"GROUNDWATER QUALITY MAPPING AND CHARACTERISTICS AQUIFER: A CASE STUDY IN KOLA RIVER WATERSHED, GIDABO SUB-BASIN, SIDAMA REGION ETHIOPIA.

M. Sc. THESIS

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A THESIS SUBMITTED TO HAWASSA UNIVERSITY DEPARTMENT OF WATER RESOURCES IRRIGATION ENGINEERING, FACULTY OF BIO SYSTEMS AND WATER RESOURCE ENGINEERING, HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES, HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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The research proposal, entitled: "GROUNDWATER QUALITY MAPPING AND CHARACTERISTICS AQUIFER: A CASE STUDY IN KOLA RIVER WATERSHED, GIDABO SUB-BASIN, SIDAMA REGION has been prepared by TESFAHUN BAYU CHERINET ID NO GPWREMW/0013/12, has met the required standard for submission in partial fulfillment of the requirement for the degree of Master of Science and has been approved by the school graduate committee of the School of FACULTY OF BIOSYSTEM AND WATER RSOURCE ENGINEERING

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I hereby declare that this thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been dully acknowledged.

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Lists of ACRONYMS & ABBREVIATIONS

BH	Borehole
DWL	Dynamic Water Level
DEM	Digital Elevation Model
EC	Ethiopian Calendar
FAO	Food and Agricultural Organization
GSE	Geological Survey of Ethiopia
GPS	Geographical positing system
K	Hydraulic Conductivity
IAEA	International Atomic Energy Agency
M.a.s.l	Meter above Sea Level
T	Tranisimisstvity
SW	Shallow Well
SWL	Static Water Level
S	Storativity
SNNPRWB	South Nation National Peoples Region Water Bureau
SRSWMEB	Sidama Region State Water Mine and Energy Bureau
WHOs	World Health Organization

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ABSTRACT

This research assessed the groundwater quality mapping and characterized aquifers in the Kola River Watershed. Two methodologies, ArcGIS-based and the Aquifer Test 3v methodology, were employed to achieve these objectives. Data were collected from completion reports of wells, springs, shallow wells, and boreholes within the study area. Laboratory tests were conducted on water samples collected from various sources to analyze physical parameters such as pH, electrical conductivity, total dissolved solids, turbidity, hardness, calcium, magnesium, sulfate nitrate, bicarbonate, fluoride, iron, and chloride.These parameters provided insights into the quality and composition of the groundwater.The Water Quality Index (WQI) method was applied to evaluate the water samples and quantify the overall water quality and evaluate by piper digram categorize water types. Kola River Watershed is characterized by a diverse range of tertiary volcanic rocks, including ignimbrite, basalt, trachyte basalt, rhyolite, and scoria basalt. The water quality assessment in the study area found elevated iron concentrations and high turbidity levels in some boreholes, exceeding the standards set by the World Health Organization (WHO).The Water Quality Index (WQI) results, a small percentage (0.72%) of groundwater samples in the study area were classified as excellent or good quality. However, a significant proportion (4.0037%) of samples fell into the category of good quality, and an additional portion (4.77%) were classified as very poor quality. The majority of groundwater samples (90.50%) were deemed unfit for drinking purposes.three water type so were beserved: CaHCO3 with low TDS, mixed CaNaHCO3 and NaCaHCO3 with moderate TDS, and NaHCO3 with high TDS. in the aquifer system of the Kola River Watershed, there are aquifers classified as moderately productive and mixed porous and fissured aquifers of moderate productivity.In a particular part, high hydraulic conductivity (K) values of 3.47 m/d, transmissivity (T) of 207 m2/d, and specific capacity (Sr) of 1.44 were recorded. In the central part, K ranged from 0.376 to 1.81 m/d, T ranged from 15.5 to 68.2 m2/d, and Sr ranged from 0.00127 to 0.461. In the lower part of the study area, K ranged from 0.135 to 10.2 m/d, T ranged from 7.27 to 10.7 m2/d, and Sr ranged from 0.00042 to 0.0374.

Key Words: *Spatial distribution, Groundwater Quality, Aquifers, pumping test, Hydraulic properties.*

1. INTRODUCTION

1.1 Background

Groundwater plays a crucial role as a source of drinking water and irrigation in Ethiopia. It serves as a reliable and accessible water source, particularly in regions where surface water may be limited or unreliable *(Tesema et al. 2023)* During drought, groundwater is often relied on to provide secure drinking water, particularly in rural Africa where other options are limited. However, the technology chosen to access groundwater significantly affects local water security *(Macdonald et al. 2019)* Over 70% of Ethiopia's water supply comes from groundwater, and only 34% of the population has access to an improved water supply. Groundwater investigation is, therefore, indispensable for ensuring sustainable and judicious use of water resources *(IAEA 2013)* Groundwater is one of the major sources of exploitation in arid and semi -arid regions. Thus for protecting Groundwater quality, data on spatial and temporal distribution are important. Geo-statistics methods are one of the most advanced techniques for interpolation of Groundwater quality (Mehrjardi et al. 2008). The values of the Water Quality Index (WQI) have been affected mainly by the concentration of dissolved ions (F, NO, $Ca^{2+,}$ and Mg^{2+}) in the ground water, and the Water quality index is one of the most effective tools to communicate information on the quality of any water body *(Reza and Singh 2010)*

Groundwater systems are vital to humanity and the ecosystem. Aquifers are determined based on the absence or presence of water table positioning, that is, confined, unconfined, leaky aquifers, and fractured aquifers (Buckner et al. 2016). Groundwater is only to a limited extent available on mountainous terrain. By directly or indirectly analyzing some obvious terrain elements, such as geologic and geomorphic landforms and their hydrologic characteristics, it is possible to determine where groundwater is found and how much of it is present in a given area *(Ndatuwong and Yadav 2014)*

Groundwater conditions (GWCs) of an area depend on aquifer hydraulic parameters such as Storativity (*Sr*) or storage coefficient (*Sc*), transmissivity (*Tr*), and hydraulic conductivity (*K*). It plays a key role concerning- groundwater flow modeling, well performance, solute, and contaminants transport assessment, and also for identification of areas for additional hydrologic testing (Singh and Tripura 2022) Variability in aquifer systems productivity and degradation of water quality by some ions of a basin is the basic problem for water resource utilization. These rocks get their water-bearing nature mainly due to secondary processes: fracturing, weathering, and karstification processes. The rocks vary in their respective groundwater productivity nature primarily because of the difference in the degree of the effect of fracturing, weathering, and karstification processes *(Kassa, et al. 2015).*

A test is conducted by pumping a well at a nearly constant rate while monitoring changes in the water level at the same pumped well and, if possible, an adjacent well *(Mawlood and Ismail 2019)*. Each formation is quite different. Welded tuff formation is described as sand, gravel, and pumice, and tuff breccia is defined as rhyolite and ignimbrite without any description of the nature of the aquifer. Therefore, the rhyolite, ignimbrite in the existing well classification is referred to as (tb) (JICA 2012).

The study area in the Kola sub-catchment highlights a concerning situation where despite the drilling of numerous wells in the past 15 years people are still not receiving adequate potable water. This inadequacy has led to an increase in non-functioning water schemes, indicating a significant challenge in meeting the demand for clean drinking water. The study aimed to provide valuable insights into the groundwater quality, spatial distribution map, and aquifer properties in the Kola sub-catchment. This information can inform decision-making processes related to water resource management, infrastructure planning, and the development of effective strategies to address the inadequate provision of potable water in the area.

1.2 Statement of the Problem

Over the past 15 years, efforts have been made to address the water needs of communities in the Kola watershed by drilling numerous wells. However, the current situation indicates that certain areas within the watershed are still experiencing a shortage of potable water. This shortage is primarily because several wells have become non-functional due to issues related to groundwater quality.

The groundwater quality problem is not consistent throughout the entire watershed. In the eastern part of the watershed, some wells and water points remain unaffected by water quality problems, providing a reliable source of clean water for the local population. However, in other areas, groundwater quality concerns have arisen, leading to the non-functionality of certain wells.

Additionally, the discharge amounts of wells and water points vary within the watershed. This variability in discharge can be attributed to the local geology, hydrogeology, and aquifer characteristics present in different parts of the watershed. These factors play a significant role in both the groundwater quality problems and the variable discharge observed within the watershed (*Source well drilling completion 1999-2007*).

According to Asha and Ayenew (2019), the use of hydrochemistry and stable isotopes in the study area allowed us to understand the hydrogeological systems, sources of recharge to the systems, variable water types and their evolution, and the flow system. As there was no systematic way of understanding the resources in the basin, this study has provided very important knowledge on the groundwater systems and clues in the sustainable utilization of the system, implications on the possible location and depth of future drilling sites for development prospects, and added the use of hydrochemistry and isotopes as tools for the study of groundwater in the basin.

Other studies targeted at contributing detailed aspects of aquifer hydraulic properties and hydrogeological features have been conducted in the lower part of the catchment. Arc GIS 9.3 and Aquifer test programs were used for the study. The hydraulic conductivity of the aquifer was found to range from $3.5\ 10^{-4}$ to $2.91\ 10^{-3}$ m/day. Likewise, the transmissivity and storativity range from $1*10^{-3}$ to $1.05*10^{-1}$ m^2/min and $8.29*10^{-5}$ to $4.11*10^{-3}$, respectively. The major aquifer units of the area are weathered and fractured basalts (Mathewos and Tebebal 2016)

Furthermore, the characterization of aquifers has been conducted in the lower Gidabo catchment (Mathewos and Tebebal 2016) of which the Kola watershed is part. However, this study considered very few numbers of boreholes and was also limited only to the lower part of the whole catchment. This shows that in-depth aquifer characterization work, which comprises the Kola watershed, was not done.

Asha and Ayenew (2019) have conducted hydro-chemical and environmental isotope analyses of the hydrogeological system of Abaya-chamo Lake, which is partially part of the Gidabo catchment. However, this research work is very general; the standard physical-chemical parameters of drinking water were not collected in detail. Similarly, no previous research work is found showing the analysis of standard physical-chemical parameters of drinking water in the Kola watershed. The above discussion shows that systemic and in-depth research work on the spatial distribution of groundwater quality mapping and aquifer characteristics has previously not been done in the specific Kola sub-catchment. So this research work will focus on collecting existing groundwater samples and conducting Physical and chemical parameter analysis, overlaying rock properties that indicate the quality of water for groundwater formations, and, in addition, collected well completion reports indicate the quality of collected wells Aquifer layers, including void space, joints, and continuing for each rock and weathering of volcanic rocks, as well as one of the most important groundwater aquifer layer storage characteristics, hydraulic conductivity, will be investigated for a better understanding of the groundwater quality mapping and aquifer characteristics of the Kola sub-catchment.

1.3 Objectives of the Research

1.3.1 General objective

The main objective of this research was to groundwater quality mapping and characterize the aquifers in Kola River Watershed.

1.3.2 Specific objectives

- The specific objectives of this research were to:
- To Assess the general geomorphological, lithological, and hydrogeological settings of the study area.
- To Determine Values of selected groundwater quality parameters, determine Water Quality index and develop spatial maps.
- To Determine hydraulic properties of the aquifer such as Transmissivity and Hydraulic conductivity from the pumping test data

1.4 Research Questions

- What are the geomorphological, lithological, and hydrogeological settings in the study area?
- What is the quality of groundwater in the study area?
- What are the values of some aquifer's characteristics in the study area?

1.4. Significance of study

The groundwater quality issues in the main rift valley area of Ethiopia pose a significant challenge, particularly regarding the availability of safe and potable drinking water. Conducting a study to evaluate the quality of water and map groundwater quality using laboratory analysis and ArcGIS can have several important implications.

2. LITERATURE REVIEW

2.1 Basic Concept

Groundwater quality comprises the physical, chemical, and biological qualities of ground water. Temperature, turbidity, color, taste, and odor make up the list of physical water quality parameters. Since most ground water is colorless, odorless, and without specific taste, we are typically most concerned with its chemical and biological qualities. Although spring water or groundwater products are often sold as “pure,” (Harter 2003).

The aquifer is an underground layer of water-bearing, permeable rock, rock fractures, or unconsolidated materials. Groundwater from aquifers can be extracted using a water well. Aquifers vary greatly in their characteristics.

A Geographic Information System (GIS) There are different definitions for Geographic Information System, each developed from a different perspective or disciplinary origin. Some focus on the map connection, some stress the database or the software tool kit, and others emphasis applications such as decision support. (Ali 1995).

A spatial map series is a collection of pages built from a single layout in which the map frame on each page shows a different map extent. The map series is built by iterating through all the features in a layer, called the index layer, creating a page for each feature. The map extent for each page is a feature.

2.2 Geological and Hydrogeological Problems for Groundwater Supply

The type of geological formation determines, for a given rainfall, the discharge and sediment load of a watershed, the process of prioritizing watersheds for the implementation of management practices should take into account the geological nature of the region. More research is needed on how various geological formations affect the hydrology of the highlands in the tropics that serve as water towers for hundreds of millions of people (Adem et al. 2020).

A large groundwater reserve within the valley floor’s Quaternary alluvial sediments and underlying Tertiary fractured volcanic rocks. Levels of salinity and sodicity do not pose constraints for agricultural water use. In the valley-floor aquifers, there would appear to be sufficient water to support large and small-scale irrigation development.

Geology is the key to hydrogeology the rocks and their disposition in space provide the framework within which the water accumulates, through which it passes, and with which it reacts the openings in the rocks provide the storage for the water, the connectivity of the opening in the rocks is the factor which permits the water to move from one place to another, and the possible chemical and biological reaction, or a combination thereof control the water quality. In addition, the relationship of the rock bodies. Thus geological history must be considered, and the origin of a particular rock's mass and its subsequent history influence whether water of suitable quality and Quantity is available for exploitation *(Welby 2000)*. Numerous water sources were discovered to be high in fluoride, mostly because of the underlying geology and the hydrodynamic characteristics of the aquifer system *(Chandrajith and Diyabalanage 2022)*. The hydrogeological system of the Dila sheet is similar to the surrounding areas in the case of the highland area in the eastern and western parts of the sheet; however, some lithological units show different productivity characteristics or are missing altogether.

The escarpment and bottom of the Rift Valley are completely different from a geological as well as hydrogeological point of view. 1. Extensive (746 km^2) and moderately productive or locally developed and highly productive porous aquifers (T = 1.1–10 m^2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of Quaternary alluvial and eluvial sediments (Qa, Qe), polygenetic infill of depressions (Ql), and volcano-sedimentary rocks (Qvs). 2. Extensive (9,626 km^2) and moderately productive fissured aquifer (T = 1.1–10 m^2/d,q = 0.011–0.1 l/s.m, with Q = 0.51–5 l/s). The aquifers consist of basalts of rift floor, ignimbrite, rhyolite, and trachyte of the highlands and escarpment (Qdi, Qwbp, Tig2, TV1, TV2, TV3, TV4, Ttr, q3N1a). 3. Extensive (5,400 km^2) and moderately or locally developed and highly productive mixed porous and fissured aquifers (T = 1.1–10 m2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of volcanic, sedimentary, and pyroclastic rocks of the Central volcanic complexes, and pumiceous pyroclastic of the Nazret group (Qwa, Qws, and Tig1). 4. Extensive (1,449 km^2) low productive fissured aquifers (T = 0.11–1 m^2/d, q = 0.0011–0.01 l/s.m, with spring and well yield Q = 0.051–0.5 l/s). The aquifers consist of high and low-grade metamorphic rocks and granite (Pg, Psm, Pumf, and Pgt). 5.

Formation (15 km^2) consisting of a minor fissured aquifer with local and limited groundwater resources – Aquiclude. The formation consists of obsidian and pitch stone (Qwo) (Agezew, T et al. 2014).

2.3 Challenges of Water Supply to Water Users

Choice of water supply interventions, environmental destabilization and degradation of catchments, inadequate funding of the water sector, poor management of water supplies, low ability and willingness to pay by the majority of the populace, low stakeholder involvement during water resources development, competing water uses, ethnic differences and unequal development of water resources. As these factors evolve, they conjoin into common interrelated higher-order problems, which include: the unsustainability of water supplies due to high operation and maintenance costs compared to revenue earnings, low investment in the water sector, and low social acceptance of interventions and conflicts (Chepyegon and Kamiya 2018), the demand for water supply is on the increase. Invariably, access to safe drinking water is required by all communities regardless of the area, level of education, and income.

The current state of inadequate water supply and infrastructure is marked by a widespread dysfunction within the water sector. As a result, reliable access to safe drinking water remains a persistent and escalating concern (Patil et al. 2015). To better meet the water demands of industry, residential use, and agriculture, there is a justified need to redistribute water resources and improve water management policies. By reallocating water in a way that aligns with the specific needs of each sector, water can be utilized more efficiently (Luczaj 2016).

2.4 Groundwater Quality Problem

Groundwater is a valuable and finite resource covering only 30% of the freshwater (3% of the total volume of water) on Earth. Both groundwater quantity and quality are becoming dominant issues in many countries. Groundwater, as a source of public water supply, presents significant advantages compared with surface water due to its protection from surface pollutants (Luczaj 2016). To monitor water quality, the methodology used remote sensing techniques to create a water quality index monitoring model. The water quality in Ebinur Lake is assessed as poor, indicating significant environmental concerns. The Water Quality Index (WQI) was utilized to evaluate the water conditions in the lake, and the obtained WQI value reached a high level of 4000.(Zhang et al. 2021). Groundwater with excessive ionic concentrations was found to be predominantly composed of the solutes Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, HCO_3, Cl^-, and SO 4 2. The findings showed that divalent cations and excessive fluoride had a significant negative impact on the dry zone (Chandrajith and Diyabalanage 2022)

A large portion of the Main Rift Valley region of the country experiences water quality issues with very high fluoride concentration, especially in the shallow productive lacustrine aquifers that cover an approximate area of about 16,000 km^2 Water quality problems, which have been long over-looked but are increasingly getting attention, are nitrate and microbiological contamination of shallow volcanic groundwater in the central highlands of small towns and rural areas due to poor sanitation practices including pit latrines, while heavy metals and organic contaminants in major metropolitan areas are also causes for concern (Patil el al. 2015).

The chemical properties indicated that the pH of water samples ranges from 6,95 to 8,06 with the electrical conductivity (EC) starting from 350 to 38,800 µS/cm. Moreover, the Total Dissolved Solids (TDS) have a value from 216 to 21,800 mg/L with a total hardness is around 134-5,395 mg/L. The water types are Ca-Mg-HCO3 and Na-Cl. Based on WQI analysis, there are 13 unfeasible samples for drinking water (Triadi Putranto et al. 2018). Studied Groundwater quality assessment using water quality index and GIS techniques in the Modjo River basin in central Ethiopia.In the research conducted in the Modjo River basin, a total of 31 groundwater samples were collected from various wells and boreholes. These samples were carefully analyzed to assess the suitability of the groundwater for drinking and irrigation purposes.

Spatial variation maps of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^-, NO_3^-, SO_4^{2-}, F^-, Cl^-) were produced using IDW interpolation in GIS. Piper pilot shows that, Ca-Na-HCO_3, Na-Ca-HCO_3 (mixed), and Na-HCO_3 water types. Ca^{2+} and Mg^{2+} are dominant in highland aquifers whereas Na^+ is dominant in rift valley aquifers. HCO_3^- is the dominant anion in all samples. The water quality index for drinking purposes shows that 3.23% and 93.54% of groundwater samples fall within excellent and good water quality (Kawo and Karuppannan 2018).

2.5 Standard for Water Quality Parameters

2.5.1 Hydrogen ion activity (PH)

Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection (see the supporting document Safe piped water; Annex 1).

For effective disinfection with chlorine, the pH should preferably be less than 8; however, lower-pH water (approximately pH 7 or less) is more likely to be corrosive. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems.

Alkalinity and calcium management also contribute to the stability of water and control its aggressiveness to pipes and appliances. Failure to minimize corrosion can result in the contamination of drinking water and adverse effects on its taste and appearance. The optimum pH required will vary in different supplies according to the composition of the water and the nature of the construction materials used in the distribution system, but it is usually in the range of 6.5–8.5 (Herschy 2012).

2.5.2 Hardness

Hardness in water is caused by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium cations. It is usually expressed as milligrams of calcium carbonate per liter. Hardness is the traditional measure of the capacity of water to react with soap, hard water requires considerably more soap to produce a lather (Herschy 2012).

Table 1 Water classes based on Hardness by Sawyer (1960)

Hardness as $CaCo_3$	Water class
0-75	Soft
75-100	Moderately hard
150-3000	Hard
>3000	Very Hard

2.5.3 Fluoride

Traces of fluorides are present in many waters, with higher concentrations often associated with groundwater. Skeletal fluorosis (with adverse changes in bone structure) may be observed when drinking-water contains 3-6 mg/l fluoride, particularly with high water consumption. Crippling skeletal fluorosis usually develops only where drinking-water contains over 10 mg/l. The risk of dental fluorosis will depend on the total intake of fluoride from all sources and not just the concentration in drinking-water. A management guidance document on fluoride is available. In some countries, fluoride may also be added to drinking water to protect against dental caries, such that final concentrations are usually between 0.5 and 1 mg/l (World Health Organization 2018).

2.5.4 Turbidity

Turbidity, typically expressed as nephelometric turbidity units (NTU), describes the cloudiness of water caused by suspended particles (e.g. clay and silts), chemical precipitates (e.g. manganese and iron), organic particles (e.g. plant debris), and organisms. Turbidity can be caused by poor source water quality, poor treatment, and, within distribution systems, disturbance of sediments and biofilms or the ingress of dirty water through main breaks and other faults. At high levels, turbidity can lead to staining of materials, fittings, and clothes exposed during washing, in addition to interfering with the effectiveness of treatment processes. Increasing turbidity reduces the clarity of water to transmitted light. Below 4 NTU, turbidity can be detected only using instruments, but at 4 NTU and above, a milky-white, muddy, red-brown, or black suspension can be visible.

Large municipal supplies should consistently produce water with no visible turbidity (and should be able to achieve 0.5 NTU before disinfection at all times and average 0.2 NTU or less). However, small supplies, particularly those where resources are limited, may not be able to achieve such levels. Visible turbidity reduces the acceptability of drinking-water. Although most particles that contribute to turbidity have no health significance (even though they may indicate the presence of hazardous chemical and microbial contaminants), many consumers associate turbidity with safety and consider turbid water as being unsafe to drink (Appendix 2.2 -Drinking Water Quality Standard 2011).

2.5.5 Total dissolved solids (TDS)

Total dissolved solids (TDS) Comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and small amounts of organic matter that are dissolved in water. TDS in drinking-water originates from natural sources, sewage, urban runoff, and industrial wastewater. Salts used for road de-icing in some countries may also contribute to the TDS content of drinking-water. Concentrations of TDS in water vary considerably in different geological regions Reliable data on possible health effects associated with the ingestion of TDS in drinking-water are not available, and no health-based guideline value is proposed. However, the presence of high levels of TDS in drinking-water may be objectionable to consumers (*WHO (2003).*

2.5.6 Chloride

Chloride in drinking-water originates from natural sources, sewage and industrial effluents, urban runoff containing de-icing salt, and saline intrusion. Excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. This can lead to increased concentrations of metals in the supply. No health-based guideline value is proposed for chloride in drinking-water. However, chloride concentrations over about 250 mg/l can give rise to detectable taste in water (Herschy 2012).

2.5.7 Iron

Anaerobic groundwater may contain ferrous iron at concentrations up to several milligrams per liter without discoloration or turbidity in the water when directly pumped from a well. On exposure to the atmosphere, however, the ferrous iron oxidizes to ferric iron, giving an objectionable reddish-brown color to the water. Iron also promotes the growth of “iron bacteria”, which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping. At levels above 0.3 mg/l, iron stains laundry, and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.3 mg/l, although turbidity and color may develop.

2.5.8 Sulfate

The highest levels usually occur in groundwater and are from natural sources. In general, the average daily intake of sulfate from drinking-water, air, and food is approximately 500 mg, food being the major source. However, in areas with drinking-water supplies containing high levels of sulfate, drinking-water may constitute the principal source of intake (Herschy 2012).

2.5.9 Sodium

Sodium salts (e.g. sodium chloride) are found in virtually all food (the main source of daily exposure) and drinking-water. Although concentrations of sodium in potable water are typically less than 20 mg/l, they can greatly exceed this in some countries. The levels of sodium salts in air are normally low concerning those in food or water. It should be noted that some water softeners can add significantly to the sodium content of drinking-water (Herschy 2012).

2.5.10 Nitrate

The most appropriate means of controlling nitrate concentrations, particularly in groundwater, is the prevention of contamination. This may take the form of appropriate management of agricultural practices, the careful siting of pit latrines and septic tanks, sewer leakage control, as well as management of fertilizer and manure application and storage of animal manures. It may also take the form of denitrification of wastewater effluents. 50 mg/l (50 000 µg/l) (World Health Organization 2018).

2.6 Causes for Shortages in Quantity of Water

Rapid urbanization is creating huge pressure on water use and infrastructure, with lasting consequences on human health and urban environments. These changes make water an increasingly scarce and expensive resource, especially for the poor, the marginalized, and the vulnerable (Eliasson 2015). The increasing reliance of agriculture and other industries on significant volumes of fresh water, and there are real problems ahead in terms of the availability of water. Several countries do not have enough groundwater to sustain their current populations. (Posterminaries 2016)

The potential impacts on water resource quality due to growing demands and climate change and/or variability arising from changes in the spreading pattern of contaminants should be considered and evaluated (Tzanakakis et al. 2020). Water is a fundamental component of life and is an essential requirement in industry. As global warming progresses, and access to water becomes a greater source of conflict it is encouraging to think that solar treatment can provide a solution to both the technological and socio-political challenges that lay ahead (Patil et al. 2015), Transmissivity values are appropriate for sustainable groundwater development, and high-yield zones have been identified for potential future development and for selecting drilling locations.(Daniel et al. 2015).

