible land for irrigation and vice versa? If yes, why and how the problem is resolved?
____
6. At what time and season critical water use conflict occurred?
____
7. Is there any domestic water use conflict?If yes, why& how it is the traditional way of conflict resolution?...
8. Who is the responsible body for solving water use conflicts?
A. Keble administration: B. Irrigation users cooperative:
C. Traditional water users association: D. YewhaAbat:E. Other (specify)

Appendix 2: Aykle (Chilga) Woreda mean monthly rainfall data

Aykel(Chilga) Rainfall[mm]

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Year Total
1980	0.0	0.0	13.9	327.9	432.7	565.4	559.8	538.8	191.1	313.0	0.0	0.0	2942.6
1981	0.0	0.0	0.0	53.7	185.8	242.1	521.6	473.7	184.4	119.0	0.3	0.4	1781.0
1982	0.0	0.0	121.2	64.1	76.9	146.1	240.2	209.1	132.3	84.9	0.0	0.0	1074.8
1985	0.0	0.0	36.0	31.7	219.7	116.6	272.3	257.2	140.2	199.9	51.9	0.0	1325.5
1986	0.0	0.0	0.1	0.0	0.0	215.4	402.9	339.3	276.7	105.2	0.7	0.0	1340.3
1987				27.4		168.7	210.4	207.8	91.9	194.9	4.3		905.4
1988	0.0	11.5	0.5	2.9	153.7	153.1	355.7	243.5	138.6	177.3	29.0	0.0	1265.8
1989	0.0	0.0	16.9	87.8	135.2	154.8	320.2	246.0	135.3	82.2	10.4	0.0	1188.8
1990	3.9	0.0	1.3	32.3	52.2	153.3	257.3	207.7	237.2	59.4	0.0	0.0	1004.6
1991	0.0	0.0					195.8	250.3	149.8	139.1	2.9	2.8	740.7
1992	0.0	0.0	0.0	49.5	0.0							0.0	49.5
1993	0.0	1.9	5.1	143.3	112.5	109.3	320.1	232.5	292.9	117.9	4.2		1339.7
1994				12.1	50.3	281.0	214.4	272.5	215.5	42.4	3.7	14.1	1106.0
1995	0.0	0.0	57.9	33.8	111.5	155.9	300.6	319.9	121.6	41.0	6.8	0.2	1149.2
1996	0.0	6.9	37.8	62.4	72.8	269.3	204.8	196.1	166.6	30.8	28.3	0.0	1075.8
1997	0.0	0.5	6.1	95.4	156.6	203.4	208.1	194.7	134.2	227.0	75.6	0.0	1301.6
1998	0.0	0.0	17.4	2.7	92.7	235.8	311.0	326.4	117.4	124.6	1.6	0.0	1229.6
1999	0.0	0.0	0.0	27.7	120.8	157.4	391.0	273.8	189.1	154.3	0.0	4.4	1318.5
2000	0.0	0.0	4.2	81.5	100.7	137.3	268.8	244.0	202.0	202.5	45.9	0.0	1286.9
2001	0.0	3.6	2.0	29.5	144.8	267.3	307.6	290.2	104.3	120.8	0.0	0.0	1270.1
2002	0.0	0.0	0.0	1.0	100.7	185.0	238.4	323.0	174.6	69.7	0.0	0.0	1092.4
2003	0.0	6.9	0.3	2.5	34.7	143.1	225.3	223.3	221.0	54.8	0.0	0.0	911.9
2004	0.0	0.0	11.0	50.9	2.5	185.6	320.7	207.5	138.7	90.8	23.2	0.0	1030.9
2005			36.8	18.6	40.6	234.8	261.5	193.3	152.3	27.3	5.6	0.0	970.8
2006	2.6	0.0	2.3	21.2	219.5	115.9	364.6	284.0	231.2	155.7	0.0	0.0	1397.0
2007	1.5	0.0	5.5	77.9	184.5	277.9	232.9	281.3	155.9	55.8	25.3	0.0	1298.5
2008	21.8	0.0	0.0	82.7	136.6	206.8	308.1	274.3	142.5	23.9	33.8	0.0	1230.5
2009	0.0	5.7	35.8	58.5	0.0	250.0	282.4	325.6	0.0	45.0	7.7	58.9	1069.6
2010	9.5	0.0	12.1	26.7	87.2	278.6	279.5	217.1	78.7	10.3	0.0	9.7	1009.4
2011		0.0	0.5	10.1	154.2	122.5	308.6	312.9	135.9	61.7	21.7		1128.1
Mean	1.5	1.4	15.7	52.3	113.6	204.7	299.5	274.7	160.4	108.0	13.2	3.4	1248.2
S.Dev	4.605677	2.94877	26.23406	63.21508	89.55352	89.66011	86.35988	78.68732	60.11598	72.41815	19.08641	11.57944	
CV	3.047												

