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ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

SCHOOL OF EARTH SCIENCES

HYDRO GEOLOGY STREAM

GROUND WATER QUALITY AND POTENTIAL ASSESSMENT OF WALGA CATCHMENT, IN CASE OF OROMIA REGIONAL STATE, SOUTH WEST SHOA ZONE, ETHIOPIA

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A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the requirement for the Degree of Masters Science in Hydro geology Stream

June,2021

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By

Leta Diro

Advisor

Tilahun Azegegn (phd)

June , 2021

Addis Ababa University

School of Graduate Studies

This is to certify that thesis prepared by Leta Diro, entitled: - Groundwater Quality and potential assessment of walga catchment, in case of Oromia regional state, south west shoa zone, Ethiopia and submitted in partial fulfillment of the requirements of the degree of Masters of Science in Hydrogeology conforms with the regulations of the University and meets the accepted standards with respect to the originality and quality.

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I declare and confirm with my signature below, that this thesis is my own work. I have followed all ethical and technical principles of research preparation, data collection, data analysis, data interpretation and compilation of this thesis. Any scholarly article that is included in the thesis has been acknowledged

Leta Diro Signature: __________

June, 2021

ACKNOWLEDGEMENTS

First and foremost, I want to thank the Almighty GOD for his love and support for his boy, as well as for being with me throughout my journey. I would like to express my thankfulness to Dr.Tilahun Azagegn, my Principal Advisor, for his unwavering support, motivation, and guidance during my studies. His insightful feedback and suggestions have greatly aided me in completing my work. I would like to express my thankfulness to Professor Tenalem Ayenew, Dr. Dessie Nedaw, and Dr. Seifu Kebede, who assisted me in learning about hydrogeology. I would like to express my thankfulness to Dgmawi Shiferaw, a chemist at the Hydrogeology Laboratory, for lending me his field instruments (EC meter) and providing purified water for my field work. My job would not have been done if it hadn't been for his help. I would like to express my gratitude to Bule Hora University for assisting and sponsoring me in pursuing my master's degree. While I express my heartfelt thankfulness to Mr Biniam Yosef (ECDSWC) for his generosity in providing me with required data, Tekelegn Wakjira (SWSIDA) for assisting me in different issues, and Miresa Aseffa for assisting me with water sample collection. The staff of the Ameya woreda water resource office, as well as friends and others, who supported me in any way in the accomplishment of this research project, will never be forgotten. I am thankful to Hard Rock Drilling and Engineering P.L.C., the South West Shoa Zone Water Resource Production and Energy Office, the National Meteorological Agency, Ethiopian Building Design and Supervision Works Company, and other private companies and individuals for their invaluable assistance in providing me with useful information. I don't know how to express my thankfulness to my family, especially my wife Barite Gudina and my mother Turu Mammo for their prayers, motivation, and support, which gave me the strength to complete this research study.

ABSTRACT

The core objective of this research is to assess groundwater quality and potential in the upper Omo-Ghibe basin of the Walga catchment using hydro chemistry, recharge estimation, and aquifer characterization using Aquifer test. Rainfall, wind speed, temperature, relative humidity, and sunshine hours were recorded from meteorological stations in the catchment and the surrounding area. In the Walga catchment, water balance, CMB and WTF was used to calculate long-term seasonal/annual average spatial and temporal groundwater recharge, real evapotranspiration, and surface runoff as a function of land-cover, soil type, topography, and hydro-meteorological factors. Surface runoff accounts for 38.75 percent of total annual precipitation, evapotranspiration accounts for 54.22 percent of total annual rainfall, and the Walga catchment's groundwater is recharged with 120mm/yr of rainfall. The catchment's mean annual recharge was found to be 7.5 percent of precipitation using the model, while surface runoff was 38.25 percent of annual precipitation. The hydraulic properties of the aquifer were calculated from the pumping test by using computer software called AQUIFER TEST to match mathematical models (type curves) to response data (water table changes). Transmissivity ranges from 3.5 x10-4 m2/day to 290 m2/day, with an average of 50.94m^2/day. Yield or discharge of bore holes values vary from 0.15 l/sec to 61 l/sec, while yield or discharge of bore holes values range from 0.15 l/sec to 61 l/sec. The hydraulic conductivity fluctuates from 0 to 16.04 m/se, with a mean of 1.2 m/se. The average yield from 72 boreholes is 430 liters per second (119.4 m3/hr), or 37152000 liters per day. Because of the impact of impermeable soils, morphology of the land, and land use land cover of the city, the study area has the lowest groundwater recharge compared to surface runoff and real evapotranspiration. To account for varying geology, the highest scale values were given to fractured mokonnin basalt and lower jimma basalt, while the lowest scale values were given to wochecha trachyte and wonchi dendi pyroclastic fall contribution in assessing groundwater potential. With the main north east to south west flow directions. In general, the area has been evaluated using safe standards for all hydro geochemical and hydrogeological parameters

Key Words: Walga catchment; Hydrogeochemical; assessing Groundwater quality and potential.

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ASL Above Sea Level

ATA Agricultural Transformation Agency

AHP Analytical Hierarchy Process

DEM Digital Elevation Model

EMPA extensive moderate productive aquifer

EHPA extensive higher productive aquifer

ELPPA extensive lower productive porous aquifer

ECDSWC Ethiopian Construction Design and Supervision Works Corporation

GPR Ground Penetrating Radar

GWR Groundwater Recharge

HDW Hand Dug Well

LULC Land use Land cover

MCDA Multi criteria decision analysis

MWIE Ministry of Water Irrigation and Energy

OLI/TIRS Operational Land Imager and Thermal Infrared Sensor

SMBM Soil Moisture Balance Method

SNNP Southern Nation, Nationalities and Peoples Representative

SRTM Shuttle Radar Topographic Mission

SWSZWREO South west shoa zone water resource and energy office

WetSpass Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State

WTWSSE Woliso Town Water Supply and Sewerage Enterprise

WTF water table fluctuation

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CHAPTER ONE INTRODUCTION

1.0 Background

Water demand is increasingly growing across the world through population growth, widespread industrialization, and agricultural practices. Water is critical to a country's economic development, particularly in a country like Ethiopia, where the economy is primarily based on agriculture. Groundwater plays an essential role in meeting the ever-increasing demand for water. Groundwater makes up a sizable portion of the natural water supply system. Water is a precious commodity. It has also served as a means of bringing people together, in addition to being a source of life. However, water access is extremely unequal both between upstream and downstream of the catchment as well as, within the countries. Most of the world's population resides in areas where water demand exceeds supply or where poor quality restricts its use. It supplies clean water for residential, agricultural, commercial, and environmental purposes. As a result, accurate groundwater resource estimation is a requirement for any long-term water production, efficiency, or management. Water scarcity, as well as inequities in access, usage, and decision-making, can endanger life, reduce quality of life, and obstruct integral human growth. Water shortages and inequity are two other causes that may lead to violent conflict.Water-related violence is already prevalent in many parts of the world, and it is expected to become more prevalent in the coming years (Hamerlynck,2013). Effective groundwater evaluation necessitates, first, a detailed understanding of the aquifer environment, second, the identification of practical steps to regulate abstraction, and third, the artificial recharge of groundwater resources. It is therefore critical to measure the aquifer's response to various inputs and output stresses. The study of groundwater requires knowledge of many of the basic principles of geology, physics, chemistry and mathematics. For example, the flow of groundwater in the natural environment is strongly dependent on the three-dimensional configuration of geologic deposits through which flow takes place. The groundwater hydrologist or geologist must therefore have some background in the interpretation of geologic evidence, and some flair for the visualization of geologic environments. He should have training in sedimentation and stratigraphy, and an accepting of the methods that lead to the emplacement of volcanic and intrusive igneous rocks(**Thangarajan, M. ed., 2007**.)The proportion of usual ground water recharge must be quantified in order to maintain ground water resources effectively (Goulburn-Murray Water (GMW), 2010). It is especially critical in areas where ground water supplies are in high demand and where such services are critical to economic growth. However, one of the greatest challenging variables to calculate in the assessment of ground water supplies is the amount of aquifer recharge. The key techniques was geomorphological, lithological, structural hydrogeological, and hydro geochemical, and was developed as a physically dependent methodology for evaluating long-term average spatial trends of surface runoff, real evapotranspiration, and groundwater recharge. There is surface water in the Walga catchment, which the community uses for various domestic and agricultural purposes, but there has been no detailed investigation into the possible assessment of groundwater supplies in the particular watershed for wise and maintainable practice and managing of the limited water resources. Thus, using hydrogeological, geological, and hydro geochemical methods, assessment of groundwater resources in that particular watershed plays a role in resolving problems related to the management, quality, and forecasting of water resources for sustainable growth. Water-lifting machinery is used for irrigation in both domestic and industrial settings. Most rivers have declined in flow and dried up during the dry season over the last few decades, forcing people to move their water supply from land to groundwater. Ground water can serve as a primary source of irrigation and domestic water.

1.1 Statement of the problem

Groundwater is one of the most essential sources of water for various purposes in the Welga catchment, as well as other parts of Ethiopia. For Woliso, Wolkite, Wonchi, Goro, Gindo Town, and the surrounding rural community, it is the largest area where groundwater is abstracted. From the past to the present, the demand for groundwater for water supply and agriculture has risen in this catchment and its surroundings. Due to intense competition among upstream and downstream users, among various types of usage, community demand exceeding availability and the long-term absence of groundwater potential area recognition, water resource managing in the area faces unique challenges. Eight woredas of Oromia Regional State (Ameyya Woliso, Wanchi, Goro, Ambo, Dawo, Dirre Inchini, and Dendi) and two woredas of SNNP share the Walga River (Abeshege and Kebena). Scarcity of water and imbalances in access, usage, and decision-making can threaten and diminish the quality of life, as well as hinder integral human growth, due to overuse of this River and its tributaries. Due to fast population growing and urbanization, as well as rising living standards, intensified irrigation agriculture, and other developmental activities such as ecotourism and industrial expansion, there is a growing competitive demand for water resources for domestic, agricultural, and other purposes in the area. This highlights the need for more research into the capacity of water resources, especially groundwater, to ensure efficient utilization. In the Welga catchment, hydrogeological and geochemical parameters were used to measure the amount of groundwater recharge using qualitative and quantitative hydrogeological parameters. Characterizing aquifer type and properties, recognizing groundwater quality differences, and mapping the area's groundwater capacity all play a part in resolving issues related to water resource potential management and preparing for long-term growth.

1.2 Objective of the Research Work

1.2.1 General Objective

The major objective of the Research work is to assess the Ground water Quality and potential of Walga catchment by identifying different parameters which has potential effect on the hydrology of the area.

1.2.2 Specific Objectives

- To assess Ground Water quality survey (EC, PH, T, TDS) and Hydrochemistry.
- To estimate ground water Recharge condition of the catchment.
- To understand the hydrogeological characteristics of the basin.
- To characterize the groundwater flow dynamics by producing groundwater contour map from field water level measurements in boreholes and hand dug wells.

1.3 Significance of the research

The study was accompanied with the aim of ensuring long-term groundwater conservation. The newly produced data during the research work would be employed as a basic input for related studies that would be carried out by another researchers, to suggest the maximum value from the catchment contained in the study area without affecting the aquifers, for irrigation, for domestic use, as a base for groundwater exploration, and as a guide for further investigation and growth. In general, the study would be assist planners and administrators in better managing the water supply and possible plans for using water from both the ground and the surface wisely by discussing the groundwater potential area.

1.4 Scope and Limitation of the Research work

The study centered on the Welga catchment Upper Omo-Gibe Basin, which is situated in central Ethiopia, 115 kilometers from Addis Ababa, and covers a certain field of about 2228 km^2. It is bordered on the NE, NW, and N by the Beda Kero, Dase Jabo, Wonchi-Dendi, and Roge mountains, and on the S by the Guraghe Mountain. Software such as ArcGIS, Global Mapper, Surfer, Aquifer Test 9.0, and Grapher 14 were used to complete this study. Geology, hydrogeology, hydro-geochemistry, meteorology, and hydrology were all included in the research. Because of the lack of good accessibility, the study area is large and difficult to handle during primary data collection. The key issues in this study were missing some meteoroidal data, enough budgets for water samples, soil sample laboratory analysis, a lack of groundwater monitoring data, and COVID-19 disruption.

1.5 Previous Work

Some previous studies also were conducted in the research area on the hydrological, hydrogeological, hydro geochemical, geological and structural evolution of the research area. Akaki-Beseka Sheet (NC 37-14) is also compiled by: Bereket Fenatw and Mihret Manaye (EIGS, 2011). In the study, factor affecting the groundwater occurrence, the productivity of aquifer and Hydro chemical characteristics of groundwater are explained. Kassahun Beyene (2005) studied ground water resource evaluation of Walga river basin; the study indicated ground water recharge, hydrogeological and Hydro chemical characteristics of the basin. Abenezer Kefeni (2007) conducted his MSc. thesis on hydro geochemical evolution in the Ambo Woliso area, he identified the hydro geochemical evolution towards west and along the flow path there are at least two water types, high TDS NaHCO3 and fresh(low TDS) CaHCO3 water. Low PH and high electrical conductivity water is limited to Ambo springs emerging sites, Wonchi and Woliso which are connected by NNW and SSE structures. The low PH is attributed to high CO2 supply from Mesozoic de-carbonation and Dandi-Wonchi related magma chamber degassing. Hassen Shube (2011) was used Isotopic and geochemical data to study the hydro geochemical evolution of thermal and hypothermal ground waters and CO2-water-rock interaction of ground waters around Wonchi, Woliso and Ambo area. Birhanu Haile (2015) worked on Characterizing the

Ground Water Resources Potential in Omo Gibe River Basin. Finite element groundwater modeling code (TAGSAC in mat lab) is used in his work to characterize and estimate the groundwater resources potential in the Omo Gibe River Basin. Tsegaye Abebe et al., (1998) studied the Yerer– Tullu Wellel volcano tectonic lineament: a trans tensional structure in central Ethiopia and the associated magmatic activity: He mentioned that an The central Ethiopian structure is oriented east-west, the Yerer Tullu-Welel volcano tectonic lineament that runs parallel to the main Ethiopian Rift and lies between the latitudes of 30°N and 30°E. 8020`N and 9005`N. Along this structures there are several central volcanoes concentrated along the latitude of 8045`N. the central volcanoes are usually located at the intersections of the above described fracture system. Abera Gonfa (2018) worked on Numerical Ground Water flow modeling of walga darge catchment In this research work, the numerical groundwater flow was identified used to study regional groundwater flow and the response of the groundwater structure to different scenarios and The study area boundary was delineated from 30m Shutter Radar Terrain Mapping (SRTM) digital elevation model (DEM) using Arc SWAT software with ArcGIS interface

1.6 Methodology and Material used

The authors of this research employ three methodologies in order to achieve the study's goal.

Pre-field work, field work, and post-field work are the three types of work.

Pre-field work:- was the first phase, which included field planning and thesis work, as well as arranging the equipment and materials required for the thesis work, and those were:-

- Collection of different literatures and relevant data (hydrogeological, geological, hydro geochemical)
- Topographic maps, satellite imageries,
- Data preparation and Organizing
- Preparation of different field equipment and Bring together
- Preparation of semi-processed hydrogeological map at 1:250000 scale.
- Identification of data gap

Fieldwork; - was a period, in which various tasks were completed both in the field and in the office, including:

- Water sample collection for chemical analysis and field water chemistry measurements like, Total dissolved solid, temperature, electric conductivity and PH).
- Understanding the hydrogeological & geological setup description

- Collection of well completion and pump test data
- Data preparation for analysis and interpretation.

Post-field work: was the process in which the entire thesis work was completed in the office, and the phase in which the collected primary and secondary data were interpreted, discussed, and presented;-

- Collection of additional data from different source
- Processing satellite imagery and DEM data for understanding geological,

  Geomorphological, hydrological, geographical features

- Analysis and interpretation of field inventoried and collected hydrogeological, geological , meteorological ad hydrometric data
- Water sample chemical analysis result interpretation and presentation.
- Characterization and classification of lithological unites in to aquifer/aquitared based on Their hydraulic parameters
- Classification of water types, quality and sources of their constitutes.
- Preparation of hydrogeological and hydro chemical map at scale 1:250,000 scale.

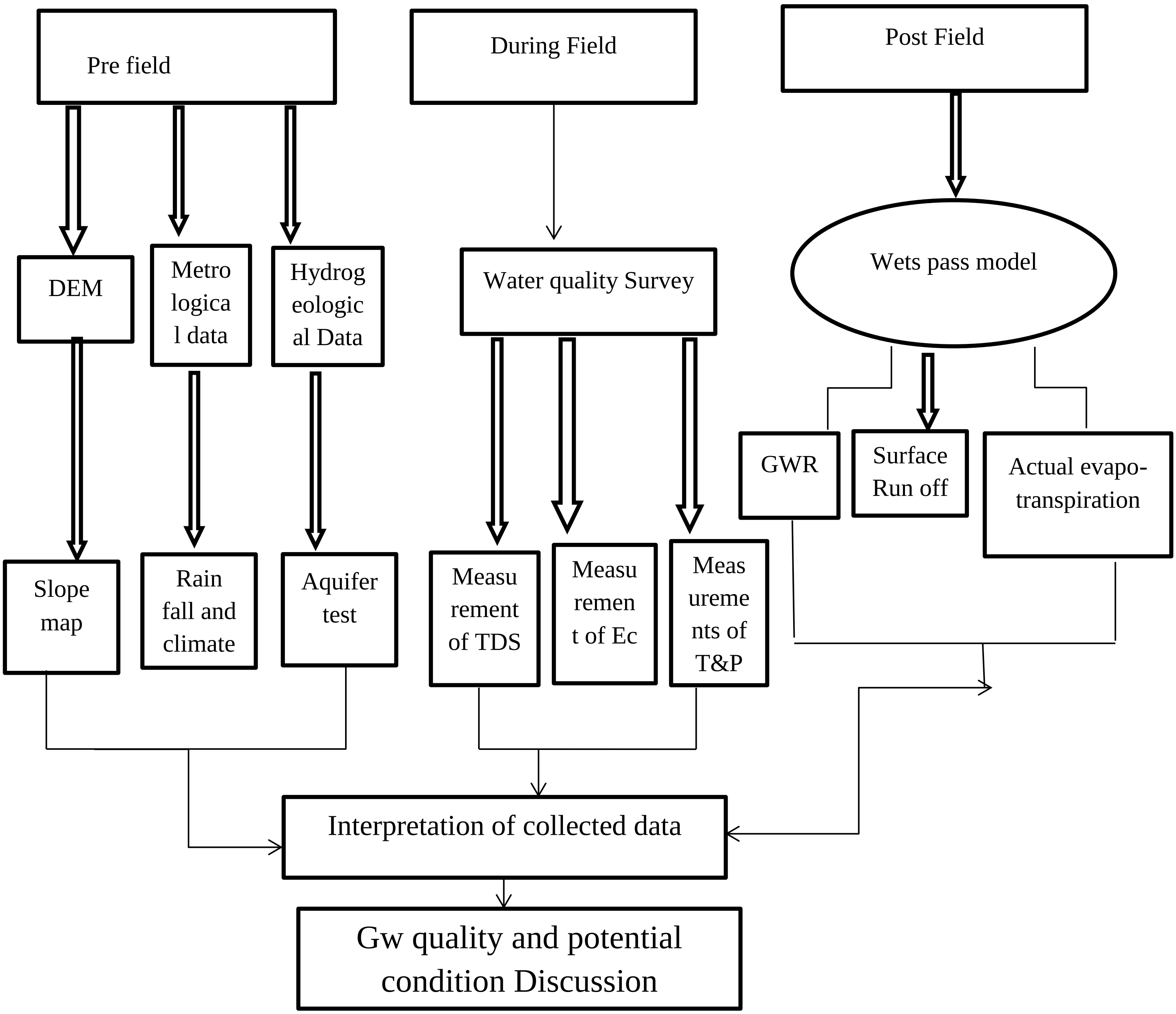
Materials used

The following materials and equipment were used to achieve the above-mentioned goals:

- Deep meter to measure water level of representative well
- Geological and hydrogeological maps with relevance and available scale
- GPS has been be used to locate specific location of well.
- 1:250,000 scale topographical map was used to give good morphological picture of the area
- Various computer software (MODFLOW, ArcGIS 10.3, Arc SWAT, ERDAS, Global Mapper 17, Surfer 10,aquifer test ,wetspass model)

A flowchart depicting the generalized approach of the research work is shown below

General Flow Chart of Research



CHAPTER TWO LITERATURE REVIEW

2.0 Perception of Ground Water Recharge

A comprehensive assessment of water resource needs and availability is required to develop and maintain a sustainable water supply. Understanding the hydro geologic physical appearance of the aquifer system and the interaction between surface and groundwater is an essential part of this effort. As the demand for groundwater grows new drilling wells is needed. and analyzed, and constraints such as well yield, well disturbance, and distance from the distribution system must be considered. Many factors, such as weather, hydrology, geology, topography, biodiversity and soil distribution, influence the incidence and movement of ground water. Groundwater occurrence is as diverse as the types of rocks in which it occurs, and as complex as the crust's development over geological time. All of the above-mentioned variables have an effect on the overall functioning of the water system, both individually and collectively, and a comprehensive evaluation of groundwater condition in any given region must consider all of them. Excessive precipitation over evaporation, which determines the magnitude of the possibility for groundwater recharge, is one of the variables that affect the key characteristics of a groundwater regime. Fluctuations in seasonal and average annual air temperature, and thus changes in critical conditions such as freezing in the aeration environment, are indicated by the balance of radiation (thermal). Beginning with the properties of the soil cover at the land surface and continuing downward through the region of aeration and through the beds of interest in the saturated zone, Lithologic composition of porous earth materials in a vertical series. The aeration zone's thickness Over-all topographic relief, which defines the geometry between the groundwater intake and discharge areas Geomorphological features of the terrain, including the micro- relief Land stream and water body regime Leakage of groundwater between aquifers The forest cover's characteristics (Prasad,2010).The amount of water that enters the saturated zone of the aquifer and contributes to replenishing the groundwater reservoir can be described as groundwater recharge in an aquifer system. Groundwater recharge refers to the amount of water that is available in the long run for both abstraction and supporting the base flow portion of rivers (Rushton, 1991). An appropriate tool for evaluating the long-term sustainable yield of the groundwater system is the evaluation of long-term natural recharge using the water balance approach in combination with the evaluation of dynamic response of the aquifer system. The estimation of the aquifer's sustained yield is needed for groundwater production and management. The current rate of recharge may become a realistic as well as theoretical limit to the sustained yield, even though it is normally constrained by local aquifer transmissivity and storativity. Estimating the rate of aquifer replenishment is perhaps the most complicated of all the ground water resource assessment metrics. The hydrological cycle's impenitent and erratic phase is groundwater recharge. It's difficult to assess the aspect of recharge from rainfall on a regional sack directly. However, several indirect methods may be used to estimate groundwater regeneration. The hydrologic budget system and the traditional water balance method are two of them. Groundwater flow system hydrograph separation process, tracer technique, and traditional modeling. The most commonly used technique for estimating ground water recharge is the traditional long-term water balance method The hydrologic budget approach has the advantage of comparing groundwater recharge to other components of the hydrologic cycle, allowing for a more comprehensive understanding of hydrology. The majority of these modeling techniques necessitate data that isn't readily accessible. However, a rough estimate is needed for planning purposes. Depending on the physical system, a specific method or a combination of methods must be used to strike the right balance between complexity and consistency efficiency (Kluwer, et al,1996). Artificially increase the amount of water recharging an aquifer in a particular region. The primary focus of this global artificial recharge effort is to preserve runoff, increase the quantity of available groundwater, and minimize and precisely control salt water intrusion. (D.K. Todd, 1959).Natural factors (geological, topographical, meteorological, hydrological, and biological) in the drainage basin influence the composition of surface and underground waters, which varies with seasonal variations in runoff quantities, weather conditions, and water levels. Human activity, such as dam construction, wetlands drainage, and flow diversion, has a direct impact on water quality (Meybeck, et al, 1996). The geochemistry of ground water may have an effect on the usefulness of aquifer systems as water sources. The types and concentrations of dissolved constituents in an aquifer system's water decide if the resource is suitable for drinking water, industrial purposes, irrigation, livestock watering, and other uses without prior treatment. Hydraulic conductivity and hydraulic gradient are terms that explain how quickly water can flow across aquifer spaces. The hydraulic conductivity of sand aquifers is higher than that of rock aquifers. The difference in groundwater height (or pressure) between two points is referred to as a hydraulic gradient. A steeper gradient causes a greater pressure differential between two points, allowing water to pass through the aquifer more quickly. Differences in groundwater levels or pressure drive groundwater movement through aquifers, which is controlled by how porous the material it passes through is. Groundwater quality varies greatly across an aquifer, through its profile and over time as a result of physical and chemical processes that change the temperature, salts and minerals it conveys (Describes, n.d.). Groundwater and surface water interactions take place in one of two ways: groundwater flows through the stream bed (gaining stream), and stream water infiltrates into the sediments. Groundwater quality varies greatly in an aquifer, across its profile, and over time due to physical and chemical processes that alter the temperature, salts, and minerals it transports (Describes, n.d.). Groundwater and surface water interactions take place in two ways: groundwater flows through the stream bed (gaining stream), and stream water infiltrates into the groundwater through the sediments (losing stream). A stream can always benefit in some places while losing in others. into the groundwater (losing stream). Often, a stream is gaining in some reaches and losing in other reaches. The hydraulic head determines the direction of the exchange flow. The elevation of the groundwater table is higher than the elevation of the stream stage in obtaining reaches. In losing reaches, on the other hand, the groundwater table is lower than the stream stage elevation (Kalbus, et al 2006). Each year, a large amount of groundwater is pumped, primarily from shallow wells, especially hand-dug wells. Over-extraction of groundwater for irrigation, agricultural, and domestic uses during the dry season has hastened groundwater depletion if not completely replenished during the rainy season (Hasanuzzaman, et.al 2017). Land subsidence, reduction in the base flow of springs and rivers during dry periods, salt water intrusion, water quality degradation, and damage to aquatic habitats have all been recorded in different parts of the world as a result of high ground water abstraction rates (Joshi et al., 2018). A water-bearing formation is known as an aquifer. An aquiclude is a geological formation that does not provide a significant amount of water to wells or springs. It's a term for a physical barrier that prevents water from flowing freely (Recharge, 1967). Aquifer characterization is a quantitative definition of the subsurface in terms of hydraulically relevant parameters like hydraulic conductivity (K), porosity (n), or any other quantity. Since real data is often inaccessible, certain parameters are often assumed for individual lithofacies. The benchmark for evaluating sustainable social-economic growth in rural communities where agriculture is the mainstay of life will be effective and efficient management of groundwater resources for sustainable development. If properly produced, the resource could be phased in for use in all year-round irrigation operations, providing ready income for communities as well as a reliable source of staple food for domestic consumption and export. Groundwater resource production and management begin with a resource assessment, quantitative estimates, and the spatial distribution of groundwater recharge in the region. These would provide primary data that would be useful in resource utilization and long-term management (Tilahun& Merkel, 2009).