In quantitative studies of groundwater hydrology for the development of water resources in an aquifer, it is essential to determine the field values of transmissivity and storage coefficient (ILO 2013). The major changes in the rift valley are related mainly to the recent improper utilization of water and land resources in the lake catchment and direct lake water abstraction aggravated intermittently by climatic changes. These changes appear to have grave environmental consequences on the fragile rift ecosystem, which demands extremely urgent needs for integrated basin-wide sustainable water (Journal et al. 2007). Extreme events water shortages have the potential to affect significant numbers of people so the need to build robust, coordinated plans which are based on scientific evidence is vital (Ratnakumari et al. 2012). Add to that factors associated with worldwide population growth, as well as increasing reliance of agriculture and other industries on significant volumes of fresh water, and there are real problems ahead in terms of the availability of water. Several countries do not have enough groundwater to sustain their current populations (Posterminaries 2016). Based on calculations with the Theis method obtained: a) The cross-section A-A has a value of Transmissivity (T) ranging between 124.27 - 966.58 m^2/day, Hydraulic Conductivity (K) ranges between 0.012 - 0.094cm/s, Storativity (S) ranges between 0.084 - 0.472. b) The cross-section B-B has a value of Transmissivity (T) ranging between 230.14 - 621.37 m^2/day, Hydraulic Conductivity (K) ranges between 0.022 - 0.060 cm/s, Storativity (S) ranges between 0.125 - 0.416. *(Selkur 2021)* Studied Characterization of Aquifers and Hydrochemistry in Volcanic Terrain of Central Ethiopia". The findings demonstrate the classification of aquifer characteristics of Sandstone aquifers with high productivity (T=100-500 m^2/d, Q=5-25 l/s). Limestone aquifers that are highly productive and/or karst (T = 50–100 m^2/d Q = 2–5 l/s). Tertiary and Quaternary basalt fissured aquifers with high productivity (T=100–500 m^2/d, Q=5–25 l/s). Entoto rhyolite and trachyte low productivity aquifers (T=1-10 m^2/d and Q=0.05 l/s) and aquiclude or small aquifers with scarce groundwater resources.

2.6.1 Hydraulic parameters

2.6.1.1 Hydraulic conductivity

The hydraulic conductivity of fy ash depends on the test method and sample preparation technique. Sample saturation significantly a-affects permeability test results; the maximum value of fy ash permeability can be achieved only by the test method that enables full sample saturation. In the case of the unsaturated sample water volumes flowing in and out were not balanced and the flow conditions remained non-steady (Falowo et al. 2019).

The values of hydraulic properties at the sites will help in safe and sustainable groundwater withdrawal planning for the future. The pumping test should be done on other Deep tube wells of the well fields to obtain catchment-wise hydraulic parameter values (Ali et al. 2022). A pumping test area was performed to characterize the general hydrogeological regime and identify in-situ characteristics of water-Bearing formation. such tests can establish boundary conditions, and the relationship between wells cone of impact in a groundwater extraction system (Falowo et al. 2019). According to the assertions and the soil layer's hydraulic conductivity values, which ranged from 0.012 to 0.094, cross sections of A and B are examples of fine, medium, and coarse sand, respectively (Singh and Tripura 2022).

2.6.1.2 Transmissivity

Interpretation of single-well tests with the Cooper-Jacob method remains more reasonable than most alternatives. Drawdowns from 628 simulated single-well tests where transmissivity was specified were interpreted with the Cooper-Jacob straight-line method to estimate transmissivity. Error and bias as a function of vertical anisotropy, partial penetration, specific yield, and interpretive technique were investigated for transmissivities that ranged from 10 to 10,000 m^2/d. Cooper-Jacob transmissivity estimates in confined aquifers were affected minimally by partial penetration, vertical anisotropy, or analyst. Cooper-Jacob transmissivity estimates of simulated unconfined aquifers averaged twice the known values. Transmissivity estimates of unconfined aquifers were not improved by interpreting results with an unconfined aquifer solution. Judicious interpretation of late-time data consistently improved estimates where transmissivity exceeded 250 m^2/d in unconfined aquifers (Halford, et al 2006)

Table 2 Classification of transmissivity potential based on (Offodile 1983)

Transmissivity m^2/day	**Transmissivity Potential**
>500	High potential
50-500	Moderate potential
0-50	Low Potential
0.5-5	Very Low Potential
<0.5	Negligible potential

2.6.1.3 Storativity (Storage coefficients)

Storativity is a measure that indicates the quantity of fluid that can be released from a porous medium when there is a unit decrease in reservoir pressure. It reflects the storage capacity of the rock and is typically represented as a dimensionless value (Abdus Satter et al. 2016).

Storage Coefficient (S) is the property of the aquifer to store water in the soil/rock pores. The storage coefficient or storativity is defined as the volume of water released from storage per unit area of the aquifer per unit decline in hydraulic head. Storativity is a measure of the amount of water in a confined aquifer; it will change with a certain change in head. As per Cooper and Jacob, 1946) and Rushton (2003), (Schlumberger Water Services, 2012) the storativity of an aquifer is analyzed with the Cooper and Jacob I time drawdown method.

2.7 Water Quality Analysis Method

2.7.1 GIS spatial interpolation

A Geographic Information System can be more powerful when some added features, represented in this case by statistical methods, are combined with its many capabilities, as described above, resulting in the generation of a good decision support system. Inverse Distance Weighting (IDW) Inverse Distance Weighting (IDW) is an interpolation technique in which interpolated estimates are made based on values at nearby locations weighted only by distance from the interpolation location. IDW does not make assumptions about spatial relationships except the basic assumption that nearby points ought to be more closely related than distant points to the value at the interpolated location. This technique determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. IDW allows the user to control the significance of known points upon the interpolated values, based upon their distance from the output point (Naoum and Tsanis 2004).

2.8 Water Quality Index

The Water Quality Index (WQI) in this study was calculated using the weighted arithmetic method. This method was originally proposed as a means to assess water quality by assigning weights to different water quality parameters based on their relative importance by Horton (1965) and developed by Brown et al. (1972). the Water Quality Index (WQI) value for the dug well water in the study area is 76.9. This value falls within the "good" category or Quality-2 category, which typically ranges from 71 to 90 on the WQI scale. It suggests that the overall water quality of the dug well water is relatively satisfactory.Additionally, the average maximum WQI value recorded for the dug well water is 92.3. This value corresponds to the "very good" quality category or Quality-1 category, which typically ranges from 91 to 100 on the WQI scale. This indicates that certain dug well points within the study area exhibit excellent water quality.(Ram et al. 2021).

The groundwater wells near the Lesser Zab River (LZR) are categorized as excellent in terms of water quality, making the water suitable for various purposes, including drinking. Conversely, wells located near the discharge channel, where degraded water flows, distribute water of poor or unsuitable quality for human consumption. The presence of KIP (unspecified acronym) is a contributing factor to the negative impact on groundwater quality. It has caused a rise in the static water level, leading to increased salinity in the groundwater. This rise in salinity is likely responsible for rendering most groundwater samples unsuitable for drinking (Awadh, *et al.* 2016).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study area is situated in the southern part of Ethiopia, specifically in the Sidama Regional State. It is located within the Main Ethiopian Rift and is surrounded by the Eastern and Western Ethiopian Plateaus. Geographically, the study area is bounded from North to South by 725042.548 N and 735142.115 N, and from East to West by 446427.06 E and 419681.839 E. The total area covered by the study is approximately 225 square kilometers, with a scale of 1:278,988. The location of the study area is depicted in Figure 3.1. Access to the study area is facilitated by a major asphalted road connecting Hawassa-Aposto to Aleta-Wondo, as well as a gravel road.

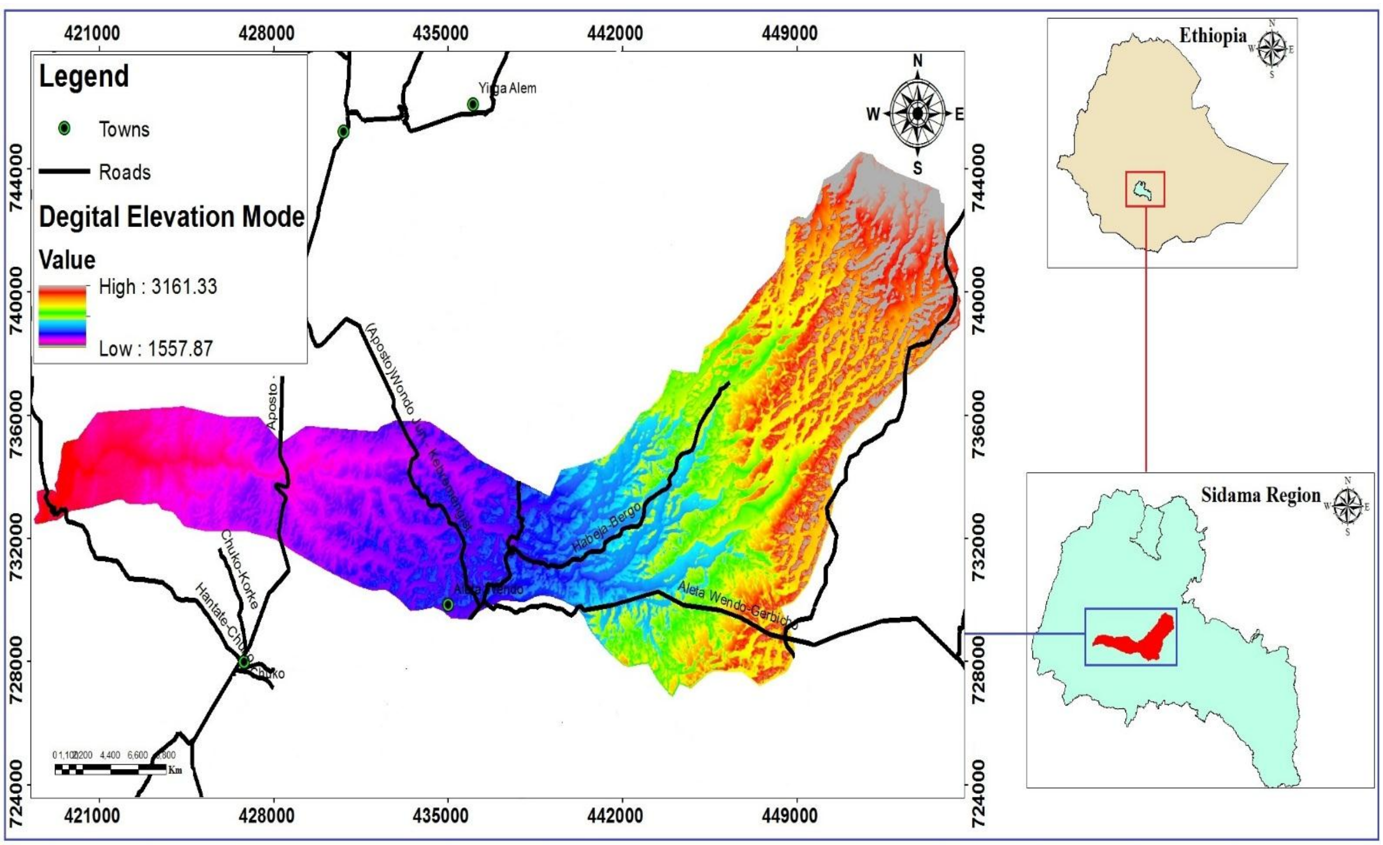

Figure 3. 1 Location Map

3.1.2 Physiography and drainage features

The study area of catchment physiography is the Eastern Highland area and the western lower land of the Rift Valley area. Eastern Highland is a more rugged topographic area; this area has a maximum elevation of 3136 m a.s.l. below escarpments and deep gorges, while the western areas have almost flat topography. The low-lying areas have flat to undulating topography with some volcanic ridges, and along the Kola River, there is a very deep gorge area. Low-lying areas north of and the southern part are almost flat.

The nature of the streams in the region is a function of the hydrologic inputs to the region and its physical, vegetative, and climatic characteristics. Most of the rivers in the sub-basins flow in an eastward direction. The Kola River flows along the eastern boundary of the Gudumo ridge. There are both perennial and intermittent stream rivers in the area. The Hoha, Afa, Gembela, and Selga Rivers are perennials that drain the area's central and southern parts from east to west.

The hydrological characteristics of the study area are described by the Hoha and Afa rivers, which discharge most of the runoff from the area. The prevailing drainage pattern in the area is structurally controlled and shows dendritic to sub-parallel types. All of the streams in the area have this drainage pattern, whereas the major rivers to the east have a west dendritic drainage pattern. The drainage system is mainly controlled by topography and geological structures.

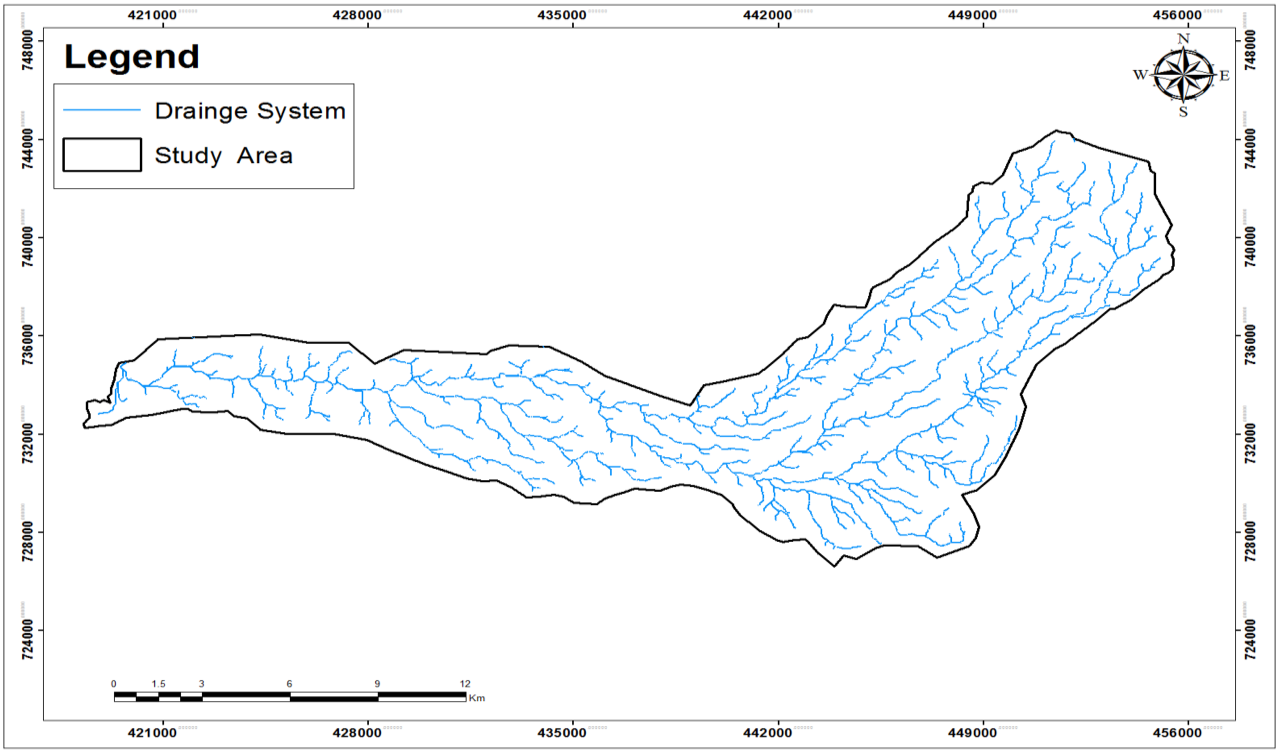

Figure 3. 2 Drainage Pattern of kola River catchment from generate ArcGIS

3.1.3 Climatic Characteristics

The climate of Ethiopia is characterized by a tropical climate moderated by altitude with a marked wet season. The eastern lowlands (elevation less than ~ 900 m.a.s.l) are much drier with a hot semiarid to desert climate. In contrast, southwestern Ethiopia is characterized by a humid tropical climate with rainfall higher than 1,000 mm. traditional classifications based on altitude and temperature show the presence of five zones (D. Gemechu, 1977).

A) The hot, arid zone covers the desert lowlands below 500 m, where average annual rainfall is less than 400 mm and average annual temperatures range between 280 ^{o}C and 340 ^{o}C or higher;

B) The warm to hot, semi-arid zone includes those areas with an altitude of 500–1,500 m, average annual rainfall generally of around 600 mm (but as high as 1,600 mm in the western lowlands of Gambella), and an average annual temperature range of 20–280 ^{o}C ;

C) The warm-to-cool, semi-humid zone covers the temperate highlands between 1,500 and 2,500 m. On average the warm to cool, semi-humid zone covers the temperate highlands between 1,500 and 2,500 m. Average annual temperatures vary between 160C and 200 ^{o}C, and annual rainfall is generally around 1,200 mm, reaching 2,400 mm in the south-west;

D) The cool to cold, humid zone includes the temperate highlands between 2,500 and 3,200 m, where average temperatures range between 100^{o} C and 160^{o} C with an annual rainfall of 1,000 mm and up to 2,000 mm in higher areas;

E) The cold, moist temperate zone covers the Afro-alpine areas on the highest plateaus between 3,200 and 3,500 m; average temperatures are below 100^{o} C, and annual rainfall averages less than 800 mm.

F) Annual temperatures vary between $160\ ^{o}$ C and 200^{o} C, and annual rainfall is generally around 1,200 mm, reaching 2,400 mm in the south-west. According to the above classification, the Kola area is situated in the range of warm to cool, semi-humid zone cool to cold humid zone. Specific to the study area climate falls in the cold humid zone to semi-humid zone.

3.1.4 Land-use and soil type of study area

3.1.4.1 Land use/land cover

Land cover type is another parameter that determines the hydrological behavior of the rivers' catchment. Land use and land cover in Kola are dominated by annual cropland, sparse forest, open shrub land, and closed grassland. The lowland of the western and some of the eastern parts of the study area are covered by crop land; the land is almost flat, which is suitable for the crop; at the top of the escarpment, the eastern direction is covered by grassland; and the rest is predominantly covered by forest land in the Kola river catchment.

Table 3. 1 Land use Land cover and its area coverage

S.No	General Description	Area Coverage (Sq.km)
1	Water	0.0022
2	Forest	106.6654
3	Grass land	17.4381
4	Crop land	49.1465
5	Shrub	2.4863
6	Urban area	49.2811
	Total	**225**

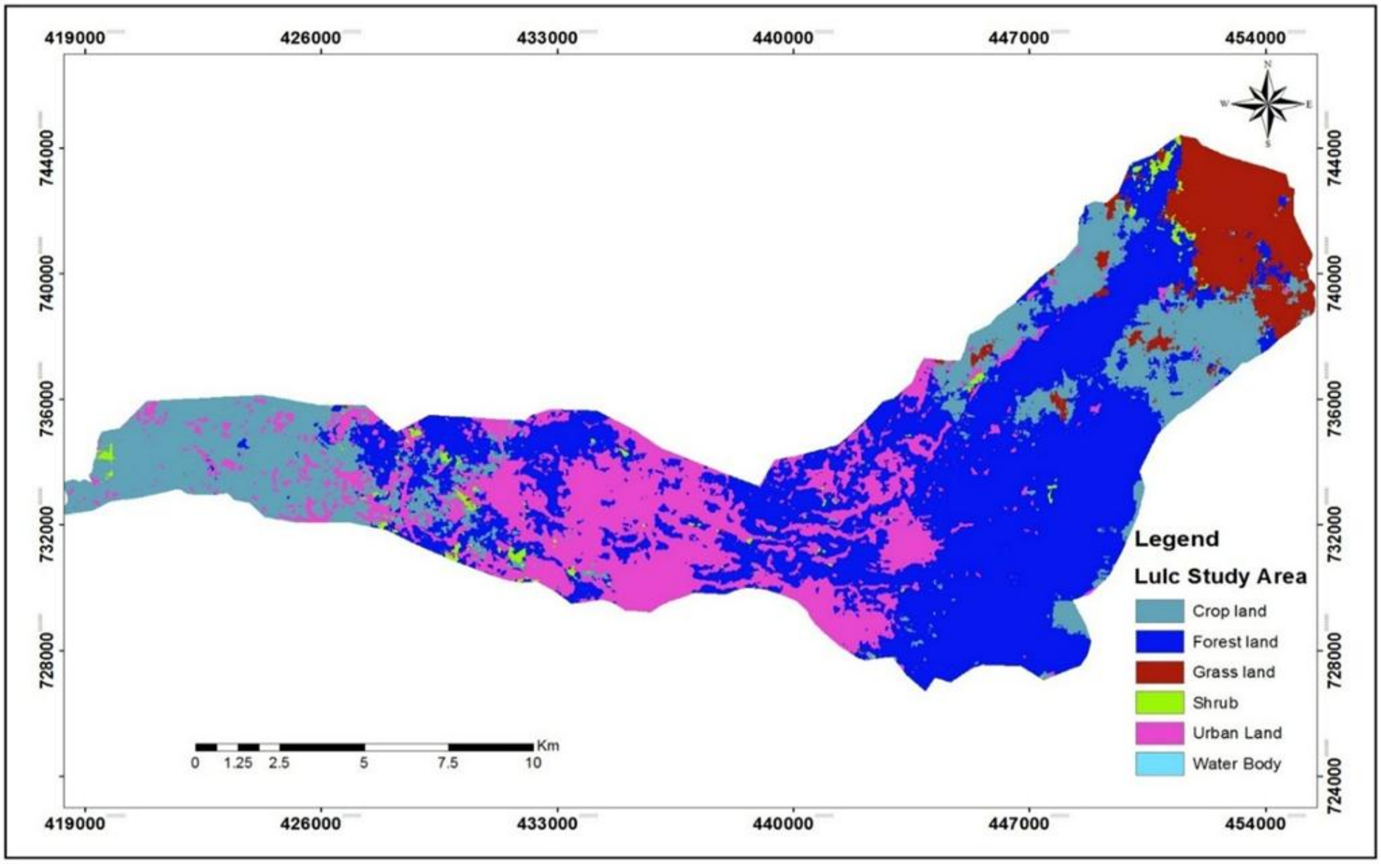

Figure 3. 3 Ethiopia land use land cover map 2016 of the study area

3.1.4.2 Soil type of the study area

The Kola River catchment area soil types are classified based on the FAO classification as five: Eutric Cambisols, Chromic Vertisols, Pellic Vertisols, Luvusols, and Eutric Regosols.

Eutric Cambisols are found lower part of the eastern escarpment different geological structural areas the soil can through weathering processes by deep gorge of steep-slope clearly show the profile of the study area soils, another case in deep gorge alluvial deposit soil in the case of steep-slope move to soft soil in the gorge that can like alluvial deposit formed and soil cambisols mainly colors brownish even if large area coverage of cambisols in study area. Therefore, the behavior of a moderate infiltration rate results in a moderately low runoff potential.

Chromic Vertisols The study area covers the lower part of the rift floor, the topographic area of the study flat, the soils mainly larger area coverage of 44.26%, and the color is Black natures. During site observation, I checked my hand for sticky and very fine texture characteristics that identify a high holding capacity of water. Separately along the Kola River flat area, the soil dry season cracks characteristic of the soils. During the rainy season in chromic vertisols, the slope is suitable, which means flat, but the chromic vertisols have a very low infiltration rate, which results in a high runoff potential.

Pellitic Vertisols The study areas were found at the final Kola River junction with the Gidabo River area; area coverage was 10.88%, which the process formed like alluvial sediments. The nature of alluvial sediments is the gravel, sand, and silt produced by the processes of transporting the Kola River and the Gidabo River. This junction area has a good infiltration rate for groundwater.

Chromic Luvisols Soil is covered in the Eastern escarpment area the study area. the dark brown and red colors and nutrient content Practical observation of the site area and soil cover by agriculture.

Eutric Regosols found very little area coverage in the northern part of the study area. The materials of this area were unconsolidated by the processes of erosion, materials like silt, gravel, clay, and sand.

Table 3. 2 FAO Soil classification and its area coverage

No.	**Soil Types**	**Area(Sq.km)**	**Area Covered (%)**
1	Chromic Vertisol	70.9774	31.54551
2	Pellic Verisols	24.5015	10.88956
3	Eutric Cambisols	99.5938	44.26391
4	Eutric regosols	1.0068	0.447467
5	Chromic Luvusols	28.922	12.85422
	Total	**225**	**100**

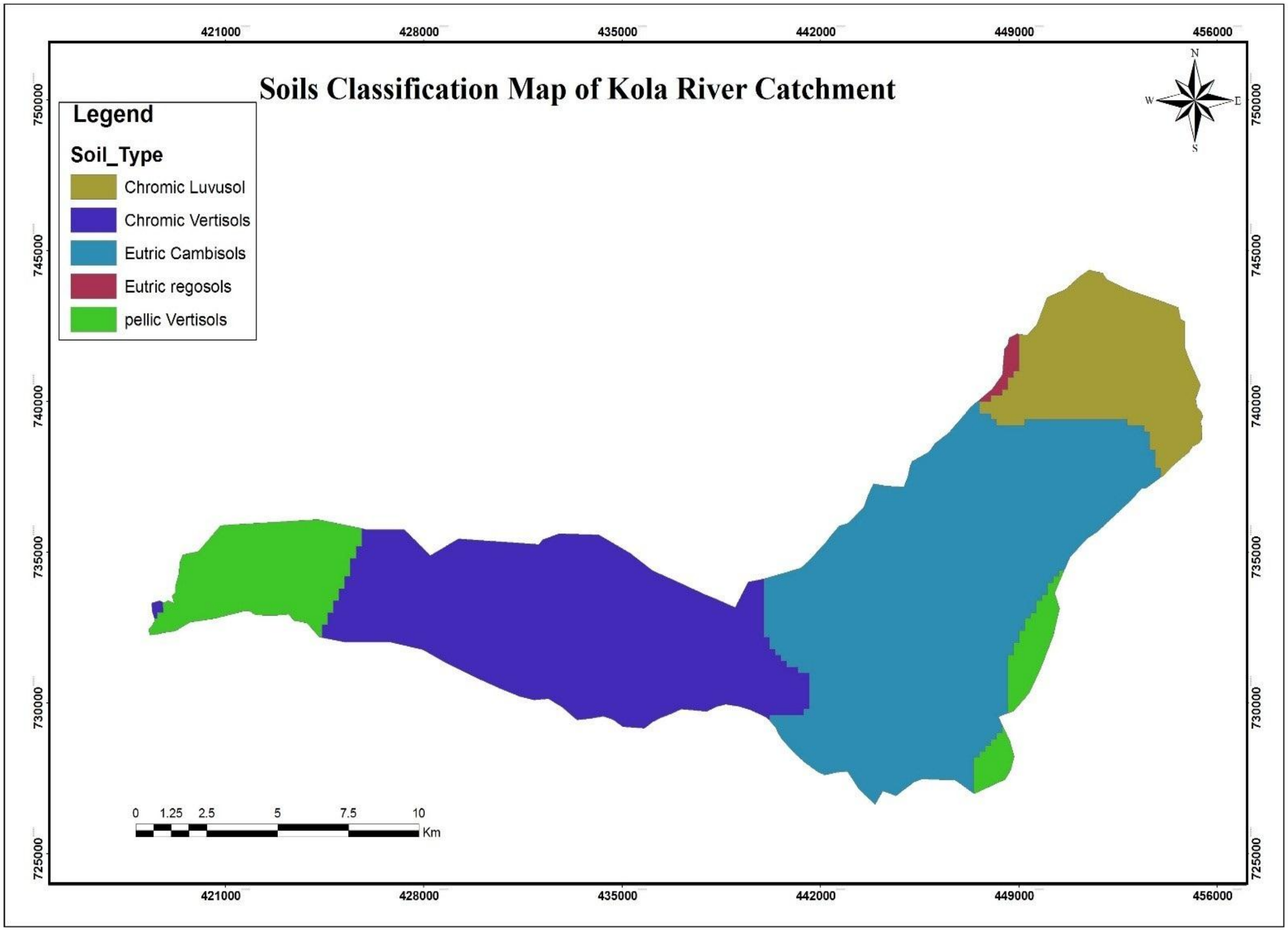

Figure 3. 4 FAO Classification map of the study area

3.1.5 General geology and hydrogeology

Precambrian metamorphic and intrusive rocks include biotite-quartz oligoclase gneiss, fine to medium-grained amphibolites (Pfqg), mafic and ultramafic rocks (Pumf), mica schist and lesser chlorite schist (Psm), granite (Pgt), lower basalt, rhyolite and trachyte (TV1), transitional mildly alkaline and sub-alkaline basalt and rhyolite undifferentiated (Try) and aphyric and porphyritic basalt with lesser vesicular basalt, minor alkali trachyte flows and tuffs (TV2). Tertiary volcanic rocks include lower basalt, rhyolite, and trachyte (TV1), transitional mildly alkaline and sub-alkaline basalt, and rhyolite undifferentiated (Try) and aphyric and porphyritic basalt with lesser vesicular bas The Nazret Group Formation in Ethiopia contains various rocks such as ignimbrites, rhyolites, basalts, and tuffs.