Appendix 3: Rainfall versus effective rainfall, Annual cycles of derived variables CROPWAT8.0

Annual Cycles of Derived Variables

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	5	4	18	32	75	115	156	153	94	51	23	9
Effective Rain Ratio [%]	99	99	97	95	86	76	50	55	81	91	96	99
Rainy Days	1	1	3	4	11	17	26	25	14	8	3	1
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	1	0	0	0	0

Appendix 4: Soil testing analysis result from Gondar testing Laboratory

Gondar Soil Testing Laboratory Analytical Result Sheet
Type: Soil
Supplier: Eneyew Wondifraw
Method: Gravimetric method

Cod No	lab No	Wt of cor & field sam.	wt of cor & O.dry sam.	Wt of cor in gm	Wt of oven dry s.in gm	vol. of cor in cm3	B.D=M/V gm/cm3	Remark
1	1244 /14	277.25	225.835	113.237	112.598	98.17	1.14696954	Bottom of the Watershed ,Amare Below Plot
2	1245 /14	260.432	219.25	105.992	113.258	98.17	1.15369257	Middle of the Watershed ,Opposite to the FTC
3	1246 /14	266.533	235.91	108.566	127.344	98.17	1.29717836	At head of the Watershed near to the bridge
4	1247 /14	246.494	209.487	107.377	102.11	98.17	1.04013446	Around Nursery Site
5	1248 /14	272.121	234.732	108.903	125.829	98.17	1.28174595	Around Nursery Site

Method: Texture hydrometer method

Code No	Lab. No	Texture by hydrometer method %OF SAND	%OF CLAY	%OF SILT	CLASS	O.M Walkely & Black)	Remark
Tehay & Zemene	1379 /14	34	30	36	Caly loam	2.958384	Top of WS
Adissu &Bilal	1380 /14	40	26	34	Loam	1.479192	Middle of WS
Amare & Mulat	1381 /14	12	54	34	Clay	1.411956	Bottom of WS

Appendix 5: Selected Curve Number values land-use lookup table for Wujraba-watershed

Curve Numbers							
LUcode	Description	Assumed imperviousness	Soil#1	Soil #2	Soil#3	Soil #4	Soil #5
1	Low density residential	30	83.4	80	85.6	74.6	81.7
2	Bare exposed rock /sand /clay (assume similar to dirt road)	Not applicable	88.1	82	90.5	71.1	85.1
3	Shrub land (assumed same as parkland)	0	74.8	69	79.3	59	71.9
4	Pasture, Grass Land, Continuous forage for Grazing	Good	99	61	74	80	

(**Source:** Annotated example of the land-use lookup table (westenbroek et al. 2010))

Appendix 6: Land use (Area), CN, S and Soil type

							Runoff compution using CN-Method	
Land Use	Area(Ha)	CN	S	Q(Run-off)	Soil Type		Land Use Type	Area(Ha)
Agricultu	480	80	2.5		Top	Clay Loam	Agriculture	480
Forest	50	69	4.49275		Middel	Loam	Forest	50
Grzing la	180	61	6.39344		Bottom	Clay	Grzing land	180
Resident	100	80	2.5				Residential	100
Others	30	82	2.19512				Others	30
	840							840