2.1Groundwater Recharge estimation approaches

Since there are so many different sources and methods of groundwater recharge, there are many different strategies for quantifying it. In terms of applicability and efficiency, each approach has its own set of limitations. Prior to selecting an effective method for quantifying groundwater recharge, the recharge study's goal should be determined, as this will dictate the necessary space and time scales for the recharge estimates (Scanlon et al., 2002). According to them, recharge estimation techniques are classified into three groups based on the three hydrologic sources, or areas, from which the data is obtained: surface water, unsaturated zone, and saturated zone. Among the techniques commonly used for recharge estimation are Chloride Mass Balance, Stable Isotopes (Rushton, 1991), Soil Moisture Balance Process (SMBM), Water table fluctuation method (Eilers et al., 2017), and WetSpass modeling method (Batelaan & De Smedt, 2001; Hasanuzzaman et al., 2017; Teklebirhan et al., 2012).

2.2 Issues that Interrupt Groundwater Recharge

According to Rukundo and Doan (2019), groundwater recharge is influenced by a variety of parameters and complex processes, all of which are influenced by a variety of factors. Precipitation is influenced by climatic factors such as wind and temperature, resulting in complex and dynamic distributions, while the amount of recharge is influenced by the intensity and spatial distribution of precipitation. According to them, the amount of net rainfall, infiltration rate, deep drainage, and the groundwater system's available storage capacity are all determined by large-scale vegetation. Any shift in vegetation, such as from forest to grassland, has a significant impact on recharge. Groundwater recharge modeling should not assume that vegetation is a constant factor because the nature of land cover has a significant impact on recharge. For example, more than a century ago, the removal of indigenous vegetation in large parts of south eastern Australia resulted in a significant increase in groundwater recharge.

Interception and transpiration are two ways that vegetation affects recharge. The amount of stored water that vegetation can remove is largely determined by rooting depth. Deep-rooted shrubs and trees will remove less water than shallow-rooted grasses (Jyrkama, 2007). The distribution of hydraulic conductivity and, as a result, percolation to the groundwater table is known to be determined by the degree of water saturation of the root zone. It also has an impact on root water uptake and thus actual evapotranspiration (Brendchet, 2004).

2.3 Characterization of the Aquifer

The permeability of bodies of saturated rocks or geological formations from which large quantities of water find their way into wells and springs is investigated (Yu et al., 2012). Aquifer is a geological formation that can store and transmit groundwater in adequate quantities so that the water can be economically utilized from the aquifer, according to Shekhar (2017). Aquifer characterization refers to the evaluation of an aquifer's three-dimensional structure, hydraulic and transport properties, and chemistry (Robert.G et al.,2016). It serves as the basis for groundwater modeling, which is widely used to assess aquifers. Aquifer heterogeneity has a far greater effect on groundwater flow direction and rates than it does on aquifer heads, so detailed aquifer characterization is especially necessary when solute transport is a concern. Aquifer characterized in terms of hydraulically significant parameters such as hydraulic conductivity (K), porosity (n), or any other applicable quantity, according to Yu et al., (2012). Since real data is often inaccessible, certain parameters are often assumed for individual lithofacies. Aquifers located at the surface are unconfined, which means they can be directly recharged by rainfall. They are recharged by slow leakage from overlying aquifers if they are submerged under sediments. Rainfall percolates down from the surface sediments to the water table. Inside the aquifers, it then flows by gravity through central, intermediate, and regional flow systems (Harold F. et al., 2015). Flow paths in local flow systems are less than 5 kilometers. They're most common in upper aquifers or unconfined broken rock in lower aquifers or basements. Changes in rainfall, mining, or land use affect these aquifers rapidly. Until it discharges to nearby streams, groundwater in a local system has a relatively limited residence period (Shekhar, 2017). The scale, amount, and degree of interconnection of pore spaces within the aquifer material are all aquifer properties that affect ground-water availability. These characteristics influence an aquifer's capacity to store and transmit ground water. The ratio of void space to unit volume of rock or soil, known as porosity, is a measure of how much ground water an aquifer can hold. The fluid-transmitting capacity of materials is affected by permeability, a property largely controlled by the size and interconnection of pore spaces within the material (Khadri & Moharir, 2016). Hydraulic conductivity and transmissivity are terms used to describe an aquifer's water-transmitting characteristics. Hydraulic conductivity is a measurement of how quickly water moves through an aquifer; it's normally expressed in gallons per day through a one-square-foot cross section under a constant hydraulic gradient (Okon et al., 2018). The hydraulic conductivity multiplied by the saturated thickness of the aquifer equals transmissivity. The storage coefficient represents an aquifer's storage characteristic (Tse & Amadi, 2010). Since the pumping test can be performed on the production well without the use of an observation well, single well tests are more common than aquifer tests with observation wells. Step-drawdown tests are a form of single well test used to assess the efficiency and basic ability of a well. Although it is possible to estimate Transmissivity in a single well test, the other parameter, Storativity, is overestimated (Dinu et.al , 2017). Comprehensive hydrogeological field surveys, data collection from various sources (Ayenew et al., 2008), pumping tests, well lithological logs, and indirect information from hydro chemical data allow the classification and characterization of aquifers and their hydraulic characteristics, including groundwater recharge and discharge conditions (Tamilnadu, 2010). Theis is responsible for the most well-known curve matching technique for estimating aquifer properties from pumping tests among groundwater hydrologists (1935). By matching the Theis form curve to water-level adjustments (drawdowns) calculated in wells during a constant-rate pumping test, the Theis method enables us to estimate the transmissivity and storativity of a non-leaky confined aquifer with infinite extent. Theis [1935] method or Jacob's semi logarithmic approximation are often used to interpret constant rate pumping tests (Meier et.al, 1998). Under the assumptions of homogeneity, a two-dimensional domain, and restricted conditions, both of these techniques use the temporal evolution of pumping-induced drawdown to obtain estimates of transmissivity and storativity. Jacob's approach is based on the fact that at large dimensionless times, the Theis well function plots as a straight line on semi logarithmic paper. Theis and Jacob techniques are based on the presumption of aquifer homogeneity in their analytical solution.

2.4 Approaches for hydrogeological characterization of Aquifers

Groundwater management policy development necessitates aquifer characterization and ambient spatiotemporal groundwater monitoring (Ewusi & Kuma, 2014). The hydrological characterization of an aquifer was carried out in this study. Certain geophysical techniques, such as Electrical Resistivity, Electromagnetic Induction, Ground Penetrating Radar (GPR), Seismic Techniques, Statistical spatiotemporal modeling, and Pumping test results, may be used to characterize aquifers. The aquifer the sub surface's petrophysical properties (porosity, permeability, seismic velocities, and so on) are used to characterize it. To better picture the subsurface, the results of this Aquifer Characterization could be observed and analyzed using various geophysical applications (WinRESIST, RADpro, etc.) and Aquifer tests (Okan et al., 2018; Yu et al., 2012; Dhar et al., 2014). Pumping tests, according to Okan et al., (2018), are valuable and useful tools for determining the hydraulic characterization of a borehole and aquifer parameters. Constant Rate Tests can provide information on drawdown and aquifer properties as a result of a given pumping rate.

2.5 GIS and RS Systems analysis

Geology/lithology, geomorphology, drainage density, rain fall, geological structures/lineaments, slope, land use/land cover, and soil of groundwater regime all influence the occurrence, origin, movement, and chemical constituents of groundwater (Gintamo 2015; Yeh, et al. 2016). There is no direct method to facilitate observation of water below the surface because groundwater occurs out of sight deep in the subsurface. Its presence or absence can only be inferred inferentially by looking at groundwater occurrence and distribution control parameters. As a result, a systematic evaluation of groundwater potential area is required to ensure wise groundwater use (Murthy etal., 2003). Groundwater potential zones are identified using a variety of techniques, including remote sensing and Geographic Information System (GIS) (Jhariya et al, 2016; Sener et al.2005; Waikar & Nilawar 2014). Both Geographical Information Systems (GIS) and Remote Sensing (RS) are now widely regarded as essential tools for groundwater research, particularly in large and complex systems (Nag, 2008). Remote sensing and Geographical Information System (GIS) techniques can be used to collect and integrate data on the input parameters in the above. The concept of integrated remote sensing and geographic information systems (GIS) has proven to be an effective tool in groundwater studies, allowing for better data analysis and interpretation (Murthy et al., 2003). The main advantages of using remote sensing and GIS techniques for groundwater exploration are the cost and time savings, the quick extraction of information on groundwater occurrence and the selection of promising areas for further groundwater exploration (Hammouri, 2012; Barakat, 2012), and its ability to generate information in both the spatial and temporal domains, which is critical for groundwater exploration (Hammouri, 2012; Barakat, 2012). (Hammouri et al., 2012; Bashe, 2017). Gintamo (2015) used an integrated Geographical information system (GIS) and remote sensing techniques to assess the groundwater potential zone in the south Ethiopian rift escarpment, specifically the Bilate River catchment in the SNNPR. In his research, he attempted to delineate and classify potential groundwater zones in the Bilate River. Landsat ETM+ imagery and ArcGIS software were used to create thematic layers for lithology, geomorphology, drainage density, lineament density, rainfall, soil, slope, and land use/ land cover. The groundwater potential map of the Weito watershed, Ethiopia's southernmost sub-basin of the rift valley lakes basin, was created using remote sensing data and geographic information systems. Using overlay analysis, thematic maps were created using Landsat 8 OLI/TIRS images, the shuttle radar topographic mission (SRTM) digital elevation model (DEM), and other data sources (Bashe, 2017). According to Hussein et al. (2017), eight major biophysical and environmental factors such as geomorphology, lithology, slope, rainfall, land use land cover (LULC), soil, lineament density, and drainage density were used to delineate groundwater potential areas in Northern Ethiopia's Wollo Zone in the Gerardo River Catchment district using geospatial and MCDA tools. Satellite images, digital elevation models (DEMs), existing thematic maps, and data from metrological stations were used to create these maps. Solomon and Quiel (2006) conducted a groundwater study in Eritrea's central highlands using remote sensing and geographic information systems (GIS). Lithology, lineament, landform, slope, vegetation, groundwater recharge, and discharge are all common features used in many groundwater resource assessments in hard rock areas, according to them. GIS techniques make it easier to integrate and analyze large amounts of data, while field studies help to confirm findings. By combining all of these approaches, researchers can gain a better understanding of the factors that influence groundwater occurrence in hard rock aquifers. A GIS approach was used by Yeh et al., (2016) to integrate five contributing factors: lithology, land cover/land use, lineaments, drainage, and slope. In the Hualian River, Taiwan, a GIS approach was used to map the groundwater recharge potential zone. They've also discovered Topography, lithology, geological structures, depth of weathering, extent of fractures, primary porosity, secondary porosity, slope, drainage patterns, landform, land use/land cover, and climate are all factors that influence the occurrence and movement of groundwater in a region.

2.6 Subsurface and Surface Water Quality

According to the 2016 Ethiopia Socioeconomic Survey, 66 percent of Ethiopians drink water from improved sources, with distribution varying depending on where they live. Protected springs, tube wells, and dug wells are the most common improved sources in rural areas, with 59 percent of the population using them. Source type also differs by region; almost all households in Addis Ababa and 72% in Tigray reported using improved sources (CSA et al., 2017). Human sewage, industrial waste from ceramics, textile, plastics, and food processing industries, urban storm water, agricultural runoff, and land growth all impacted the lake, according to an analysis of physico-chemical characteristics of water collected from different sampling sites of Lake Hawassa, Ethiopia (Haile & Mohammed, 2019). In Ethiopia, groundwater is a significant source of drinking and irrigation water. In addition, mapping the spatial variation of groundwater parameters is critical for designing new groundwater schemes and managing groundwater supplies. Kawo & Karuppannan, (2018) obtained and analyzed groundwater samples in the Modjo river basin to assess the suitability of groundwater for drinking and irrigation. They used the WQI and SAR to determine the consistency of drinking and irrigation water, and the majority of samples indicate that groundwater is appropriate for both drinking and irrigation. The key water quality issue in Ethiopia's rift valley is due to high fluoride levels in the groundwater (Tekle-Haimanot et al., 2006). They tested 1438 water samples and found that 24.2 percent had fluoride concentrations higher than the WHO's prescribed optimum concentration of 1.5 mg/l. Natural factors (geological, topographical, meteorological, hydrological, and biological) in the drainage basin influence the composition of surface and underground waters, which varies with seasonal variations in runoff quantities, weather conditions, and water levels. Human activity, such as dam construction, wetlands drainage, and flow diversion, has a direct impact on water quality (Meybeck et al.,1996; Ayenew, 2006).The geochemistry of ground water may have an effect on the usefulness of aquifer systems as water sources. The types and concentrations of dissolved constituents in an aquifer system's water decide if the resource is suitable for drinking water, industrial purposes, irrigation, livestock watering, and other uses without prior treatment (Canora etal., 2019). The quality of an aquifer can differ dramatically through its profile and over time. Physical and chemical processes in aquifers can affect salinity, temperature, pH levels, heavy metals, and organic substances, such as: Dissolved rocks and minerals are transported and redeposited as groundwater travels along the flow path; Evaporation from high water tables causes minerals and salts to accumulate in groundwater; Changes in groundwater levels that draw salt water into an aquifer; chemical reactions that alter the chemistry of groundwater; or thermal causes such as volcanoes, hot rocks, or the sun that heat the groundwater (Lapworth et al.,2017).

2.7 Aspects of Ground Water management

It's important to remember that groundwater isn't a resource that can be abused simply because it's plentiful. If a groundwater source has been established, it is important to ensure that the well is sustainable and that no unhealthy activity in the surrounding area is causing problems with groundwater quality or quantity. Groundwater, like surface water, has many consequences for the environment if it is not properly handled. Groundwater users often neglect groundwater issues until they have progressed to a critical stage. Groundwater management is relatively easy in the early stages of production, when water abstraction is less than natural recharge. However, once the development reaches a point where the abstraction equals or exceeds natural recharge, the management issues become even more severe. Lowering groundwater levels, which results in higher power costs to raise the water, deepening of wells, and pump modifications are some of the solutions to groundwater problems. Land subsidence, salt water intrusion into fresh water aquifers, and increasing groundwater levels are all possibilities. The implications of aquifer production, water quality, hydro geochemical aspects, and, where necessary, the organized activity of surface and groundwater sources and storage capacities must be fully considered for successful management. Most problems result from conscious human action and ideally therefore, might be prevented by good management practices. Groundwater management is a broad concept that includes both day to day operations of well fields and long-term concerns such as future water demand, possible sources of supply, Economics, Environmental, social, and political issues, among other things. The following are some of the more common aspects of groundwater management practices: In a restricted aquifer, drawdown does not go below the confining stratum's foundation. In an unconfined aquifer, drawdown does not exceed 50 to 60% of the saturated thickness. The well must be constructed and maintained in such a way that it never runs dry. This means that the impact of nearby wells, as well as any long-term water level fall, must be considered. To minimize the risk of pollutants entering the aquifer, well systems, including abandoned wells, should be inspected for signs of degradation on a regular basis. Groundwater water quality should be monitored on a regular basis. Any emissions emergency should be dealt with according to predetermined procedures. Artificial recharge is a groundwater management technique that can be used in areas with a decreasing water level, salt water intrusion, land surface subsidence, and other issues. Artificial recharge also aids in the conservation of groundwater and the expansion of water supplies (N.B Narasimha Prasad,2017)

2.8 Missing Data Estimation

Accessing reliable data is one of the first steps in any hydrological or meteorological research. Precipitation data, on the other hand, is often incomplete. Damaged measuring instruments, calculation errors, and geographical scarcity of data (data gaps) or changes to instrumentation over time, a change in the measurement location, a change in data collectors, measurement irregularity, or extreme topical changes in the environment of a zone can all contribute to incomplete precipitation data (Sattari et al., 2016). He also mentioned that effective water resource preparation and management is contingent on the availability of reliable and precise precipitation data in meteorology stations. Meteorologists, hydrologists, and environmentalists all over the world face the challenge of estimating missing climatological data. It's especially critical in mountain and forest areas, where meteorological stations are scarce and observed climatological data are heavily influenced by topography and forest microclimate (Xia et al,1999, Aslan et al., 2013). Xia et al. (1999) used six methods to estimate the missing data for daily maximum, minimum, mean air temperature, water vapor pressure, wind speed, and precipitation. They discovered that when it came to estimating missing data, the multiple regression analysis method was the most effective. The method of multiple regression analysis was found to be the most effective in estimating missing data, according to them. The coefficients for all of the significant neighbor stations are determined using step-wise regression in the multiple regression models (Edmond Moeletsi, Phumlani Shabalala, De Nysschen, & Walker, 2016). Data on rainfall is critical for hydrological modeling, agricultural planning, and water budget estimation. As a result, estimating the missing value in the rainfall series is critical for performing an effective rainfall analysis. Different methods for estimating missing rainfall data for specific regions are used for this purpose (Romman et al., 2019). Aslan et al., (2013) chose six techniques based on their literature review and previous experience: simple arithmetic averaging, inverse distance method, normal ratio method, single best estimator, multiple regression analysis, and the traditional UK meteorological office method (constant ratio or constant difference and closest station method). Different weather elements, such as rainfall, temperature, and humidity, must be measured and archived. Long-term weather data can influence decisions in a variety of industries, including agriculture, aviation, hydrology, and engineering. For the successful design and operation of natural resource management systems, accurate and complete climatological data is critical (Edmond et al., 2016). Missing or faulty climate data must be estimated in order to provide a complete dataset, especially for modeling purposes, according to Edmond et al., (2016). The accuracy of the estimates is determined by several factors, including the proximity of the stations used and the location of the covering stations in relation to obstacles such as mountains.

CHAPTER THREE GENERAL OVERVIEW OF THE STUDYAREA

3.1. Location

The Walga catchment is located in the upper Omo-Gibe basin in central Ethiopia, in the Oromia Regional State's South West Shoa district, about 115 kilometers south of Addis Ababa along the Jimma main asphalt route. This catchment includes eight woredas in Oromia regional state and two in SNNPR. The river's catchment area includes the Wonchi-Dandi mountain range, Beda kero, Roge, and Dase jabo, and flows south to the Omo Ghibe basin. Geographically, the area stretched 8 0 00'90 0' north, and from 37.20 to 38.50 east, covering 2228.12km2**.**

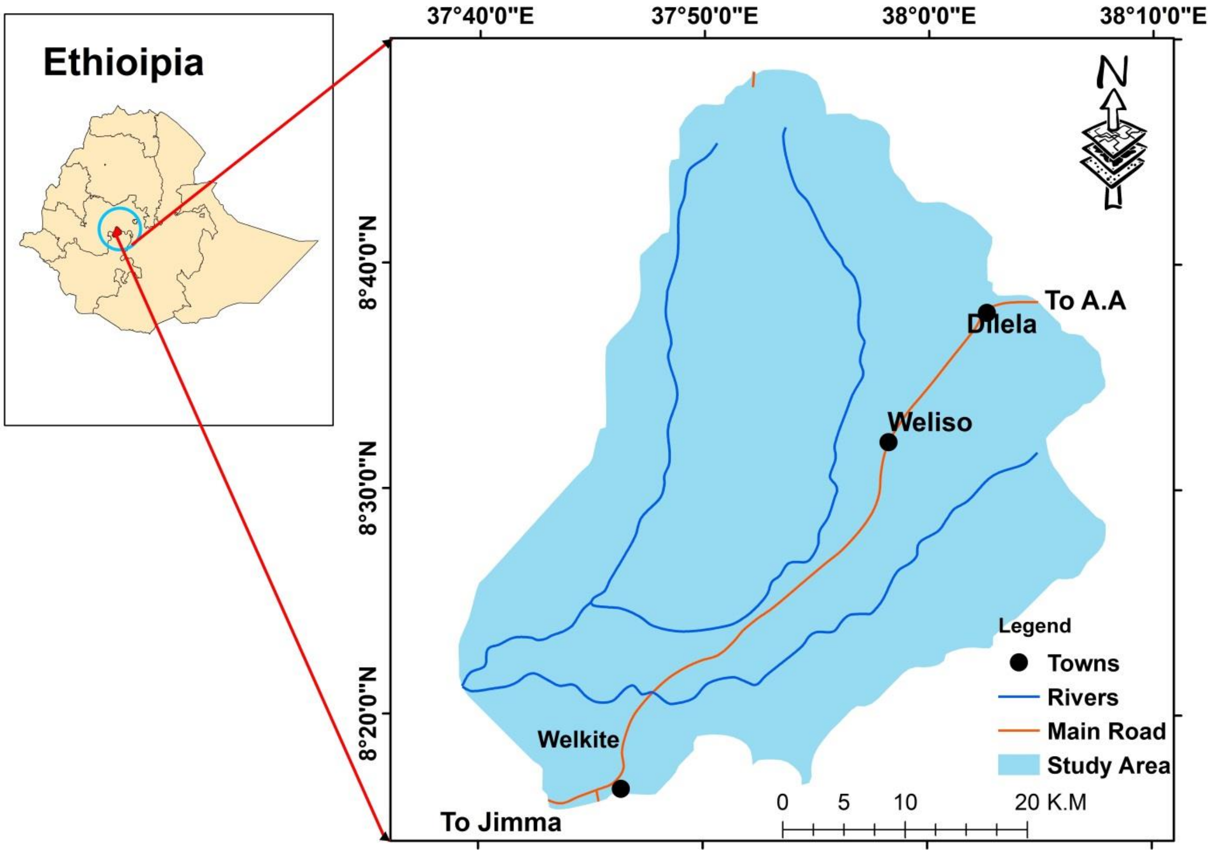


Figure 1 location map of Welga catchment

The farming system in the area is a typical Ethiopian mixed crop-livestock system. As a result, for people who live sedentary lives, land and livestock are the most important resources. Crop production is the primary source of income for the watershed's residents. Livestock such as cows, oxen, sheep, and poultry may help farmers supplement their income. For wood fuel and building, the farmers depend heavily on the forest.

3.2 Physiography

The study area is characterized by large Mountains and various volcanic rocks. The elevation varies from 1164 m.a.s.l near Gibe gorge to 3360 m.a.s.l at the northern (Wonchi Caldera). Highly elevated Volcanic Mountains and Spatter Cones are common in the northern, northeastern and northwestern parts of the study area. The central and southern portions are characterized by flat undulating plain topography. Surface water hydrology shows that the area is at a water divide of three basins namely the Omo - Gibe, Awash and Abay basin. The drainage pattern of the area is controlled by the rift shoulder uplifted topography and the predominant fracture systems and the central volcanoes. Most of the major rivers follow the NE– SW lineament trend. The major river that drains the study area is the Walga River. Small rivers like Amenya, Tilku Jara, Kulit and Darge flows from north to south, joining Walga river, which further drains due south west to join the Gibe river outside the study area. The deep gorges, incised river valleys, and rolling plains are a specific feature of the study area.

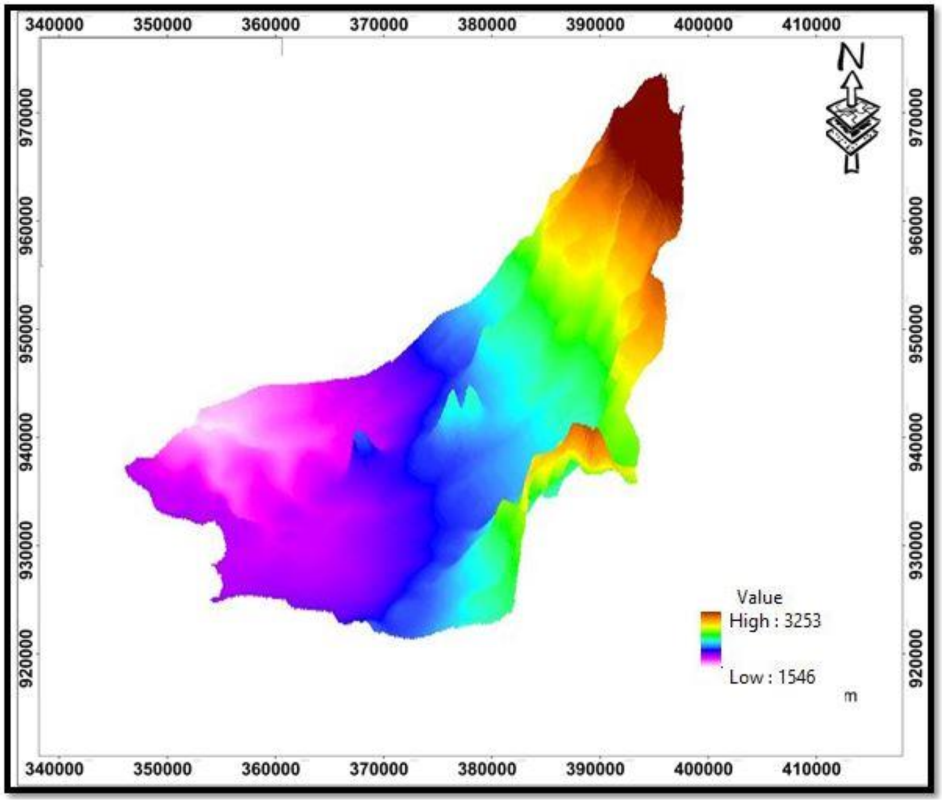


Figure 2:Physiographic Map of the Welga catchment

3.3. Features of the drainage system

The area is situated at the confluence of three basins: Abaya, Awash, and Omo-Ghibe. The rift shoulder uplifted topography, as well as the dominant fracture systems and central volcanoes, influence the drainage pattern of the region. The NE–SW lineament is followed by most of the major rivers. The Walga catchment's drainage system is characterized by three major water bodies: Lake, rivers and stream.