The ignimbrites are of a light gray to gray color and contain rhyolite and trachytic rock fragments with a fine and compacted ground mass. The aphyric basalts are dark gray in color and form small hills. Alkaline and per-alkaline silicic rocks, rhyolite domes, and ignimbrites are the dominant features and have coarser rock fragments with a fine ground mass. Stratified silicic ignimbrites, unwelded tuffs, ash flows, rhyolites and trachyte, trachytic Tuffs with minor basalts, and alkali trachyte flows and sediments are exposed in the eastern part of the map sheet.

The dominant rock type is basalt but there are some trachytes and rhyolite ignimbrites present. Quaternary volcanic rocks include coarse un-welded pumiceous pyroclastic, ignimbrites and diatomite (Qdp, Qdi) of the Dino formation, basalts and scoria cones (Qwbp), per alkaline silicics (Qws), pumice and unwelded tuff (Qwpu), rhyolite lava (Qwa), obsidian (Qwo), eluvium (Qe), alluvial deposits (Qa), polygenetic infill (Ql), and re-sedimented pyroclastic, lacustrine, clays diatomites (Ql). These sediments form the infill of tectonic depressions and former calderas (Agezew, T. et al. 2014).

3.1.6 Regional Hydrogeological

The pre-rift sequences are particularly exposed in this area, covering the eastern escarpment and adjacent highlands the mixed aquifer consists of various types of inter-granular and fractured permeability. The porous material does not act as an independent aquifer, but it contributes rather to the safe yield of the wells. The aquifers are recharged directly by percolating rain water as well as indirectly by the overlaying aquifers. The average yield of the aquifer is about 2 l/s and the median is 1.3 l/s; however, some cold springs have an extraordinary yield with multiple eye springs and discharge of several hundreds of liters, which serve as a water supply for small towns and the surrounding villages. Aquifers show both unconfined and confined water table conditions.

The frequency of yield of water points from mixed aquifers in the Rift Valley, the eastern escarpment, and adjacent highlands. This ignimbrite has variable physical and hydrogeological properties differing from place to place depending on the fracture intensity, thickness of the fractured portion, degree of alteration, and the physical properties of the overlying rock. When the fracture connectivity is favorable, spring discharge of up to 4 l/s is measured from the fractured and jointed ignimbrite. Regolith forms large (more than 100 ha) and small plains on the rift floor and in the eastern highlands. The yield of dug wells is 0.25–0.5 l/s. Shallow groundwater levels vary from 10 to 30 m (aquifers are shown in the hydrogeological map in yellow oblique stripes). The thickness of the saturated part of the aquifer is about 10 to 25 m when fully saturated after the rainy season. Groundwater can be developed by hand digging (a common practice) and manual drilling.(Kryštof et al. 2018). Basalts usually form less viscous, thin lava flows and may be significantly affected by weathering and brecciation and may be inter-bedded with lacustrine or fluviatile deposits.

The continuity of joints and fractures in both horizontal and vertical planes provides the aquifers with their hydraulic continuity within adjacent aquifers. The frequency of yield of water points from the fissured aquifers hosted by various volcanic rocks in the Rift valley, eastern escarpment, and adjacent highlands. Trachytic and rhyolitic lava flows, often thicker than basalts and less widespread, are located closer to the source of the volcano or extrusion. Jointing, fissures, and regional faulting represent the major sources of secondary permeability. Where these flows are extensive, springs may occur and aquifers have potentially high yields. Ignimbrites are the most widespread formation; they occur in the eastern highlands, escarpment slopes, and piedmont areas and on the rift floor. The formation is productive as a result of its secondary fracture permeability. Outcrops are mostly well-jointed. Yields from both wells and springs may vary widely. Local investigation is essential to determine the available yield and the extent and depth of the groundwater resources. The formation is often inter-bedded with volcanic clastic and even sedimentary materials (Kryštof et al. 2018).

3.2 Data Collection and Analysis

3.2.1 Geomorphological, lithological, and hydrogeological setting

Gathering data from office-level maps and on-site locations of schemes provides detailed information on various aspects such as geology, geomorphology, hydrogeology, land use, land cover, and soils. Each map focusing on the site's exploration quarry provides valuable insights into the geological composition and characteristics of the area. This information is crucial for understanding the distribution of different rock types, and mineral deposits. Additionally, maps related to hydrogeology offer insights into the groundwater resources in the research area. They provide information about the aquifer systems, water-bearing formations, and potential groundwater flow paths.

Using ArcGIS 10.8 software to digitize and analyze various maps related to the research area's geology, geomorphology, hydrogeology, land use, land cover (LULC), and soils provides a comprehensive understanding of the area's characteristics. Digitizing these maps based on both office data and field observations allows for accurate representation and analysis of the spatial features. This approach ensures that the maps reflect the actual conditions of the research area.

Furthermore, incorporating digital elevation models (DEMs) with a resolution of 12.5 x 12.5 meters enables a detailed examination of the drainage networks within the research area. Understanding the drainage patterns is crucial for assessing the flow of water and its interaction with the surrounding landscapes.

3.2.2 Groundwater quality determination and development spatial maps

3.2.2.1 Water quality determination

In January 2023, a total of 8 groundwater samples were collected from existing wells in the Kola sub-basin. The sampling process was carried out according to the technique depicted in Figure 3.5 of the research. Each borehole was pumped for four hours before collecting the water samples. The samples were carefully collected using properly cleaned and labeled bottles directly at the site level. In addition to the collected samples, secondary data from 12 previously gathered laboratory water analysis data from various water sources such as boreholes, springs, and shallow wells were also utilized in the study. The study conducted in the Kola sub-basin involved both physical and chemical measurements. Physical and chemical. For physical measurements, in-situ tests and measurements were conducted directly at the sampling locations using portable instruments and field kits. The Hanna Combo tester HI98129 was used as an example of a portable instrument capable of measuring parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), temperature. Chemical measurements, on the other hand, were conducted using laboratory analysis. The HACH DR-6000 instrument is commonly used in laboratories to analyze a wide range of parameters, including hardness, calcium (Ca^{2+}), magnesium (Mg^{2+}), fluoride (F^-), bicarbonate (HCO_{3-}), nitrate (NO_{3-}), iron

(Fe^{2+}), chloride (Cl^{-}), sulfate (SO_4^{2-}). Determine the anion and cation content in the water samples. In the study conducted in the Kola sub-basin, ion chromatography and atomic absorption spectrophotometry were employed for the analysis of anions and cations.

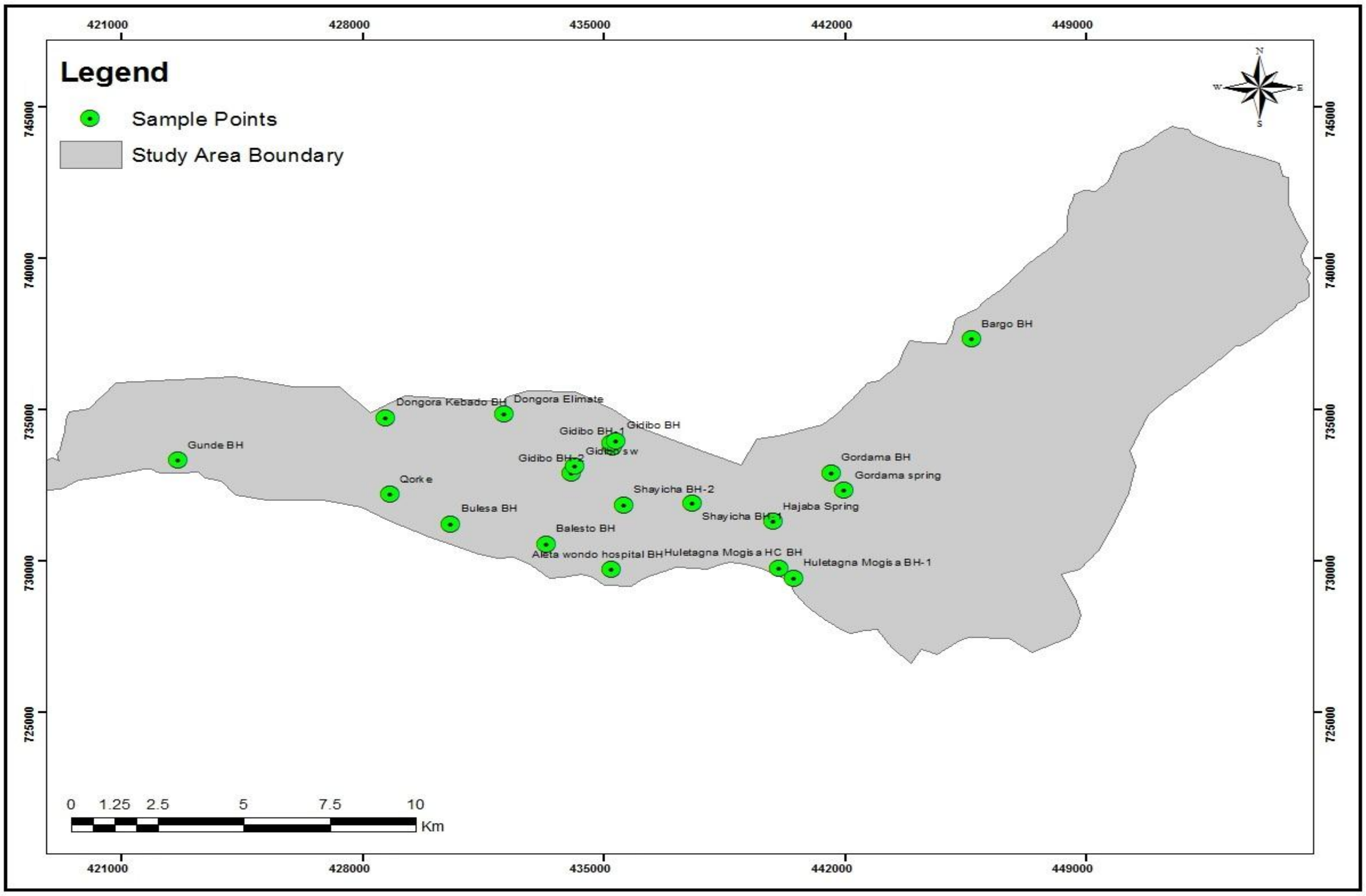

Figure 3. 5 Location of Water sampling

Table 3. 3 Groundwater quality parameters determination methods and instrument used

Parameters	Units	Determination Method	Instruments use mode
PH		On-site measurement	Hanna Combo tester HI98129
EC	µS/cm	>>>>>	>>>>>
TDS	mg/l	>>>>>	>>>>>
Turbidity	NTU	>>>>>	>>>>>
Total Hardness	mg/l	Titration	HACH DR-6000
Ca^{+}	mg/l	>>>>>	>>>>>>
Mg^{+}	mg/l	Photometer 10ml	>>>>>>
HCO_3^{-}	mg/l	Photometer 25ml	>>>>>>
Cl^{-}	mg/l	>>>>>>	>>>>>>
SO_4^{2-}	mg/l	Photometer 10ml	>>>>>>
F^{-}	mg/l	Photometer 25ml	>>>>>>
Fe^{2+}	mg/l	Photometer 10ml	>>>>>>
NO_3^{-}	mg/l	>>>>>>	>>>>>>

3.2.2.4 Piper Diagram and Water type

Gather water quality data for major and minor cations (e.g., calcium, magnesium) and anions (e.g., bicarbonate, sulfate, and chloride) from reliable secondary sources. Ensure that the data covers a representative range of sampling locations within the Kola catchment area and includes measurements for the desired parameters. Use Aquachem Software to import the water quality data and to generate a Piper plot based on the imported data. The plot provides a graphical representation of the dominant ions in the water samples and allows for the identification of different water types based on their relative positions within the plot.

3.2.2.2 Spatial Analysis

Using ArcGIS 10.8 and the inverse distance weighted (IDW) interpolation method to produce spatial distribution maps of physicochemical parameters in the Kola area is indeed a valuable approach. By utilizing this methodology, the study can effectively visualize and analyze the spatial patterns of various physicochemical parameters across the study area.

The availability of data from multiple sources such as boreholes, springs, and shallow wells allows for a comprehensive assessment of water quality in the Kola area. The analysis results obtained for parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, hardness, calcium, magnesium, fluoride, carbonate, nitrate, iron, chloride, and sulfate provide valuable information about the composition and characteristics of the water samples.By incorporating the WHO (2011) drinking standards for each physicochemical property, the spatial results included in the maps provide important information regarding the suitability of groundwater for drinking purposes.

WQI Analysis

WQI has been determined using the drinking water quality standard recommended by the World Health Organization (WHO 2017). The Water Quality Index has been calculated using the weighted arithmetic method, which was originally proposed by Horton (1965) and developed by Brown et al. (1972). The weighted arithmetic water quality index (WQI) is represented in the following way.

$$\mathrm{WQI} = \sum_{i=1}^{n} (\mathrm{WiQi}/\mathrm{Wi})$$

Where n = number of variables or parameters, Wi= unit weight for the ith parameter, Q_i= quality rating (sub-index) of the ith water quality parameter. The unit weight (W_i) of the various water quality parameters is inversely proportional to the recommended standards for the corresponding parameters.

$$W_i = K/S_n$$

Where, W_i= unit weight for the i^{th} parameter, S_n= standard value for i^{th} parameters, K = proportional constant, The value of K has been considered '1′here and is calculated using the mentioned equation below,

$$K = 1/\sum / (1/S_n)$$

Table 3. 4 Weight of chemical parameters of Groundwater

Physical-Parameters	Units	BIS Standard/WHO	1/Sn	Wi=k/Sn
PH		8.5	0.117647059	0.026702349
EC	µS/cm	300	0.003333333	0.000756567
TDS	mg/l	500	0.002	0.00045394
Turbidity	NTU	5	0.2	0.045393993
Total Hardness	mg/l	300	0.003333333	0.000756567
Ca^+	mg/l	75	0.013333333	0.003026266
Mg^+	mg/l	30	0.033333333	0.007565666
HCO_3^-	mg/l	600	0.001666667	0.000378283
Cl^-	mg/l	250	0.004	0.00090788
SO_4^{2-}	mg/l	200	0.005	0.00113485
F^-	mg/l	1.5	0.666666667	0.151313311
Fe^{2+}	mg/l	0.3	3.333333333	0.756566553
NO_3^-	mg/l	45	0.022222222	0.005043777
			∑Wi=4.405869281	∑Wi =1

$$\mathbf{Qi = 100[(V_o-V_i)/ (S_n-V_i)]}$$

Where V_o= observed value of the i^{th} parameter at a given sampling site, V_i= ideal value of the i^{th} parameter in pure water, and S_n= standard permissible value of the i^{th} parameter (Ram et al. 2021).

Table 3. 5 Classification of water quality based on weighted arithmetic WQI (Brown et al 1972)

WQI	**STATUS**
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
Above 100	Unsuitable for drinking

3.2.2.4 Aquifer systems and determine hydraulic properties

Well-completion reports from ten different locations in the Kola research area were gathered. The information obtained from these reports, such as the static water level, dynamic water level, total drawdown, discharge, and lithological logging, will be valuable for understanding the characteristics of the groundwater system in the area.

The involvement of drilling companies like South Water Works Construction Enterprise and Sidama Regional Water Mines Energy Bureau is commendable. The pumping test data they provided will further enhance the analysis of the groundwater system by providing additional information on lithological properties. AquiferTest 3v is a software commonly used for analyzing pumping test data and determining hydraulic properties of aquifers. It provides a range of analysis methods, including the Cooper-Jacob method and the Theis method, to interpret pumping test data and estimate hydraulic properties.

The Cooper-Jacob method involves plotting the observed drawdown against time during a pumping test, and theoretical drawdown values are calculated using the Theis equation or similar analytical solutions. These theoretical drawdown values are then plotted on the same graph as the observed drawdown-time data.

RESULTS AND DISCUSSION

4.1 Geomorphology, Lithology, and Hydrogeological Setting

4.1.1. Geomorphology

The geomorphological setting of the study area linear ridges in the western part near the Gidabo River suggest elongated elevated features running parallel to each other. These ridges may result from geological processes such as volcanic activity and tectonic forces. Volcanic eruptions can deposit lava flows or volcanic ash, creating linear ridges. Tectonic forces can uplift and deform the landscape.

The presence of a deep gorge in this area indicates significant erosion and down cutting by the Gidabo River over time, likely influenced by this volcanic and tectonic event. The eastern part of the area is characterized by a major river gorge, indicating the presence of a significant river that has eroded deeply into the landscape. The river's erosive power, in combination with other factors like geology and climate, has resulted in the formation of a deep and narrow gorge. The presence of this prominent river gorge suggests that the river has played a significant role in shaping the landforms in this region over time.

The presence of steep slopes in the northing direction area of the Kola River catchment suggests a dynamic and active landscape. It indicates ongoing geomorphological processes that are shaping the landforms in this area. The undulating side slopes suggest a more gentle relief with small-scale variations in elevation, likely influenced by a combination of erosion and deposition processes. Some areas may undergo erosion, leading to the removal of soil and sediments, while others may experience deposition, resulting in the accumulation of materials and the formation of small-scale landforms.

In the middle of the Kola River, there is a recent accumulation of Boulder Basalt, which originates from the upper part of the escarpment. This accumulation suggests that boulders composed of basaltic rock have been transported and deposited in this area. Others there are four existing quarry sites where rock explosions and excavation activities are taking place. These human activities have the potential to significantly alter the natural geomorphological processes and landforms in the Kola catchment area. Quarrying involves the extraction of rock materials, which can disrupt the existing landscape and geological formations. The top part of the eastern escarpment features high mountains, contributing to the area's geomorphological diversity. These mountains are likely to exhibit rugged terrain, and steep slopes, and potentially display alpine features influenced by the prevailing climate and underlying geological conditions.

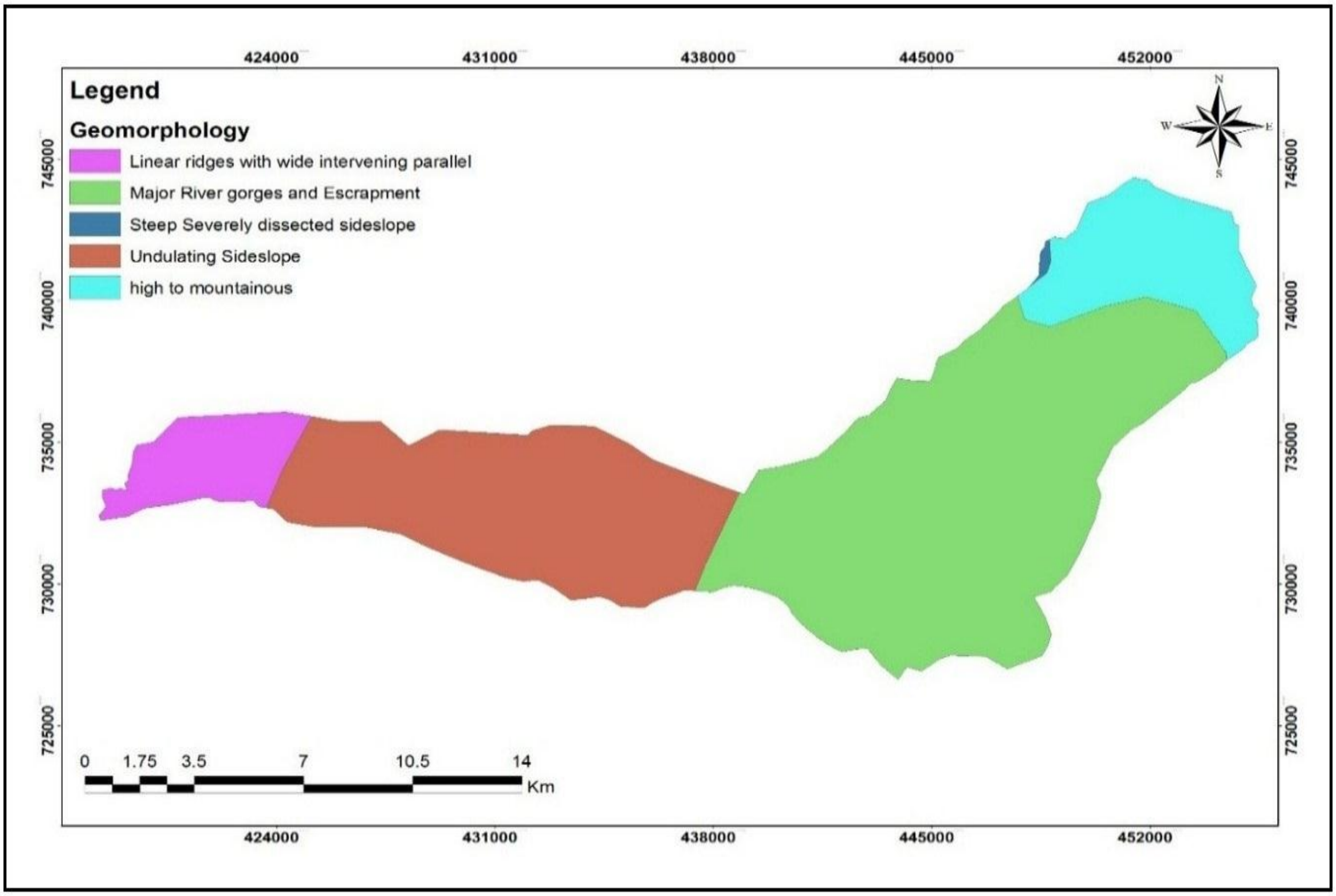

Figure 4. 1 Rift Valley Geomorphological map of the study area

4.1.2 Lithological of study area

Basalt volcanic rocks: The study area in the middle of the Kola River catchment features exposed basalt volcanic rocks. A fault line traverses the area from north to south, intersecting the Kola River. Within the river's central section, there are moderately weathered and fractured basalt formations, along with rounded boulder materials originating from the upper eastern part of the Kola catchment. Additionally, in certain areas, both the upper and lower portions of the river in the central section are covered by a thick layer of red clay soil.

Ignimbrite: The ignimbrite unit is prominently visible in the western region of the Kola River catchment. This rock type exhibits a grayish-green color and is characterized by its abundance of crystals, including orthoclase, quartz, and traces of amphiboles and pyroxenes. the specific properties of the rocks found in the primary quarry site within the Kola River area. It is worth noting that the ignimbrite is vertically jointed, indicating the presence of distinct fractures and separations within the rock formation.

Rhyolite: The rhyolite rock formation is found in the eastern part of the area, specifically in the rift escarpment that runs along the axis of the rift floor. These rhyolites consist of extensive deposits of rhyolite lava flow and domes, as well as obsidian, with layers of pyroclastic materials interspersed. The rhyolites in the Gudumo Ridge area are concentrated along an intensely tectonized zone that trends in an NNE-SE direction.

Scoria: In the Kola River catchments, there is a small area in the northern direction that is covered by scoria, a type of volcanic rock with a vesicular texture. However, in the lower part or western direction around the river, there are more than three Quarry Sites where the geological formations are extensively exposed in the subsurface.

The Quarry Sites reveal distinct layers of different rock types. The uppermost layer is composed of red clay soil, estimated to be around 0.5 meters thick. Below the clay layer, there is a layer of ignimbrite rocks, which are volcanic rocks formed from pyroclastic flows. Further down, there is a layer of welded tuff, which is a type of volcanic rock formed from the consolidation of pyroclastic deposits. Finally, the lowest layer consists of scoria basalts, characterized by their vesicular texture resulting from trapped gas bubbles during solidification

Trachyte basalt**:** in the study area, the exposed rock formations predominantly consist of trachyte basalt. These trachyte basalt deposits are more prominently found in the eastern and southern directions of the area. Additionally, there are also areas in the northern direction where trachyte basalt formations are present. The study area showcases a combination of trachyte basalt coverage in various directions, highlighting the geological diversity of the region.