Appendix 7: Summary of Rainfall runoff relationship using SCS method

Agricultu	480Ha	CN	S -inch	Month	P(Rain- n	P(Ra-inch	Q(Runoff	Q-Runoff	Rmm*Area ha		Total-mn	T-mm*A-	QT-inch	QT-mm
	480	80	2.5	Jan	1.5	0.05906	-0.08756	-2.22391	-1067.48		0	0		
	480	80	2.5	Feb	1.4	0.05512	-0.08805	-2.23652	-1073.53		0	0		
	480	80	2.5	March	15.7	0.61811	-0.01708	-0.43385	-208.247		0	0		
	480	80	2.5	April	52.3	2.05906	0.16457	4.17997	2006.39		4.17997	2006.39		
	480	80	2.5	May	113.6	4.47244	0.4688	11.9075	5715.59		11.9075	5715.59		
	480	80	2.5	June	204.7	8.05906	0.92093	23.3916	11228		23.3916	11228		
	480	80	2.5	July	299.5	11.7913	1.39142	35.3422	16964.2		35.3422	16964.2		
	480	80	2.5	Aug	274.7	10.815	1.26834	32.2158	15463.6		32.2159	15463.6		
	480	80	2.5	Sept	160.4	6.31496	0.70107	17.8071	8547.42		17.8071	8547.42		
	480	80	2.5	Oct	108	4.25197	0.44101	11.2015	5376.74		11.2016	5376.74		
	480	80	2.5	Nov	13.2	0.51969	-0.02949	-0.749	-359.52		0	0		
	480	80	2.5	Dec	3.4	0.13386	-0.07813	-1.98439	-952.509		0	0	5.35613	136.046
Forest 50	50	69	4.49275	Jan	1.5	0.05906	-0.09086	-2.30778	-115.389		0	0		
	50	69	4.49275	Feb	1.4	0.05512	-0.09113	-2.31479	-115.74		0	0		
	50	69	4.49275	March	15.7	0.61811	-0.05164	-1.3117	-65.5849		0	0		
	50	69	4.49275	April	52.3	2.05906	0.04944	1.25567	62.7834		1.25567	62.7835		
	50	69	4.49275	May	113.6	4.47244	0.21873	5.55566	277.783		5.55566	277.783		
	50	69	4.49275	June	204.7	8.05906	0.47032	11.946	597.301		11.946	597.301		
	50	69	4.49275	July	299.5	11.7913	0.73212	18.5959	929.796		18.5959	929.796		
	50	69	4.49275	Aug	274.7	10.815	0.66363	16.8563	842.814		16.8563	842.814		
	50	69	4.49275	Sept	160.4	6.31496	0.34797	8.83852	441.926		8.83852	441.926		
	50	69	4.49275	Oct	108	4.25197	0.20326	5.16284	258.142		5.16284	258.142		
	50	69	4.49275	Nov	13.2	0.51969	-0.05855	-1.48706	-74.3532		0	0		
	50	69	4.49275	Dec	3.4	0.13386	-0.08561	-2.1745	-108.725		0	0	2.68547	68.2109
Grzing la	180	61	6.39344	Jan	1.5	0.05906	-0.09209	-2.33906	-421.031		0	0		
	180	61	6.39344	Feb	1.4	0.05512	-0.09228	-2.34399	-421.918		0	0		
	180	61	6.39344	March	15.7	0.61811	-0.06453	-1.6391	-295.038		0	0		
	180	61	6.39344	April	52.3	2.05906	0.0065	0.16502	29.7036		0.16502	29.7036		
	180	61	6.39344	May	113.6	4.47244	0.12546	3.18668	573.602		3.18668	573.602		