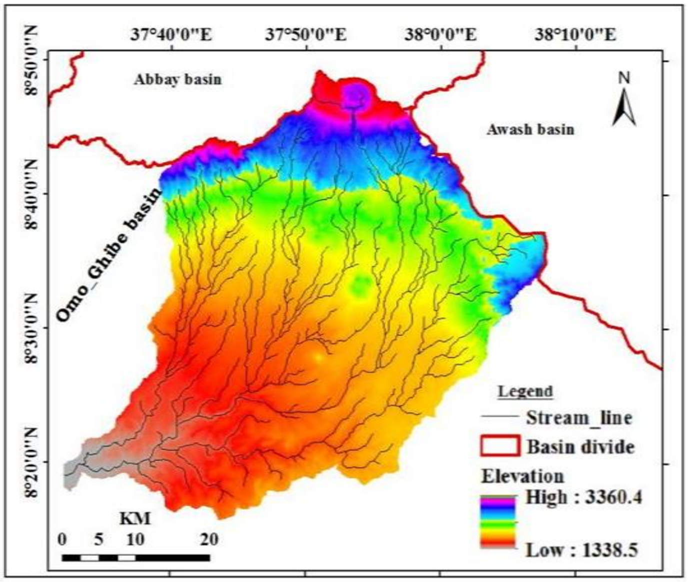


Figure 3: Drainage System of Walga catchment

Major perennial rivers crossing the watershed is Walga, while Ejersa, Rebu, deddebia, amegna, kulit and others are small rivers that are joining Walga and draining to Omo Ghibe basin. They are characterized by dendritic drainage pattern; however major rivers in the area are parallel to each other indicating that they are structurally controlled. Walga and Rebu are gauged at the location of 0345831m Easting and 0921338 m Northing and 0366029 m Easting and 0923114 m Northing respectively. Geographically Walga catchment is located at the Southwestern part of Ethiopia and falls within Oromia and SNNP National Regional States. The woredas and zones falling within the Walga catchment was generated from Ethio GIS data using ArcGIS 10.4.1. It covers three zones namely South west Shoa , West Shoa of Oromia and Gurage zone of SNPPR. Of the total catchment area 86.01% and 13.99% fall within Oromia and SNNP Regional States respectively. Similarly, 0.47%, 85.54%, and 13.99% of the total catchment area fall within West Shoa, South West Shoa and Gurage zones respectively. Here the share of West Shoa zone is very small and close to zero as compared to the total area. The list and area of regions, zones, and woredas that fall within the Walga catchment indicated in the table below

Table 1 : Contributions made by Woreda to the Walga catchment**.**

No	Region	Zone	Woreda	Area (km)	Percentage (%)
1	Oromia	West Shoa	Dendi	0.72	0.03
2	Oromia	West Shoa	Dire Enchini	2.4	0.11
3	Oromia	South West shoa	Goro	362.83	16.28
4	Oromia	South West shoa	Wonchi	447.09	20.06
5	Oromia	South West shoa	Woliso	455	20.42
6	Oromia	South West shoa	Ameyya	634.27	28.46
7	Oroma	South West shoa	Dawo	7.04	0.32
8	Oromia	West Shoa	Ambo	7.3	0.33
9	SNNP	Gurage	Abeshge	183	8.21
10	SNNP	Gurage	Kebena	128.69	5.78
	Total			2228.34	100

3.4. Slope and Elevation

Digital elevation model (DEM) was downloaded from the Shuttle Radar Topography Mission (SRTM) data sets of the United States Geological Survey (USGS). The lowest (minimum) elevation point in the watershed is 1546 m in the downstream part and the highest is 3253 m in the upper stream part, while the average elevation of the watershed is 2399.5m .The slope map of the watershed is derived from the digital elevation model using the spatial analyst tool of ArcGIS 10.4.1. The slope ranges from 0^0 to 46^0 with a mean of 4.11 and standard deviation of the slope is 4.25.

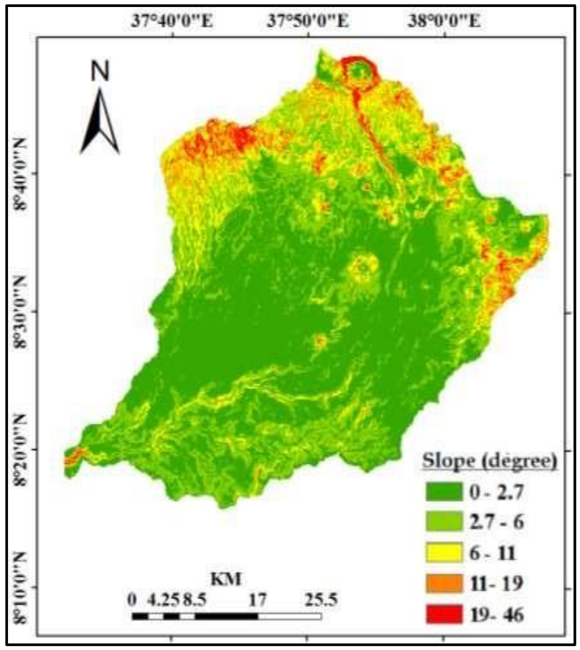


Figure 4: Slope and Elevation map of the Welga catchment

3.5. Land Cover Land Use

The important characteristic of the runoff process that affects infiltration, erosion, and evapotranspiration is Land use. The main crops grown in the area are maize, wheat, teff, sorghum, barley, been, pea and different types of vegetables. Land cover units having different areal coverage are Vegetated area, grass and shrub lands, bare land, settlement, Agricultural area and open water body of Lake Wonchi. Climatic elements such as precipitation, temperature, humidity, sunshine, and wind are affected by geographic location and altitude. Seasonal classification over the study area is thus mainly based on the average rainfall distribution pattern over the year. Classification process and analysis of the different LULC classes were done using one Landsat satellite images covering the Landsat 8 OLI/TIS acquired on 27 Nov, 2020. These images includes; L8 OLI/TIRS (path 169, rows 54). The Landsat images were down-loaded from United States Geological (USGS) Earth Explorer (https://earthexplorer.usgs.gov/). The selection of the Landsat satellite images dates was influenced by the quality of the image especially for those with limited or low cloud cover. Each Landsat was Georeferenced to the WGS_1984 datum and Universal Transverse Mercator Zone (UTM) 37 Northern coordinate system. For this study, only supervised classification was performed. Using the Image Classification toolbar and Training Sample Manager of ArcGIS 10.4, it was determined the training samples were representative for the area and statistically separate. Then a maximum likelihood classification was performed from the toolbar. The classified image was then cleaned to create the final land-use map as shown below

Table 2: The Walga catchment's land cover and use

No	Classes	Area (km^2)	Area (%)
1	Agriculture	1587.36	71.24
2	Mixed forest	78.43	3.52
3	Settlement	62.55	2.81
4	Bare Soil	0.35	0.02
5	Grass & shrub Lands	495.73	22.25
6	Water body	3.75	0.17
7	**Total**	**2228.17**	**100.00**

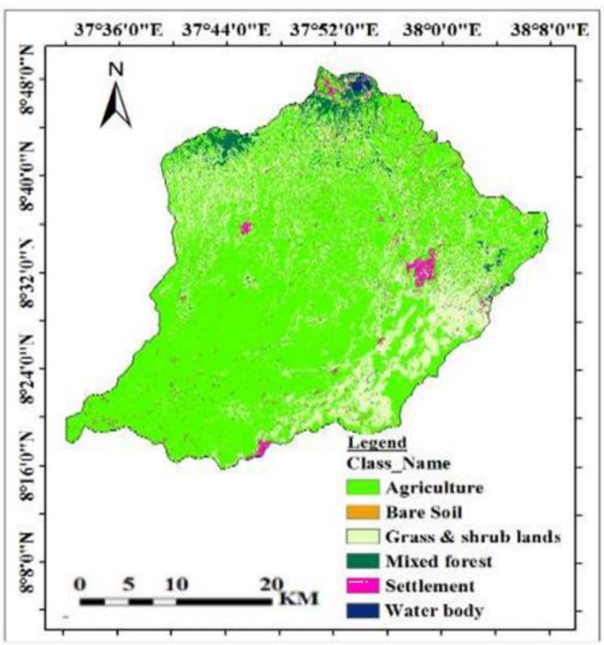


Figure 5: Land use land cover map of welga catchment

3.6 Typical and Coverage of Soil in Welga catchment

The soil map of Welga catchment was extracted from the soil map of Ethiopia (scale 1:250,000) obtained from ministry of Water Irrigation and Energy. The major textural system of the clay used in WetSpass is based on soil texture developed by FAO class based on the percentage of silt, clay and sand. Based on that the major soil classification of walga catchment is clay (11.78%), clay loam (70.5%), sandy clay loam (13.73%) and sandy loam (4%)

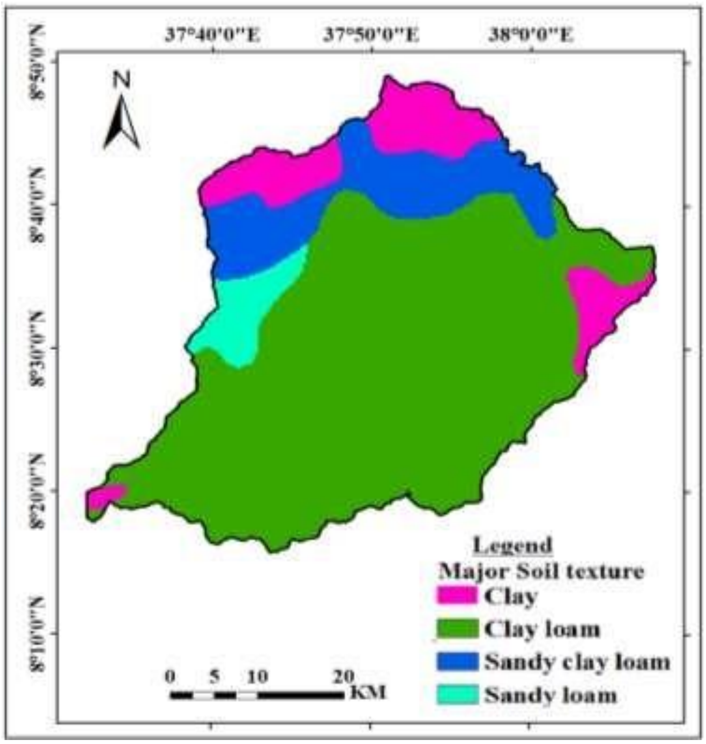


Figure 6: Soil map of Walga catchment (Source: MoWEI**)**

Table 3: Soil texture distribution in the Welga catchment.

S.N	**Major soil texture**	**CODE**	**Area**	**Area (%)**
1	clay loam	9	1571	70.4997
2	sandy clay loam	7	305.88	13.7264
3	sandy loam	3	89.06	3.99676
4	Clay	12	262.44	11.7772
5	**Total**		**2228.38**	**100**

3.7 Climate Condition of Welga catchment

3.7.1 Rainfall

This is specific term which involved droplet of water from the atmosphere to the ground. In Welga catchment the key rainy season is June to September, with a unimodal (single peak) rainfall pattern. The maximum average monthly rainfall observed at Haro meteorological station (figure 8) since 2018 is 344.1 mm, while the minimum and maximum average annual rainfall at Ambo and Ameyya respectively are 1014.48 mm and 1828 mm. The catchment's high and minimum temperatures are 20.5°C and 18.8°C, respectively. The area receives an average of 1357.43mm of rain each year.

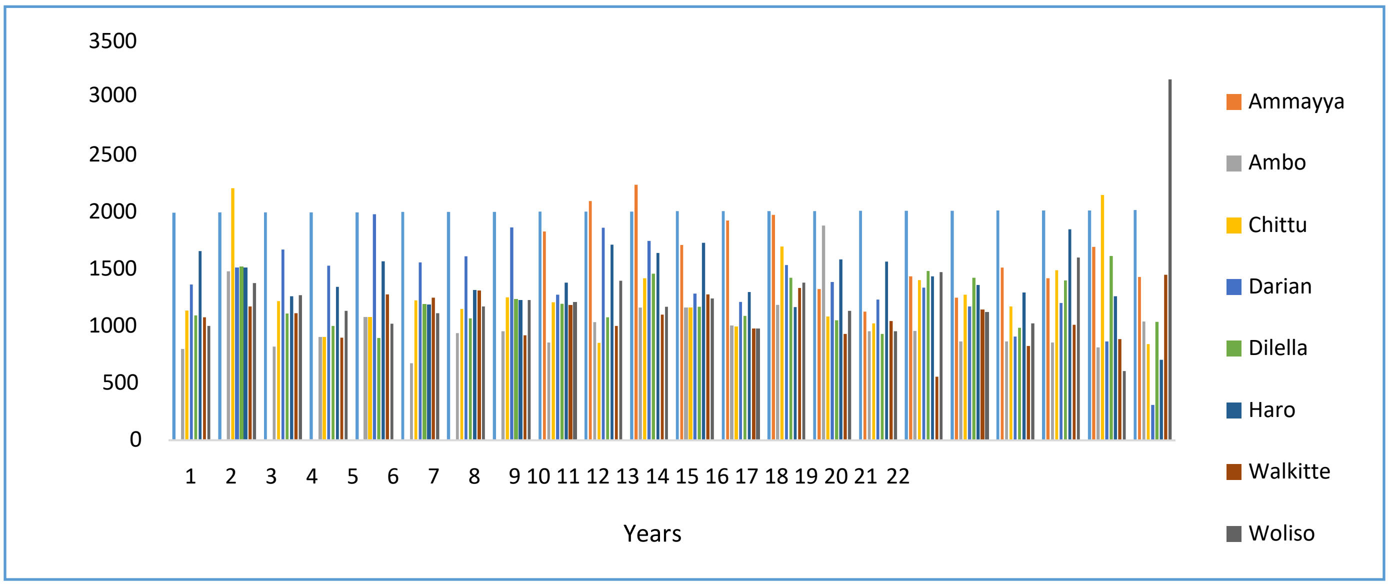


Figure 7: Spatial distribution of rainfall of Walga catchment

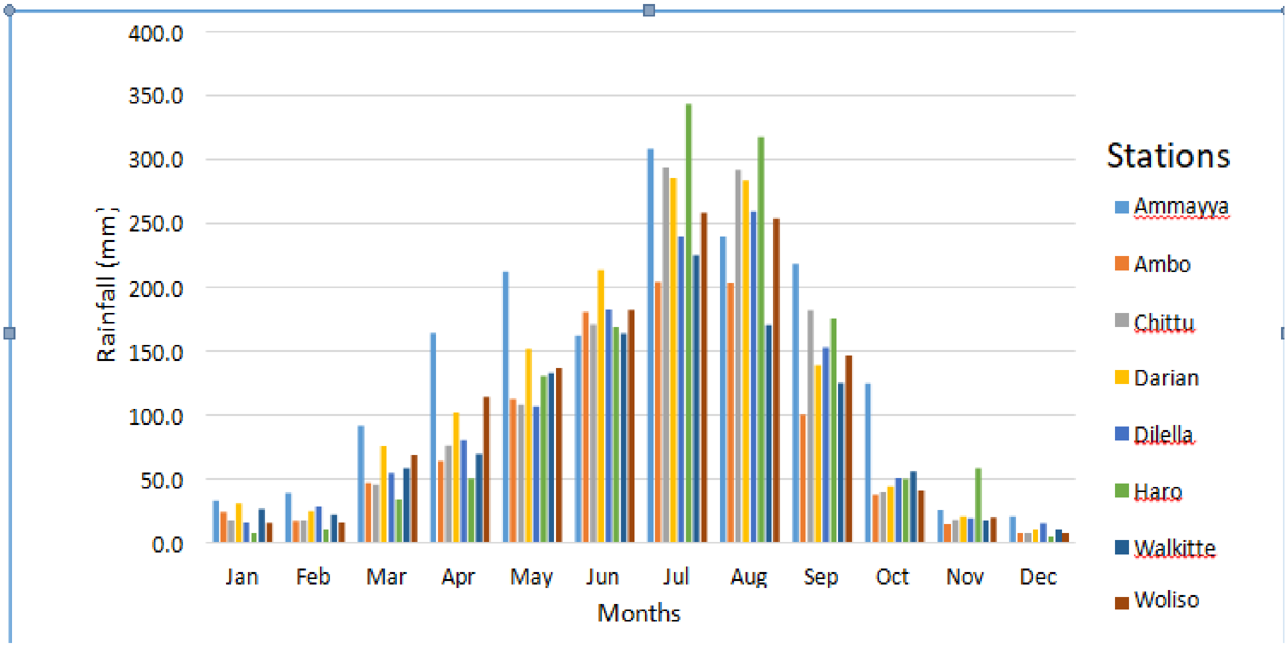


Figure 8: Mean monthly Rainfall (1997-2018)

Table 4: Walga meteorological stations' average monthly rainfall (1997-2018)

Station	UTM X	UTM Y	Z	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ammayya	362400	947000	2277	33.4	39.2	91.9	164.7	212.6	162.4	308.9	240.1	218.8	124.8	25.9	20.9
Ambo	371879.6	993784.3	2068	24.2	17.4	47.3	64.1	112.5	180.8	204.4	203.6	100.9	37.7	14.3	7.2
Chittu	380556.7	940168.3	2150	17.5	17.5	45.7	76.3	108.3	171.3	294.4	292.5	182.4	39.9	17.9	8.2
Darian	377536	961369.8	2604	31.4	24.9	76.1	102.3	152.1	213.9	285.7	284.2	139.1	44.4	20.8	9.9
Dilella	393893.9	955151.2	2429	16.0	28.7	55.0	80.7	107.0	183.2	239.9	259.7	153.3	51.0	19.2	15.7
Haro	374048.3	972252.7	3119	7.9	10.0	34.1	50.7	130.9	169.3	344.1	318.4	175.9	50.2	58.4	4.2
Walkitte	369000	917905	2000	26.7	22.0	58.6	69.6	133.3	164.3	225.4	170.8	125.4	56.4	17.7	10.5
Woliso	387542.4	945677.7	2058	15.9	16.2	69.2	114.6	137.3	182.9	258.8	254.0	146.8	41.0	20.1	7.3

3.7.2 Precipitation

Is the general term which occurs as rain waters (solid, liquid) falling for the atmosphere to ground and it involved rain, drizzle, snow, hail, sleet and etc. The study area's annual precipitation map was generated using long-term rainfall data collected at meteorology stations in the catchment and surrounding study area. Incomplete precipitation data at all stations was filled using linear regression, and data from eight meteorological stations in the Walga river catchment and nearby stations was analyzed using GIS and its spatial analyst method (interpolation). The areal distribution of precipitation over the catchment was determined using kriging spatial interpolation. As a result, the area receives an average of 1357.43mm of rain per year. The average annual rainfall in the summer is 794 mm, while the average rainfall in the winter is 541 mm.

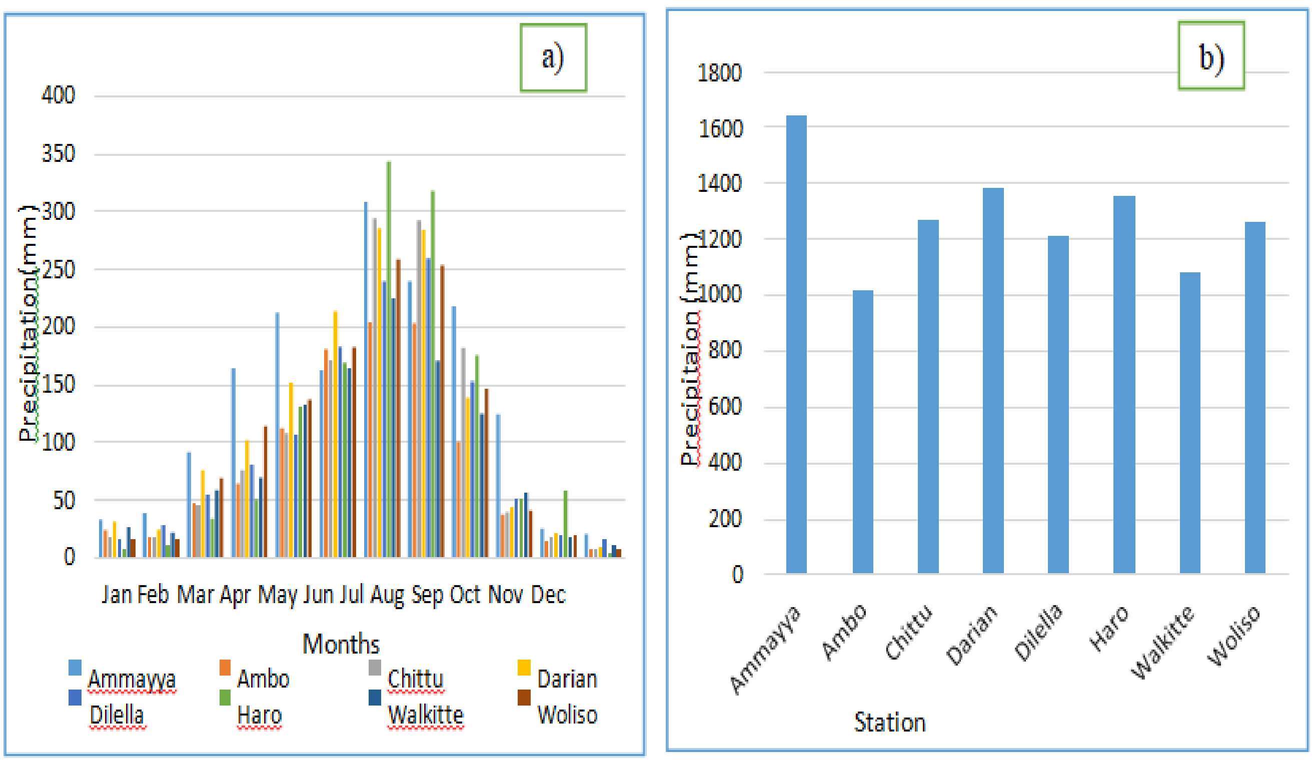


Figure 9: a) Mean monthly precipitation b) Mean Annual precipitation

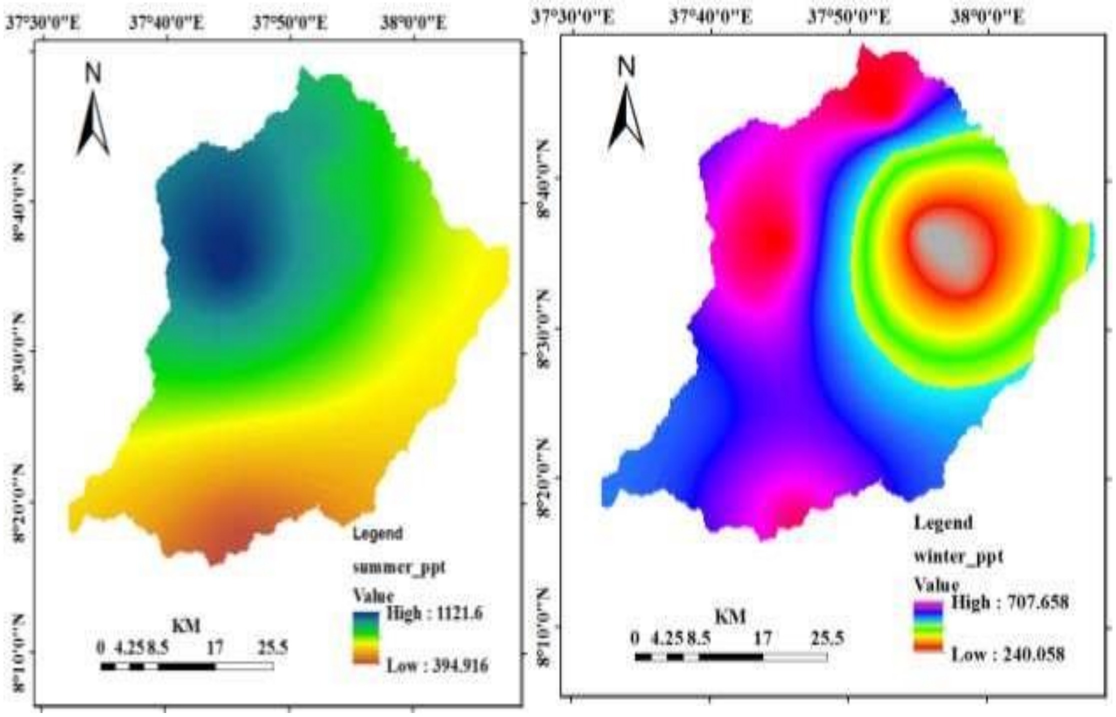


Figure 10: Summer and winter precipitation map of Walga watershed

3.7.3. Temperature

Only four weather stations have temperature records. Ameyya has 15 years of records, while Ambo, Woliso, and Wolkite have more than 30 years. The average temperature in the summer is 17°C, while the average temperature in the winter is 19.980°C. The annual average minimum and maximum temperatures are 17.40 degrees Celsius and 20.40 degrees Celsius, respectively. Since December 2013, Walkite station has recorded the lowest monthly temperature, while the highest monthly temperature has been recorded since November 2015.