Table 4. 1 Geological formation and its area coverage

S.N	Geology	Area Coverage (Sq.km)	Area Coverage (%)
1	Ignimbrite	75.71	33.65
2	Basalt Volcanic Rocks	42.68	18.97
3	Rhyolite Basalt	31.61	14.05
4	Trachyte Basalt	74.14	32.95
5	Scoria	0.86	0.38
	Total	**225**	**100**

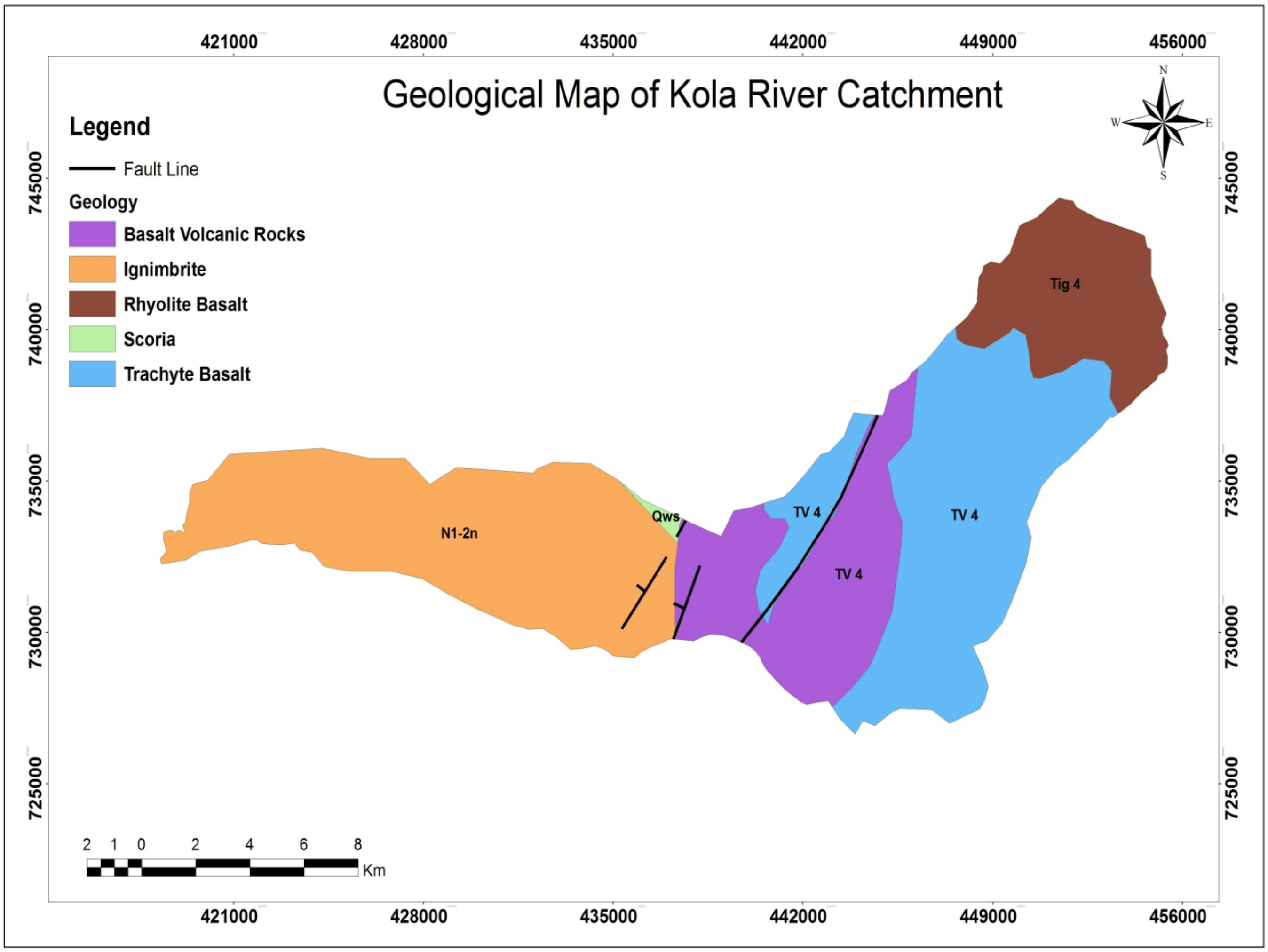

Figure4. 2 Geological map of the study area from Geological Survey of Ethiopia

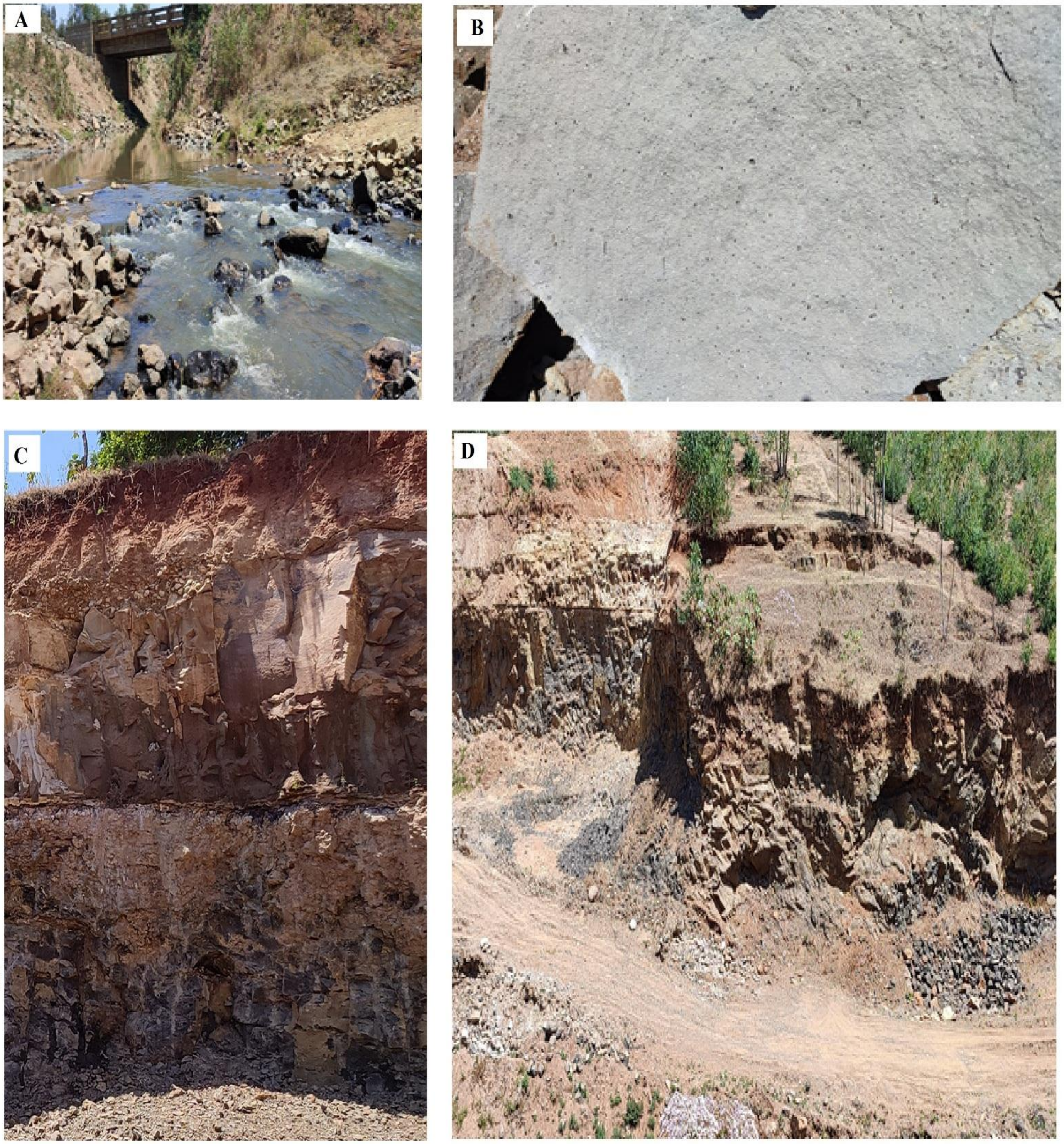

Figure 4. 3 **A,** Kola river deposit **B,** Ignimbrite **C,** Quarry Layers **D,** Site Basaltic rocks

4.1.3 Hydrogeological Setting

Inside the Kola River watershed, more than 12 water supply boreholes and 33 shallow wells have been drilled to provide water resources. Shallow wells typically have depths ranging from 35 to 90 meters, with static water levels between 18 and 23 meters. These wells are classified as shallow due to their relatively limited depth. On the other hand, water supply wells are deeper, ranging from 40 to 220 meters in depth, with static water levels varying between 12 and 58 meters.

The deepest recorded water level of 80.5 meters is found in a borehole that was drilled to a depth of approximately 220 meters, while the shallowest water level was recorded in a borehole with a depth of 100 meters. Among the inventory of boreholes near the study area, the maximum discharge is observed to be 35 liters per second in Shyicha kebele.

According to information gathered from the town water resources office, three boreholes are currently operational and used for the town's water supply. These boreholes yield a combined discharge of 10 to 12 liters per second. However, four other boreholes in the Gidibo Kebele area, near the Kola River, are non-functional and closed. These boreholes failed to serve the town due to concerns about water quality and incomplete penetration.

This suggests that careful consideration and assessment of water quality is necessary for successful borehole operation in the area. The presence of springs in the region indicates the potential for further exploration of groundwater resources. The inventory data suggests that shallow water levels are observed in the vicinity of the study area. However, the regional groundwater level is generally deep, while shallow water levels are found in the developed shallow boreholes.

The hydrogeological map of the area indicates that there is an extensive, moderately productive aquifer covering a wide area in the western part of the study area, as well as the eastern part characterized by mixed porous and fissured aquifers. The water level in the surveyed area varies with the topography, and recharge mainly occurs in the Gudumo mountainous areas.

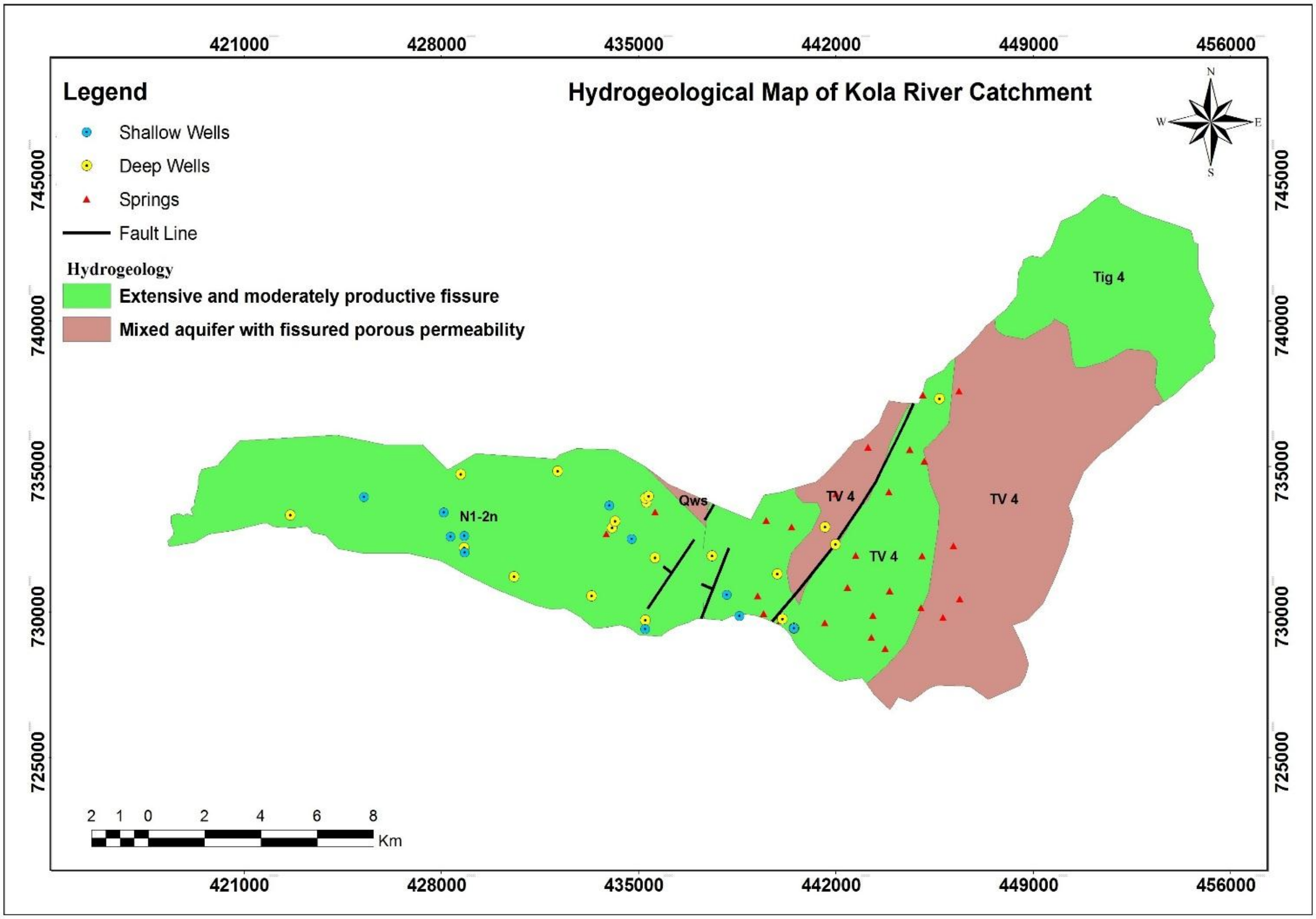

Figure 4.4 Hydrogeological map from Geological Survey of Ethiopia

Figure 4. 5 Source of Investigation A, non-functional Gidibo BH **B,** Non-functional Gidibo BH-2 **C,** Hajaba on-spot protected spring **D,** Gidibo BH-3 Drilling **E,**Gordama on-spot protected spring **F,** Shiyicha Pump Test Borehole

4.2 Groundwater Quality and Develop Spatial Maps

4.2.1 Groundwater quality parameters

Hydrogen-Ion Activity (PH)

The study conducted in the Kola research area found that the groundwater pH values ranged from 5.39 to 8.9, with an average value of 7.1. According to the World Health Organization (WHO) guidelines, the acceptable pH range for drinking water is specified as 6.5 to 8.5 (WHO, 2011).

The lowest pH value was observed in the Balesto Deep Well and the eastern part of Gordama and Hajiba Spring, indicating slightly acidic conditions. The highest pH value of 8.9 was found in the center of the Kola Shiyicha Deep Well, representing an alkaline condition. This variation in pH values across the study area can be attributed to deep groundwater circulation along fault lines.

The higher pH values observed in the eastern direction may be a result of the groundwater interacting with alkaline minerals or geological formations in that area. Conversely, the lower pH values near the recharge area can be attributed to oxidizing conditions and the leaching of metals from the underlying geological formations.

Electrical Conductivity (EC)

In the study area, the electrical conductivity (EC) values of groundwater ranged from 64.5 to 514 μS/cm, with an average value of 289.25 μS/cm. It is important to note that the acceptable range for drinking water, according to WHO guidelines (2011), falls within this range.

The highest EC value of 514 μS/cm was observed in the Gunde Borehole, indicating a higher concentration of dissolved substances in the groundwater in that specific location. On the other hand, the lowest EC value was found at the Bargo Borehole, which is located in the eastern direction of the study area. The increase in EC near the Gidabo River can be attributed to the presence of more dissolved matter in the groundwater within the Gidabo basin.

The Gidabo basin is situated in the central rift valley area and constitutes 60% of the research area. These areas tend to exhibit higher EC values due to the abundance of dissolved substances in the groundwater.

Conversely, the steep gorge ridge eastern escarpment, which makes up 40% of the study area and serves as a recharge zone, records the lowest EC values. The recharge zone is characterized by the infiltration of relatively cleaner water, resulting in lower concentrations of dissolved substances and hence lower EC values.

Total Dissolved Solid

In the research area of the Kola sub-basin, the Total Dissolved Solids (TDS) in groundwater were found to range from 32.15 to 322 mg/l, with an average value of 177.075 mg/l. It is worth noting that the permissible range for drinking water, according to WHO guidelines (2011), is 500 mg/l.

The highest recorded TDS value of 322 mg/l was observed at the Aletawondo Hospital borehole, indicating a relatively higher concentration of dissolved solids in the groundwater at that location. On the other hand, the lowest TDS value of 32.15 mg/l was found in the eastern part of Gordama Spring. This suggests that the TDS levels in the groundwater of the research area are within acceptable limits and do not pose a significant concern for drinking water purposes.

Similar to the electrical conductivity (EC) values, there is an increase in TDS near the Gidabo River in the research area. This can be attributed to the high contact of subsurface rocks, which leads to higher concentrations of dissolved solids in the groundwater. Even in areas such as Dongora Elimate and Qoreke Western, where higher levels of magnesium and calcium cations are present, TDS values are elevated.

However, in the eastern region of the study area, TDS values are comparatively lower. This may be due to different geological and hydrogeological conditions in that area, resulting in reduced concentrations of dissolved solids in the groundwater

Turbidity

The turbidity values ranging from 0 to 250 NTU, with an average of 125 NTU, indicate a significant variation in water clarity within the research area. According to the World Health Organization (WHO) guidelines from 2011, the permissible range for turbidity in drinking water is 5 NTU. The highest recorded turbidity value of 250 NTU at the Huletgna Mogisa Borehole suggests a relatively high level of suspended particles in the water in that location. On the other hand, several boreholes, including SBH-1, GoBH, GoSP, HajSP, GBH, GSW, DoE, GundeBH, and BaBH, recorded a turbidity value of 0 NTU, indicating clear water with no visible suspended particles.

The geology of the research area plays a role in the turbidity variations observed. The presence of thick red clay soils in the underlying profile of boreholes, intercalated with aquifer layers, can contribute to higher turbidity values. These clay soils may contain fine particles that can become suspended in the water, leading to increased turbidity. Additionally, the issue of high iron bacteria concentration mentioned is of significant concern. Iron bacteria can contribute to increased turbidity levels and affect water quality.

The well-completion reports and logging samples indicating the intercalation of red clay soils and aquifer layers suggest that these formations may be associated with higher turbidity values due to the presence of suspended particles. It is interesting to note that in boreholes where the lowest turbidity result of zero NTU was observed, there was no intercalation of red clay soil layers. Instead, fractured volcanic rocks were found. These fractured rocks may contribute to clearer water by allowing better filtration and reduced presence of suspended particles.

Hardness

In the catchment area of the Kola River, the hardness of water varies depending on the subsurface geological components. The hardness ranges from 20.6 to 72 in the case of soft water and 78 to 98 for moderately hard water. The presence of black basalt boreholes in the aquifer layer can contribute to the hardness of the water, particularly due to the magnesium concentrations associated with these geological features. Magnesium is one of the minerals that contribute to water hardness.

In the collection of data from twenty water quality schemes, According to this classification, twelve of the schemes were classified as soft water, representing 70% of the total. Soft water indicates lower levels of hardness. On the other hand, seven schemes were classified as fairly hard, indicating relatively higher levels of hardness.

It is important to note that water hardness is primarily caused by the presence of dissolved minerals, such as calcium and magnesium, in the water. Higher concentrations of these minerals result in harder water. The classification of water as either soft or hard can have implications for various applications, including household use, industrial processes, and the efficiency of certain water treatment methods.

Calcium Ion (Ca^{2+})

In the Kola study area, the calcium concentration in the water ranges from 8.8 to 26.5 mg/l, with an average value of 17.65 mg/l. It is important to note that the maximum permissible range for calcium in drinking water, according to WHO guidelines from 2011, is 75 mg/l. The highest recorded calcium result was found in the Dongora Kebedo Borehole, while the lowest values were observed in the Balesto Borehole. However, despite the variations in calcium concentrations among different water schemes in the Kola community, all the recorded calcium results fall within the acceptable range for drinking water. The fact that the calcium values in the study area are within the permissible range indicates that the water is considered potable and suitable for drinking purposes. Calcium is a natural mineral that is commonly found in water sources and is not typically a concern for health at the observed concentrations.

Magnesium Ion (Mg^{2+})

The watershed study area's magnesium results indicate that there is very little in the lower Gidabo River in a westerly direction. Two already-existing magnesium-increasing boreholes, Qorke and Bargo. Magnesium concentration in those two areas of the earth's crust Due to the basaltic rocks' high magnesium and iron concentration, basalt volcanic rocks are naturally occurring. Magnesium levels are rising when compared to other water sample analysis systems. The maximum amount of magnesium that should be allowed in water is 50 mg/l, as per WHO guidelines.

In the watershed study area, the results indicate that there is a relatively low presence of magnesium in the lower Gidabo River, particularly in a westerly direction. However, two specific areas, namely Qorke and Bargo, have existing boreholes where the magnesium concentration is known to be higher.

The high magnesium concentration in these areas can be attributed to the presence of basaltic volcanic rocks, which naturally contain elevated levels of magnesium and iron. The geological composition of basaltic rocks contributes to the increased magnesium levels observed in the water samples from these areas.

Bicarbonate Ion (HCO_3^-)

The primary geological subsurface generation of bicarbonate is limestone-rich rocks, which have a high concentration of HCO3-, and some volcanic-acidic rocks, which also have some effect on bicarbonate production. Geothermal volcanic areas also contribute to the development of bicarbonate to some extent. Volcanic rocks and ignimbrite materials predominate in the bottom portion of the study area's geological formations. Based on laboratory analysis of sample data, it can be seen that bicarbonate concentrations range from 97 mg/l to 332.82 mg/l, with the concentrations increasing in the study area's major rift-valley while decreasing in the area's upper basalt geological formation when compared to lower.

Chloride Ion (Cl^-)

The chloride concentration spatial map distribution reveals that it is slightly growing in the center of Aletawondo Town, with a maximum value of 35 mg/l in groundwater, which compares to WHO's not high. In contrast, in the upper and lower portions of the study area, the population is not densely populated and chloride concentrations are very low because there is no pit waste disposal activity.

The population around Aletawond Town indicates that the activities of waste materials deposited in pits that happen to contaminate shallow groundwater. Therefore, one of the obvious indicators in Hajaba village is the source of spring chloride, and the result is 0.05 mg/l, which is quite little.

The WHO's acceptable range for chloride concentration in all collected water schemes is 250 mg/l.

Sulfate Ion (SO_4^{2-})

The watershed's Sulfate parameters produced a relatively minor result on the spatial analysis map. Sulfate, particularly in groundwater, contributes to the creation of subsurface pyrite, gypsum, and mining areas by increasing the concentration of sulfate in mine rocks.

Therefore, all existing boreholes in the research area's subsurface formation show that all volcanic rocks may be reflecting a small quantity of sulfate ions. The greatest recommended limit of sulfate in drinking water is 250 mg/l, according to the WHO. The greatest recommended level of sulfate in drinking water has been determined by the WHO to be 250 mg/l.

Fluoride Ion (F^-)

In the Rift Valley study area, the fluoride concentration in the water is relatively high when compared to the standard set by the World Health Organization (WHO). This high fluoride content can be attributed to geological formations, particularly volcanic-acidic materials and alluvial deposits present in the region. These geological factors contribute to the elevated levels of fluoride in the water sources.

The study area includes the eastern highland Rift-escarpment in the lower portion of the Rift Valley zone. In this lower portion, the fluoride levels in the water samples range from a minimum of 0.12 mg/l to a maximum of 1.02 mg/l. It is important to note that these values are still within the acceptable range for drinking water.

The World Health Organization has set a guideline for fluoride concentration in drinking water, recommending a limit of 1.5 mg/l. The fluoride levels recorded in the lower portion of the study region fall below this guideline, indicating that the water is suitable for drinking purposes.

Iron (Fe^{2+})

The iron concentration in the studied area ranged from 0.02 to 6.17 mg/l, with an average value of 3.095 mg/l. The World Health Organization (WHO) has set a tolerable range for iron concentration in drinking water, which is 0.3 mg/l. The maximum recorded iron concentration value of 6.17 mg/l was observed in the Huletgna Mogisa Borehole, while the minimum recorded value of 0.02 mg/l was found in the Dongora Elimate borehole within the research area.

The presence of highly weathered black basaltic rocks and thick red clay soils in the geological profile of the area contributes to the iron content. These geological factors play a role in the genesis of iron concentrations in the water. It is worth noting that the issue of extraordinarily high iron bacteria concentration is of significant concern. Iron bacteria are microorganisms that can contribute to elevated iron levels in water sources.

Based on the data provided, it is evident that some boreholes in the study area show contamination levels above the WHO drinking water standards. These boreholes include GBH-2, BuBH, AWH-BH, HuMBH-1, and DKBH. However, there are boreholes in the Kola Sub-basin where the drinking water quality remains within acceptable limits. These boreholes include SBH-1, GBH-1, BaBH, Gunde BH, GoBH, GoSP, HajSP, GBH, GSW, DoE, Bargo, and Qorke BH

Nitrate (NO_3^-)

The range of nitrate concentration in the research area varies from 0.1 to 13.36 mg/l, with an average value of 6.73 mg/l. The highest recorded value was reported in the Qorke Borehole, while the lowest value was observed in the Huletegna Mogisa Borehole.

According to the WHO's standard acceptable value of 50 mg/l, the findings of the borehole laboratory analysis show that the minimum value is 0 and the maximum value is 13.36 mg/l. Since the nitrate result falls below the WHO's acceptable range, it is advised that the community drink the water in the research area.

4.2.2 Spatial distribution Maps

The water quality parameters, such as hydrogen ions (pH), electrical conductivity, total dissolved solids (TDS), turbidity, and total hardness, calcium, magnesium, bicarbonate, chloride, sulfate, fluoride, iron, and nitrate, Geo-statistical interpolation can be employed to generate maps that depict the spatial variations and patterns of these parameters throughout the study area.

The spatial distribution PH concentration map (Figure 4.6) indicates an increasing trend from the eastern to western direction in the central part of the study area. This suggests that the water in the central region becomes more acidic as you move from east to west.

The spatial distribution conductivity and total dissolved solids (TDS) maps (Figure 4.6) show an increasing trend from east to west in terms of drinking water quality. This implies that the conductivity and TDS levels in the drinking water increase as you move from the eastern side to the western side of the study area.

The spatial distribution turbidity concentration map (Figure 4.6) indicates an increasing trend from the northern to southern part of the study area. Additionally, there is a specific increase in turbidity from the southern to western part of the study area. This suggests that the water becomes increasingly turbid as you move from north to south, with a further increase in turbidity towards the western part.

The distribution pattern indicates that the turbidity concentrations fall within the acceptable limit of 5 NTU (Nephelometric Turbidity Units) recommended by the World Health Organization (WHO) when moving from north to both the western and eastern directions. However, there is an increase in turbidity concentrations when moving from north to south, with the concentrations exceeding the WHO's recommended standard of 5 NTU. This suggests that the water in the southern part of the study area has higher levels of turbidity, which may be a cause for concern in terms of water quality.