	180	61	6.39344	June	204.7	8.05906	0.30225	7.67726	1381.91		7.67726	1381.91		
	180	61	6.39344	July	299.5	11.7913	0.48623	12.3502	2223.04		12.3502	2223.04		
	180	61	6.39344	Aug	274.7	10.815	0.4381	11.1278	2003		11.1278	2003		
	180	61	6.39344	Sept	160.4	6.31496	0.21628	5.49359	988.845		5.49359	988.845		
	180	61	6.39344	Oct	108	4.25197	0.11459	2.91064	523.915		2.91064	523.914		
	180	61	6.39344	Nov	13.2	0.51969	-0.06938	-1.76233	-317.22		0	0		
	180	61	6.39344	Dec	3.4	0.13386	-0.0884	-2.2454	-404.173		0	0	1.68942	42.9112
Resident	100	80	2.5	Jan	1.5	0.05906	-0.08756	-2.22391	-222.391		0	0		
	100	80	2.5	Feb	1.4	0.05512	-0.08805	-2.23652	-223.652		0	0		
	100	80	2.5	Mar	15.7	0.61811	-0.01708	-0.43385	-43.3848		0	0		
	100	80	2.5	Apr	52.3	2.05906	0.16457	4.17997	417.997		4.17997	417.997		
	100	80	2.5	May	113.6	4.47244	0.4688	11.9075	1190.75		11.9075	1190.75		
	100	80	2.5	Jun	204.7	8.05906	0.92093	23.3916	2339.16		23.3916	2339.16		
	100	80	2.5	Jul	299.5	11.7913	1.39142	35.3422	3534.22		35.3422	3534.22		
	100	80	2.5	Aug	274.7	10.815	1.26834	32.2158	3221.58		32.2159	3221.59		
	100	80	2.5	Sep	160.4	6.31496	0.70107	17.8071	1780.71		17.8071	1780.71		
	100	80	2.5	Oct	108	4.25197	0.44101	11.2015	1120.15		11.2016	1120.16		
	100	80	2.5	Nov	13.2	0.51969	-0.02949	-0.749	-74.9		0	0		
	100	80	2.5	Dec	3.4	0.13386	-0.07813	-1.98439	-198.439		0	0	5.35613	136.046
Others 30	30	82	2.19512	Jan	1.5	0.05906	-0.08652	-2.19765	-65.9294		0	0		
	30	82	2.19512	Feb	1.4	0.05512	-0.08709	-2.212	-66.3601		0	0		
	30	82	2.19512	Mar	15.7	0.61811	-0.00626	-0.15897	-4.76899		0	0		
	30	82	2.19512	Apr	52.3	2.05906	0.20062	5.09566	152.87		5.09566	152.87		
	30	82	2.19512	May	113.6	4.47244	0.5471	13.8964	416.893		13.8964	416.893		
	30	82	2.19512	Jun	204.7	8.05906	1.06203	26.9756	809.267		26.9756	809.267		
	30	82	2.19512	Jul	299.5	11.7913	1.59787	40.5859	1217.58		40.5859	1217.58		
	30	82	2.19512	Aug	274.7	10.815	1.45769	37.0254	1110.76		37.0254	1110.76		
	30	82	2.19512	Sep	160.4	6.31496	0.81163	20.6155	618.464		20.6155	618.464		
	30	82	2.19512	Oct	108	4.25197	0.51545	13.0925	392.774		13.0925	392.774		
	30	82	2.19512	Nov	13.2	0.51969	-0.02039	-0.51789	-15.5367		0	0		
	30	82	2.19512	Dec	3.4	0.13386	-0.07578	-1.92487	-57.746		0	0	6.1924	157.287
										Total	540.5	94759.7		