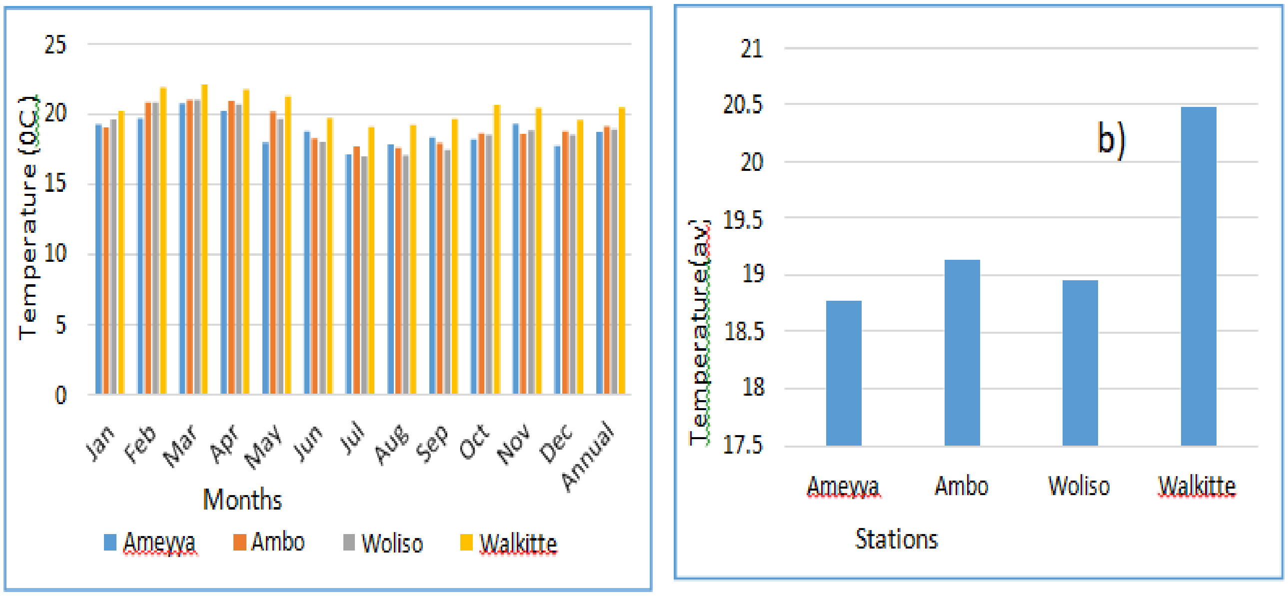


Figure 11: a) Long term mean monthly temperature b) Annual mean temperature of each station

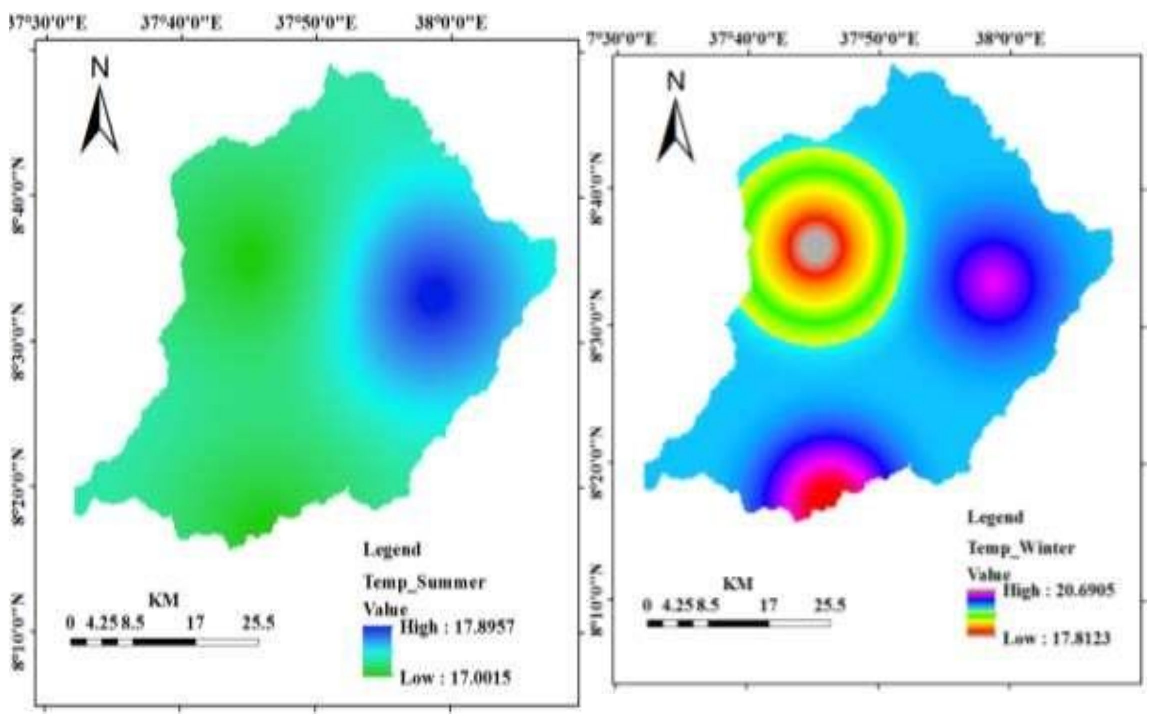


Figure 12: Summer and winter average Temperature of Walga catchment

3.7.4. Wind Speed

Only the Ambo and Woliso stations have wind speed data. These data were applied consistently across the watershed. Summer and winter wind speeds are 1.12 m/s and 5.37 m/s, respectively.

Annual wind speeds are 3.84 meters per second, 2.13 meters per second, 3.24 meters per second, and 0.26 meters per second, respectively

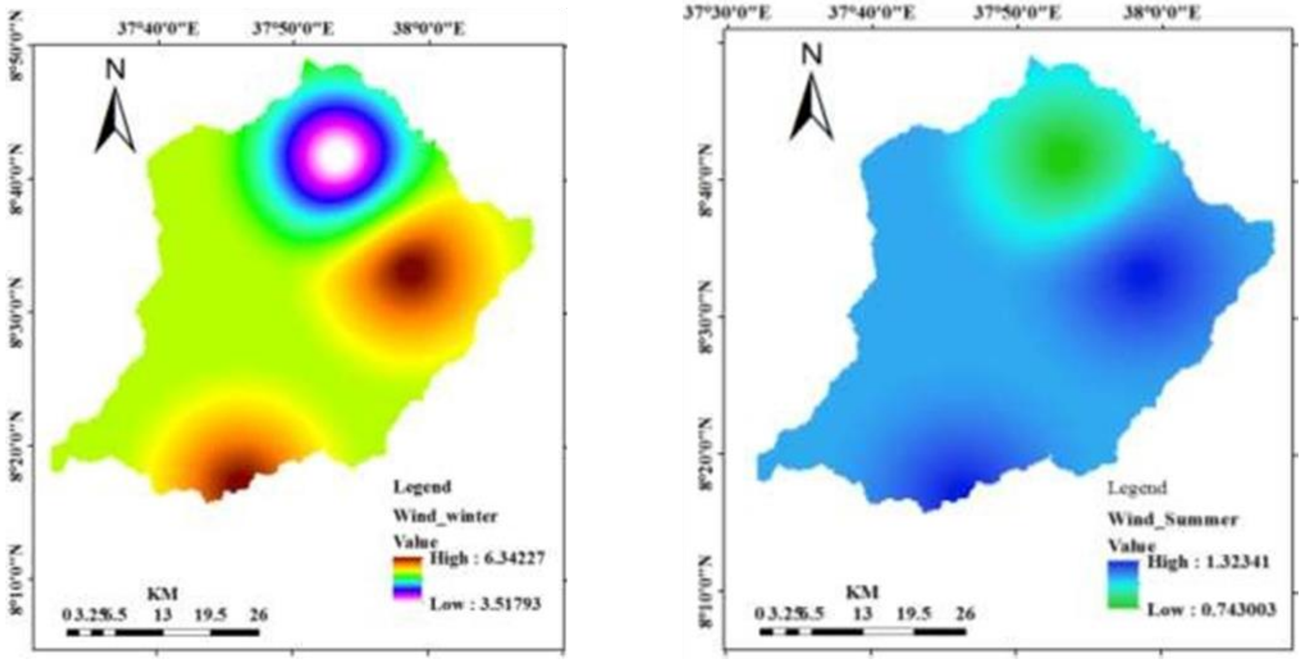


Figure 13: Summer and winter average wind speed map of Walga catchment

3.7.5 Potential Evapotranspiration

Provided an abundant supply of soil moisture, potential evapotranspiration (PET) is the maximum amount of water that can be extracted from a land surface by evapotranspiration (ET) as the total of both evaporation and transpiration (Amatya et.al, 2014). Several different methods for estimating PET for various types of land covers, from soil surface to crop, water, and vegetation, have been developed, tested, and applied over the last few decades, ranging from empirical to temperature-based to physically-based process models. For two meteorological stations that reported minimum and maximum temperature, wind speed, sunshine hours, and relative humidity, potential evapotranspiration of the Walga watershed was calculated using FAO CROPWAT software based on Penman-Montieth. PET, like other meteorological data, the monthly results were split into two seasons: four months of summer (rainy season) and eight months of winter (dry season) (Dray season). Finally, interpolation was used to transform the PET values of each season into spatially distributed grid maps. PET grid maps were combined with other input parameters in the WetSpass model(Tekelegn Wakjira,2020,masters thesis) to predict recharge and real evapotranspiration for both seasons (AET). Summer potential evapotranspiration is 354 mm, while winter is 982 mm, and the average annual potential evapotranspiration is 1336. 5 mm, PETs of 1311.07 mm and 1386.6 mm, respectively, are the minimum and maximum annual PETs

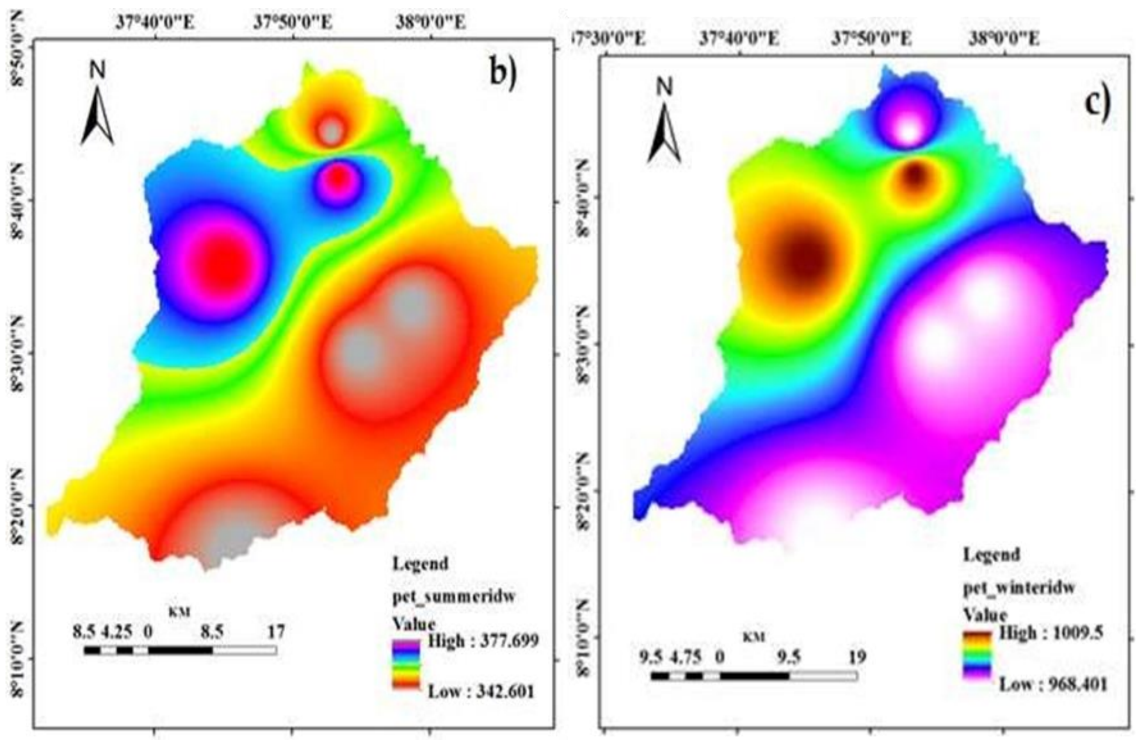


Figure 14: a) Annual PET b) Summer PET and c) Winter PET of walga catchment

3.7.6 Actual evapotranspiration

Real evapotranspiration is difficult to quantify directly, so it is calculated from potential evapotranspiration. The total real evapotranspiration per pixel in a WetSpass model is measured as the amount of evaporation from open water, impervious surface region, bare soil, interception of vegetated area, and the transpiration of the vegetated cover (Salem et al., 2019). Evaporation from open water, trees, and the ground surface are all examples of evapotranspiration, which returns water to the atmosphere and thereby completes the hydrologic cycle. Often, transpiration is the absorption of water from the soil through plant roots, the transport of water through the plant into the leaf, and the evaporation of water from the leaf's interior into the atmosphere. Real evapotranspiration is one of the water balance components used in the WetSpass model to assess groundwater recovery in the Walga watershed. The model estimated that the watershed's annual evapotranspiration will be 282.39 mm at the minimum and 1336.4 mm at the limit, with 736 as the mean AET, accounting for 54.22 percent of the overall annual rainfall lost to evapotranspiration (Tekelegn Wakjira,2020,unpublished masters thesis). The winter season loses about 58.2 percent of total annual evapotranspiration, while the summer season releases the remaining 41.8 percent. Low cloud cover, low relative humidity, and a longer time range in the winter season cause this difference. As a result, winter evapotranspiration is higher than summer evapotranspiration. Since these areas are covered by cultivated crop, forest, and also have high annual rainfall, the production annual evapotranspiration grid map shows that high annual evapotranspiration is observed in the northern, central, and north eastern parts of the catchment. Poor density of forest and woods, as well as low annual rainfall result in lower annual real evapotranspiration in the southern and southeastern parts of the catchment. The annual evapotranspiration value of the Walga river catchment varies with land-use/land-cover in general. As a result, the main influencing factors of evapotranspiration in the catchment are land use/land cover

CHAPTER FOUR GEOLOGICAL BACKGROUND AND HYDROGEOLOGY OF THE STUDY AREA

4.1. Regional Geology

Walga catchment lies within the main Ethiopian rift. The rift floor and escarpments are highly faulted due to volcanic eruption. All geological Eras and Periods are manifested in the country through their relics as basement (metamorphic), sediments and sedimentary rocks, and volcanic. The plateau and the rift part encompasses the major parts of the country (Ethiopia) including the central land mass of the country where volcanism and volcanic have played a remarkable role in the geological set-up of the area. The geological formations in the catchments include

Dendi-Wonchi Pliocene VolcanoesWachacha trachyte, Adama group (middle) welded to partially welded pyroclastic deposits, and Tarmaber

4.1.1. Tarmaber-Magezez Formation(TMP)

Tarmaber Megezez Formation (Ntb) is the name given to the younger shield volcanoes that date from the Pliocene to the Miocine epochs. Basaltic shield volcanism has been commonly used in the southern part of the northwestern plateau and the southeastern plateau, with the latter thought to mark the rifting of the Main Ethiopian Rift (EIGS, 1999). This unit is located in the center of the study area and extends to the west, east, and south. Plagioclase, pyroxene, and opaque minerals make up this fine-grained volcanic rock (EIGS, 2010).

4.1.2Wechecha Trachytes and Dendi- wenchi pyroclastic(WT)

The north east, south, north, and northwestern portions of the study area are exposed to this unit. Trachyte and pyroclastic material make up this unit. The products of Mount Dendi, an isolated elliptical cone with a NE-SW direction, are among the pyroclastic materials found near and around Wenchi and Dendi lakes. There are two crater lakes at the summit of the cone, Wenchi and Dendi, with diameters of 2 and 1.5 kilometers, respectively. A pile of ignimbrites was formed by pre-caldera volcanic activity, which was accompanied by ash flows, pumice falls, and surge deposits. Since some distal ash was found in river cut sediments on the plateau, the caldera-forming eruption's product may have been dispersed as far as Dire Inchini (WWDSE,2015).

Entoto formation (lower), trachyte lava flows with pyroclastic deposits intercalated with sediments, and upper trachyte flows and pyroclastics: upper trachyte flows with plagioclase phyric basalt, ignimbrite, pyroclastic falls and flows, and agglomerate

Oligocene volcanics: Rhyolite and trachyte flows with small basalts in the upper volcanic of Jimma.The pre-rift volcanic eruptions were of the central or fissure kind. Similarly, the Quaternary post-rift volcanic was the result of a sequence of eruptions rather than a single eruption. Woliso-Ambo basalts are a type of Quaternary volcanic composed primarily of basalts and found in the Woliso area.

4.1.3. Adama Pyroclastics, Welded to Partially Welded Pyroclastic Flows(WPF)

Along the major Ethiopian Rift and neighboring plateau margins, the Adama Group is named after a sequence of rhyolite-trachyte plugs, stratoid flows, ignimbrites, pumice, ash fall tuffs, and distinctive lacustrine sediments containing coal and lignite deposits. In the Ethiopian Rift, the Adama Group reaches a thickness of 200-300 m, although it is thinner on the adjacent plateau margins (MoWR, 1995; EIGS, 1999). The Party (Welded to Partly Welded Pyroclastic Flows) extends from Woliso to Wolkite to the south. It's a fine-grained, densely welded rock with vitrophyric fiamme and lithic fragments interspersed with ash and unwelded tuffs, as well as related Rhyolitic lava flows (GSE, 2010).

4.2 Geological and structural Setting of the study area

The geological structures, mainly faults, are oriented northeast- southwest and north-south (northwest and southeast). A fault has played a leading role for groundwater movement and storage as well as in displacing different rocks in the area. Sometimes an abruption of different lithology or the presence of volcanic outbreaks such as in the center of the town is observed mainly due to different geological structures. The hydrogeological set-up of Walga catchment is controlled by both lithology and geological structures, which is common in many cases, as manifested in the geomorphology of the area. The weathered basalt (fractured Scoraceous, etc.) and pyroclastic along with faults has the leading role in the occurrence, movement and geo-chemical properties of groundwater in the area. Based on the feasibility study documents and the field visit as well as lithological logging of existing wells, the major aquifer in Woliso area is fractured and scoraceous basalts; this forms multilayer aquifer system. Some existing boreholes in the area are artesian confirming the multilayer aquifer nature of the area. Pyroclastic, mainly pumice and tuff are also another aquifer in the area, commonly intercepted at depth. This aquifer is perceived to be the sources of high fluoride content of groundwater. There are boreholes in the area that were closed due to their high fluoride content (Woliso town water source study)

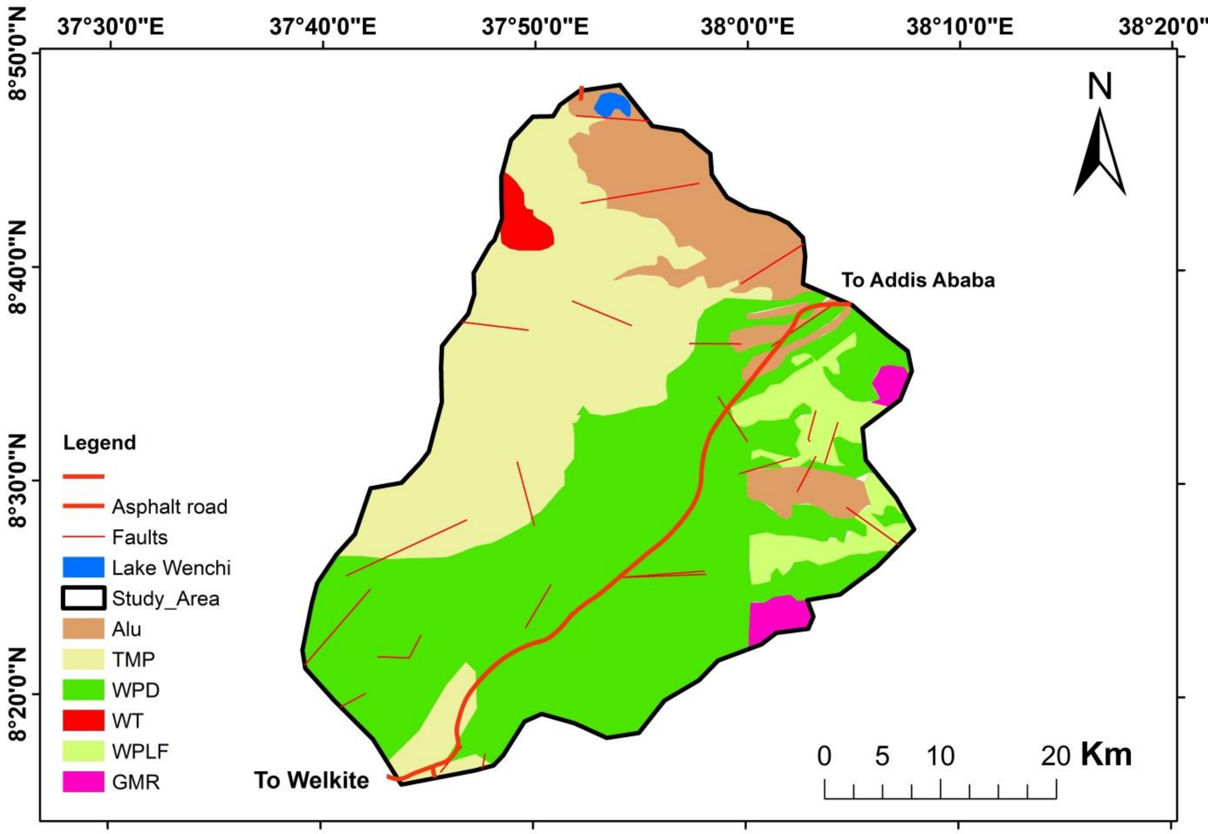


Figure 15**:** Geological map of Welga catchment (modified from ETGS)

4.3 Hydrogeology of the study Area

The hydrogeological set-up of Walga catchment is controlled by both lithology and geological structures, which is common in many cases, as manifested in the geomorphology of the area. The weathered basalt (fractured Scoraceous, etc.) and pyroclastic along with fault has the leading role in the occurrence, movement and geo-chemical properties of groundwater in the area. Based on the feasibility study documents and the field visit as well as lithological logging of existing wells, the major aquifer in Woliso area is fractured and scoraceous basalts; this forms multilayer aquifer system (source: SWSZWREO). Some existing boreholes in the area are artesian confirming the multilayer aquifer nature of the area. Pyroclastic, mainly pumice and tuff are also another aquifer in the area, commonly intercepted at depth. This aquifer is perceived to be the sources of high fluoride content of groundwater. A lot of bore holes were closed due to their high fluoride content. Ideally the occurrence, distribution, and availability of groundwater should be evaluated in terms of the distribution of aquifers and aquitards: that is, in terms of the distribution of the hydrogeological properties of the rock framework, hydraulic continuity (Toth, 2004). According to the hydrogeological characteristics, a good aquifer must be sufficiently permeable and transmissive that is porous and interconnected with enough storage to result a suitable and productive yield. Those intrinsically or secondarily openings formed within a rock which includes primary porosities and fractures or joints control the occurrence and movement of subsurface water. In the study area many shallow source springs come out through the regolith surfaces of volcanic rocks and serve as main water supply for small communities especially in the highland areas. The spring discharge varies spatially depend on geology and the degree of fracturing. The existing data shows that hydrogeological system of the catchments is composed of both porous and fissured permeable volcanic aquifers typically Tertiary and Quaternary volcanic. The fissured volcanic aquifers are composed of basalts, ignimbrites and trachytes. Basalt and partially welded pyroclastic flows of Nazerate group (mainly ignimbrite) are generally highly fractured extensive and permeable and have been classified as high productive aquifers with yield up to 5-25 l/s. The transmisivity varies from 100 to 500 m2 /d. High degree of weathering and fracturing is observed from geological log as well as vertical and lateral permeability’s can be favored by columnar jointing and inter lava flows. Thermal springs around Woliso and warm artesian well in the same area appears to be controlled by the E-W structures of the tectono-magmatically active YTVL and/or the Late Miocene protorifts with heat being derived from Pleistocene magmatism in the area (WWDSE, 2015). Analyzing available data and previous work, groundwater yield varies with respect to geology and wells depth. Tarmaber-Magezez formation, which is fractured and weathered trap serious basalts, are the most extensive and main productive aquifer of the area. Fractured Basalt is the major water bearing formation. The hydrogeological structure of the study area was divided into four hydrogeological groups. These are: 1) Extensive and high productive fissured aquifers- (T= 100-500 sq. m/d, with well & spring yield 5-60 l/s) and includes: Tarmaber-Magezez formation and partially welded pyroclastic flows of Nazret group (mainly ignimbrite). 2) Extensive and porous moderately productive Aquifers-These aquifers include Dendi-wenchi pyroclastic deposit. Transmisivity varies from 50 to 100km2 /d by spring and well discharge of 2- 5l/s. The groundwater hosting part of this unit is the primary permeability resulted from the availability of primary effective porosity. The ground water availability is highly dependent on the grain size, distribution as well as sorting. 3) Extensive and moderate productive fissured aquifers- These aquifers include Mekonen Basalt, Jima Lower Basalt & Nazret pyroclastics, (T=50-100 sq. m/d, with well & spring discharge 2-5 l/s). 4) Extensive and low productive fissured and/or porous Aquifers- These are Wechecha trachytes. (T= 1-10 m2 /d with spring and well discharge 0.05-0.5 l/s. These units are minor aquifers with limited groundwater occurrence. Based on field data together with the pumping test data analysis, the volcanic aquifer is not entirely unconfined type. Some part of the basin, typically woliso area shows Semi-confined and confined aquifer type with artesian groundwater conditions. This is presumably due to relatively thick clay (mostly altered ash) and massive basalt, as it was verified from borehole lithological logs. Previous works shows that EGS (2011) and OWWDSE (2017) the groundwater flow direction in the basin coincides with the topography following the surface water flow direction. The flow is partly controlled by the structure (Volcano tectonic lineament) and partly by the geomorphology of the area.