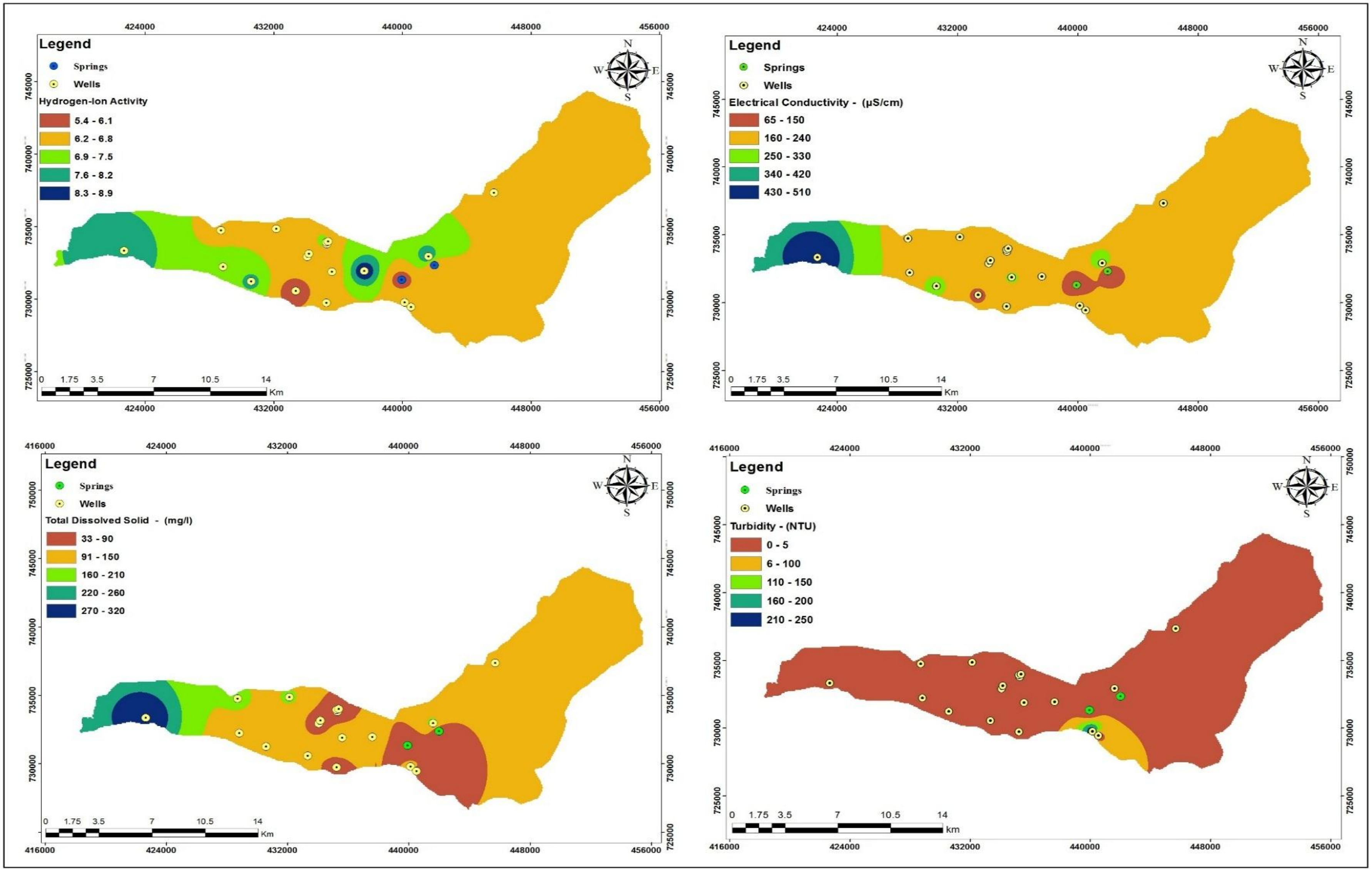

Figure 4. 6 Spatial distribution map physicochemical parameters PH,EC,TDS &Turbidity

Figure 4.7 shows the spatial distribution maps of hardness and calcium in the Kola study area. The distribution pattern indicates that the concentrations of both hardness and calcium increase from the western to the eastern direction. Hardness refers to the concentration of minerals, primarily calcium and magnesium, in the water. Similarly, calcium concentration specifically focuses on the presence of calcium ions in the water. The spatial distribution maps indicate that the levels of both hardness and calcium rise as you move from the western part of the study area toward the eastern part.

Figure 4.7 indicates that the spatial distribution map of magnesium concentration in the Kola catchment area shows a slight increase in the central part, and these concentrations fall within the acceptable range set by the World Health Organization (WHO). The fact that the magnesium concentrations in the central part of the Kola catchment, as depicted in Figure 4.7, are within the acceptable range of WHO standards is a positive finding. It indicates that the magnesium levels in the water in this area meet the recommended guidelines for drinking water quality.

Figure 4.7 indicates that the spatial distribution map of bicarbonate concentration in the Kola catchment area shows an increasing trend from the half of the eastern direction to the western part. Bicarbonate is an important parameter in water quality analysis and is typically associated with alkalinity. The increasing trend of bicarbonate concentration from the half of the eastern direction to the western part suggests that the water in these areas contains higher values of bicarbonate compared to the surrounding areas.

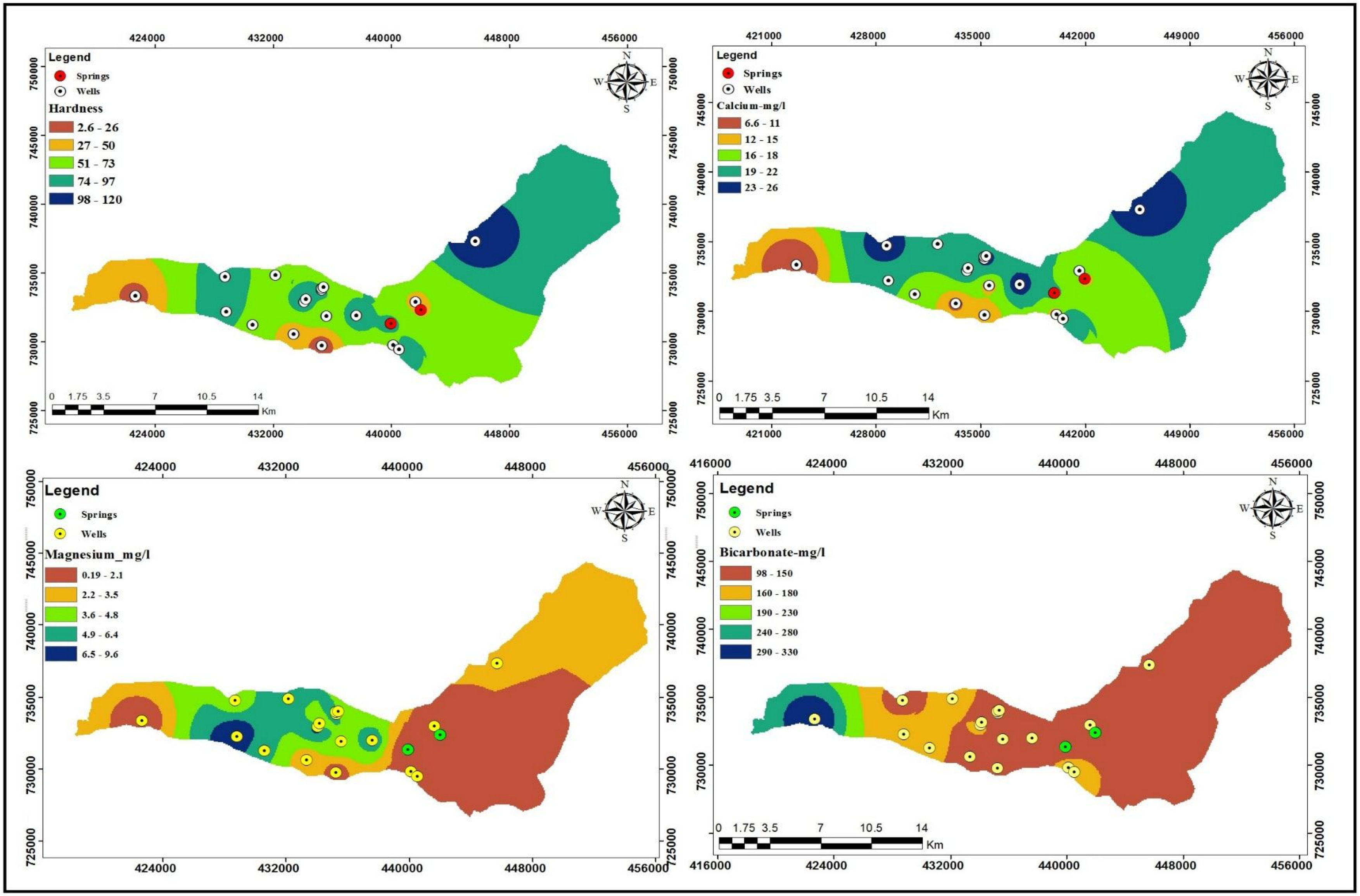

Figure 4. 7 Spatial distribution map physicochemical parameter Hardness, Ca^{2+}, Mg^{2+} & HCO_3

Figure 4.8 shows the spatial distribution map of sulfate concentration in the study area. The map indicates that the sulfate concentration is within an acceptable range according to the World Health Organization's (WHO) recommendations, except for some areas in the north-west and north- south where the concentration may be higher.

(Figure 4.8) shows the spatial distribution map of fluoride concentration in the study area. The map indicates that the fluoride concentration exhibits a slight increasing trend from the central to the western part. The increasing trend suggests that the fluoride concentration in the water gradually rises as you move from the central region toward the western part of the study area. This information provides insight into the spatial variability of fluoride levels across the area under investigation.

Figure 4.8 shows the spatial distribution map of iron concentration in the study area. The map indicates that the iron concentration exhibits a highly increasing trend in the central part of the south direction. However, it is concerning to note that the iron concentration in this central part of the south direction exceeds the acceptable range of 0.3 mg/l. This suggests that the iron levels in the water in that specific area are higher than the recommended limit for safe consumption.
Figure 4.8 shows the spatial distribution map of nitrate concentration, and Figure 4.9 shows the spatial distribution map of chloride concentration in the Kola catchment area.

According to the maps, both nitrate and chloride concentrations in the central part of the Kola catchment are relatively small. Additionally, the ranges of concentrations depicted in the maps are within the acceptable limits set by the World Health Organization (WHO).

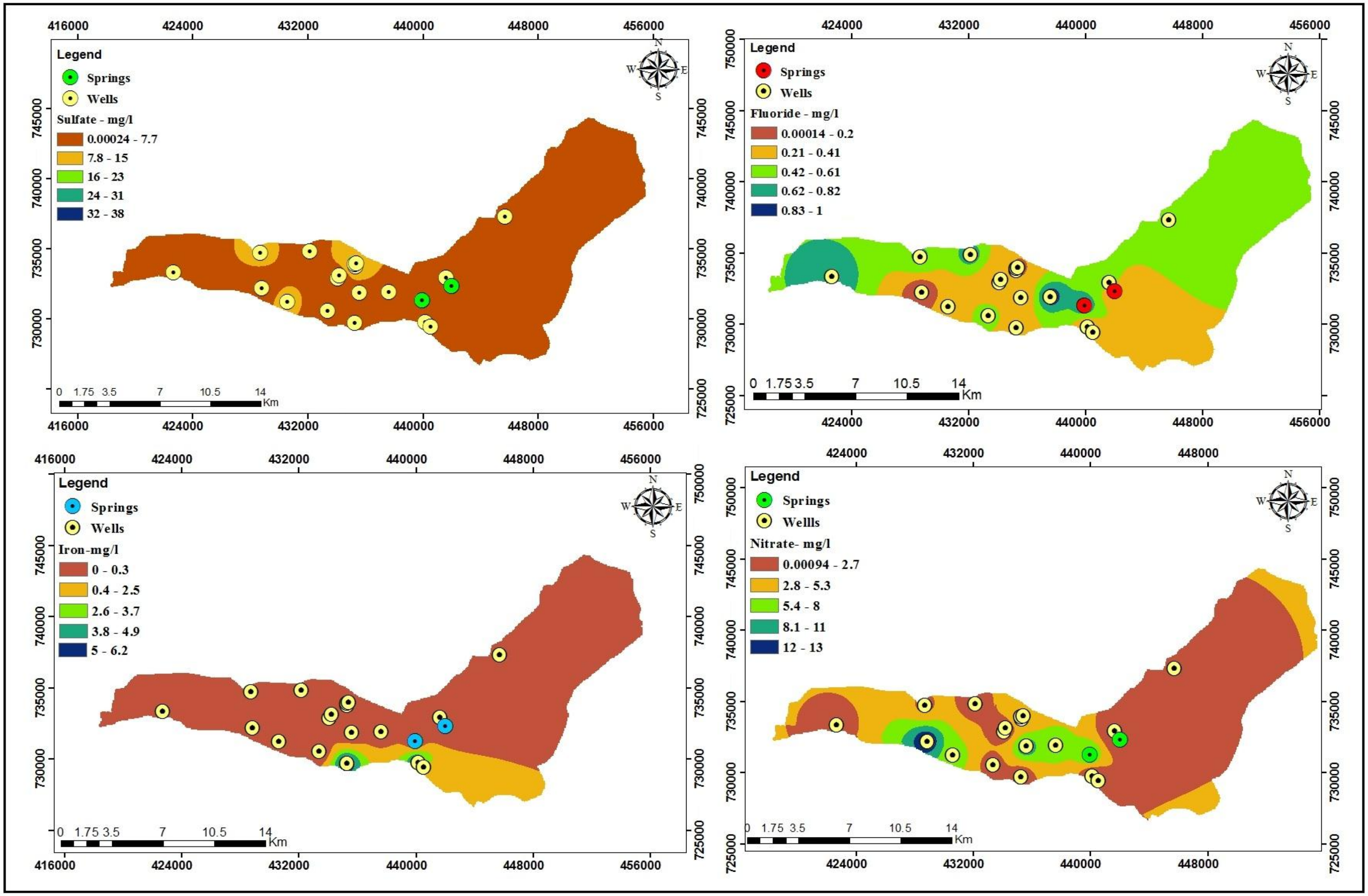

Figure 4. 8 Spatial distribution map physicochemical parameters SO_4^{2-}, F^-, Fe^{2+} and NO_3^-

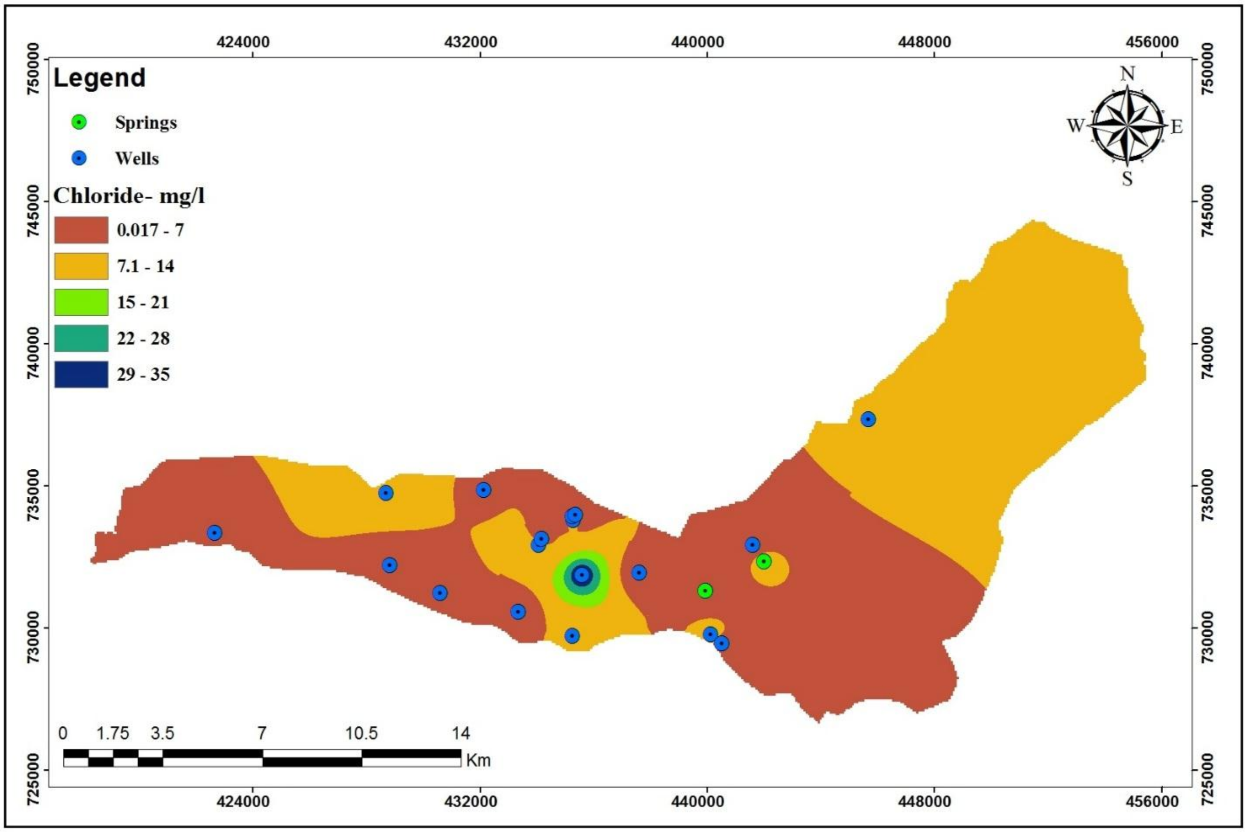

Figure 4. 9 Spatial distribution map physicochemical parameters Cl^-

4.2.3 Water Quality Index Result

Based on the Water Quality Index (WQI) results presented in Table 4.3, the maximum recorded value was 1785.67. The lowest WQI values were found in Gordam Borehole, Gordama Spring, Hajba Spring, and Bargo Borehole, indicating better water quality in these sources. The higher WQI values observed in the Kola research area can be attributed to increased turbidity and iron concentrations in the borehole samples. The presence of iron concentrations can be linked to the geological formation of red clay soil intercalated with fractured aquifer layers in the study area. Based on the WQI results, it can be concluded that 0.71% of the groundwater samples in the study area are classified as excellent, 4.003% as good, 4.77% as very poor, and 90.50% as unfit for drinking purposes. Specifically, according to the WQI results in the Kola area, samples from Aletawond Hospital–BH, Huletegna Mogisa Health Center, Ggidabo BH-3/Burka/, Dongora

Kebado, Gidabo BH-2, and Bulesa BH are considered unacceptable for drinking water standards. Therefore, these water sources should only be used for irrigation purposes.

Table 4. 2 Classification of water quality index the study area

No	Sampling Names	Source Types	WQI Values	Status
1	Shayicha BH-1	Borehole	89.68	Very Poor
2	Shayicha BH-2	Borehole	86.47	Very Poor
3	Gidabo BH-1	Borehole	76.63	Very Poor
4	Gidabo BH-3/Burka/	Borehole	114.53	Unfit for Consumption
5	Gidabo BH-2	Borehole	401.70	Unfit for Consumption
6	Balesto BH	Borehole	11.32	Excellent
7	Bulesa BH	Borehole	131.38	Unfit for Consumption
8	Gunde BH	Borehole	27.19	Good
9	Aletawond Hosptal -BH	Borehole	1602.20	Unfit for Consumption
10	Huletegna Mogisa Health center	Borehole	1785.67	Unfit for Consumption
11	Huletegna Mogisa -1	Borehole	342.02	Unfit for Consumption
12	Gordama	Borehole	42.93	Good
13	Gordama	Spring	38.63	Good
14	Hajaba	Spring	37.96	Good
15	Gidabo	Borehole	131.38	Unfit for Consumption
16	Gibado	Shallow Well	28.86	Good
17	Donkogra kebado	Borehole	282.48	Unfit for Consumption
18	Dongora Elimate	Borehole	13.80	Excellent
19	Qorke	Borehole	36.39	Good
20	Bargo	Borehole	12.7446	Excellent

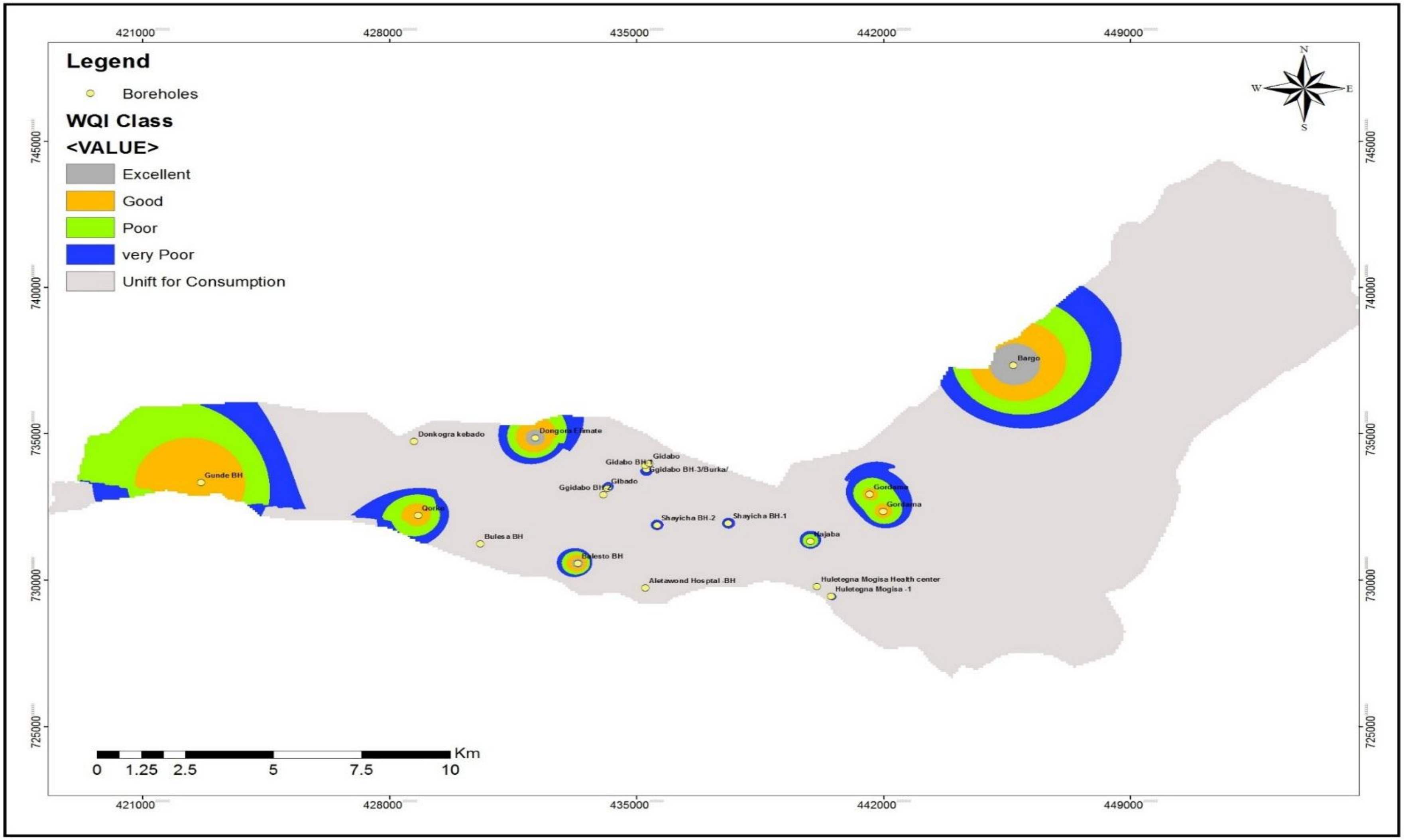

Figure 4. 10 Spatial Interpolation of Water Quality Index (WQI)

4.2.4 Piper plot Interpretation

Groundwater types

The piper plot of the chemical data helps to identify different water types. Three major groups of water types (Ca-HCO_3, mixed Ca-Na-HCO_3 and Na-Ca-HCO_3, and Na-HCO_3) were identified in the area. The classification of the waters into group of groundwater types is based on major and minor cations and anions in the water samples of secondary data. From the spatial distribution of groundwater types in the area, hydrogeological system characterization has been made and dominant hydrochemical processes were also defined (Fig. 4.12)

Table **4. 3** hydro chemical type in the study area.

ID	SAMPLEID	LOCATION	WATERTYPE
6	Balesto BH	1	Na-Ca-HCO3
12	Bargo BH	1	Na-Ca-Mg-HCO3
7	Bulesa BH	1	Na-Ca-HCO3
10	Dongora Elimate	1	Na-Ca-HCO3
13	Dongora highlands	1	Ca-Na-HCO3
9	Dongora Kebado BH	1	Ca-Na-HCO3
3	Gidibo BH-1	1	Ca-Na-HCO3
5	Gidibo BH-2	1	Na-Ca-Mg-HCO3
4	Gidibo BH-3/Burka/	1	Na-Ca-Mg-HCO3-SO4
8	Gunde BH	1	Na-HCO3
11	Qorke	1	Na-Ca-Mg-HCO3
1	Shayicha BH-1	1	Ca-Na-HCO3
2	Shayicha BH-2	1	Na-Ca-HCO3

The $CaHCO_3$ water type that includes $CaHCO_3$, $CaMgHCO_3$ and $MgCaHCO_3$ are observed in all the sub-basins for water samples obtained dominantly from depression springs in parts of the study area. This groundwater type is characterized by very low TDS, often less than 500 mg/l, hence they represent early stage of geochemical evolution in recharge area and shallow depths of rapid circulation, relatively low residence time in sub surface, without significant water–rock interactions.

The second group of water types in the Kola catchment area consists of mixed CaNaHCO3 and NaCaHCO3. These water types are representative of groundwater circulating in intermediate zones in terms of depth and travel distance from recharge areas. The water samples for this group were obtained from both shallow and deep wells. The waters in this group have moderate TDS values. For low TDS samples from some deep wells belonging to this group, the possible explanation is that the sample is dominated by local recharge; The water type in this group represents intermediate stage of geochemical evolution, with considerable travel distance from recharge area and/or at a relatively deeper part of the aquifer or mixing effect of local recharge with regional flow system. This in turn signifies that the groundwater belonging to this group is in the intermediate zone between the recharge and discharge areas.