Appendix 8: Summery of spring water points

Springs water discharge measurement(August 2013)

Point	X	y	Elevation(meter)
Spring1	291073	1389726	2171
Spring2	291062	1390297	2172
River1	291073	1389726	2171
River2	291072	1389668	2171

Appendix 9-a: Water Coverage Sources and Types for Aykel town and The Surrounding kebels

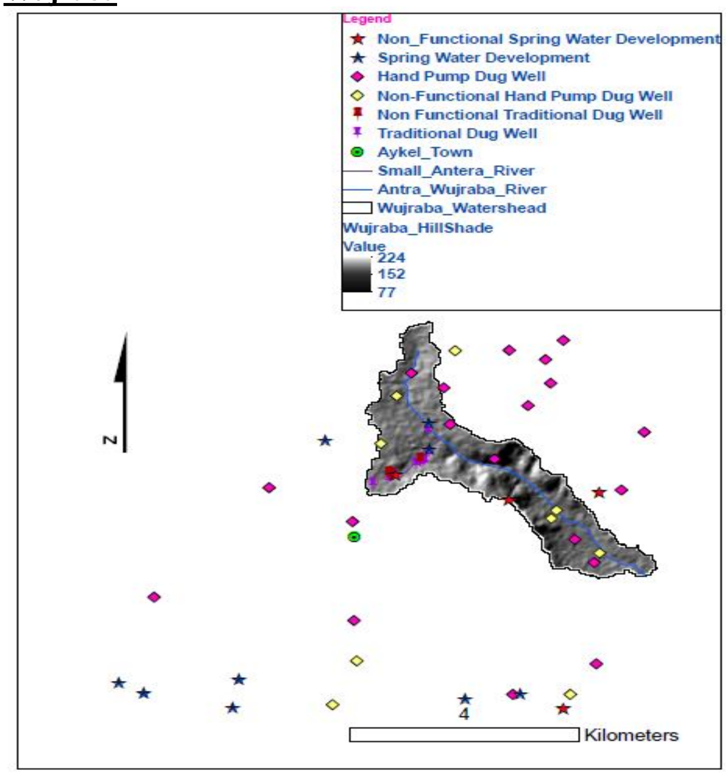
No.	Keble	Sub. Keble	Water Infrastructures		Coordinate point			Numbers of Users			Remark
			HandPump Dug Well	Developed Spring	X	Y	Z	Male	Female	Sum. T	
1	Anegwuaba	Kolabage	1		0293213	1391174	2175	300	440	740	
2		TacheWanyge No.1	1		0293436	1392115	2154	150	195	345	
3		Felsha Meske No.1	1		0291538	1391885	2192	150	102	252	Non-Fun.
4		Alem Kura	1		0292485	1391896	2198	300	198	698	
5		Sehembeko Gedel	1		0291448	1390269	2141	100	104	204	
6		Derese Meda	1		0292230	1389504	2140	100	120	220	
7		Balarege	1		0292816	1390680	2125	200	210	410	
8		Tach .Wanyge No.2	1								Ongoing p.
9		Daba. Matebya	1		0291339	1391074	2184	160	190	350	
10		Buladge School								270	
11		Felsha Meske No.1								300	Temp.R.
12		Seli Sefer		1						360	
13		Waneza School	1		0293120	1391689	2135	200	235	435	
14	N-Awudarda	Ande Ayetetashe	1		0293409	138314	1919	115	121	235	
15		Tache Nara	1		0294010	1385000	1919	200	650	365	
16		Baskura	1							250	
17		Megergeriya	1							260	
18		Tabot Mewureja	1		0289390	1384100	2148	400	516	916	
19		Chelirege	1	1	0492530	1384987	1965	140	103	243	
20		Kertuge	1		0291705	1384229	1985	45	80	125	
21		Banbote No-1	1		0292552	1384331	1972	394	598	988	
22	N-Awudarda	Banbote No-2		1	0292665	1384339	1958	394	594	988	
23		Wujraba No-1	1		0293222	1388200	1980	232	200	432	
24		Wujraba No-2	1		0293637	1387740	1949	160	164	324	
25		Gemuzere	1		0294852	1390100	1973	125	100	225	
26		Naserage		1	0294056	1388764	1973	50	66	116	
27		Sabuse	1	1	0294449	1388825	1945	190	103	293	
28		Chongerge		1	0292467	1388623	1972	139	120	259	
29		Swuena	1		0293972	1387227	1926			300	
30		Kosege								250	
31		Enekwuraba								200	
32		Seklage	1	1	029207	1388798	2013	130	130	260	Tempory.R
33		Itaba	1							270	
34		Mahel Nara		1						230	
35		Megergiya		1	0293430	1384028	1917	144	200	344	Non-fun
35		Baeriya Mesk	1		0293555	1384327	1926	193	153	344	Non-Fun
36	Ey. Seraba	Gwunage	1		0290772	1391395	2204	100	124	224	
37		Mahalege		1	0287629	1384050	2776	1500	1942	3442	Serba Two
38		Medre-Genet		1	0285636	1384582	2118	300	300	600	
39		Defera		1	0287743	138464	2202	200	224	424	
40		Medhanilyaloum		1	0286070	1384355	2131	100	120	220	
41		Geneta	1		0289765	1385953	2149	500	585	1085	
42		Adisge	1					145	148	293	
43		Alekeche Wonze	1		0289816	1385066	2148	220	180	400	Not Finish
44	Teb.Serako	Teber	1		0288277	1388878	7097	400	424	824	
45		Abezu	1		0289738	1388131	2252	150	169	319	
46		Yefaku	1					145	148	293	
47		Dokuma Bet		1	0289253	1389913	2046	190	160	350	
48		Sengota	1		0286263	1386470	2011			300	
49		Shumaya	1		0290513	1390893	2173	150	173	323	Non-Fun
50		Taneba	1		0290238	1389845	2214	170	188	388	Non-Fun

(**Source**: District Water Office (2014)

Appendix 9-b: Traditional Hand Dug wells Point data of Wujrbra Micro Watershed/2014/

Functinal Traditional Hand Dug wells				
Point	x	y	z(m)	Kbele
1	290408	1389140	2118	
2	291061	1390156	2171	
3	290093	1388969	2243	02 Aykel
4	290391	1389073	2221	
5	290408	1389140	2118	
6	290414	1389149	2216	A1
7	290385	1389180	2223	
8	290385	1389180	2223	
9	290382	1389204	2221	
10	290460	1389154	2118	Teber ser
11	290849	1389417	2185	
12	290929	1389480	2185	
13	290929	1389480	2185	Hagosse I
14	290969	1389509	2182	
15	290934	1389434	2186	Boba Nur
16	291004	1389502	2182	Kese Gob
17	290983	1389466	2182	
18	291079	1389660	2170	
Non functinal Traditional Dug Wells				
1	290414	1389149	2216	
2	290385	1389180	2223	
3	290385	1389180	2223	
4	290929	1389480	2185	

Appendix 10: Map of waters supply map of Aykel providence and hill shade effect of Wujraba



Appendix 11: Pictures Taken during surveying at Different Parts of the Watershed to Show the status of the water Supply infrastructures

a b c



d e f



g h i



jk l