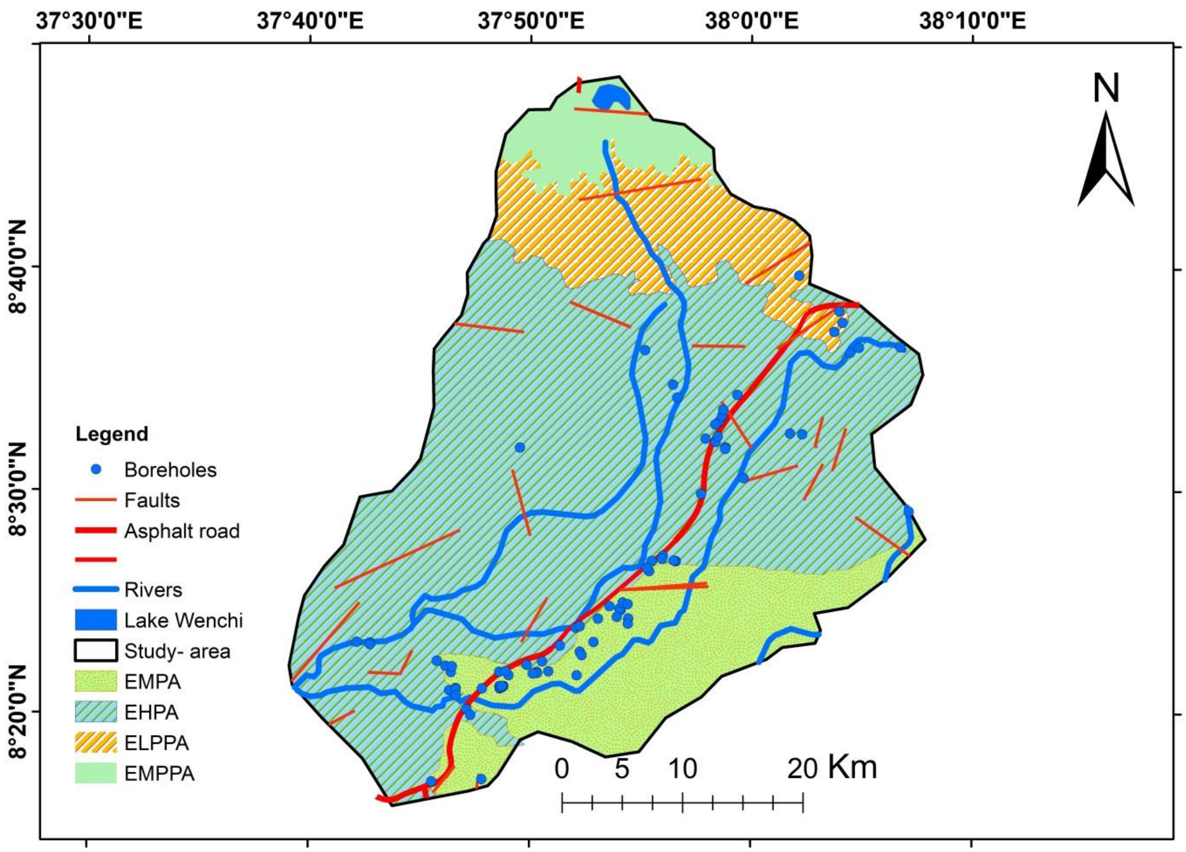


Figure 16: Hydrogeological map of Welga catchment (modified from, EGS)

4.3.1 Surface runoff

To estimate the surface runoff of Walga catchment WetSpass uses runoff coefficient which varies its value with vegetation type, soil type and slope. The surface runoff of Walga catchment shows variation with land-use, soil type, slope, topography, precipitation and the other meteorological parameters (Tekelegn Wakjira, 2020) un published masters thesis

Table 5: Run of Coefficient (RC) Calculated for Walga Basin from catchment hydrologic data

S.n	Gauging station	Area of the catchment (km^2)	Annual precipitation(mm)	Total annual Runoff (mm)	R.c
1	Welga	2222km^2	1357.43	519.16	R.c=TRo/Apn
2					0.38

This means that runoff, which is affected by lithology, structures, physiography, vegetation, land use, climate, and soil type, loses about 38% of the precipitation component from catchments.

4.4 Estimation of groundwater recharge of Welga catchment

Recharge is a crucial consideration when assessing groundwater resources, but it is difficult to measure. By subtracting seasonal and annual surface runoff and evapotranspiration, the WetSpass model estimates seasonal and annual long-term spatial distribution quantities of groundwater restore in the Walga catchment as a spatial variable based on soil texture, land use land cover, slope, and meteorological conditions by subtracting the seasonal and annual surface runoff from the seasonal and annual precipitation respectively(Tekelegn Wakjira,2020). The annual groundwater recharge in the Walga catchment ranges from 0 to 564.17 mm, with a mean value of 102.2 mm. The estimated annual recharge of groundwater is 7.5 percent of the average annual precipitation. The total groundwater recharge is calculated to be 227.7 MCM based on this. The amount of penetration into the groundwater is determined by a variation of factors, including vegetation cover, slope, soil composition, water table elevation, the presence or absence of confining beds, and others. Natural vegetation cover, flat topography, permeable soils, a deep water table, and the absence of confining encourage recharge and other factors. Natural vegetation cover, flat topography, permeable soils, a deep water table, and the lack of confining beds all aid to encourage recharge (Graf & Przybyek, 2018). Recharge areas are usually found on topographic high ground, while discharge areas are found on topographic low ground. The area's topographic configuration alone might not be sufficient to identify it as recharge and discharge areas. Land use/land cover, soil types, and land morphology all play a role in dividing an area into recharge and discharge areas. Precipitation is higher in the highlands than in the lowlands..

Because of the sand clay loam soil texture (relative proportions of clay, silt, and sand), dense forest, vegetation, and high rainfall, the northern and northwestern parts of the study area experience high groundwater recharge. High groundwater recharge is also enhanced by soil surface roughness (ploughed land), cultivated crop land and irrigation area, gentle to moderate slope, and lower drainage density in the eastern and south eastern parts of the study area. Owing to high drainage density, steep slope, impermeable clay soil, and poor ground cover, the south and south western parts of the study area have low groundwater recharge. Wonchi Lake is graded as low groundwater recharge during the summer and annual groundwater recharge maps, and the lake and groundwater recharge surface water during the dry season. Kasahun Beyene (2005) conducted a study titled "groundwater resources evaluation of the Walga river basin" over a 1786.75 km2 area, with a groundwater recharge estimate of 174.42mm using the water balance process. Abera Gonfa (2018) used the SWAT model to estimate the spatial variability of ground water recharge in the Walga catchment based on precipitation distribution, soil type, land cover, and topography (slope class).According to his research, cumulative groundwater recharge to shallow aquifers was calculated to be 315mm/yr using the SWAT model, which is 24.4 percent of the study area's annual rainfall level. Components of the annual water balance summarized in table below

Table 6: Annual water balance of Welga catchment

	Annual(mm)		
Water balance component	min	max	mean
Precipitation	1003	1827	1357.43
Evapotranspiration (AET)	282.39	1336.4	736
Runoff (RO)	99.6	1244.76	519.16
Recharge (GR)	0	564.17	102.2
Change in storage	P-AET-RO-GR = 0.07		

Using the WetSpass model, the annual recharge of the Welga catchment is 102.2mm per year,(Tekeleng wakjira,(2020) un published masters thesis with a 0.07 shift in storage.WetSpass is the best approach for simulating groundwater recharge since it is a dynamic state spatially distributed water balance model. Due to high actual evapotranspiration and high surface runoff, the simulated groundwater recharge is minimal. The components of a simulated annual and seasonal water balance are shown in the annex

4.4.1 Chloride Mass balance Method

This is one of the recharge calculation approaches that uses chloride as an environmental tracer since it is highly soluble, conservative, and not readily absorbed by plants. Because of its easy data specifications, the chloride mass-balance approach is convenient and inexpensive. It also needs chlorine concentrations in precipitation and groundwater, as well as the catchment's annual precipitation. Due to insufficient chlorine concentration data in precipitation and ground water, there is some ambiguity. It is difficult to obtain chloride concentrations in precipitation that cover the entire catchment rather than some selected station from which it can be extrapolated. Recharge can be estimated by:

$$R = P*Cl^{-}_{P}/Cl^{-}_{gw} \quad (1)$$

where R is Recharge (mm/yr) , P is rainfall (mm/yr) , Cl^{-}_{P} is weighted average chloride concentration in rainfall (mg/l) , and Cl^{-}_{gw} is average chloride concentration in ground water (mg/l)

Table 7: Summary of chloride concentrations in precipitation from five selected walga catchment stations

S.N	Source of CL^{con}_{P}	CL^{con}_{P}	The source of $CL^{con}_{Gw(from}$ analysed water samples)	CL^{con}_{Gw}
1	Ameya station	0.003 mg/l	BH1	0.03 mg/l
2	Woliso Station	0.004 mg/l	BH2	0.02 mg/l
3	Wonchi Station	0.005 mg/l	BH3	0.02 mg/l
4	Wolkite Station	0.006 mg/l	SW4	0.03 mg/l
5	Darian Station	0.005 mg/l	SW5	0.03 mg/l
6	-	-	SW6	0.13 mg/l
7	-	-	BH7	0.04 mg/l
8	-	-	SW8	0.03 mg/l
9	-	-	SW9	0.06 mg/l
Average	-	0.0046	Average	0.043

P of the year = 1357.4mm , $cl_{con\ P\ average\ of\ the\ five\ station}$ = 0.0046 and $Clcon_{average\ GW\ of\ the\ nine\ bore\ hole}$ = 0.043,Therefore GWR 1357.4mm (0.0046mg/l / 0.043mg/l) = 145.2mm/yr

4.4.2 Ground water Table Fluctuation Method

The water-table fluctuation (WTF) approach is frequently used to estimate groundwater recharge but it is also criticized for several limitations, especially that it is limited to calculating local recharge because most aquifers are somewhat heterogeneous. This study aims at measuring groundwater recharge with the WTF approach on a broader geographic scale by comparing results from WTF with those obtained from alternative approaches. The WTF approach was then applied to observation wells in aquifers in the Welga watershed, where groundwater recharge had previously been assessed using a variety of methodologies. The water table fluctuation (WTF) approach assumes that water table rises are caused by recharge water entering the groundwater. To use the method, you would need an estimation of the particular yield of the groundwater level fluctuation area. The water-table fluctuation (WTF) approach uses an interpretation of water-level variations in observation wells to predict groundwater recharge. As a result, the average individual yield of the 20 bore holes was 6.77, and the water table fluctuation was 16.66m. The recharge of the area was estimated to be 112.8m by using R=h*sy, i.e. 16.66*6.77

Table 8: The following is a general description of the ground water recharge estimation system used in the catchment

S.no	Estimation method	Recharge value	Uncertainty
1	Water balance method	102.2mm/yr	Due to the minimal data available, acceptance is tepid.
2	Chloride mass balance method	145mm/yr	Since only one season's chlorine concentration in precipitation was used, the results were accepted with some skepticism.
3	Water table fluctuation method	112.8mm/yr	Because of the small bore hole water level calculation, it was accepted with some skepticism.
4	Average of estimated recharge of the catchment	120mm/yr	It may almost be compared to the annual recharging of the catchment.

4.5 The depth of the groundwater

For accessible locations, a deep meter was used to determine groundwater depth (static water level) through an observation pipe built during the construction of water well. South West Shoa Water Resource Development and Energy Office and Ethiopian Construction Design and Supervision Works Corporation provided groundwater depth and spring data for inaccessible bore hole sites (ECDSWC). The surface elevation was subtracted from the measured static water level, and a raster map was generated using kriging spatial interpolation.

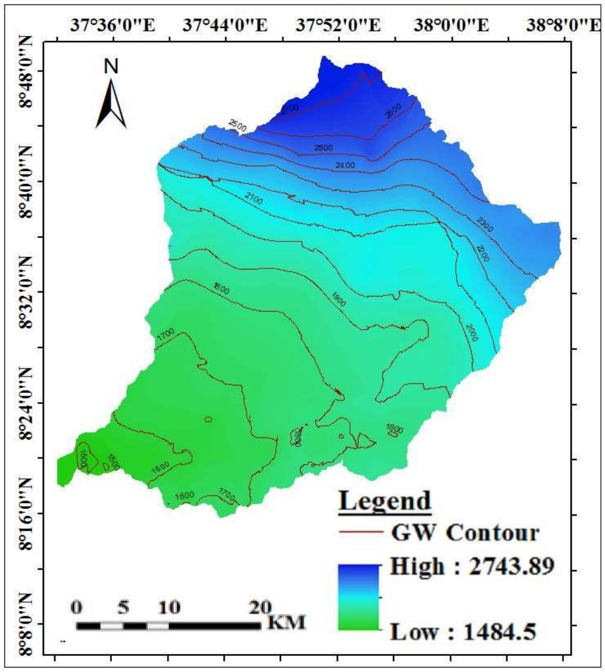


Figure 17: Groundwater depth and its contour map

4.6. Welga catchment discharge status (l/s)

The Walga catchment's topography varies from low land to very high elevated fields. Areas of recharge include topographically elevated lands such as the Wonchi, Beda Kero, and Roge mountains. The presence of springs at the intersection of the elevated and low land areas characterizes discharge areas, which are mainly found at the foot of mountains. The existence of shallow ground water depths up to 6 meters and an abundance of artesian style springs and bore holes in areas starting from Senkole down to Weliso and Walga can be called discharge zones. The presence of several contact springs at various elevations means that there is a shallow groundwater circulation in addition to the regional flow of groundwater

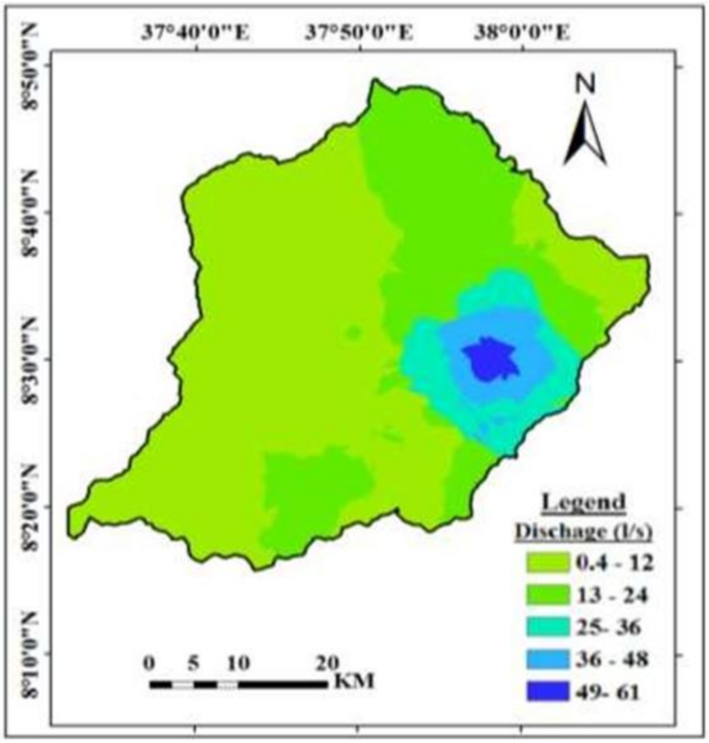


Figure 18: Spatial distribution of groundwater discharge using IDW

Government and non-governmental organizations provided data on groundwater discharge measured from a bore hole during a pumping test. The yield in the sample area varies from 0.4 to 60.7 liters per second. In the field, the average borehole yield is 3.6 l/s. In ignimbrite and basalt volcanic rocks around Woliso, a high discharge well producing 60.7 l/s was discovered, while low discharge wells producing less than 1 l/s were also discovered. At Meti walga, 5 km from Woliso town, free flowing (artesian wells) are formed from fractured basalt, and at Gurura town, following the Walga catchment, a freely flowing without water tapping facilities. Cold and hot springs with low topography can discharge up to 25 liters per second

4.7. Specific Capacity

A well's Specific Capacity is calculated by dividing the pumping rate (gpm) (Q) by the drawdown in feet (s). Specific capacity can also be used to calculate the well's design pumping rate or overall yield, as well as the transmissivity of the formations penetrated by the well screens.

$$Sc = Q/\Delta S \quad \ldots\ldots X1$$

Where Sc is specific capacity, Q well discharge and ΔS is change in draw dawn

The initial Specific Capacity can be used to estimate a well's maximum pumping rate. The maximum pumping rate is determined by multiplying the Specific Capacity by the maximum drawdown available.

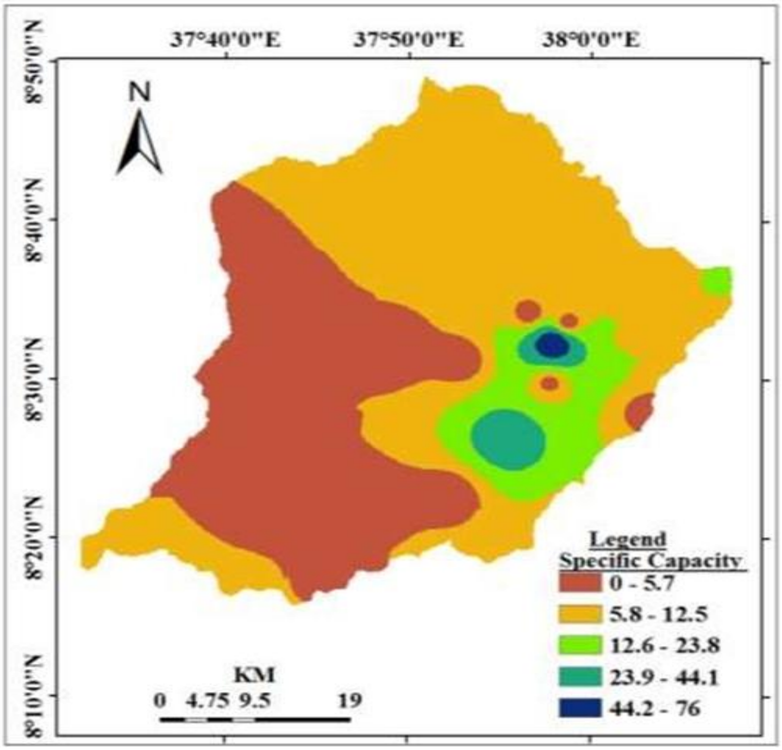


Figure 19: Spatial distribution of specific capacity of Welga catchment using IDW

The initial Specific Capacity value can also be used to calculate the aquifer's transmissivity (T). The rate at which water is transmitted through an aquifer with a unit width and a unit hydraulic gradient is known as transmissivity. It's calculated by multiplying the aquifer's hydraulic conductivity (K) by the thickness of the aquifer (b).The greater the aquifer's capacity to move water and the lower the well's drawdown, the higher the transmissivity

4.8. Transmissivity (T)

Pumping tests are the most accurate way to determine aquifer parameters. This test entails drawing water from a well at a certain temperature and watching the water level change. The period between the start of pumping and the start of an appreciable flow of water from the aquifer to the well is largely determined by the aquifer's transmissivity (Khadri & Moharir, 2016). The rate at which water of a given density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient is called transmissivity (m2/day). It can also be described as the amount of water that can be transported horizontally through a unit width by the aquifer's full saturated thickness under a hydraulic gradient. It is determined by the liquid's properties, the porous media's thickness, and the thickness of the porous media. Since single well aquifer testing may provide the benefit of Transmissivity while avoiding the expense and accessibility of multi-well aquifer testing, the test data is generally analyzed using Cooper-(1946) Jacob's straight line process. As it is shown on the following map the transmissivity of the study area faces high at the north east part due to the geology (wechecha trachyte) and has high hydraulic gradient

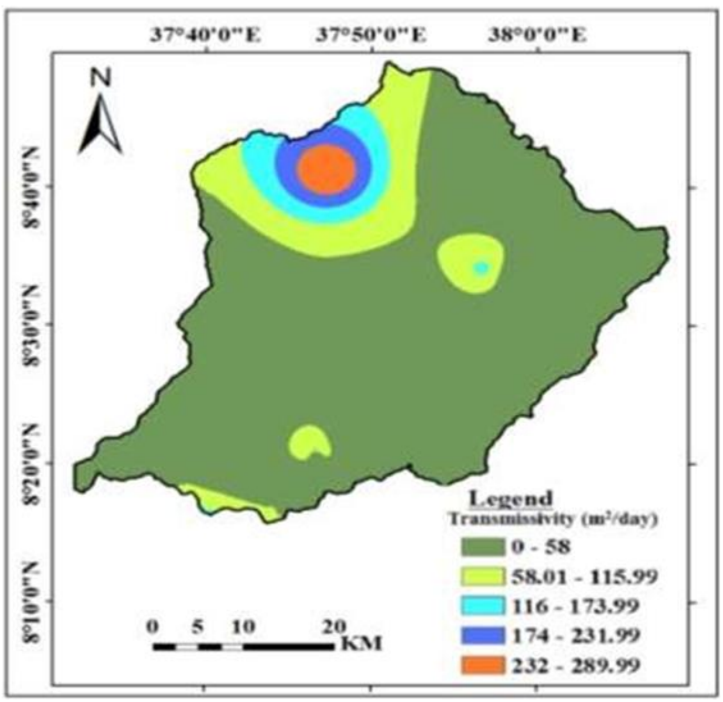


Figure 17: Using IDW, display the spatial distribution of transmissivity in the Welga catchment

4.9 Hydraulic conductivity (K)

The ease with which water can pass through a unit thickness of an aquifer is measured quantitatively as permeability. The expression connects hydraulic conductivity K and transmissivity T. As a result,

$K = T/b$

…………………………………………………………………………………………………..x2

Where b = saturated thickness of the aquifer, which is equivalent to total screen length (Tse & Amadi, 2010). As it is shown on the following map hydraulic conductivity of welga catchment faces high at the north east part due to the geology (wechecha trachyte) ,has high hydraulic gradient and other geological structural control

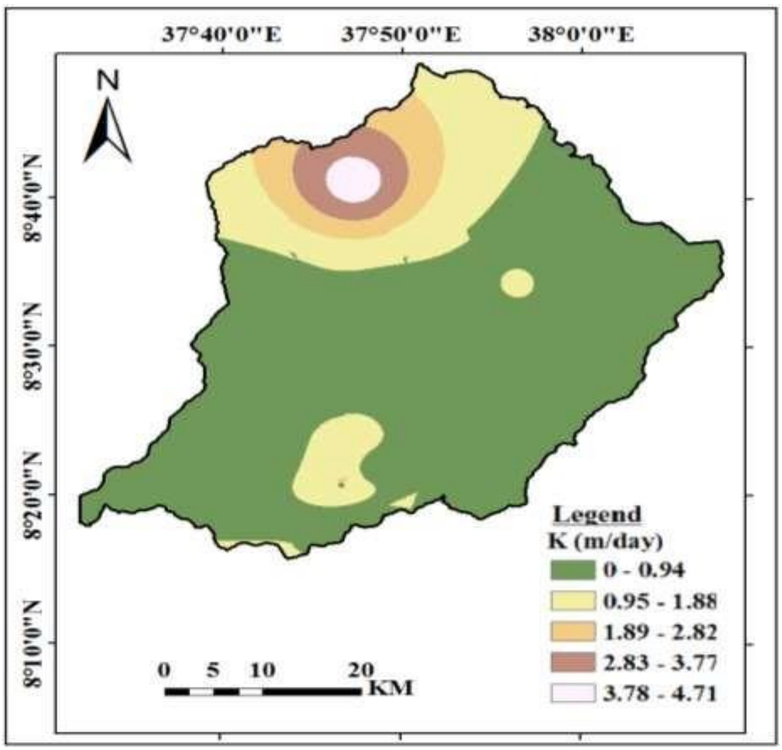


Figure 18:The distribution of hydraulic conductivity in the Welga catchment

4.9.1. Characterization of the Aquifer in the Welga catchment

Pumping tests are one of the methods used in the study area (Walga catchment) to assess the performance and efficiency of a well, as well as to define and parameterize the hydraulic properties of an aquifer for a large number of bore holes. On a single well, step drawdown, constant discharge, and recovery tests were performed to estimate hydraulic parameters. The hydraulic properties of the aquifer were calculated from the pumping test by using computer software called AQUIFER TEST to match mathematical models (type curves) to response data (water level changes). The Cooper Jacob's Straight-line was used to analyze the drawdown pumping test results over time. Since it is based on the most basic assumptions, this approach was chosen. Table below shows borehole properties such as depth, screen intervals (assumed aquifer thickness), static and dynamic water levels, drawdown, and yield, as well as the Cooper-Jacob aquifer constants T, K, and Sc.