The third water type group in the area, which is NaHCO3. These water samples were obtained from a well with high Total Dissolved Solids (TDS) values in the downstream part of the Gidabo River, specifically in the extreme discharge area. The NaHCO3 water type is characterized by the dominance of sodium (Na) and bicarbonate (HCO3) ions. This composition suggests that the water in this group is alkaline or has a high pH value.

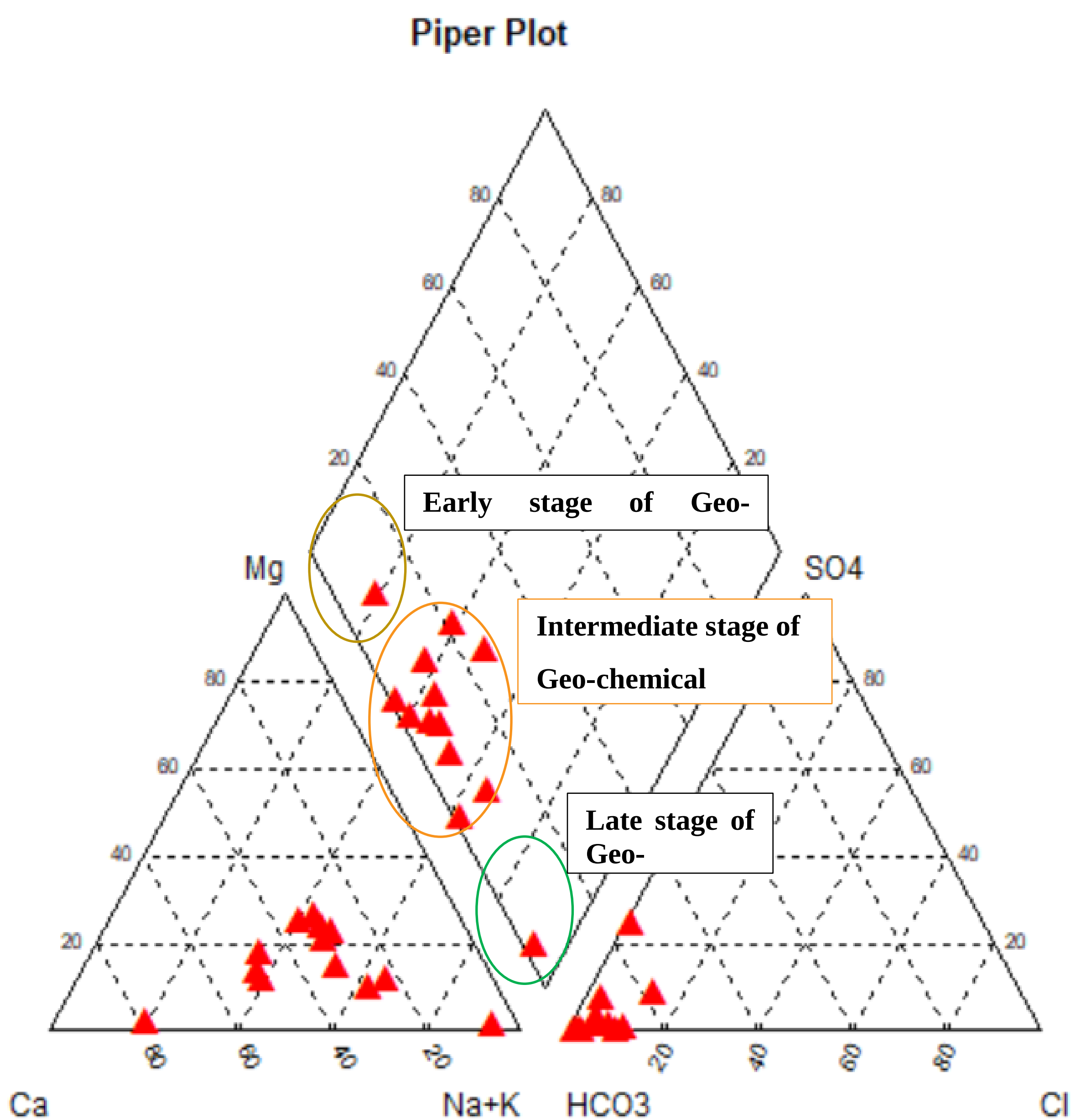

Figure **4. 11** Piper plots of secondary geochemical data from deep wells

4.4 Characterize the Major Aquifer System

According to the hydrogeological system of the Dila sheet map the classification area Extensive (746 km^2) and moderately productive or locally developed and highly productive porous aquifers, Extensive (9,626 km^2) and moderately productive fissured aquifer, Extensive (5,400 km^2) and moderately or locally developed and highly productive mixed porous and fissured aquifers and Extensive (1,449 km^2) low productive fissured aquifers (Agezew, T. et al. 2014).

The major aquifer system in the study area is based on highly permeable formation and, a fractured nature, and the yield supply is very high in most of the study area Bargo BH aquifer: It has a 90-meter thickness of basalt with varying weathered and fractured conditions. The discharge is 18.6 L/s, with a transmissivity of 178 m^2/d and a permeability of 1.08 m/d. The Bargo BH aquifer is characterized as a moderately productive aquifer, Shiycha BH-1 and BH-2 aquifer with a borehole thickness of 35 m in severely fractured Basalt and Basalt with sand.

The aquifer has a yield of 31 L/s, a transmissivity of 60.5 m^2/d, and a permeability of 1.51 m/d. Gidibo Borehole aquifer: The lithological characteristics indicate the presence of 17.5 meters of moderately fractured basalt and 70 meters of moderately fractured ignimbrite.

The well has a discharge rate of 20 L/s, a transmissivity of 15.5 m^2/d, and a permeability of 0.236 m/d. This aquifer is also classified as a moderately productive aquifer and Gidibo Borehole aquifer: The lithological characteristics indicate the presence of 17.5 meters of moderately fractured basalt and 80 meters of moderately fractured Basalt and Coarse sand formation. The well has a discharge rate of 25 L/s, a transmissivity of 15.5 m^2/d, and a permeability of 0.236 m/d. This aquifer is also classified as a moderately productive aquifer.

Aletawondo BH-2 aquifer: It consists of a 59-meter thickness of fractured basalt rocks. The discharge capacity is 5 L/s, with a transmissivity of 68.2 m^2/d and a permeability of 1.71 m/d. This aquifer is classified as a moderately productive aquifer, BH Balesto aquifer: The main aquifer of the well consists of 10 meters of fractured basalt and 32.5 meters of coarse sand formation. It has a discharge of 10 L/s, a transmissivity of 19.7 m²/d, and a permeability of 0.546 m/d, making it a moderately productive aquifer, Bulesa borehole aquifer:

The main aquifer layers consist of 52 meters of highly weathered fractured ignimbrite, 10 meters of highly fractured trachyte basalt, and 5 meters of weathered sand. The discharge is 9.5 L/s, with a transmissivity of 25.8 m²/d and a permeability of 0.445 m/d. This aquifer is characterized as a mixed porous and fissured aquifer of moderate productivity and Gunde BH consists of 27.5 meters of gravel with sand, 25 meters of highly weathered and fractured basalt, and 25 meters of fractured ignimbrite. Gunde BH has a discharge of 7 L/s, a transmissivity of 7.2 m²/d, and a permeability of 0.135 m/d.

4.4.1. Hydraulic properties

Hydraulic Conductivity

The analysis results are presented in Table 6.5. The hydraulic conductivity values of the aquifer range from 0.135 to /day, with an average value of 5.43 × 10^$^{-2}$ m/day. The highest recorded value of hydraulic conductivity was observed in the Bargo Borehole, which is located in the eastern parts of the catchment. This indicates that the aquifer materials surrounding this borehole are highly permeable. These materials likely consist of weathered fractured basalt rocks, which can contribute to the higher hydraulic conductivity.

Conversely, the lowest value of hydraulic conductivity was found in the Gunde Borehole, situated in the south of the Gidabo River. The materials surrounding this borehole may have lower permeability, resulting in a lower hydraulic conductivity value. Hydraulic conductivity represents the ability of an aquifer to transmit water. Higher hydraulic conductivity values indicate that the aquifer has greater permeability and can transmit water more easily. Lower values suggest reduced permeability and decreased water transmission capacity.

Transmissivity

The Gunde Borehole and Dongora Kebado Borehole in the study area exhibit low aquifer transmissivity values, measuring in the range of 7.27 and 10.7 m²/day, as indicated in Table 5. Aquifer transmissivity refers to the ability of an aquifer to transmit water under a hydraulic gradient. During the aquifer test, which lasted for a continuous 6 hours or 360 minutes, the water level in these boreholes showed a moderate recovery.

The water level rose from 99.87 meters to 57.93 meters within this time frame. This suggests that the aquifer has a moderate capacity to recharge and recover after pumping. In contrast, in the eastern and central regions of the Kola area, transmissivity values are observed to be higher. This can be attributed to the geological formation of this region, which is predominantly characterized by fractured basalt.

Fractured basalt formations tend to have higher permeability and allow for greater water transmission, resulting in higher transmissivity values. However, as we move in a western direction, transmissivity values show a decreasing trend. This is likely due to the presence of ignimbrite and volcanic tuff components that make up the geological structure in this area. These materials may have lower permeability, leading to reduced water transmission capacity and lower transmissivity values.

Table 4. 4 Hydraulic Conductivity Value of Study kola catchment

		Cooper-Jacob	**Thesis**	**Mean**
Wells Name	**Aquifer Thickness/m/**	**K m/d**	**K m/d**	**K(m/d)**
Aletawondo BH-1	60	0.783	0.883	0.833
Aletawondo BH-2	40	1.71	3.03	2.37
Gidibo BH	65.4	0.236	0.303	0.2695
Shayicha BH-1	41.2	1.50	1.81	1.655
Shayicha BH-2	29	152	1.39	76.69
Balesto BH	36	0.546	0.649	0.5975
Bulesa BH	58	0.445	0.376	0.4105
Bargo Well	68.63	2.62	3.47	3.045
Gunde BH	54	0.135	0.157	0.146
Dongora Kebado BH	60	10.2	1.39	5.795

Table 4. 5 Transmissivity Value of study kola Catchment

		Cooper-Jacob	Thesis	Mean
Wells Name	**Aquifer Thickness/m/**	**T [m^2/day]**	**T [m^2/day]**	**T [m^2/day]**
Aletawondo BH-1	60	47	50.3	48.65
Aletawondo BH-2	40	68.2	121	94.6
Gidibo BH	65.4	15.5	19.8	17.65
Shayicha BH-1	41.2	60.5	72.4	66.45
Shayicha BH-2	29	44	40.3	42.15
Balesto BH	36	19.7	23	21.35
Bulesa BH	58	25.8	21.8	23.8
Bargo Well	68.63	178	236	207
Gunde BH	54	7.27	84.9	46.085
Dongora Kebado BH	60	10.7	13.8	12.25

Storativity (Storage Coefficients)

In the Kola catchment, Table the storativity results of the wells indicate that the eastern part, particularly the Bargo Borehole (Sr 1.44), and the central part, including the Shayicha BH-1 and BH-2 wells (Sr 0.461, Sr 0.371) have the highest values. This suggests that the geological subsurface in these areas is characterized by highly fractured basalt rocks.

The presence of fractures in the basalt formations enhances the storage capacity of the aquifer, resulting in higher storativity values. On the other hand, in the western part of the catchment, the storativity values show a decreasing trend. This can be attributed to the geological formation changes that occur from place to place in this region.

The geological characteristics in the western part may differ from the highly fractured basalt rocks found in the eastern and central areas, leading to lower storativity values. These variations in storativity reflect the heterogeneity of the subsurface geology and its impact on the storage capacity of the aquifer within the Kola catchment.

Table 4. 6 Storativity Value of study kola catchment

		Thesis
Wells Name	**Aquifer Thickness/m/**	**Storativity /Sr**
Aletawondo BH-1	60	0.084
Aletawondo BH-2	40	0.0585
Gidibo BH	65.4	0.0603
Shayicha BH-1	41.2	0.461
Shayicha BH-2	29	0.371
Balesto BH	36	0.0583
Bulesa BH	58	0.00127
Bargo Well	68.63	1.44
Gunde BH	54	0.0374
Dongora Kebado BH	60	0.00042

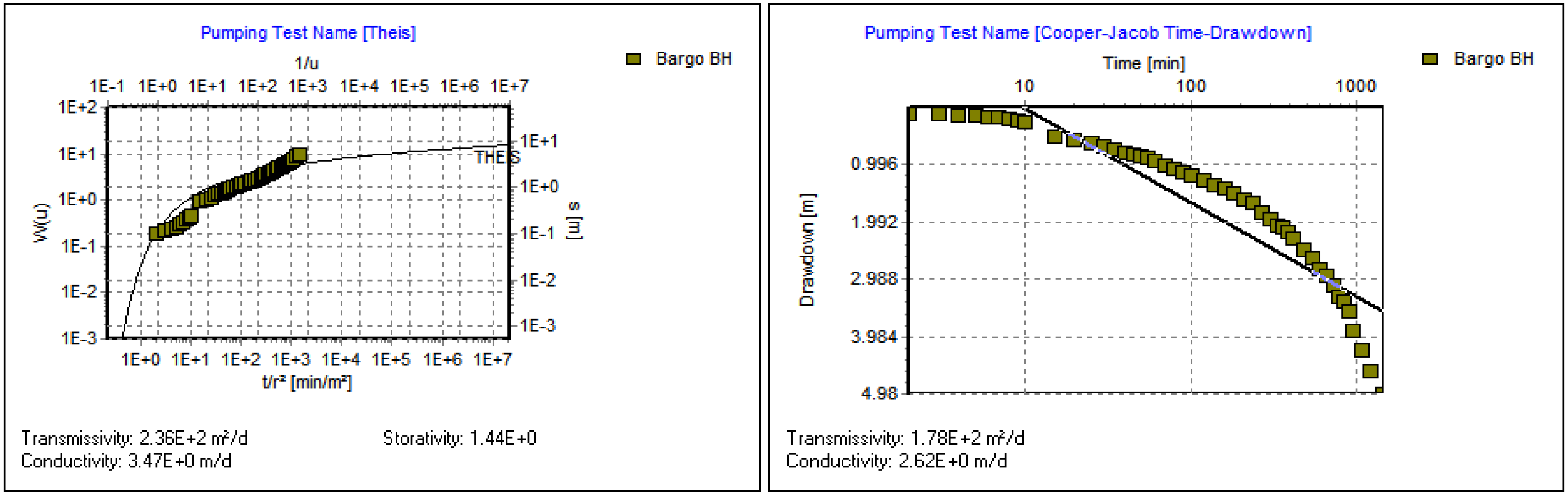

Figure 4. 12 Cooper-Jacob and Thesis Curve matching of Bargo BH

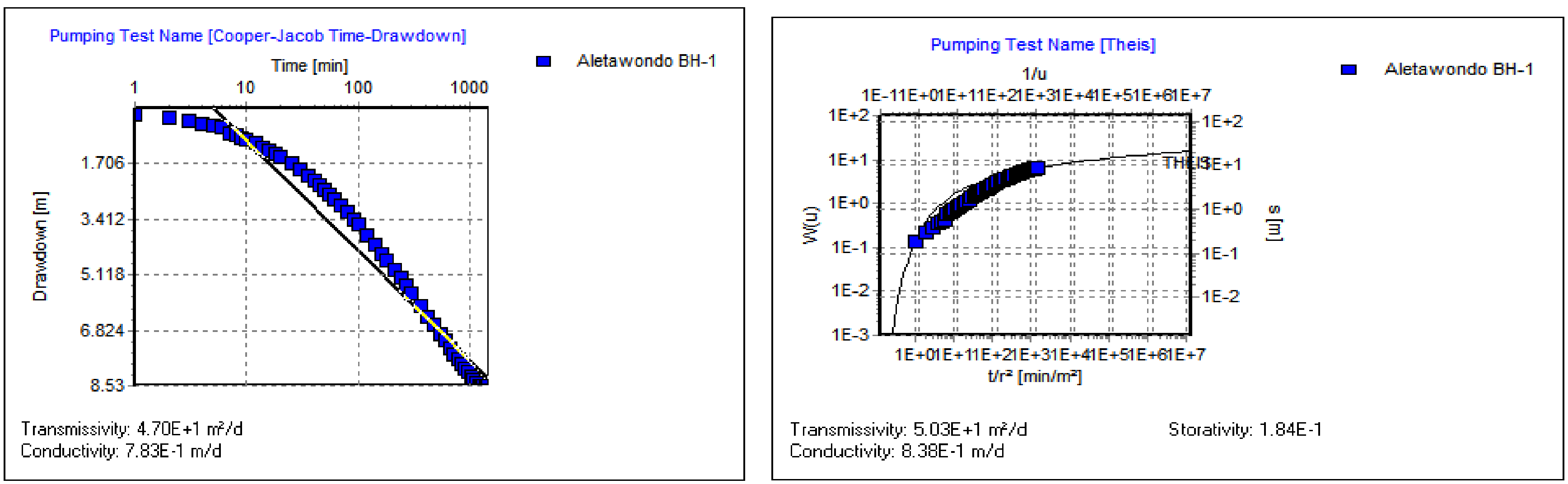

Figure 4. 13 Cooper-Jacob and Thesis curve matching central part of Aletawondo BH

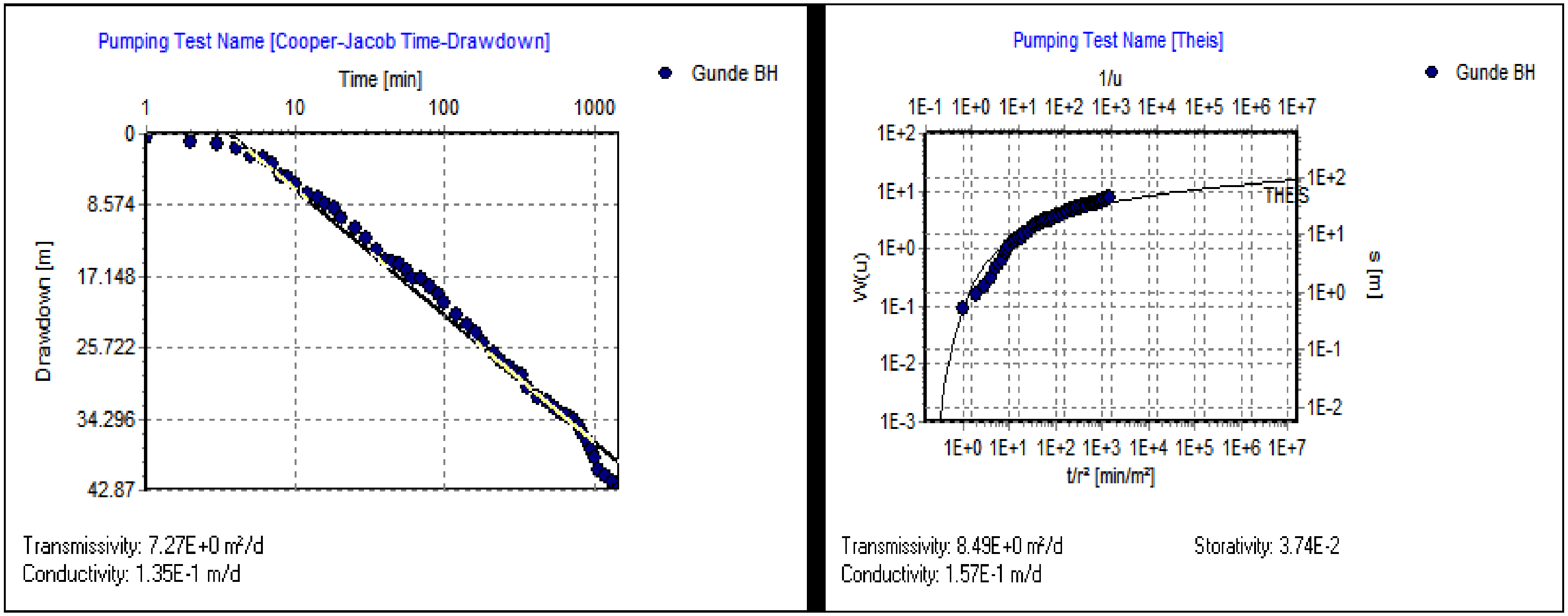

Figure 4. 14 Cooper-Jacob & Thesis curve matching Lower part of Gunde BH

5. SUMMARY AND CONCLUSION

5.1 Summary

The region has undergone significant geomorphological changes due to volcanic and tectonic events, leading to the formation of a deep gorge in the Rift Valley. However, human activities such as quarrying have transformed the gorge into an area with wide erosion and fractured rock formations. Steep slopes and easily weathered soil have cleared the deep gorge, resulting in material accumulation in the lower slope area. The eastern part of the research site has experienced gradual geomorphological changes, including the deposition of rounded boulders in the central section of the Kola River. These changes highlight the dynamic nature of the region, influenced by both natural processes and human interventions.

Basalt volcanic rocks are exposed in the middle of the area, with a fault line running through and intersecting the river. Moderately weathered and fractured basalt formations, along with rounded boulders, are found in the central section of the river. The western region prominently displays ignimbrite, a grayish-green rock type with crystals such as orthoclase and quartz. Rhyolite formations are present in the eastern part, characterized by rhyolite lava flows, domes, obsidian, and pyroclastic materials. Scoria, a vesicular volcanic rock, covers a small area in the northern direction. The Quarry Sites in the western part reveal distinct layers including red clay soil, ignimbrite rocks, welded tuff, and scoria basalts. Trachyte basalt deposits are predominant in the eastern, southern, and some northern directions. The region showcases a combination of these geological formations, highlighting its diverse nature.

In the Kola River watershed, there are numerous water supply boreholes and shallow wells providing water resources. Shallow wells range from 35 to 90 meters deep, while water supply wells reach depths of 40 to 220 meters. The water levels in these wells vary, with static levels between 12 and 58 meters for water supply wells and 18 to 23 meters for shallow wells.

Some boreholes have notable discharge rates, with a maximum of 35 liters per second observed in one borehole in Shyicha Kebele. Currently, three operational boreholes supply water to the town, yielding a combined discharge of 10 to 12 liters per second. However, four boreholes in the Gidibo Kebele area near the Kola River are non-functional due to water quality concerns and incomplete penetration.

The presence of springs in the region indicates potential for further exploration of groundwater resources. The hydrogeological map shows an extensive aquifer in the western part of the study area, with moderate productivity. The eastern part features mixed porous and fissured aquifers. Water levels vary according to the topography, with recharge occurring primarily in the Gudumo mountainous areas.

PH: The pH values range from 5.39 to 8.9, with an average of 7.1. The lowest pH is observed in the Balesto Deep Well and the eastern part of Gordama and Hajiba Spring, indicating slightly acidic conditions, while the highest pH is found in the center of Kola Shiyicha Deep Well, representing an alkaline condition.

Electrical Conductivity (EC): The EC values of groundwater range from 64.5 to 514 μS/cm, with an average of 289.25 μS/cm. These values fall within the acceptable range for drinking water according to WHO guidelines. The highest EC value is observed in the Gunde Borehole, indicating a higher concentration of dissolved substances in the groundwater, while the Bargo Borehole records the lowest EC value.

Total Dissolved Solids (TDS): The TDS values in groundwater range from 32.15 to 322 mg/l, with an average of 177.075 mg/l. The WHO guidelines specify a permissible range of 500 mg/l for drinking water. The highest TDS value is observed at the Aletawondo Hospital borehole, indicating a relatively higher concentration of dissolved solids, while the eastern part of Gordama Spring records the lowest TDS value.

Turbidity: Turbidity values in groundwater range from 0 to 250 NTU, with an average of 125 NTU. The WHO guidelines recommend a turbidity range of 5 NTU for drinking water. The highest recorded turbidity value is found at the Huletgna Mogisa Borehole, indicating a relatively high concentration of suspended particles, while several other boreholes exhibit a turbidity value of 0 NTU, indicating clear water with no visible suspended particles.

Water Hardness: The water hardness varies based on the geological components of the subsurface. Soft water has a hardness range of 20.6 to 72, while moderately hard water falls between 78 and 98. The presence of black basalt boreholes contributes to water hardness, primarily due to the magnesium concentrations associated with these geological features.

Calcium Concentration: The calcium concentration in the water samples ranges from 8.8 to 26.5 mg/l, with an average of 17.65 mg/l. These values fall within the permissible range for calcium in drinking water according to WHO guidelines.

Magnesium: The watershed study area exhibits a relatively low presence of magnesium except for two specific areas, Qorke and Bargo, where higher concentrations are observed due to the presence of basaltic volcanic rocks.

Chloride: The center of Aletawondo Town shows a slight increase in chloride levels in groundwater, but the maximum value of 35 mg/l falls within the acceptable range set by the WHO for drinking water.

Fluoride: The Rift Valley study area shows relatively high fluoride concentrations in the water due to geological formations. The fluoride levels are within the acceptable range for drinking water.

Iron: The iron concentrations in the water samples range from 0.02 to 6.17 mg/l, with an average of 3.095 mg/l. Some boreholes show contamination levels above the WHO drinking water standards.

Nitrate: The nitrate concentrations in the water samples range from 0.1 to 13.36 mg/l, with an average of 6.73 mg/l. The highest nitrate concentration is reported in the Qorke Borehole, while the lowest value is recorded in the Huletegna Mogisa Borehole.

The study area has three water types: $CaHCO_3$ with low TDS, indicating early geochemical evolution and shallow circulation; mixed $CaNaHCO_3$ and $NaCaHCO_3$ with moderate TDS, suggesting intermediate geochemical evolution and longer travel distance from recharge areas; and $NaHCO_3$ with high TDS, found in the extreme discharge area downstream, indicating alkaline water with high pH.

The aquifers Aletawondo BH-1, Aletawondo BH-2, Gidibo Borehole, Bargo BH, and BH Balesto are all classified as moderately productive aquifers. On the other hand, Shiycha BH-1, Bulesa borehole, Gunde BH, and Dongora Kebado BH are classified as mixed porous and fissured aquifers of moderate productivity.

The Kola River watershed displays a range of hydraulic conductivity values within the aquifer, with the highest recorded value observed in the Bargo Borehole and the lowest in the Gunde Borehole. This indicates variations in permeability and the ability of the aquifer to transmit water. The aquifer transmissivity values are low in the Gunde Borehole and Dongora Kebado Borehole, suggesting limited water transmission under a hydraulic gradient. In contrast, the eastern and central regions of the Kola area exhibit higher transmissivity values due to fractured basalt formations, while transmissivity decreases towards the western direction due to the presence of ignimbrite and volcanic tuff components. These findings reflect the geological diversity and water transmission capacities within the Kola River watershed.