Table 9: Summary of aquifer properties

Properties	Max	Min	Ave
Well Depth (m)	473.58	12	105.35
SWL (m)	98	0	17.66
Q (l/s)	60.7	0.15	4.09
Sc (l/s/m)	75.79	0.0167	9.39
DD(m))	147.8	3.72	45.66
T (m2 /day)	290	0.00045	50.94
K (m/sec)	16.04	0	1.2

In the Welga catchment, government, private, NGOs, and cooperation have drilled wells ranging in depth from 12 meters (hand dug wells) to 474 meters (bore holes), with an average depth of 105 meters. Yield or discharge (Q) rates vary from 0.15 to 61 liters per second (figure 21). The 72 boreholes' average discharge rate is 4.09 l/s. The lithologies of cracked basalt and ignimbrite aquifers produce the highest discharge in the Walga catchment, while pyroclastic collapse produces the lowest. The average transmissivity is 50.94 m2 /day, with a range of 3.5 x10-4 m2 /day to 290 m2 /day. The lowest transmissivity values of 3.5x10-4 m2 /day indicate weak permeability in pyroclastic lithologic formations, as well as low well discharge. The low T values also mean that it would take a long time for the aquifers to replenish the water that was pumped out of the wells. The hydraulic conductivity varies from 0 to 16.04 m/se, with a mean of 1.2 m/s (figure 24). The average yield from 72 boreholes is 430 liters per second (119.4 m3 per hour), or 37152000 liters per day. In most boreholes, cover drawdowns of 3.72 to 147.8 meters were reported, indicating the aquifer materials' relative inefficiency as hydraulic structures

4.9.2 Map of Ground water potential zoning

Groundwater potential zones map were delineated and graded using all of the thematic maps as follows: very good (most critical, high groundwater potential), good (important), satisfactory (less important), and bad (not much important) potential zones (figure 34 Alluvial plains, lacustrine sediments, fracture valleys, and valley fills, which lead to low slope and high lineaments density areas, are very strong potential zones. Structured hills and escarpments, which lead to high run-off, are mostly found in the good areas. Mountain peaks, plateaus, and escarpments with steep cliffs, where consolidated pyroclastic fall and less eroded acidic rocks occur, have poor groundwater potential areas. According to the table below, 65.8% of the Walga catchment is covered by areas with satisfactory groundwater potential, 0.72 percent by areas with very good groundwater potential, and 1.53 percent by areas with no groundwater potential. Strong groundwater capacity covers a low groundwater table, gentle slope, and low drainage density.

Table 10: Groundwater potential zone coverage in the Welga catchment

No	Groundwater potential zone	Area Coverage (km2)	Percentage
1	Very good	16	0.72
2	Good	712	31.96
3	Satisfactory	1466	65.80
4	Poor	34	1.53

Due to high human activity, drainage, and geomorphology, the total ground water potential zone in the Welga catchments is very limited, but the general ground water potential zone is dependen t on geology, geomorphology, and different geohydrological properties such as hydraulic conduc tivity, storativity, trasmissivity, and others

4.9.3 Hydro-geochemistry and Subsurface water quality

Water quality refers to the chemical, physical, and biological characteristics of water, usually in terms of its suitability for a specific reason. The Walga catchment's groundwater is mostly used for drinking and irrigation. As a result, quality requirements are dependent on the use of water for a specific reason, and quality levels must be maintained in water supply for various uses in order to prevent negative consequences. To put it another way, whether a given quality of groundwater is appropriate for a given use is determined by the parameters or requirements of reasonable quality for that use (Patil et al., 2012). In Ethiopian volcanic terrain and associated Plio-Quaternary sediments, Ayenew (2006) conducted a large survey to investigate the spatial variation of the major ions composition of surface and groundwater systems. Broad hydro chemical variations were discovered, which were influenced by geological, geochemical, geomorphological, and climatological factors. The study of the chemical composition of natural waters is known as hydro-geochemistry (Canora et al., 2019; Rajesh et al., 2019). Natural waters' chemical composition is influenced by both geogenic (natural) and anthropogenic sources. As precipitation hits the earth, it interacts with dirt, rock, and organic debris, naturally dissolving additional chemicals in addition to any contamination caused by human activities (Rahmanian et al., 2015).The amount of solute in the initial rain, the degree of reaction with rock and soil, the loss of constituents due to precipitation or absorption, and the loss of water due to evaporation, transpiration, or reaction with minerals are all factors that influence the level of trace and major elements. One of the most significant natural changes in groundwater chemistry, according to Rahmanian et al., (2015), occurs in the soil. Carbon dioxide is abundant in soils, and as it dissolves in groundwater, it forms a weak acid capable of dissolving several silicate minerals. Groundwater can dissolve substances it encounters or deposit some of its constituents along the way as it travels from recharge to discharge area (Nur et al., 2012).Temperature and pressure levels, as well as the types of rock and soil formations from which the groundwater flows, and probably the residence time, all influence the final consistency of the groundwater. The current research examined the hydrochemistry of groundwater in the Walga watershed in order to determine the consistency of groundwater and its suitability for drinking and agricultural purposes by analyzing laboratory results. Hydro geochemical investigations are crucial in determining the potential of groundwater resources. A basin is being studied. It contains information on: The interaction of water with geological materials or the atmosphere, Different geochemical processes that regulate the chemical evolution of ground water, The source of numerous bodies of water (both surface and subsurface), Conditions of groundwater flow and anthropologist. The primary aim of this study's hydro chemical investigations is to differentiate between the origins of various water bodies and to better understand groundwater dynamics. The data is also used to construct a conceptual groundwater flow model for the basin. Various methods have been used to achieve this goal, including: geochemical data analysis using aquifer test software for hydro chemical facies, Geochemical modeling to arrive at a definitive insite on the potential cause of certain problems and geochemical constituents and groundwater constituents

4.9.4 Water sample collected and analyzed

During this study nine water samples were collected in the field from different water bodies. The deep circulation of the recharging water may also be related with the northwest- southeast oriented fractures that are supposed to form the youngest scoria cinder cones in the area. Water samples were collected from various woredas in the study area, including Woliso, Wonchi, Goro, and Ammeya. Some parameters like TDS, PH, Eh, turbidity, etc are measured both in the field and laboratory. Representative water samples were collected carefully by prescribed standard methods. The sample are collected in one liter polyethylene plastic bottle and preserved before analysis for two days in 4 pocks without any disruption. The analysis was made in the laboratory of water resources bureau of Oromiya (Addis Ababa) between December 10, 2020 up to December 15, 2021.Accuracy of the analysis was assessed and reaction error for each sample was checked to be less than 5 % . The chemical analysis result is summarized in table below

Table 11: water sample collected from field work and analyzed.

No.	Parameter	Tsige Genba-SW	Dembeli Keta-BH	Meti walga-BH	Mari - SW	Hudad 2-BH	Bareda - BH	Leman abu	Tumi sombo 1	Tumi sombo 2	WHO Guideline
GPS	Northing	08^{0}33’46”	08^{0}35’24’’	08^{0}34’16”	08^{0}32’52”	08^{0}24’49”	08^{0}30’08”	08^{0}26’47”	08^{0}35’58”	08^{0}36’24”	
	Easting	037^{0}47’02”	037^{0}59’10’’	037^{0}56’42”	037^{0}42’53”	037^{0}40’09”	037^{0}44’16”	037^{0}55’05”	037^{0}48’32”	037^{0}46’29”	
	Elevation	1573m	1741m	1688m	1521m	1370m	1470m	1552m	1659m	1672m	
1	pH	7.3	7.55	7.8	6.09	7.17	7.35	7.7	6.51	7.17	6.5-8.5
2	E. Conductivity, µSm/cm	1685	318	837	421	683	329	462	492	428	
3	Total Dissolved Solid, mg/l	842	159.1	418	218	341	164.6	231	246	214	1000
4	Salinity , mg/l	842	153.1	411	202	331	158.4	222	237	206	
5	Turbidity. NTU	0.42	0.01	0.01	0.01	2.21	4.75	0.01	1.01	0.01	<5
6	Temperature	21.4	22.1	23.2	23	23.1	23	22.6	22.8	23.3	18-25
7	Iron, total, mg/l	5.985	0.20	0.35	0.00	0.70	0.27	0.25	0.34	0.16	0.3
8	Sulfate, mg/l	1	1	0	1	0.00	2.16	5	0.75	1.90	
9	Nitrite, mg/l	0.02	0.01	0.01	0.01	0.02	0.04	0.01	0.05	0.04	3
10	Phosphate, mg/l	0.05	0.47	0.09	0.13	0.13	0.43	0.11	0.8	0.17	
11	Chlorine total, mg/l	0.03	0.02	0.02	0.03	0.03	0.13	0.04	0.03	0.06	0.5

Nine water samples were collected in the Welga catchment (study area) and analyzed for total dissolved salt, turbidity, phosphate, nitrate, sulphate, salinity, and other parameters. According to this report, all criteria were below WHO standards, indicating that there was no health risk associated with the poor water quality in the study area (walga catchment).

Figure 19: Dembeli Ketas Artesian boro hole (around Woliso)

4.9.5. Phsio chemical parameters

In order to understand the physical properties of water, physiochemical parameters such as total dissolved solids, hydrogen strength, and water temperature have been studied in the study area

4.9.6. Total dissolved solid (TDS) and electrical conductivity

TDS stands for total dissolved solids, which refers to the inorganic salts and small quantities of organic matter that are found in solution in water. Calcium, magnesium, sodium, and potassium cations, as well as carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions, are the most common constituents. TDS levels were less than 1000 mg/l (WHO) in all of the water samples collected from the study area, ranging from 159.1 to 842. The water is suitable for drinking and agricultural use in terms of total dissolved solids

4.9.7 Hydrogen strength (PH)

The pH of water is a measurement of how acidic or basic it is. The range is 0 to 14, with 7 being the neutral value. Acidity is indicated by a pH less than 7, whereas a pH greater than 7 indicates a base. The pH of water is an extremely significant indicator of water quality. The PH value of the samples in the study area ranges from 6.09 to 7.7. The lowest value was found in a shallow well water sample from Mari, and the highest value was found in a deep well water sample from Lemman Abu near Gurura town. The carbon dioxide-bicarbonate-carbonate equilibrium in natural water is largely responsible for PH regulation. All of the area's samples had PH values that were not higher than the WHO standard (6.5-8.5)

4.9.8Temperature

The temperature of the collected samples was between 21.4 and 23.3 degrees Celsius, which is below the WHO normal (18-25 degrees Celsius), and it was safe for drinking and irrigation. Water quality for drinking and other uses can be influenced by temperature.

4.9.9Turbidity

Turbidity is a metric for determining how visible a liquid is. When a light is shone through a water sample, the amount of light scattered by the substance in the water is determined. Turbidity rises as the intensity scattered light increases. Turbidity is caused by clay, silt, very small inorganic and organic matter, algae, dissolved colored organic compounds, plankton, and other microscopic organisms (USGS, 1998). Turbidity has an effect on water quality, with turbidity levels in the Welga catchment ranging from 0.01 to 4.75, which is below WHO requirements (less than five)

4.9.9.1 Laboratory result data Collected and interpreted

Chemical groundwater result data were collected from Woliso town water supply and sewerage authority, Southwest Shoa Zone water resource development and energy office and Ethiopian Construction Design and Supervision Works Corporation (ECDSWC). A total of 148 schemes (72 BH, 13 HDW, 17SHW and 46 spring) laboratory results data were collected and analyzed using piper diagram and chart. Data collected contains physical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, temperature (T), and ions including Ca^{2+} , Na^{+} , K^{+} , Mg^{2+},Cl^{-} , SO_4^{2-} , NO_3^{-} and HCO_3^{-}

Table 12:Descriptive statistics of water quality parameters in compliance with WHO guidelines (Kurniawan et al., 2019).

Parameter	**Max**	**Min**	**Mean**	**STDE**	**WHO limits**
Temp. ^{o}C	40. 5	7.08	23.63	12.53	
Ph	9.66	6.37	7.56	0.78	6.5-8. 5
Electrical Conductivity(µS/cm)	1172.1.00	185.9	535.03	317.54	-
T. Dissolved Solid 1050c	750.6	138.47	292.7	115.12	1000
Ammonia(mg/l NH3)	1.51	0.00	0.28	0.29	25
Sodium (mg/l Na)	300.00	4.50	80.27	69.06	200
Potassium (mg/l k)	23.50	0.09	7.23	4.93	200
Total Hardness(mg/l CaCo3)	421	40	114.49	58. 57	300
Calcium (mg/l Ca)	155.80	2.28	33.13	34.96	200
Magnesium (mg/l Mg)	66.70	0.55	9.62	11.71	150
Total Iron (mg/l Fe)	4.29	0.00	0.18	0.59	0.3
Manganese (mg/l Mn)	2.20	0.00	0.14	0.31	1
Fluoride (mg/l F)	16.40	0.00	1.40	2.90	1. 5
Chloride (mg/l Cl)	127.50	0.00	15.98	21.49	600
Nitrite (mg/l No2)	1.00	0.00	0.12	0.26	1
Nitrate (mg/l No3)	84.70	0.00	10.54	17.91	10
Alkalinity(mg/l CaCo3)	948.00	5.63	238.38	160.92	200
Carbonate (mg/l CO3)	90.00	0.00	22.79	16.48	-
Bicarbonate (mg/l HCO3)	1156.60	31.72	279.26	198.58	-
Sulphate (mg/l SO4)	169.80	0.10	14.76	32.18	250
Phosphate (mg/l PO4)	23.00	0.08	1.08	4.00	50

4.9.9.2 Physico-chemical Analysis

According to Patil et al., (2012), physicochemical parameter analysis is critical for obtaining an accurate picture of water quality and comparing the effects of various physicochemical parameter values to standard values. Physical (temperature, turbidity, color, and tastes and odor) and chemical (total solids, total dissolved solids, total suspended solids, specific conductance, PH, dissolved oxygen, hardness, and alkalinity) analysis were performed on previously collected laboratory results to determine the quality characteristics of groundwater.

4.9.9.3 Classification and presentation of analytical results

Piper diagrams outline such basic concepts in a graphic technique that appears to be an efficient method in separating analytical data for crucial analysis of dissolved constituents in water sources (Tank & Chandel, 2010; Rajesh et al., 2019). The Piper diagram is divided into three sections: two trilinear diagrams at the bottom and one diamond-shaped diagram in the centre. The relative concentrations of cations (left diagram) and anions (right diagram) in each sample are depicted in the trilinear diagram. The concentrations of eight major ions (Na+, K+, Mg2+, Ca2+, Cl, CO32-, HCO3 and SO42-) are represented on a trilinear diagram by grouping the K+ with Na+ and the CO32- with HCO3, resulting in a reduction of the number of plotting parameters to six (Amadi et al., 2014). The relative concentrations of cations and anions are plotted in the lower triangles on the Piper diagram, and the two points that result are extended into the central field to reflect total ion concentrations. The Piper diagram may also demonstrate the degree of mixing between freshwater and saltwater.The Piper diagram can also be used to sort groundwater samples into different hydro-chemical facies based on their dominant ions. In order of dominance, the water in the area is dominated by Na-Cl-facies, Ca-Mg-HCO3-facies, Na-Ca-SO4-facies, Ca-Mg-Cl-facies, Na-K-Cl-facies, and facies.

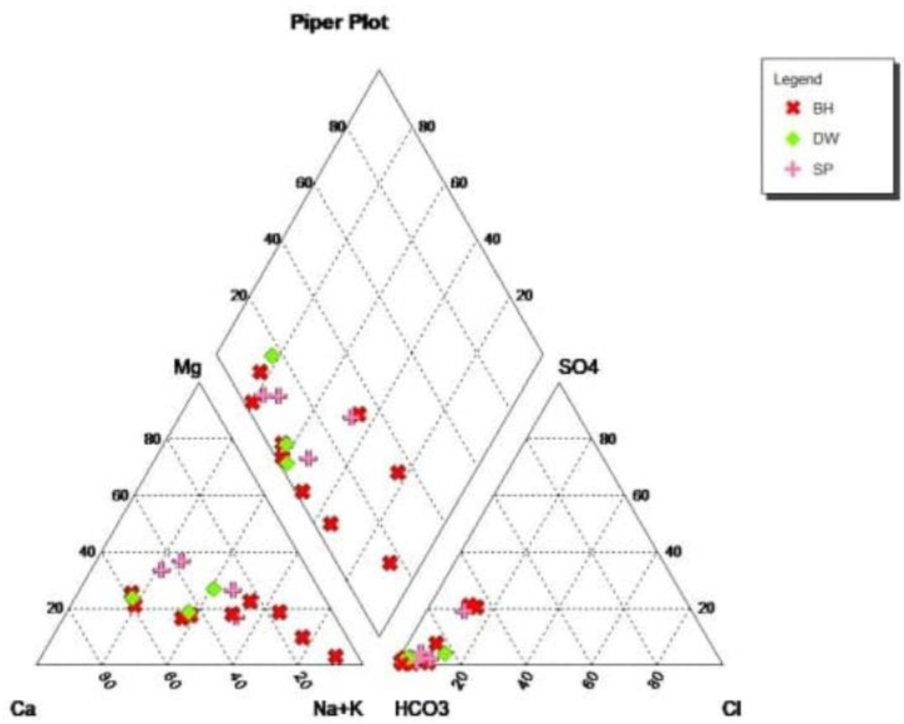


Figure 20: piper plot of hydro chemical sample presentation of walga catchment

4.9.9.4 Variations in the Quality of Drinking Water

When assessing a basin's water supply capacity, the quality of the water is just as critical as the quantity. As a result, determining the quality of natural water for specific uses in accordance with standards established by various organizations such as the World Health Organization (WHO) is required.

4.9.9.5 Fluoride

Fluoride is a naturally occurring element of water that is absorbed from certain rocks or found in geothermal waters. Fluoride enrichment of water is mostly caused by rock-water interaction (Dinu et al., 2017; Tekle-Haimanot et al., 2006). In developing countries, fluoride concentrations in ground drinking water that exceed the WHO norm value pose a significant health, social, and economic threat. The presence of high fluoride levels is predicted in the Ethiopian Rift Valley, where deep wells are the primary source of drinking water (Halford et al., 2006; Demelash et al., 2019).

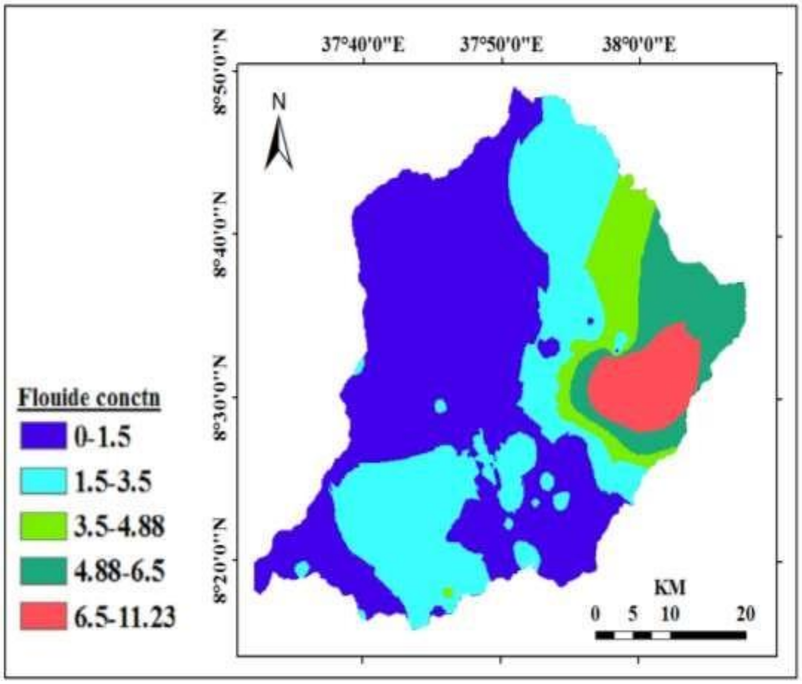


Figure 21: Fluoride concentrations are distributed spatially

Table 13: Fluoride coverage in the Welga catchment.

No	Level of Fluoride	Area km^2	Percent(%)
1	0-1.5	1099.512	49.34
2	1.5-3.5	671.1984	30.12
3	3.5-4.88	149.976	6.73
4	4.88-6.5	182.088	8.17
5	6.5-11.23	125.4528	5.63

Fluoride is helpful for calcification of dental enamel when present in small quantities (0.8 to 1.0 mg/l) in drinking water, but when present in higher levels, it induces dental and skeletal fluorosis. Fluoride levels in drinking water that are too high have been linked to cancer. The maximum amount of fluoride that can be consumed is dictated by the temperature; in colder climates, a higher amount of fluoride can be consumed (Fejerskov et al., 1994)

4.9.9.6 Industrial use

The majority of the upper limits for companies whose goods are used by humans do not surpass the human-set limits for drinking water. The American Water Works Association has set some additional concentration limits for certain industries, which are described in the table below.

Table 14: Limits on fluoride concentrations in industries (after Todd, 1980, and Hem 1992)

S.No	*Type of industry*	*Ranges in recommended limits concentrations of F- (mg/l)*
1	Brewing	1.0
2	Carbonate beverage	0.2-1.0
3	Drinking	1.4-2.4
4	Food canning and freezing	1.0
5	Food equipment, washing	1.0
6	Food processing, general	1.0
7	Canned, dried, frozen fruits and vegetable	1.0
8	Soft-drinks bottling	It is forbidden to consume more than the human body needs.

4.9.9.7. The Assumption source of fluoride in the welga catchment(study area)

Also in similar hydrogeological conditions, fluoride (F-) contamination varies, necessitating research into the geochemical processes and special characteristics of water that may be responsible for F- ion assimilation. Within the same watershed or sub-basin, groundwater with similar chemical composition or ionic make-up can have different fluoride concentrations. Reddy et al. (2010) studied the geochemistry of groundwater in the Wailpalli watershed in Andhra Pradesh, India, and found that aquifer material plays a significant role in the contribution of fluoride to the groundwater. The presence of excessive fluoride in groundwater, its negative effects on human physiology, and its source and origin in the subsurface have piqued the interest of a diverse group of scientists (e.g. Handa 1988, Jain et al. 1999, Kundu et al. 2001, Saxena and Ahmed 2001, Raju et al. 2009a). Fluorine can be found in a variety of places in nature, including rocks, soils, waters, plants and other living things, slag, and fluxes. Fluoride is required in small amounts to prevent dental caries, especially in children. Fluoride concentrations in drinking water of 1.5–2 mg/L can cause dental mottling, which is most common in children under the age of 12, and skeletal fluorosis when fluoride concentrations in drinking water reach 4–8 mg/L. (Apambire et al. 1997, Raju et al. 2009a). In hard-rock and semi-arid areas, a lack of good-quality water is becoming a major problem, and groundwater sources are increasingly declining in many parts of the Indian subcontinent (Raju and Reddy 2007). The spatial distribution and problem associated with high fluoride incidence in the Woliso area have not yet been studied. This investigation has highlighted the occurrence of high fluoride in the Woliso area and attempts to draw attention to the problem in the future. Since the area is part of the Yerer-Tullu Wellel volcnotectonic structures and was connected to the MER during its formation, it shares some characteristics with the rift in fluoride occurrence. Fluoride is often associated with volcanic activity, geothermal activity, and granite rocks in Ethiopia. F concentrations in thermal high PH waters are predicted to be particularly high (Redda, 2002). Active seismic zones and recent acidic central volcanic complexes are the only places where high fluoride concentrations can be found. (Tenalem Ayenew, 2004) .To display the distribution of fluoride in the basin, a map is generated without any buffering from the collected water samples. The Woliso area has a high fluoride occurrence, as seen on the diagram. This occurrence is concentrated along the Ambo-Butajira axis, which is the area's most recent volcano-tectonic structure. This is supported by the presence of fluoride in a thermal spring sampled along this line from Woliso town. The spatial distribution of fluoride concentration in the study area is sparse. As shown in fig 28, the eastern part of the study area (woliso area) has high fluoride content, which may be due to rock contact or lithological form. Another aspect is the high expansion of farm land in the eastern part of the area. Farmers use fertilizer for their farms over several years, and that fertilizer may be sour.

4.9.9.8. Hardness

When water is evaporated in boilers, metallic ions react with sodium soaps to form solid soaps or scummy residue, and when water is evaporated in boilers, negative ions react with solid boiler scale to form solid boiler scale (Camp, 1963). Divalent cations like calcium and magnesium, as well as alkaline earth metals like iron, manganese, and strontium, are the most common sources. It's a measure of the concentration of alkaline salts in water, mostly calcium and magnesium. Hardness is usually expressed in milligrams per liter equivalent $CaCO_3$ as the total concentration of Ca^{2+} and Mg^{2+}. The amount of calcium and magnesium concentrations, both expressed as $CaCO_3$ in mg/l, determines total hardness. Calcium and magnesium concentrations, both expressed in milligrams per liter of $CaCO_3$.

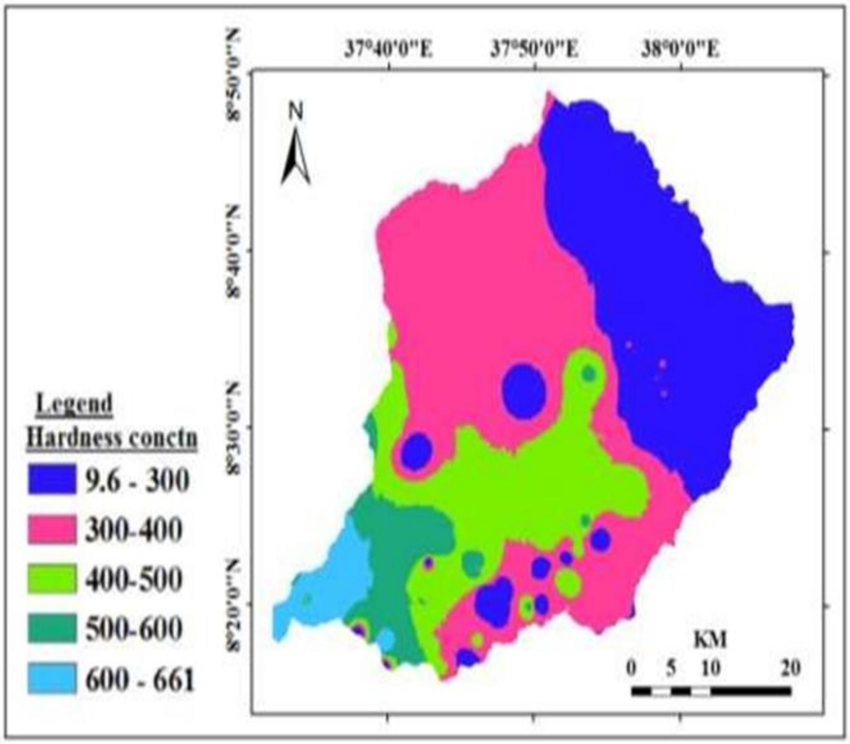


Figure 22: Total Hardness of the Walga Catchment: Spatial Distribution

Table 15: Hardness coverage in the Welga catchment.