5.2 Conclusion

Analyzing the physical and chemical parameters of groundwater through laboratory results and using ArcGIS analysis with interpolation techniques like Inverse Distance Weighting (IDW) can provide a better understanding of the Kola catchment area by visualizing the spatial distribution and variations in water quality across different locations.

Analyzing the aquifer using secondary data from well completion reports and raw pumping data, along with aquifer test software tools like AquiferTest v3, can indeed provide valuable information about the groundwater aquifer characteristics in the Kola catchment area. This analysis can contribute to an overall understanding of the hydraulic properties in the catchment.

The fact that the WQI approach and the lab testing schemes resulted in similar classifications further reinforces the confidence in the findings. With four classes- excellent, Good, Very poor, and Unfit for Consumption becomes easier to understand and communicate the overall groundwater quality status.

The research can focus on the available data from other parts of the research area while acknowledging the data gap in the eastern escarpment. This can involve analyzing data from nearby boreholes or extrapolating information from surrounding areas to gain insights into the broader groundwater system.

By drilling boreholes to greater depths, researchers can access water from deeper aquifer layers and assess the quality of the groundwater. This deeper exploration can provide valuable information about the quality of the water as it relates to different aquifer layers within the research area.

6. RECOMMENDATION

- Before initiating any groundwater exploration activities, it is highly recommended to conduct a comprehensive Groundwater Quality Assessment to understand the overall water quality study catchment area.
- To reduce pipe material damage and ensure a sustainable water supply for the community, it is recommended to use iron-free or HDPE (High-Density Polyethylene) pipeline materials in the design of the water supply system.
- Recommendation for future construction of wells properly seal or grout the well with cementing materials to prevent the migration of turbid water from surrounding formations into the wellbore.

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ANNEXES

Annex 1: Boreholes and Springs Water Quality Data

			GPS- Location						Physico - Chemical Analysis Result							
No	Site Name	Easting	Northing	PH	EC	TDS	Turbidity	Total Hardness	Ca^{+}	Mg^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	F^{-}	Fe^{2+}	NO_3^{-}
WHO Standard				6.5-8.5	400	1000	5		75	150		250	400	1.5	0.3	50
					(µS/cm)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
1	Shayicha BH-1	437597	731931	8.9	229	115	0	90	26	6.1	150	1.3	0	1.02	**0.3**	7
2	Shayicha BH-2	435581	731867	6.35	269	135	**9**	50	12	4.8	122	35	3.7	0.12	0.28	11.88
3	Gidibo BH-1	435272	733778	6.5	142.4	71.2	4	84	26	4.37	141.5	11	1	0.12	0.18	0.86
4	Gidibo BH-3/Burka/	435239	733918	7.6	197	99	**23.3**	90	20	9.7	159	1.3	42	0.41	**0.35**	7
5	Gidibo BH-2	434058	732902	6.55	166.9	84.45	**10**	90	20	9.72	175.7	15.5	2	0.05	**1.55**	0.898
6	Balesto BH	433333	730562	5.39	142	92	0	30	8.8	1.92	97.6	0.91	0.11	0.57	0.01	1.11
7	Bulesa BH	430573	731227	7.7	266	133	4	60	16	4.9	183	3.8	12	0.25	**0.49**	7.5
8	Gunde BH	422646	733334	8.2	514	322	0	20.6	6.59	0.99	332.8	5.41	0.59	0.8	0.07	1.33
9	Aleta wondo hospital BH	435238	729723	6.31	159	79.5	**50**	2.5	9.8	0.9	129	7	2	0.2	**6.16**	0.1

10	Huletagna Mogisa HC BH	440107	729770	6.55	195.9	97.95	**250**	59	10.4	1	160	10	0	0.17	**6.17**	0.1
11	Huletagna Mogisa BH-1	440511	729444	6.34	174	87	**10**	98	25	0.5	170	5	0	0.4	**1.29**	1.2
12	Gordama BH	441604	732926	8.2	342	171	0	44	18	1	139	0.01	0	0.61	0.14	0.
13	Gordama spring	441979	732335	5.93	64.3	32.15	0	46	13	0.5	120	10	0	0.07	0.14	0.1
14	Hajaba Spring	439921	731312	5.65	85.86	42.93	0	78	19	0.65	115	0.05	0	0.84	0.06	9.7
15	Gidibo BH	435359	733980	6.28	142	71	0	45	23	0.75	143	2	3	0.01	0.14	5.7
16	Gidibo sw	434165	733127	6.24	151.2	75.6	0	72	21	0.1	123	0.25	1	0.54	0.09	0.1
17	Dongora Kebado BH	428687	734735	6.54	230	160	**38.69**	82	26.4	3.84	129.3	13.12	11.43	0.66	**0.90**	1.94
18	Dongora Elimate	432127	734852	6.61	233	160	0	70.3	19	5.52	166.5	5.96	1.71	0.76	0.02	0.33
19	Qorke	428801	732211	7.1	230	120	20	90	20.8	9.12	168.4	2.5	0	0	0.07	13.36
20	Bargo BH	445674	737328	6.35	227	142	1.095	120	25.60	13.44	143.96	9.40	0.10	0.53	0.02	0.38
	Average Values															

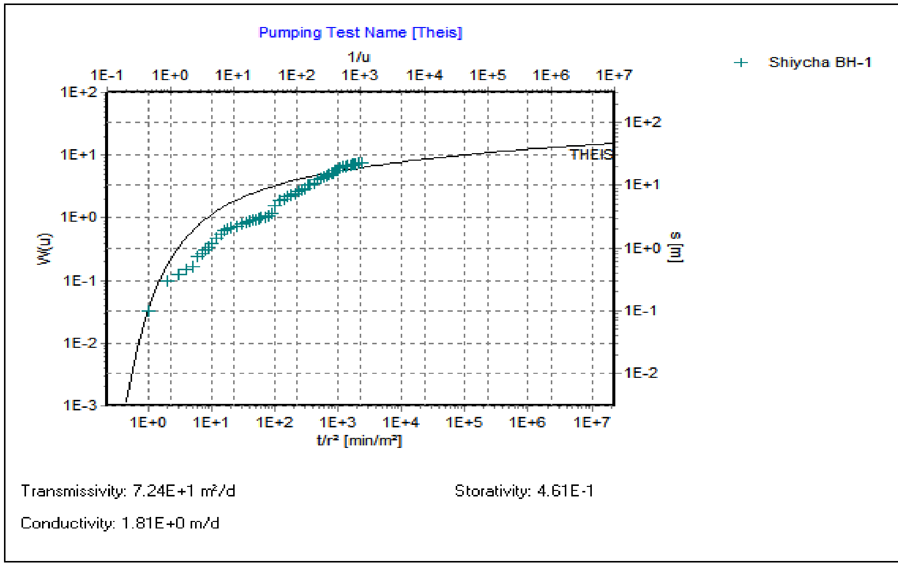
Annex 2: Aquifer Characteristic Result Boreholes

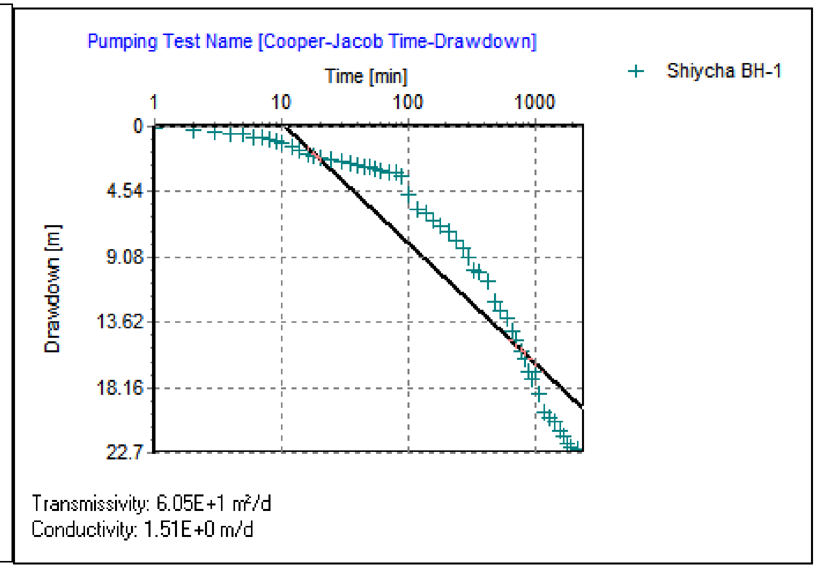
				Cooper-Jacob Time vs Drawdown method	Thesis method
No	**Boreholes-Location**	**Depth/m/**	**Aquifer Thickness/m/**	**T [m^2/day]**	**T [m^2/day]**
1	Aletawondo BH-1	152	60	4.70 x 10	5.03 x10
2	Aletawondo BH-2	162	40	6.82 x 10	$1.21x10^{+2}$
3	Gidibo BH	220	65.4	1.55 x10	1.98x10
4	Shayicha BH-1	104	41.2	6.05 x10	7.24 x10
5	Shayicha BH-2	64	29	4.40 x10	4.03 x10
6	Balesto BH	145	36	1.97x10	2.30x10
7	Bulesa BH	196	58	2.58 x10	2.18 x10
8	Gunde BH	210	54	$7.27 x 10^{+0}$	8.49 x10
9	Dongora Kebado BH	172	60	1.07 x10	1.38 x10

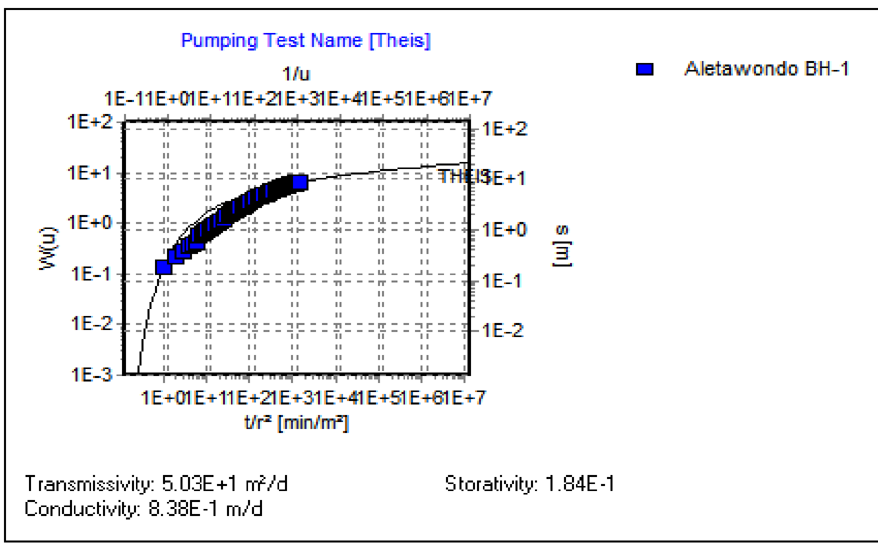
Annex 2. 1 Aquifer Characteristic Result Boreholes

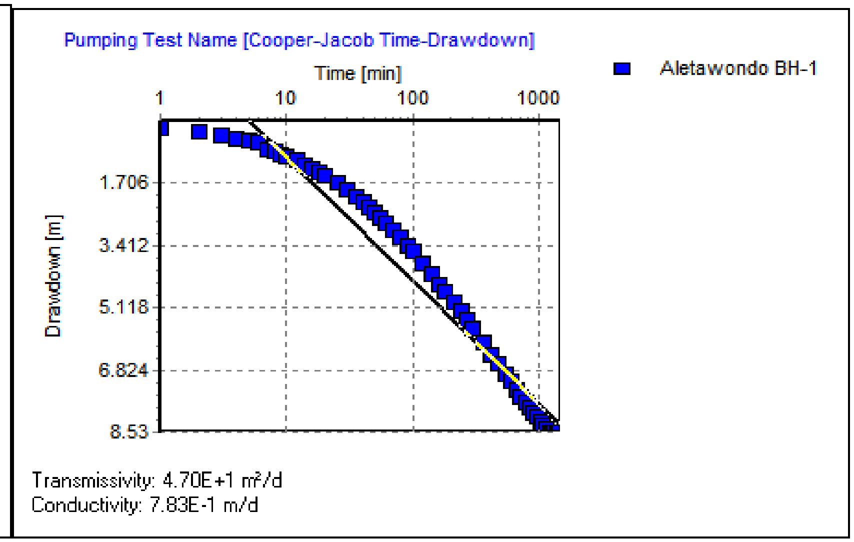
			Thesis-Method
No	**Boreholes-Location**	**Aquifer Thickness/m/**	**Storativity /Sy/**
1	Aletawondo BH-1	60	1.84×10^{-1}
2	Aletawondo BH-2	39	5.85×10^{-2}
3	Gidibo BH	63.8	6.03×10^{-2}
4	Shayicha BH-1	29	4.61×10^{-1}
5	Shayicha BH-2	42	3.71×10^{-1}
6	Balesto BH	43	5.83×10^{-2}
7	Bulesa BH	58	1.27×10^{-4}
8	Gunde BH	61	3.74×10^{-2}
9	Dongora Kebado BH	51	4.20×10^{-4}

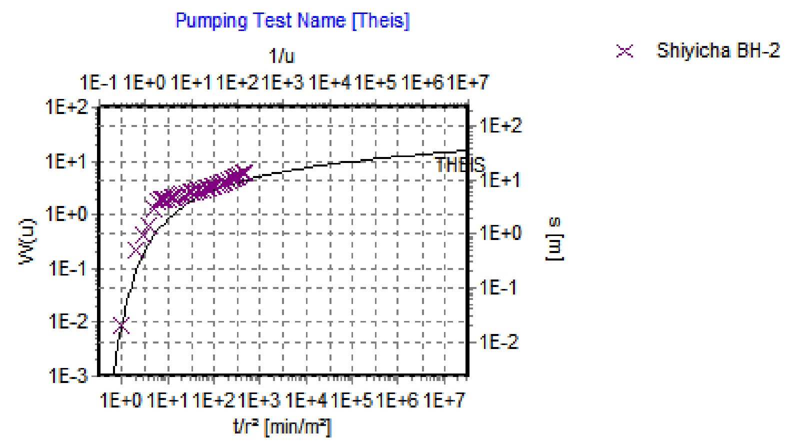
Annex 2. 2 Aquifer Analysis Result of Graphs



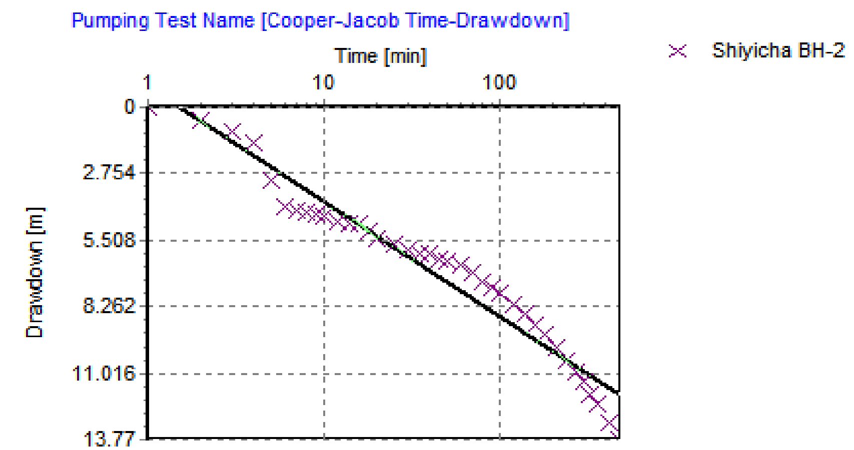




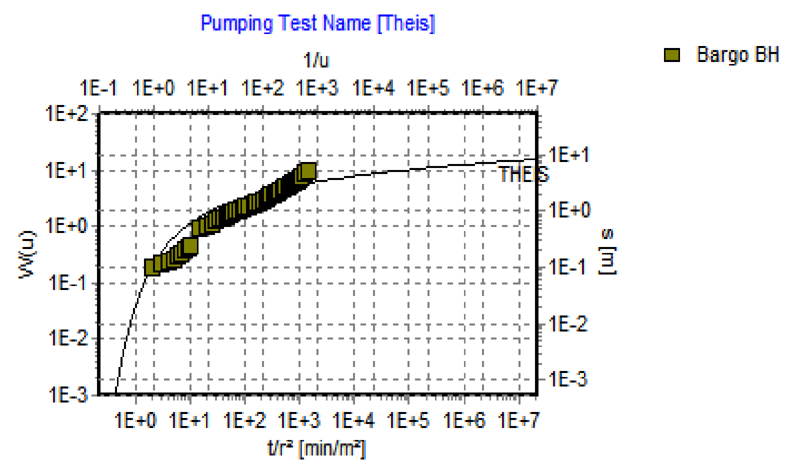




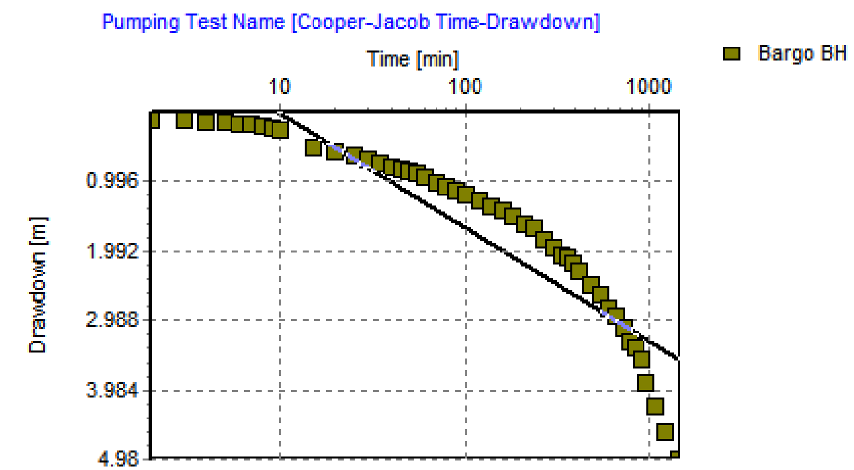
Transmissivity: 4.03E+1 m²/d
Conductivity: 1.39E+0 m/d
Storativity: 3.71E-1



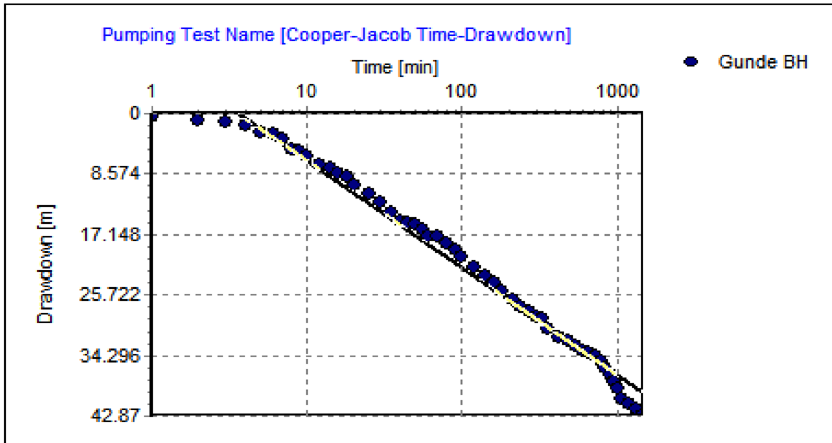
Transmissivity: 4.40E+1 m²/d
Conductivity: 1.52E+0 m/d



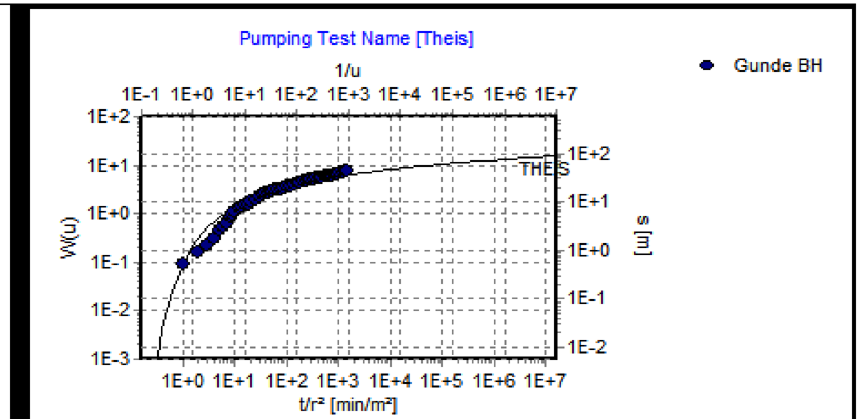
Transmissivity: 2.36E+2 m²/d
Conductivity: 3.47E+0 m/d
Storativity: 1.44E+0



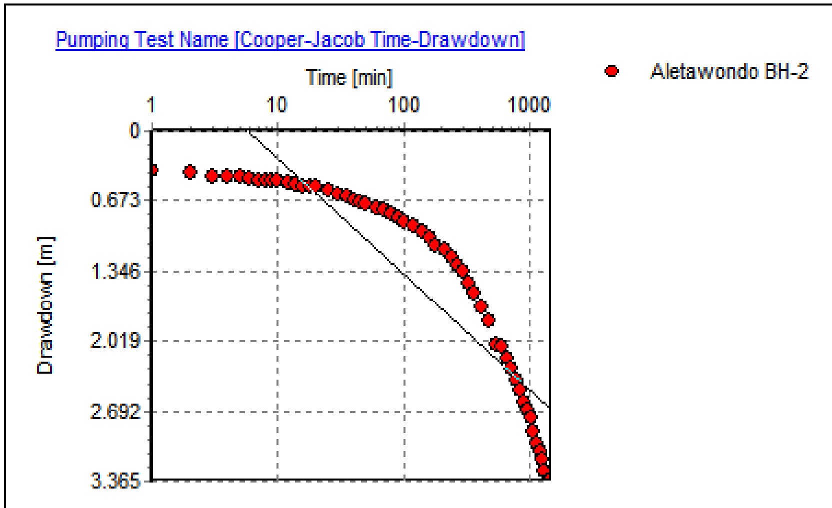
Transmissivity: 1.78E+2 m²/d
Conductivity: 2.62E+0 m/d



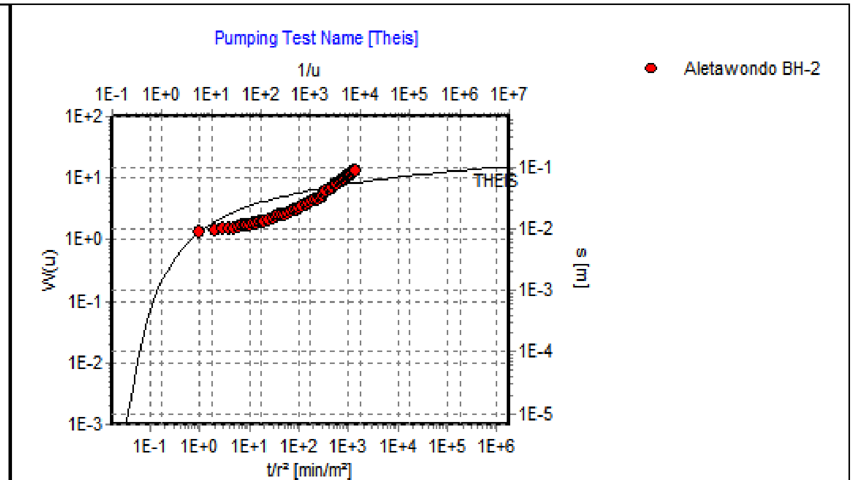
Transmissivity: 7.27E+0 m²/d
Conductivity: 1.35E-1 m/d



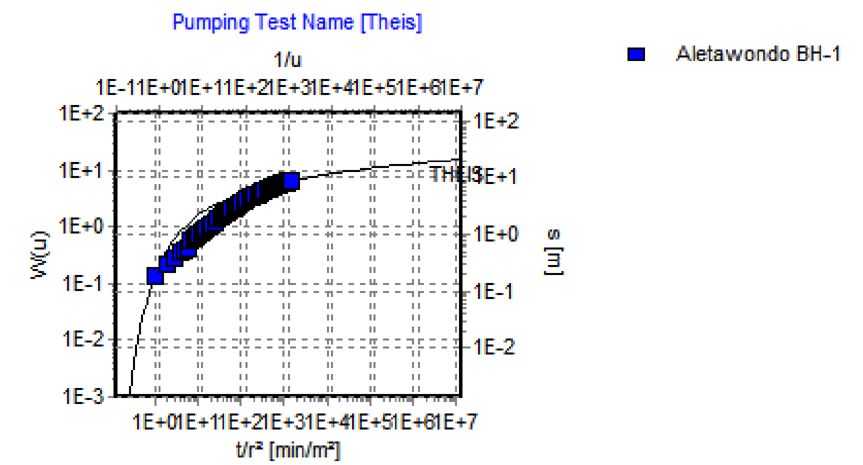
Transmissivity: 8.49E+0 m²/d
Storativity: 3.74E-2
Conductivity: 1.57E-1 m/d



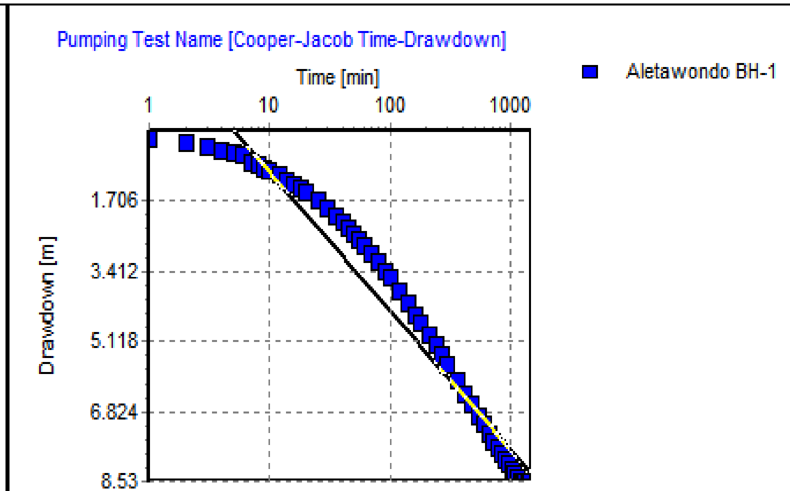
Transmissivity: 7.15E+1 m²/d
Conductivity: 1.79E+0 m/d