No	Hardness	Area	Percent (%)
1	9.6 – 300	725.9184	32.58
2	300-400	858.9888	38.55
3	400-500	419.3568	18.82
4	500-600	143.7552	6.45
5	600 – 6615	80.208	3.60

4.9.9.9. Water quality in irrigation systems

Since salts can affect both soil structure and crop yield, salinity levels are the primary water quality in most irrigation situations. Because of sodium's impact on the soil, irrigation water containing significant quantities of sodium is of particular concern and poses a sodium threat (Tank & Chandel, 2010). SAR, or sodium adsorption ratio, is a common way to express sodium hazard.

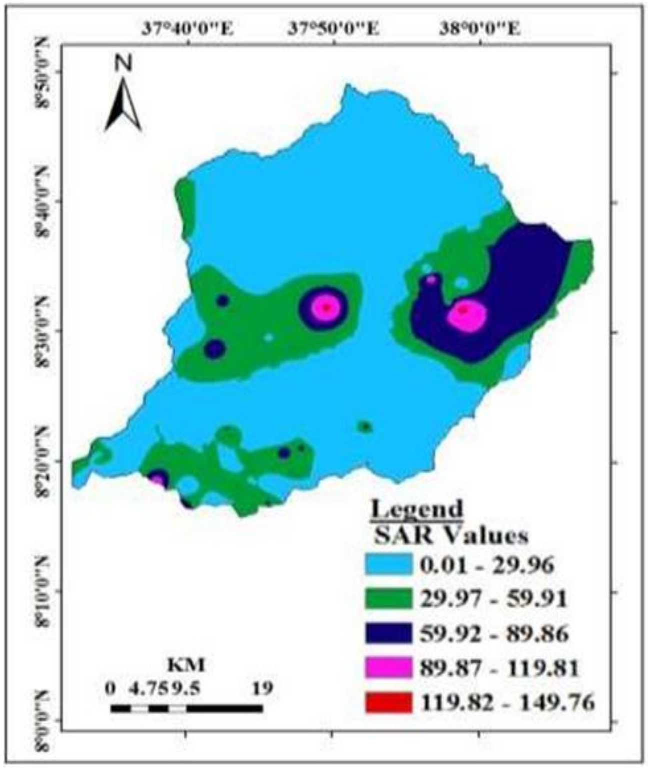


Figure 26:The Welga catchment SAR values are distributed spatially

The TDS (total dissolved solids) or the EC (electrolyte content) of water are commonly used to determine its salinity (electric conductivity). TDS (total salinity) is measured in parts per million (ppm) or milligrams per liter (mg/L) units (Kumar, 2014). The EC is an excellent indicator of crop salinity risk. Excessive salinity inhibits the absorption of water and nutrients from the soil by lowering osmotic activity in plants (Tank & Chandel, 2010).

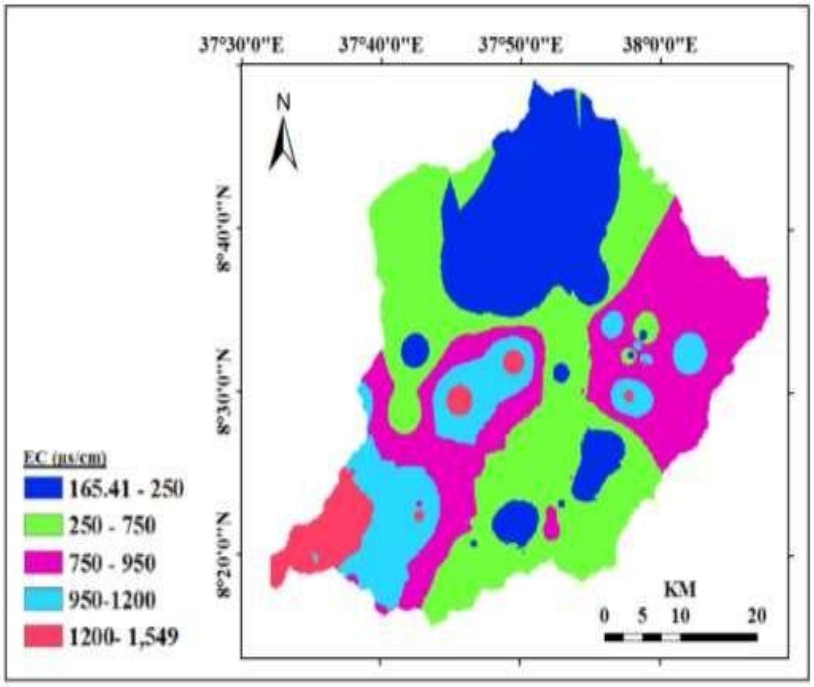


Figure 27: The EC distribution in the Welga catchment

The sodium content of irrigation water is usually expressed as a percentage of the total sodium content. Irrigation water can contain up to 60% sodium, according to Indian standards. To calculate percent Na, Tank and Chandel (2010) devised the following equation

$$Na\% = (Na^{+}+K^{+})100/(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}) \ldots\ldots\ldots\ldots x3$$

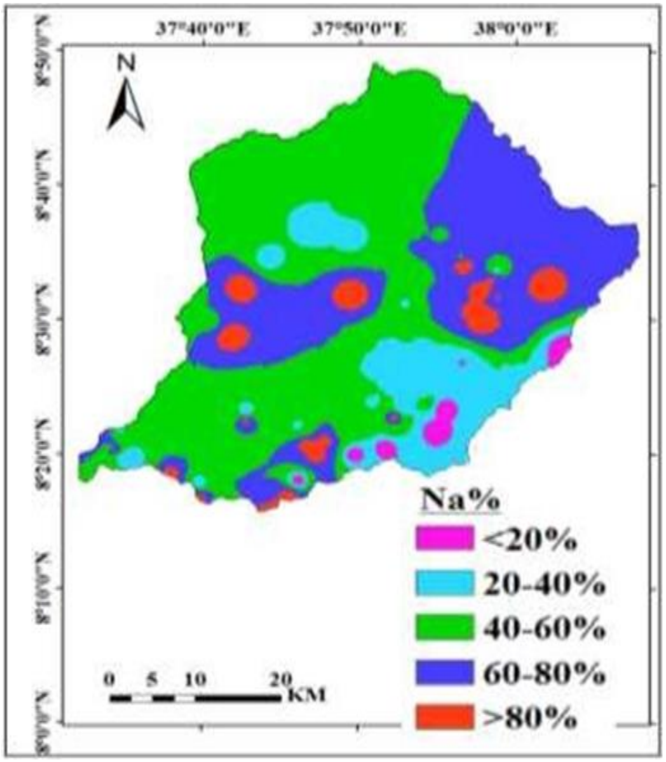


Figure 28: The percentage of sodium in the Welga catchment is distributed spatially

Table 16: EC distribution across the Welga catchment.

No	EC (µs/cm)	Area	Percent (%)
1	165.41 - 250	517.133	23.2
2	250 - 750	770.026	34.6
3	750 - 950	569.275	25.5
4	950-1200	268.978	12.1
5	1200- 1,549	102.816	4.6

Table 17:Evaluation of irrigation water quality using EC and SAR (adapted from Tank and Chandel, 2010)

Water class	Excellent	Good	allowable	Doubtful	Unsuitable
EC (μs/cm)	0-250	251-750	751-2250	2251-3000	3000
Na%	<20%	20-40%	40-60%	60-80%	>80%
Sodium hazard of water	Low	Medium	High	Very high	-
SAR values	1-10	10-18	18-26	>26	-

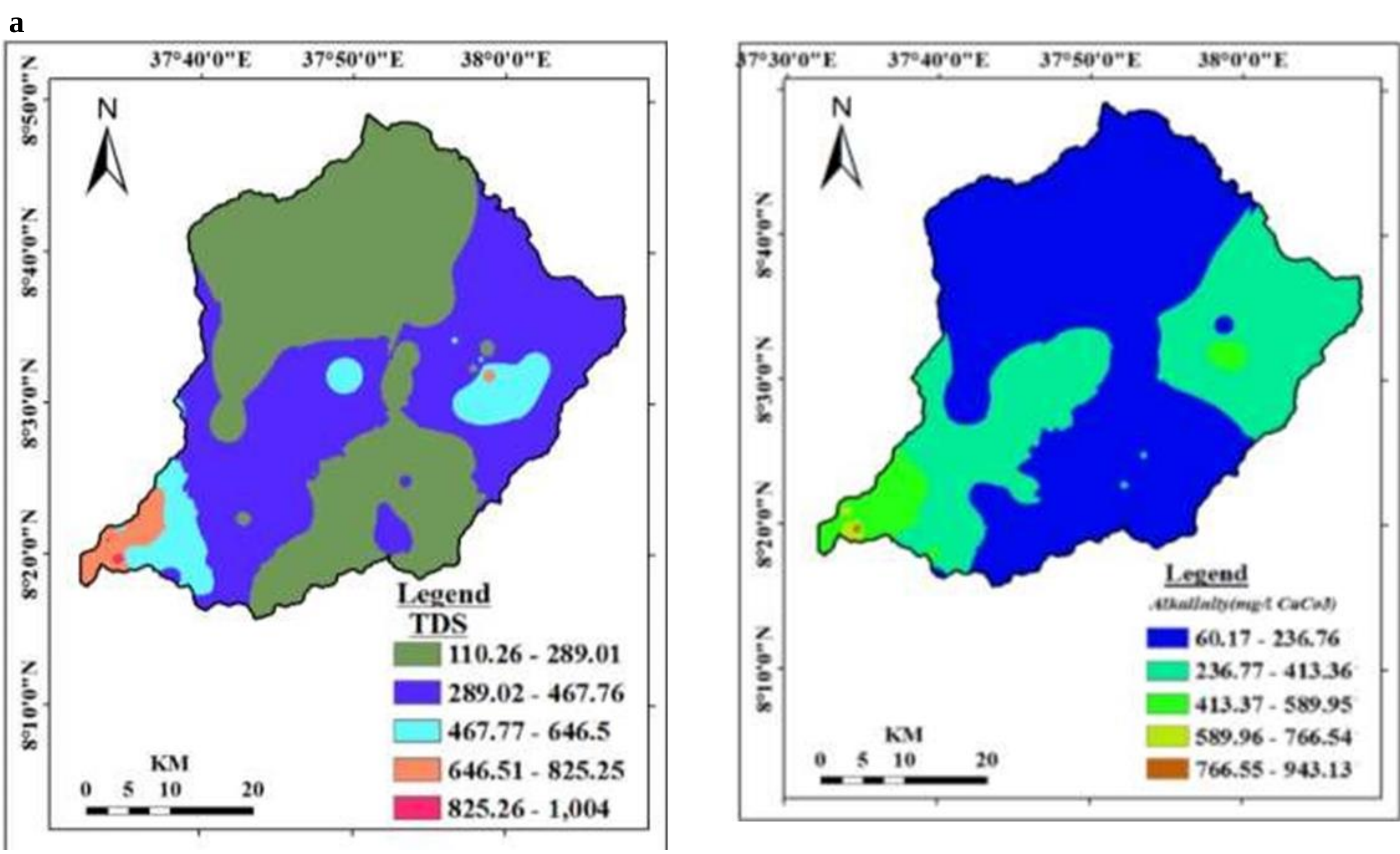


Figure 29: a, Spatial distribution of TDS and b, Spatial distribution of Alkalinity in mg/l of CaCO3 in the Welga catchment

CHAPTER FIVE RESULT AND DISCUSSION

5.1. Result

5.l.1 Groundwater Potential Zone condition

Ground water resource in walga catchment were unevenly distributed in spatially and temporal domains. Effectively utilizing the ground water resource was an imperative task due to climate change and expansion of human activity to the area. Using geology, hydrogeology characterization, and hydro geochemistry the area has low ground water potential zone and to improve this condition the artificial recharge reforestation and minimizing abstraction rate must be implemented to the area. The recharge state, aquifer characterization by using complete pumping test data, and water quality (hydro chemistry) were all factors in the evaluation of ground water resources. Recently, groundwater has been the subject of extensive investigation and analysis in order to alleviate the catchment's water scarcity. Geology, soil type, geomorphology, precipitation, and runoff are all factors that influence ground water potential. The study area takes into account all parameters (walga Catchment). Even though for future water management, the ground water potential zone condition provides assessment and prediction with information about the ground water potential condition to use wisely. The Walga catchment was divided into four groundwater potential zones after a spatially analyzed weighted overlay analysis of different thematic maps. The area has a very good groundwater potential of 46.6 km2, while 0.87 km2 of bare impermeable rock has a very poor groundwater potential. Good groundwater potential is defined by a high amount of rainfall, a gentle slope, fractured rocks, low drainage density, adequate groundwater coverage, and a sand clay loam area

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5.1.2. Ground water and surface water interaction

To better understand the relationship between surface and groundwater, various physical, chemical, and biological investigation approaches can be used. Various hydro meteorological, hydrogeological and geomorphological physical parameters are studied in the Walga River Basin. The Walga River flows down from the highlands of Wonchi caldera (3360m.a.s.l.) to the lower Walga town area of the basin gauging station (1164m). The river flows through medium, moderate, and high permeability aquifer systems. The basin receives a lot of rain in the summer, but it is dry in the winter. During long dry winters, the bottom of the stream channel is still above the local water level in the basin, as shown by hand dug wells. As a result, during the summer, the high amount of rain that occurs in the Walga basin saturates the subsurface formations that contribute to the Walga River's flow, allowing it to gain rather than lose its initial volume of discharge. During long dry winters, on the other hand, the water level gradually drops below the river channel's bed, and the stream starts to feed ground water, resulting in the stream becoming a losing stream. As a result of this condition, the surface and ground water in the basin interact continuously. The lake's bed also serves as a groundwater source.

5.2. Quality of Groundwater

5.2.1. Drinking water

Table *(12)* shows a statistical overview of groundwater data. The pH of most groundwater varies from 6.37 to 9.66, with a mean of 7.6. The pH of water is used to determine whether it is acidic or alkaline, and the majority of the water samples from the Walga catchment are classified as alkaline, indicating that the water has been disinfected and is above the WHO maximum limit. The maximum pH value of 9.66 was measured at Goru kersa site of Goro woreda and the minimum pH value of 6 was measured at Galeyi rogda deep bore hole of 459m depth extracted from fractured basalt aquifer.

5.2.3. Electrical Conductivity

Water's ability to conduct electric current is known as conductivity. Electric current is carried through water by the presence of dissolved solids such as calcium, chloride, and magnesium. At the Kulit/shola ber shallow bore hole site downstream of the Walga catchment, the maximum electrical conductivity was 1172.1 S/cm, while the minimum was 185.93 S/cm. Mineral water is expected to have high mineral content, resulting in a higher conductivity value, according to Rahmanian et al., (2015). They went on to say that conductivity has no direct effect on human health. It's used for a variety of things, including determining the mineralization rate (the presence of minerals like potassium, calcium, and sodium) and estimating the amount of chemical reagents used to treat the water.

High conductivity can reduce the visual value of water by imparting a mineral taste to it. The conductivity of water is crucial to monitor in both industrial and agricultural activities. The spatial distribution map of EC (S/cm) in the Walga catchment shows that the northern part is classified as low EC, while the southern part is classified as high EC. High conductivity water can corrode the metal surfaces of equipment like boilers and home appliances like water heaters and faucets.

5.2.4. Total Dissolved Solids

The maximum inorganic matter and minimum amounts of organic matter (TDS) found in a water sample from the area are 750.6 mg/l and 138.47 mg/l, respectively, with a mean of 292.7 mg/l (figure 33). The WHO has set a limit of 1000 mg/l as the maximum allowable concentration. All water samples from the Walga catchment, on the other hand, are below the maximum allowable limits.

5.2.5. Fluoride

The maximum fluoride concentration of 16.4 mg/l was recorded at the Negash logde site medium bore hole of 297m depth, while the minimum, mean, and standard deviation of fluoride concentration in the Walga catchment were 0, 1.4, and 2.9, respectively. Due to high fluoride concentrations above the WHO's maximum allowable limit, many bore holes for Woliso town water supply and private bore holes (mercy, lions club, and Negash lodge) have been closed. Fluoride concentrations are distributed in space. The Walga catchment (figure 28) demonstrates that the area is significantly larger than the WHO's permissible limit. F- Concentrations are caused by soil contamination as a result of the use of phosphate fertilizers and pesticides that leach into the aquifer in this area, which is classified as intensive agriculture. Excess natural fluoride, nitrate/nitrite, and arsenic, according to WHO (2017) guidelines for drinking water quality, are the chemicals of greatest health concern in some natural waters. Chemical contaminants can be removed using some commercial water treatment technologies designed for small applications. Anion exchange with activated alumina or iron-containing products, for example, is an effective way to reduce excess fluoride levels. Fluoride concentrations have also been reduced using bone char.

5.2.6. Total Hardness

Hardness values in the Walga catchment are 421, 40, 114.5, and 58.47, respectively. Because hardness levels found in drinking water pose no health risk, the WHO has not established a guideline value for it. Water with a hardness of more than 200 mg/l may cause scale deposition in treatment plants, distribution systems, pipework, and tanks within buildings, depending on the interaction of other factors such as pH and alkalinity. It will also lead to excessive soap consumption and the formation of "scum" (WHO, 2017)

5.3. Water quality in irrigation systems

The spatial distribution of the study area shows that the study area is primarily ideal for irrigation in terms of electrical conductivity (EC).With a mean of 507.26 and a standard deviation of 174.36, the spatial distribution of EC ranges from 165 to 1549. Because it is a measure of sodium hazard to crops, SAR is an important parameter for determining groundwater suitability for irrigation. In the study area, SAR values range from 0.01 to 149.76, with a mean of 30.22 and a standard deviation of 20.68. The Walga catchment has a salinity range of low to high, according to the irrigation water quality index based on SAR values adapted from Kuma (2014). Spatial distribution of Na^{+}, percentage of sodium ranges from 0.004 to 95.9, while53 and 14.2 is the mean and standard deviation of Na%. It shows, majority of the study area is in between 40-60% which is allowable quality of water for irrigation (table 15)

5.4. Groundwater classification

The physico-chemical parameters of groundwater quality in the Walga catchment are represented by a piper diagram, which shows that the category of water type is bicarbonate, with the Na-HCO3 type leading the way, followed by Ca-Na-HCO3 type, and Mg-HCO3 type.

5.5. Discussion

5.5.1 Analyzing hydro-meteorological data

Each of the hydro-meteorological elements must be quantified in order to estimate the hydrological balance of a basin. Rainfall, wind speed, temperature, humidity, and sunshine hours are the most basic meteorological data. Groundwater recharge, actual evapotranspiration, and surface runoff have all been calculated in this manner.

5.5.2. Rainfall

The study area was characterized by a unimodal (single peak) rainfall pattern, which was based on rainfall data collected in and near the study area. It is the most important determinant of a region's hydrologic cycle. Because the hydrological cycle is so important to the ecology, geography, and land use of the Walga catchment, precipitation presents both challenges and opportunities in land and water management. Rainfall is the most important type of precipitation in the catchment. Rainfall is a key climatic variable that reveals the nature and climate of the

Walga Catchment. Summer (June-August), autumn (September-November), winter (December-February), and spring (March-May) are the four seasons in the catchment (March to May). June, July, August, and September are the most rainy months, and the rest of the year is classified as dry.

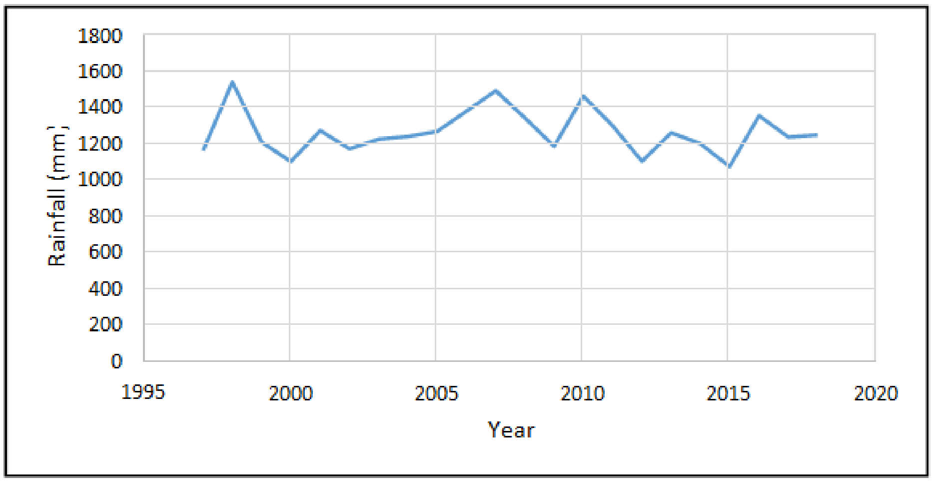

Figure 23: Annual average rainfall in the Welga catchment

The rain fall pattern over the years showed variation, with the area receiving the most and least rainfall in the years 1998 and 2015, respectively. In the year 2010, the area's rainfall also showed a downward trend.Using point rainfall data from meteorological stations, the distributed rainfall map is created using the interpolation tool by kriging in the ArcGIS spatial analyst module. As a result, the area receives an average of 1357.43 mm of rain per year. Summer rainfall averages 794.08mm, while winter rainfall averages 541.19mm (figure 10)

5.5.3. Temperature

Ordinary kriging is used to convert each season's average temperature values into spatially distributed grid maps. Four months of summer and eight months of winter were used to divide the monthly temperature data into two seasons. Temperature grid maps for both seasons were converted to ASCII files and used in the WetSpass model with other input parameters (Tekelegn wakjira,2020 ,un published masters thesis)

The National Meteorological Service of Ethiopia provided mean, minimum, and maximum temperature data collected over a 22-year period at meteorological stations in Woliso, Wolkite, Ameyya, and Ambo (1987-2018). According to the data, the Walga catchment has high temperatures in the months of February, March, and April, and low temperatures in the month of October. The graph below depicts the monthly average, maximum, and minimum temperatures at Woliso weather station over time.

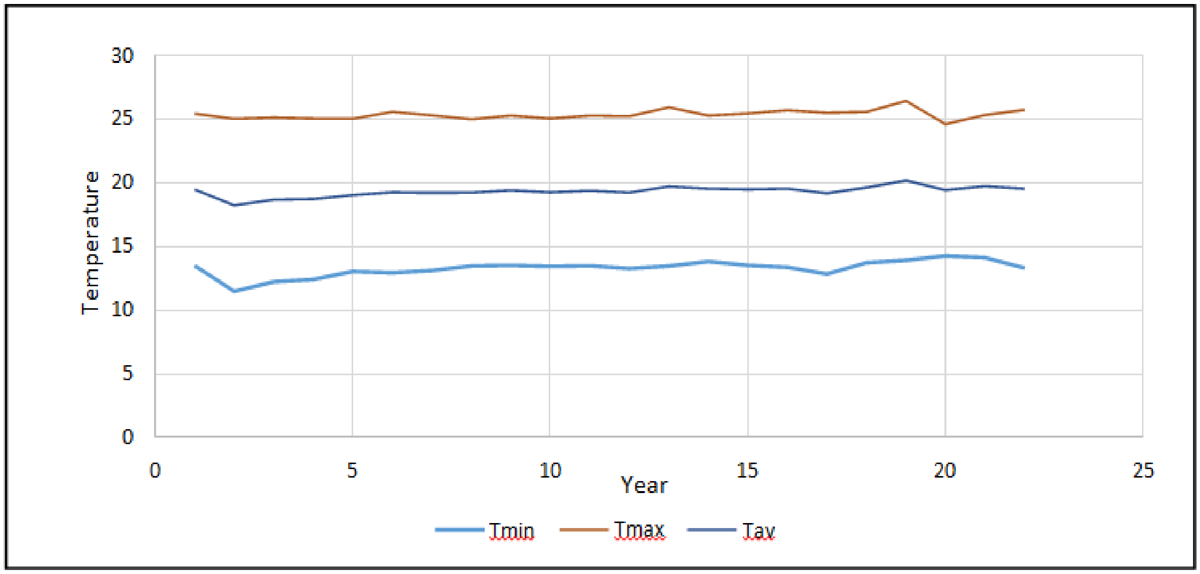

Figure 24 : Temperatures in the Welga catchment on a monthly basis, (minimum, maximum, and average)

5.5.4. Wind Speed

For a few meteorological stations, wind speed data is available. Over the watershed, these data were used consistently. Wind speed data is divided into two seasons, with four months of summer (June to September) and eight months of winter (October to February) (October to May). After that, using the ordinary kriging interpolation method, the average wind speed values for each season were interpolated and converted to grid maps. Wind speed grid maps were converted to ASCII file format and used as input parameters in the WetSpass model for both seasons. Summer and winter wind speeds are 1.12 and 5.37 meters per second, respectively

5.5.5. Potential evapotranspiration

According to Dereje & Nedaw (2019), evapotranspiration is a critical component of a basin's water budget because it removes water from the system and regulates soil moisture content, groundwater recharge, and stream flow. Using two meteorological stations that recorded minimum and maximum temperatures, wind speed, sunshine hours, and relative humidity, the FAO CROPWAT software was used to calculate potential evapotranspiration of the Walga watershed. PET calculated monthly results are divided into two main seasons, 4 months of summer (rainy season) and 8 months of winter, similar to other meteorological data (Dray season). Finally, kriging interpolation was used to convert the PET values from each season into spatially distributed grid maps. Summer average potential evapotranspiration is 354.3 mm, while winter average potential evapotranspiration is 982 mm, and the average annual potential evapotranspiration is 1336.5 mm, with minimum and maximum annual PETs of 1311 mm and 1387 mm, respectively.

5.5.6. The depth of the groundwater

For groundwater depth mapping, a total of 175 water schemes had their static water levels collected. Water depth (SWL) was subtracted from the height above sea level to get the ground water level elevation. The average depth of groundwater is 1865m, while the minimum and maximum groundwater levels are 1484m and 2592m, respectively. The Walga catchment's static water level (depth to groundwater table) varies from free flowing (artesian) to 98 meters, with an average depth of 16 meters (37). The interpolation tool by kriging in ArcGIS spatial analyst module is used to create a distributed groundwater depth map using collected groundwater data.

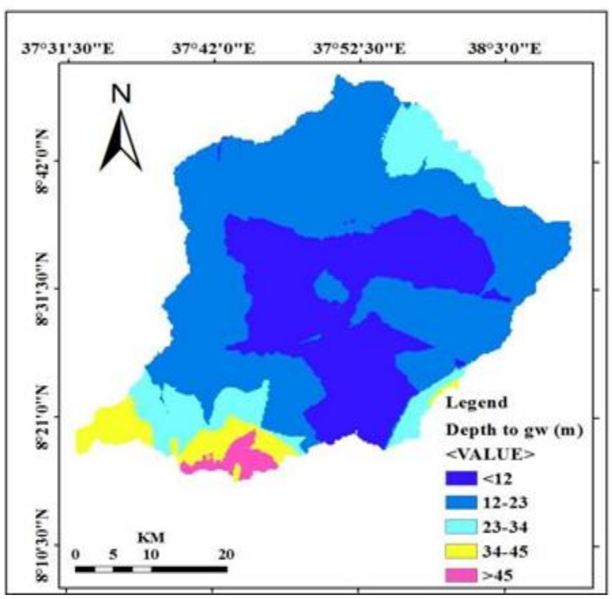

Figure 25: Spatial depth to Ground Water table in the Welga catchment

5.6. Subsurface water and surface water interaction

To better understand the relationship between surface and groundwater, various physical, chemical, and biological investigation approaches can be used. Various hydro meteorological, hydrogeological and geomorphological physical parameters are studied in the Walga River Basin. The Walga River flows down from the highlands of Wonchi caldera (3360m.a.s.l.) to the lower Walga town area of the basin gauging station (1164m). The river flows through medium, moderate, and high permeability aquifer systems. The basin receives a lot of rain in the summer, but it is dry in the winter. During long dry winters, the bottom of the stream channel is still above the local water level in the basin, as shown by hand dug wells. As a result, during the summer, the high amount of rain that occurs in the Walga basin saturates the subsurface formations that contribute to the Walga River's flow, allowing it to gain rather than lose its initial volume of discharge. During long dry winters, on the other hand, the water level gradually drops below the river channel's bed, and the stream starts to feed ground water, resulting in the stream becoming a losing stream. As a consequence of this situation, the surface and ground water in the basin communicate continuously. The lake's bed also acts as a groundwater source

5.7. Ground water quality and hydro geochemistry

Water quality refers to the chemical, physical, and biological characteristics of water, usually in terms of its suitability for a specific reason. The Walga catchment's groundwater is mostly used for drinking and irrigation. As a result, quality requirements are dependent on the use of water for a specific reason, and quality levels must be maintained in water supply for various uses in order to prevent negative consequences. To put it another way, whether a given quality of groundwater is appropriate for a given use is determined by the parameters or requirements of reasonable quality for that use (Patil et al., 2012). In Ethiopian volcanic terrain and associated Plio-Quaternary sediments, Ayenew (2006) conducted a large survey to investigate the spatial variation of the major ions composition of surface and groundwater systems. Broad hydro chemical variations were discovered, which were influenced by geological, geochemical, geomorphological, and climatological factors. The study of the chemical composition of natural waters is known as hydro-geochemistry (Canora et al., 2019; Rajesh et al., 2019). Natural waters' chemical composition is influenced by both geogenic (natural) and anthropogenic sources. As precipitation hits the earth, it interacts with dirt, rock, and organic debris, naturally dissolving additional chemicals in addition to any contamination caused by human activities (Rahmanian et al., 2015).The amount of solute in the initial rain, the degree of reaction with rock and soil, the loss of constituents due to precipitation or absorption, and the loss of water due to evaporation, transpiration, or reaction with minerals are all factors that influence the level of trace and major elements. One of the most significant natural changes in groundwater chemistry, according to Rahmanian et al., (2015), occurs in the soil. Carbon dioxide is abundant in soils, and as it dissolves in groundwater, it forms a weak acid capable of dissolving several silicate minerals. Groundwater can dissolve substances it encounters or deposit some of its constituents along the way as it travels from recharge to discharge area (Nur et al., 2012).Temperature and pressure levels, as well as the types of rock and soil formations from which the groundwater flows, and probably the residence time, all influence the final consistency of the groundwater. The current research examined the hydrochemistry of groundwater in the Walga watershed in order to determine the consistency of groundwater and its suitability for drinking and agricultural purposes by analyzing laboratory results. Hydro geochemical investigations are crucial in determining the potential of groundwater resources. A basin is being studied. It contains information on: The interaction of water with geological materials or the atmosphere, Different geochemical processes that regulate the chemical evolution of ground water, The source of numerous bodies of water (both surface and subsurface), Conditions of groundwater flow and anthropologist. The primary aim of this study's hydro chemical investigations is to differentiate between the origins of various water bodies and to better understand groundwater dynamics. The data is also used to build a basin-wide conceptual groundwater flow model. As of the date examined, the consistency of ground water and the composition of hydro geo chemistry in the Welga catchment are almost healthy

CHAPTER SIX CONCLUSION AND RECOMMENDATION

6.1. Conclusion

Water demand is increasingly growing across the world as a result of population growth, widespread industrialization, and agricultural practices. Groundwater plays an important role in meeting the ever-increasing demand for water. Groundwater makes up a sizable portion of the natural water supply system. Water is a valuable resource that requires careful preparation and management in order to make the best use of it. Identifying the amount of spatial and temporal recharge and characterizing aquifer properties are critical for effective groundwater management. In the Walga catchment, WetSpass, chloride mass balance and water level fluctuation were used to calculate long-term seasonal/annual average spatial and temporal groundwater recharge, real evapotranspiration, and surface runoff as a function of land-cover, soil type, topography, and hydro-meteorological factors. Surface runoff accounts for 38.75 percent of total annual precipitation, evapotranspiration accounts for 54.22 percent of total annual rainfall, and the Walga catchment's groundwater is recharged with 120mm/yr of annual rainfall. The average water balance of this catchment is 0.07mm, demonstrating that WeSpass provides accurate groundwater recharge estimates. Owing to high evapotranspiration and surface runoff, less groundwater recharge is simulated, resulting in a decrease in the water table. The region has a lot of farm land and a lot of loose vegetation, so the recharge is minimal. It also has a negative effect on meeting the growing demand for water in the Walga catchment. Recharge is the most common way for water to join an aquifer. Hydrogeological data was collected to classify the aquifer properties, and aquifer hydraulic properties were calculated from the pumping test by fitting mathematical models to answer data using computer software called AQUIFER TEST. The Cooper Jacob's Straight-line was used to analyze the drawdown pumping test results over time. The lithologies of broken basalt and ignimbrite aquifers produce the highest discharge in the Walga catchment, while pyroclastic collapse produces the lowest. The catchment's low T values imply low permeability in the pyroclastic lithologic formations, which translates to low discharge to wells, and that it will take a long time for the aquifers to replenish water removed during pumping. Rainfall is the primary source of groundwater recovery in the Walga catchment. Rainfall has been given the most weight when assessing the groundwater capacity of the Walga catchment. To account for varying geology, the highest scale values were given to fractured mokonnin basalt and lower jimma basalt, while the lowest scale values were given to wochecha trachyte and wonchi dendi pyroclastic fall contribution in assessing groundwater potential. By combining all of the thematic maps (Rainfall, Lithology, Slope, Groundwater depth, Soil, LULC and Drainage density) With the main north east to south west flow direction, the area has limited ground water potential. In general, the area has been evaluated using safe standards for all hydro geochemical and hydrogeological parameters

6.2 Recommendation

Owing to various factors such as deforestation, agricultural expansion (71.24 percent), population increases, and poor water resource management from society, the recharge of the walga catchment is decreasing over time. WetSpass input data and pumping test data were created using meteorological data with a large number of missing values that were filled using linear regression; the outcome can be modified with correct hydro meteorological data, soil, and land use land cover input. Since quality varies spatially and temporally, recent water sample data will alter what is presented in this work, the water chemistry used in this research is based on laboratory data collected from various offices and primary collected water sample from field work. As a result, For management and scientists interested in studying the Walga catchment, properly recorded hydrogeological and hydro geochemical data is critical. Raising public awareness about the importance of water conservation is essential. Since shallow and deep groundwater supplies receive less groundwater recharge, groundwater monitoring is a crucial first step in assessing and maintaining them. Due to the expansion of agriculture and vegetation clearance, artificial recharge is needed in the area to allow for water penetration into the subsurface and to prevent soil erosion. Further groundwater chemistry research is required in order to provide accurate groundwater information for drinking and irrigation water supply. Because of the area's complex microstructure and geology, a thorough analysis of the ground water potential zone using geophysical methods is recommended in order to obtain potential zone without losing it due to structure disturbance. In general, a complete well inventory with all pertinent data is needed for effective water planning and management, as well as making working easier for future researcher

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Annex 1 Annex I Mean monthly Rainfall of welga catchment

years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	40.37857	0.1	66.54286	107.5557	74.31429	179.9714	271.4571	178.9129	102.4143	88.79286	51.91429	0.4
1998	53.18571	35.45714	72.58571	76.4	158.2214	274.0686	330.0929	318.2743	153.43	66.93857	4.008571	0
1999	8.785714	3.485714	27.45714	20.91429	104.4143	183.3714	281.0714	272.8286	151.8957	153.0429	0.185714	3.301429
2000	1.575714	2.628571	10.61429	78.91143	90.45714	142.5271	250.5714	235.3057	187.1286	59.81429	30.48571	13.57143
2001	5.528571	10.08571	90.2	60.88571	148.6857	190.4	322.4143	256.2	117.8	55.15714	13.74286	2.357143
2002	54.98571	40.02857	129.5286	46.74286	77.3	213.2286	247.3757	234.7343	85.82857	2.998571	0	40.52857
2003	31.11429	37.82857	73.11429	115.0571	18.94286	191.8714	290.5143	275.9429	153.7114	15.51429	6.914286	15.35714
2004	61.7	19.37143	43.97	111.5857	54.67143	220.2429	261.7271	247.2857	163.0429	46.95714	5.228571	6.457143
2005	49.32083	1.997917	92.03542	110.6604	89.65833	181.575	257.55	221.3625	175.9875	61.2	27.475	0.55
2006	6.5125	27.8875	104.7375	86.86125	115.875	183.5625	296.5175	312.8313	140.2875	60.5375	23.50292	22.0875
2007	40.875	56.7	54.7375	84.125	175.5125	248.9	322.7875	270.5	205.4625	33.85	0	0
2008	0.277083	3.7	8.160417	49.00417	200.4125	206.25	326.875	276.7375	140	63.25417	67.5	1.60625
2009	31.1325	25.2275	47.11875	68.52125	82.76125	122.1125	253.1875	300.475	117.2625	106.8563	0.78125	31.2625
2010	19.95	69.7	76.325	87.4125	186.2125	188.6688	315.4813	312.4792	144.8125	9.479167	17.18958	36.375

2011	19.7625	8.39875	44.3625	91.3	154.7958	187.46	264.0517	290.4038	183.8917	14.64458	39.15625	1.23375
2012	6.271875	7.198333	23.55292	87.10313	75.44396	170.1354	271.0425	216.385	201.9531	34.62813	6.708333	4.998958
2013	2.538958	6.163333	62.21583	121.8713	134.7938	171.7646	261.0736	247.3625	152.5538	87.8125	12.53125	1.873958
2014	13.00688	37.79125	64.2125	47.17708	193.1613	143.3646	281.0958	183.8854	187.9146	40.59438	9.187292	1.417708
2015	15.73875	18.2375	55.87	42.49	143.6613	166.5963	265.6083	202.3625	122.9	7.445625	20.59104	13.90271
2016	27.91458	7.1375	54.21875	165.3	224.3338	189.1031	196.105	243.72	183.41	30.24	20.48083	13.62271
2017	2.48875	24.13875	39.57375	68.79875	138.0388	157.445	230.5263	270.9094	155.7313	112.2125	33.22688	4.585
2018	9.91875	13.85	73.6675	163.4813	189.1588	154.8013	167.8925	200.3775	107.4888	61.49875	100.0238	7.0775

Annex 2 Hydrogeological Parameters

SN	**X**	**Y**	**Z**	**Depth,m**	**SWL,m**	**Aquifer_Lith.**	**Q,l/s**	**Sc, l/s/m**	**DD,m**	**T, m^2/day**	**EC (µS/Cm)**	**Temp._ ^{o}C**	Water Point Type	**Remark**
1	358290	926080	1699	459	82.0	Fractured Basalt	11	0.1970	53	20	994	28	DBH	
2	364751	906029	1910	307	173.1	basalt	0.75		47.15				DBH	
3	370781	943250	1867	470.5	29.3	Bsaltic	16.37	0.3	53.7	43.1	974	24.7	DBH	
4	385801	939409	1953	473.6	65	Basalt and ignimbrite	60.7	2.76	22.02	6.66	920	30	DBH	
5	389562	922209	1931	450	98	pyroclastic	20.3	0.41	49.13	36	488		DBH	
6	375734	926348	1787	360	8.9	Fractured Basalt	3	0.0169	148				DBH	
7	357700	944225	1822	360	25	Basaltic	5.3	0.043	124	24	287		DBH	
8	383826	947387	2058	265	0	Fractured Basalt	22	0.2861	77	125			DBH	Artesian

9	408282	939498	2311	360	22	Pyroclastic	24	1	43	43	413		DBH	
10	363415	915588	1788	280	98	Pyroclastic	3	0	23	3	414		DBH	
11	337295	929032	1526	354	114	Fractured trachy Basalt & scoriacious basalt							DBH	
12	376617	902505	1941	347	57	Pyroclastic	25	4	7	604	425		DBH	
13	386183	943986	2023	108	0	Basaltic overlaid by Ash	5.00	76	75.79		303	29	DBH	
14	387305	945410	2052	100	0	Pyroclastic			54.66				MBH	
15	387549	945858	2067	93	0.0	Basaltic overlaid by Ash	11.10		12.68				MBH	Artesian
16	389339	940715	1992	50	28.5	Pyroclastic							SBH	
17	408475	952876	2276	50	10	Basaltic							SBH	
18	407460	953526	2277	36	9	Trachy basalt							SBH	
19	381158	951315	2099	60		Basaltic							SBH	
20	383469	948467	2071	60	0	Basaltic					150	18.4	SBH	
21	415254	939047	2378	47									SBH	
22	412826	949736	2260	50	0	Pyroclastic							SBH	
23	402350	951544	2426	60	26.73	Pyroclastic	0.18	18	16.37				MBH	
24	393964	957477	2489	61	39.12	Basaltic	0.14	6	8.58				MBH	
25	397276	954511	2394	61	17.45	Basaltic	0.55	6	36.55				MBH	
26	397540	953574	2376	60	17.93	Pyroclastic	0.15	6	34.87				MBH	
27	396861	952816	2388	36	20.48	Trachy basalt	2.17	6	4.17				SBH	
28	398182	951093	2377	62	14.13	Pyroclastic	1.30	6	32.92				MBH	
29	400409	954207	2376	48	21.58	Pyroclastic	4.00	6	4.65				SBH	
30	398901	951499	2400	60	24.43	Basaltic	1.30	12	21.03				MBH	
31	400317	931223	2150	66	38.35	Pyroclastic	0.12	23	14.75				MBH	
32	394200	944338	2214	62	36.5	Pyroclastic	0.16		18.39				MBH	
33	381500	933000	1928	100	7.33	Pyroclastic	5.60	42	3.72				MBH	
34	393191	944399	2153	47	0	Pyroclastic	20.00	12			741	40.5	SBH	

35	342165	903933	1654	45	0	Basaltic					300	24.1	SBH	
36	339077	902523	1685	60	20	Basaltic					250	20.7	MBH	
37	342000	903672	1669	60		Basaltic							MBH	
38	342369	903357	1655	8	1	Basaltic					320	18.7	HDW	
39	337131	931265	1525	39	10						320	20.7	SBH	
40	337249	931410	1538	41	15		3.00				320		SBH	
41	337246	929566	1538	52	33		3.50				480		SBH	
42	337688	927934	1548	54	11		1.50				970		SBH	
43	338664	924779	1527	51	23	Basaltic	1.75				560		SBH	
44	340300	924367	1551			Basaltic					470		MBH	
45	340966	924430	1558	130		Basaltic					500		DBH	
46	339029	924979	1519			Basaltic					520	20.8	MBH	
47	341088	924567	1557	81	35	Basaltic	2.00				400	20.9	MBH	
48	340662	924050	1547	54		Basaltic	2.50				410	21.9	SBH	
49	342102	923134	1526	58	42	Basaltic	2.50				530	22.7	SBH	
50	343453	924775	1587	61	41	Basaltic	3.50				430	23.1	MBH	
51	342266	922432	1533	54		Basaltic					500	22.2	SBH	
52	343035	921923	1547	92	48	Basaltic	3.5				500	23.1	MBH	
53	343578	920886	1540	70		Basaltic					580	23	MBH	
54	344574	921296	1549			Basaltic					390	21	MBH	
55	344752	920691	1535	69	36	Basaltic	0.50				410	19.5	MBH	
56	344600	920184	1532	81	24	Basaltic	3.00				430	20.5	MBH	
57	345006	920268	1521	82	27	Basaltic	1.75				360	21.8	MBH	
58	345108	920062	1545	74	50	Basaltic	0.50				380	21.8	MBH	
59	346814	919983	1582	74	50	Basaltic	0.50				380	22.1	MBH	
60	346819	920574	1562			Basaltic					370	21.3	MBH	
61	349391	918430	1632			Basaltic					330	21.8	MBH	
62	347338	916729	1582	78	42	Basaltic					420	20.7	MBH	

63	348795	916923	1624	115		Basaltic							DBH	
64	348571	919246	1612			Basaltic					370	24.4	MBH	
65	350867	918698	1615	52	16	Basaltic	1.00				370	20.7	SBH	
66	352791	917485	1668	10		Basaltic					390	19.5	HDW	
67	352585	915007	1691	80		Basaltic					330	22.4	MBH	
68	353117	915342	1719	39		Basaltic							SBH	
69	352065	916658	1683	90		Basaltic							MBH	
70	355341	916638	1732	204		Basaltic							DBH	
71	354023	915772	1716	84		Basaltic					320	22.3	MBH	
72	355882	914531	1541	84		Basaltic					310	22	MBH	
73	356903	915385	1761	85		Basaltic							MBH	
74	356884	914283	1716			Basaltic					350	21.5	MBH	
75	357443	913873	1722	64		Basaltic					350	20.2	MBH	
76	360489	912322	1747	82		Basaltic					280	20.9	MBH	
77	387659	946376	2065	93	0	Basaltic	11.1		12.68				MBH	
78	388820	947604	2085	148	5	Basaltic							DBH	
79	375409	928322	1846	80	7.46	Basaltic	5.6				200	23.2	MBH	
80	375733	928451	1846	14	2	Basaltic					230	21.6	HDW	
81	377246	929075	1861	12	2	Basaltic					260	17.7	HDW	
82	387025	943705	2052		9	Basaltic							HDW	
83	387835	943260	2037	297	5	Basaltic	7.50				1185		MBH	
84	387802	943130	2034	300	5	Basaltic	7.50		44.04		180	16.9	DBH	
85	386986	945147	2050	133	0	Basaltic	11.10				845		DBH	
86	383711	933823	1926	15	9	Basaltic							HDW	
87	383586	933863	1925	15	8	Basaltic					150	18.4	HDW	
88	383538	933892	1926	15	10	Basaltic					200	17.6	HDW	
89	382633	934291	1913	15	8	Basaltic					180	21.1	HDW	
90	382560	934038	1924	16	11	Basaltic					150	18	HDW	
91	381713	933854	1896	100	7.46	Basaltic	5.6				339		DBH	
92	381304	933280	1896	16		Basaltic					200	19.3	HDW	
93	379119	929764	1869	12	2.20	Pyroclastic					180	17	HDW	

94	379015	929886	1856	10		Pyroclastic					140	18.5	HDW	
95	379757	929087	1905	12		Pyroclastic	3.00				210	22.6	HDW	
96	379726	928664	1879	15		Pyroclastic					250	20.1	HDW	
97	378805	929216	1870	15		Pyroclastic					150	19	HDW	
98	378206	930111	1858	50	5	Pyroclastic					270	21.4	HDW	
99	379297	930413	1864	22		Pyroclastic					250	19.1	HDW	
100	379714	930273	1872			Pyroclastic					210	22	HDW	
101	374091	926846	1829	17		Basaltic					200	20.6	HDW	
102	376875	927146	1803			Pyroclastic					230	22.8	HDW	
103	375881	926048	1788	12	10	Pyroclastic					200	20	HDW	
104	375476	924377	1812	9	8.2	Pyroclastic					310	19.1	HDW	
105	372612	925524	1814	20	14	Basaltic					140	18.8	HDW	
106	372198	924591	1761	15	11	Pyroclastic					180	19.7	HDW	
107	372148	924659	1780	14	13	Pyroclastic					158	20.5	HDW	
108	372178	924570	1783	10	9	Pyroclastic					190	19.7	HDW	
109	371819	924542	1773	60		Pyroclastic					260	25.6	MBH	
110	373129	924713	1781			Pyroclastic					310	23.8	MBH	
111	371319	925254	1793	9	8	Pyroclastic					140	16.6	HDW	
112	369812	924396	1828	19	14.70	Pyroclastic					190	19	HDW	
113	369056	924670	1812	10		Pyroclastic					200	19.2	HDW	
114	369578	924736	1829	17	13.40	Pyroclastic					180	18.8	HDW	
115	369399	923494	1807	12		Pyroclastic							HDW	
116	369057	923489	1812	18	5.20	Pyroclastic					430	19.8	HDW	
117	369100	923299	1801	9	1.80	Pyroclastic					200	19.2	HDW	
118	369141	923357	1808	8	3.00	Pyroclastic					300	20.1	HDW	
119	369254	923373	1804	9	1.60	Pyroclastic					310	18.8	HDW	
120	369317	923493	1818	10	5.70	Pyroclastic					230	20.5	HDW	
121	369255	923511	1831	19	10.60	Pyroclastic					170	20.6	HDW	
122	367619	923308	1730			Pyroclastic					260	20.6	MBH	
123	365029	924648	1743	60	28	Pyroclastic	0.40				300	20.5	MBH	
124	363868	925587	1748	75		Basaltic							MBH	
125	364581	925183	1753	23	12.60	Pyroclastic					340	20.4	HDW	
126	365125	925132	1763	14	7.60	Pyroclastic					260	20.1	HDW	
127	358314	927117	1671	7	3	Basaltic					330	20	HDW	

128	357207	927172	1647	8	3	Basaltic					330	22.4	HDW	
129	358319	926963	1676	195		Basaltic							DBH	
130	364905	923161	1690	152	11.74	Basaltic	7.20		44.83	56.92			DBH	
131	365433	923338	1693	200	34.55	Basaltic	2.40		104	0.616			DBH	
132	365427	923242	1688	103	2.96	Basaltic	8.40		6.63	221.4			DBH	
133	365447	922747	1713	152	53.68	Basaltic	4.68		83.13	1.76	240	24.4	DBH	
134	366319	921583	1738	160		Basaltic	5.50						DBH	
135	366637	921104	1746	146	29.38	Basaltic	10.0		51.92		439		DBH	
136	369148	915960	1831	105		Pyroclastic							DBH	
137	369104	915815	1828	81	21.83	Pyroclastic	2.00		15.32	4.83			MBH	
138	372001	916722	1843	68.5	11.95	Pyroclastic	2.50		39.39	13.73	348	25.1	MBH	
139	369592	915660	1838			Pyroclastic					200	20	HDW	
140	369739	915686	1849	14	8	Pyroclastic					210	20.1	HDW	
141	367564	915793	1864			Pyroclastic					323		MBH	
142	365168	908852	1845	105		Basaltic					300	16.9	DBH	
143	365732	908980	1825			Basaltic					280	14.8	MBH	
144	364468	907392	1894	78		Basaltic					131.5	18.7	MBH	
145	358908	904545	1857			Pyroclastic					241	21.6	MBH	
146	355924	903192	1809	73		Basaltic							MBH	
147	352242	903636	1744	75		Basaltic					310		MBH	
148	393894	886062	2764	175	92.95		5.95	25.32	14.1	39.2			DBH	
149	398319	885302	2881	175							92.4	14	DBH	
150	397933	884153	2869	188									DBH	
151	399310	885059	2905	48									SBH	
152	406040	939023	2071			Pyroclastic					237	24.7	MBH	
153	403037	937939	2256	10		Pyroclastic					225	17.5	HDW	
154	387202	944167	2043		2	Basaltic							HDW	
155	347532	943211	1815	175		Basaltic							DBH	
156	349638	939008	1781	54	10	Basaltic	0.40				360	20.9	SBH	