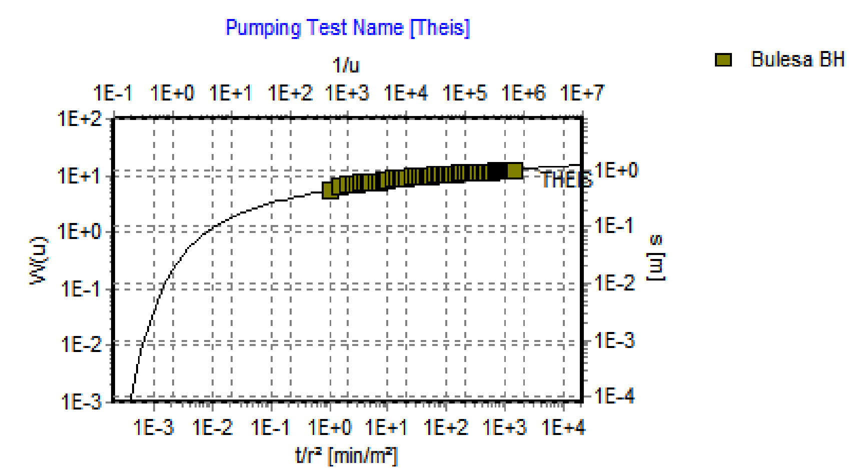
Transmissivity: 5.18E+3 m²/d
Storativity: 2.50E+0
Conductivity: 1.29E+2 m/d



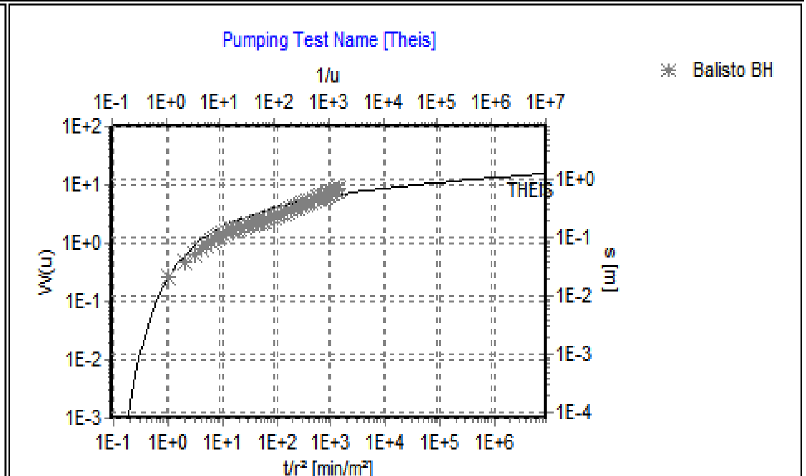
Transmissivity: 5.03E+1 m²/d
Conductivity: 8.38E-1 m/d
Storativity: 1.84E-1



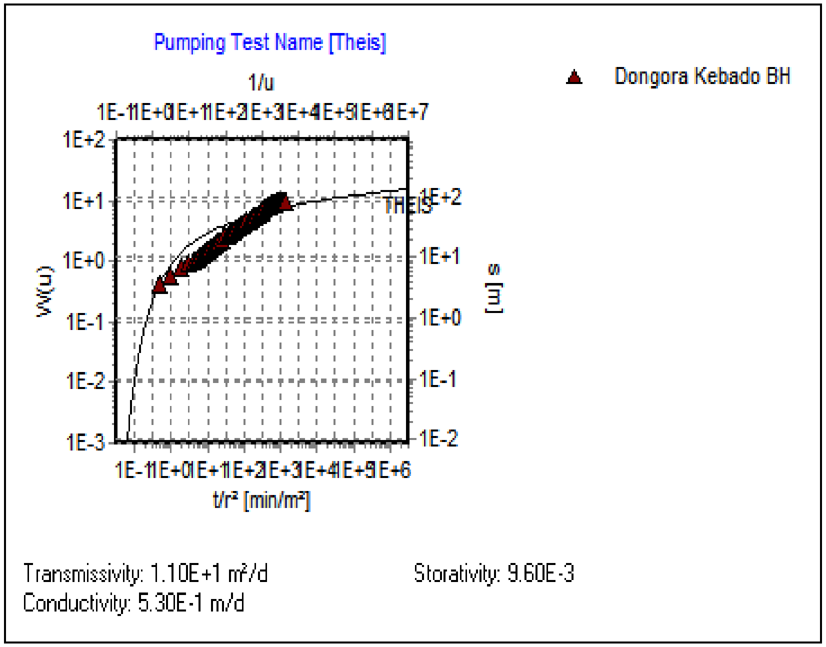
Transmissivity: 4.70E+1 m²/d
Conductivity: 7.83E-1 m/d



Transmissivity: 8.59E+2 m²/d
Conductivity: 1.48E+1 m/d
Storativity: 4.98E-3



Transmissivity: 9.20E+2 m²/d
Conductivity: 2.56E+1 m/d
Storativity: 2.33E+0


Pumping Test Name [Theis]
Dongora Kebado BH
1/u
W(u)
s [m]
THEIS
t/r² [min/m²]
Transmissivity: 1.10E+1 m²/d
Storativity: 9.60E-3
Conductivity: 5.30E-1 m/d

Annex 3 Pumping Test Raw Data Sheets

Annex 3. 1 Aletawondo BH-1

Annex 3.1 a Aletawondo BH-1 Constant Pumping Test data sheet

Time since pumping started, min	Water Level(m)	Draw Down(m)	Discharge Measurement Q(l/s)
0.5	22.34	0.18	10.76
1	22.52	0.11	10.76
2	22.63	0.09	10.76
3	22.72	0.09	10.76
4	22.81	0.05	10.76
5	22.86	0.07	10.76
6	22.93	0.17	10.76
7	23.1	0.08	10.76
8	23.18	0.07	10.76
9	23.25	0.06	10.76
10	23.31	0.09	10.76
12	23.4	0.13	10.76
14	23.53	0.1	10.76
16	23.63	0.09	10.76
18	23.72	0.11	10.76
20	23.83	0.19	10.76
25	24.02	0.19	10.76
30	24.21	0.18	10.76
35	24.39	0.16	10.76
40	24.55	0.14	10.76
45	24.69	0.15	10.76
50	24.84	0.16	10.76
55	25	0.14	10.76
60	25.14	0.18	10.76
70	25.32	0.22	10.76
80	25.54	0.2	10.76
90	25.74	0.19	10.76
100	25.93	0.3	10.76
120	26.23	0.31	10.76
140	26.54	0.27	10.76
160	26.81	0.19	10.76
180	27	0.29	10.76
210	27.29	0.27	10.76
240	27.56	0.24	10.76
270	27.8	0.24	10.76
300	28.04	0.36	10.76
360	28.4	0.33	10.76

420	28.73	0.27	10.76
480	29	0.27	10.76
540	29.27	0.21	10.76
600	29.48	0.21	10.76
660	29.69	0.21	10.76
720	29.9	0.17	10.76
780	30.07	0.12	10.76
840	30.19	0.15	10.76
900	30.34	0.11	10.76
960	30.45	0.13	10.76
1020	30.58	0.11	10.76
1080	30.69	0.09	10.76
1140	30.78	0.09	10.76
1200	30.87	0	10.76
1260	30.87	-0.01	10.76
1320	30.86	-0.01	10.76
1380	30.85	0	10.76
1440	30.85	-30.85	10.76

Annex 3.1 b Aletawondo BH-1Recovery Pumping Test data sheet

Time since Recovery started, min	Water Level(m)	Residual Draw Down(m)
0.5	30.85	1.21
1	29.64	0.16
2	29.48	0
3	29.48	0.11
4	29.37	0.09
5	29.28	0.09
6	29.19	0.09
7	29.1	0.04
8	29.06	0.07
9	28.99	0.08
10	28.91	0.12
12	28.79	0.11
14	28.68	0.18
16	28.5	0.11
18	28.39	0.08
20	28.31	0.22
25	28.09	0.22
30	27.87	0.24

35	27.63	0.18
40	27.45	0.2
45	27.25	0
50	27.25	0.41
55	26.84	0.11
60	26.73	0.33
70	26.4	0.27
80	26.13	0.25
90	25.88	0.24
100	25.64	0.45
120	25.19	0.27
140	24.92	0.25
160	24.67	0.22
180	24.45	0.35
210	24.1	0.34
240	23.76	0.19
270	23.57	0.17
300	23.4	0.38
360	23.02	23.02

Annex 3. 2 Aletawondo BH-2

Annex 3.2 a Aletawondo BH-2 Constant Pumping Test data sheet

Time since pumping started, min	Water Level(m)	Draw Down(m)	Discharge Measurement Q(l/s)
0.5	85.16	0.38	5
1	85.54	0.03	5
2	85.57	0.03	5
3	85.6	0	5
4	85.6	0	5
5	85.6	0.01	5
6	85.61	0.02	5
7	85.63	0	5
8	85.63	0.01	5
9	85.64	0	5
10	85.64	0.02	5
12	85.66	0.01	5
14	85.67	0.02	5
16	85.69	0.01	5
18	85.7	0	5

20	85.7	0.04	5
25	85.74	0.03	5
30	85.77	0.03	5
35	85.8	0.03	5
40	85.83	0.02	5
45	85.85	0.02	5
50	85.87	0.03	5
60	85.9	0.02	5
70	85.92	0.05	5
80	85.97	0.04	5
90	86.01	0.04	5
100	86.05	0.03	5
120	86.08	0.06	5
140	86.14	0.06	5
160	86.2	0.07	5
180	86.27	0.05	5
210	86.32	0.07	5
240	86.39	0.08	5
270	86.47	0.06	5
300	86.53	0.12	5
330	86.65	0.1	5
360	86.75	0.14	5
420	86.89	0.13	5
480	87.02	0.24	5
540	87.26	0.02	5
600	87.28	0.13	5
660	87.41	0.11	5
720	87.52	0.12	5
780	87.64	0.1	5
840	87.74	0.11	5
900	87.85	0.08	5
960	87.93	0.09	5
1020	88.02	0.15	5
1080	88.17	0.11	5
1140	88.28	0.08	5
1200	88.36	0.09	5
1260	88.45	0.12	5
1320	88.57	0.11	5
1380	88.68	0	5
1440	88.68	-88.68	5

Annex 3.2 b Aletawondo BH-2 Recovery Pumping Test data sheet

Time since Recovery started, min	Water Level(m)	Residual Draw Down(m)
0.5	88.68	0.58
1	88.1	0.02
2	88.08	0.01
3	88.07	0
4	88.07	0
5	88.07	0
6	88.07	0
7	88.07	0
8	88.07	0
9	88.07	0
10	88.07	0.01
12	88.06	0.02
14	88.04	0
16	88.04	0
18	88.04	-0.06
20	88.1	0.07
25	88.03	0
30	88.03	0.01
35	88.02	0.01
40	88.01	0.01
45	88	0.02
50	87.98	0.01
60	87.97	0.01
70	87.96	0.02
80	87.94	0.01
90	87.93	0.01
100	87.92	87.92

Annex 3. 3 Gidibo BH-1 Pumping Test Raw Data Sheet

Annex 3.3 a Gidibo BH-1 Step drawdown Test data sheet

Step-1 Q = 14 L/s		**Step-2 Q= 18 l/s**		**Step-3 Q= 20 L/s**	
Time(min)	**Water level**	**Time(min)**	**Water level**	**Time (min)**	**Water Level**
0	27.8	120	34.3	240	47.1
1	28.1	121	34.9	241	49.3
2	28.33	122	35.1	242	50.4
3	28.9	123	35.8	243	51.35
4	29.1	124	35.95	244	52.5
5	29.9	125	36.2	245	53.6
6	30.1	126	36.55	246	54.35
7	30.4	127	36.7	247	55.4
8	30.6	128	36.9	248	56.3
9	30.75	129	37.1	249	57.9
10	30.85	130	38.1	250	58.3
12	30.95	132	38.8	252	59.4
14	31.1	134	39.3	254	59.7
16	31.25	136	39.85	256	59.9
18	31.35	138	40.15	258	60.35
20	31.43	140	40.25	260	60.4
25	31.65	142	40.8	265	60.81
30	31.8	150	41	270	62.3
35	32	155	41.8	275	62.55
40	32.1	160	42.3	280	62.85
45	32.4	165	42.9	285	63
50	32.75	170	43.3	290	63.7
55	32.85	175	44.1	295	64.1
60	32.9	180	44.9	300	64.9
70	33.2	190	45.3	310	65.3
80	33.45	200	45.8	320	65.7
90	33.85	210	46.1	330	65.8
100	34.1	220	46.8	340	66.1
120	34.3	240	47.1	350	

Annex 3.3 b Gidibo BH-1 Constant Pumping Test data sheet

Time since pumping started, min	Water Level(m)	Draw Down(m)	Discharge Measurement Q(l/s)
0	27.8	1.3	20
1	29.1	1.25	20
2	30.35	0.75	20
3	31.1	0.9	20
4	32	1.3	20
5	33.3	0.5	20
6	33.8	0.3	20
7	34.1	1.7	20
8	35.8	1	20
9	36.8	1	20
10	37.8	1.3	20
12	39.1	1.26	20
14	40.36	0.74	20
16	41.1	0.7	20
18	41.8	0.55	20
20	42.35	1.05	20
25	43.4	0.78	20
30	44.18	0.92	20
35	45.1	1.9	20
40	47	1.3	20
45	48.3	1.23	20
50	49.53	1.57	20
55	51.1	1.2	20
60	52.3	0.5	20
70	52.8	0.9	20
80	53.7	0.2	20
90	53.9	0.2	20
100	54.1	1.7	20
120	55.8	0.9	20
140	56.7	3.55	20
160	60.25	1.7	20
180	61.95	2.6	20
210	64.55	1.25	20
240	65.8	0.53	20
270	66.33	0.47	20
300	66.8	0.5	20
330	67.3	0.1	20
360	67.4	1.15	20
420	68.55	0.9	20
480	69.45	1.05	20

540	70.5	1.1	20
600	71.6	1.05	20
660	72.65	1.05	20
720	73.7	1	20
780	74.7	0.12	20
840	74.82	0.88	20
900	75.7	1.05	20
960	76.75	1.05	20
1020	77.8	2.03	20
1080	79.83	0.77	20
1200	80.6	0.1	20
1320	80.7	0.95	20
1440	81.65	1.3	20
1560	82.95	1.84	20
1680	84.79	1.11	20
1800	85.9	1.73	20
1920	87.63	0.97	20
2160	88.6	0.93	20
2400	89.53	0.42	20
2640	89.95	0.01	20
2880	89.96	1.84	20
3120	91.8	1	20
3360	92.8	0.3	20
3600	93.1	0.21	20
3840	93.31	-93.31	20

Annex 3.3 c Gidibo BH-1 Recovery Pumping Test data sheet

Time since Recovery started, min	Water Level(m)	Residual Draw Down(m)
0	93.31	4.21
1	89.1	3.8
2	85.3	5.3
3	80	1.9
4	78.1	1.8
5	76.3	1.5
6	74.8	3.67
7	71.13	0.23
8	70.9	2.6
9	68.3	3.2
10	65.1	1.37
12	63.73	3.26
14	60.47	0.87
16	59.6	2.3
18	57.3	1.87
20	55.43	4.2
25	51.23	1.23
30	50	2.2
35	47.8	1.5
40	46.3	2.57
45	43.73	0.83
50	42.9	0.8
60	42.1	0.27
70	41.83	0.23
80	41.6	0.37
90	41.23	0.23
100	41	0.27
120	40.73	0.18
140	40.55	0.22
160	40.33	0.2
180	40.13	0.2
210	39.93	0.18
240	39.75	0.32
270	39.43	0.32
300	39.11	0.2
330	38.91	0.21

360	38.7	38.7

Annex 3. 4 Shiyicha BH-1 Pumping Test Raw Data Sheet

Annex 3.4 a Sheyicha BH-1 Step drawdown Test data sheet

Step-1 Q = 20 L/s		Step-2 Q= 25 l/s		Step-3 Q= 31 L/s	
Time(Min)	**Water level(m)**	**Time (min)**	**Water level(m)**	**Time (min)**	**Water Level(m)**
0	10.2	120	13.1	240	19.3
1	10.6	121	13.3	241	19.45
2	10.8	122	13.5	242	19.8
3	10.95	123	13.55	243	19.9
4	11.03	124	13.61	244	20.1
5	11.1	125	13.65	245	20.35
6	11.18	126	13.71	246	20.4
7	11.25	127	13.79	247	20.7
8	11.3	128	13.85	248	20.85
9	11.35	129	13.91	249	21
10	11.4	130	13.95	250	21.3
12	11.45	132	14.1	252	21.7
14	11.53	134	14.3	254	21.95
16	11.63	136	14.5	256	22.1
18	11.67	138	14.8	258	22.7
20	11.7	140	15	260	22.95
25	11.74	142	15.2	265	23.3
30	11.78	150	15.5	270	23.8
35	11.83	155	16	275	24
40	11.9	160	16.4	280	24.5
45	11.95	165	16.9	285	24.9
50	12.05	170	17.1	290	25.15
55	12.15	175	17.55	295	25.6
60	12.61	180	17.9	300	25.95
70	12.73	190	18.1	310	26.2
80	12.85	200	18.5	320	26.4
90	12.9	210	18.8	330	26.55
100	12.95	220	19	340	26.6
120	13.1	240	19.3	350	16.75

Annex 3.4 b Sheyicha BH-1 Constant Pumping Test data sheet

Time since pumping started, min	Water Level(m)	Draw Down(m)	Discharge Measurement Q(l/s)
0	10.8	0.1	31
1	10.9	0.2	
2	11.1	0.07	
3	11.17	0.08	
4	11.25	0.05	
5	11.3	0.23	
6	11.53	0.07	
7	11.6	0.15	
8	11.75	0.08	
9	11.83	0.17	
10	12	0.21	
12	12.21	0.29	
14	12.5	0.2	
16	12.7	0.15	
18	12.85	0.08	
20	12.93	0.12	
25	13.05	0.15	
30	13.2	0.2	
35	13.4	0.11	
40	13.51	0.09	
45	13.6	0.08	
50	13.68	0.07	
55	13.75	0.15	
60	13.9	0.05	
70	13.95	0.05	
80	14	0.3	
90	14.3	1.2	
100	15.5	1.1	
120	16.6	0.21	
140	16.81	0.57	
160	17.38	0.37	
180	17.75	0.4	
210	18.15	0.65	
240	18.8	0.5	
270	19.3	0.55	
300	19.85	1	
330	20.85	0.03	
360	20.88	0.72	
420	21.6	1.35	
480	22.95	0.65	

540	23.6	0.5	
600	24.1	0.9	
660	25	0.7	
720	25.7	0.8	
780	26.5	0.4	
840	26.9	0.9	
900	27.8	0.6	
960	28.4	-0.6	
1020	27.8	1.6	
1080	29.4	1.25	
1200	30.65	0.35	
1320	31	0.3	
1440	31.3	0.6	
1560	31.9	0.5	
1680	32.4	0.4	
1800	32.8	0.3	
1920	33.1	0.2	
2160	33.3	0.2	
2400	33.5	-33.5	

Annex 3.4 c Sheyicha BH-1 Recovery Pumping Test data sheet

Time since Recovery started, min	Water Level(m)	Residual Draw Down(m)
0	35.56	3.66
1	31.9	2.8
2	29.1	1
3	28.1	0.8
4	27.3	0.5
5	26.8	0.5
6	26.3	0.5
7	25.8	0.4
8	25.4	0.4
9	25	0.3
10	24.7	-0.05
12	24.75	0.4
14	24.35	0.35
16	24	0.9
18	23.1	0.4
20	22.7	1.4
25	21.3	0.5
30	20.8	0.2
35	20.6	0.15
40	20.45	0.27
45	20.18	0.18

50	20	0.2
55	19.8	0.4
60	19.4	0.3
70	19.1	0.1
80	19	0.1
90	18.9	0.1
100	18.8	0.1
120	18.7	0.05
140	18.65	0.25
160	18.4	0.1
180	18.3	0.25
210	18.05	0.2
240	17.85	0.85
270	17	0.7
300	16.3	0.4
330	15.9	0.6
360	15.3	0.5
420	14.8	1.8
480	13	13

Annex 3. 5 Balesto BH Pumping Test Raw Data Sheet

Annex 3.5 a Step drawdown Test data sheet

Step-1 Q = 6 L/s		Step-2 Q= 8.5 l/s		Step-3 Q= 10 L/s		Step-4, Q= 12 l/S	
Time(min)	Water level	Time(min)	Water level	Time (min)	Water Level	Time (min)	Water Level
0	51.05	0	54.89	0	59.5	0	63.89
1	51.51	1	55.15	1	59.98	1	64.5
2	51.78	2	55.42	2	60.43	2	64.98
3	52.09	3	55.66	3	60.8	3	65.45
4	52.32	4	55.9	4	61.09	4	65.8
5	52.49	5	56.11	5	61.35	5	66.11
6	52.65	6	56.3	6	61.5	6	66.41
7	52.78	7	56.57	7	61.64	7	66.65
8	52.92	8	56.8	8	61.8	8	66.82
9	53.05	9	56.98	9	61.97	9	66.94
10	53.14	10	57.12	10	62.1	10	67.11
12	53.29	12	57.3	12	62.28	12	67.33
14	53.43	14	57.45	14	62.43	14	67.55
16	53.57	16	57.61	16	62.59	16	67.74
18	53.7	18	57.78	18	62.72	18	67.9
20	53.78	20	57.92	20	62.83	20	68.07
25	53.96	25	58.15	25	62.98	25	68.52

30	54.11	30	58.37	30	63.15	30	68.76
35	54.26	35	58.59	35	63.3	35	68.78
40	54.4	40	58.82	40	63.42	40	69.17
45	54.52	45	59	45	63.55	45	69.4
50	54.65	50	59.19	50	63.68	50	69.61
55	54.77	55	59.36	55	63.8	55	69.8
60	54.89	60	59.5	60	63.89	60	
70		70		70		70	
80		80		80		80	
90		90		90		90	
100		100		100		100	
120		120		120		120	

Annex 3.5 b Balesto BH Constant Pumping Test data sheet

Time since pumping started, min	Water Level(m)	Draw Down(m)	Discharge Measurement Q(l/s)
0	51.05	0.83	10
1	51.88	0.68	
2	52.56	0.55	
3	53.11	0.59	
4	53.7	0.39	
5	54.09	0.42	
6	54.51	0.36	
7	54.87	0.28	
8	55.15	0.27	
9	55.42	0.24	
10	55.66	0.36	
12	56.02	0.28	
14	56.3	0.29	
16	56.59	0.21	
18	56.8	0.18	
20	56.98	0.33	
25	57.31	0.29	
30	57.6	0.29	
35	57.89	0.26	
40	58.15	0.22	
45	58.37	0.22	
50	58.59	0.23	
55	58.82	0.23	
60	59.05	0.46	
70	59.51	0.47	
80	59.98	0.45	

90	60.43	0.38	
100	60.81	0.49	
120	61.3	0.54	
140	61.84	0.43	
160	62.27	0.63	
180	62.9	0.87	
210	63.77	0.81	
240	64.58	0.71	
270	65.29	0.71	
300	66	0.65	
330	66.65	0.56	
360	67.21	0.9	
420	68.11	0.83	
480	68.94	0.78	
540	69.72	0.66	
600	70.38	0.69	
660	71.07	0.62	
720	71.69	0.62	
780	72.31	0.64	
840	72.95	0.61	
900	73.56	0.54	
960	74.1	0.6	
1020	74.7	0.55	
1080	75.25	0.75	
1200	76	0.95	
1320	76.95	0.79	
1440	77.74	-77.74	

Annex 3.5 c Balesto BH Recovery Pumping Test data sheet

Time since Recovery started, min	Water Level(m)	Residual Draw Down(m)
0	77.74	0.79
1	76.95	0.95
2	76	0.81
3	75.19	0.74
4	74.45	0.75
5	73.7	0.69
6	73.01	0.76
7	72.25	0.75
8	71.5	0.61
9	70.89	0.74
10	70.15	1.15
12	69	0.88
14	68.12	0.82

16	67.3	0.75
18	66.55	0.79
20	65.76	1.46
25	64.3	1.3
30	63	0.89
35	62.11	0.83
40	61.28	0.84
45	60.44	0.84
50	59.6	0.58
55	59.02	0.62
60	58.4	0.5
70	57.9	0.39
80	57.51	0.36
90	57.15	0.25
100	56.9	0.28
120	56.62	0.28
140	56.34	0.23
160	56.11	0.31
180	55.8	0.19
210	55.61	0.21
240	55.4	0.22
270	55.18	0.18
300	55	0.22
330	54.78	0.18
360	54.6	0.45
420	54.15	0.44
480	53.71	0.26
540	53.45	0.44
600	53.01	53.01

Annex 3. 6 Bulesa BH Pumping Test Raw Data Sheet

Annex 3.6 a Bulesa BH Constant Pumping Test data sheet

Time since pumping started, min	Water Level(m)	Draw Down(m)	Discharge Measurement Q(l/s)
0.5	46.36	17.64	11.28
1	64	3.2	
1.5	67.2	1.15	
2	68.35	0.7	
2.5	69.05	0.35	
3	69.4	0.67	
3.5	70.07	0	
4	70.07	0.1	
4.5	70.17	0.67	
5	70.84	0.48	
6	71.32	0	
7	71.32	1.04	
8	72.36	0.35	
9	72.71	0.39	
10	73.1	0.71	
12	73.81	0.49	
14	74.3	0.44	
16	74.74	0.36	
18	75.1	0.26	
20	75.36	0.74	
25	76.1	0.53	
30	76.63	0.4	
35	77.03	0.41	
40	77.44	0.36	
45	77.8	0.32	
50	78.12	0	
55	78.12	0.38	
60	78.5	0.44	
70	78.94	0.3	
80	79.24	0.33	
90	79.57	0.23	
100	79.8	0.32	
110	80.12	0.12	
120	80.24	0.34	
140	80.58	0.3	
160	80.88	0.21	
180	81.09	0.31	
210	81.4	0.3	
240	81.7	0.2	

270	81.9	0.3	
300	82.2	0.3	
330	82.5	0.1	
360	82.6	0.3	
420	82.9	0.3	
480	83.2	0.23	
540	83.43	0.21	
600	83.64	0.21	
660	83.85	0.18	
720	84.03	0.09	
780	84.12	0.13	
840	84.25	0.09	
900	84.34	0.15	
960	84.49	-0.01	
1020	84.48	0.11	
1080	84.59	0.11	
1140	84.7	1.19	
1200	85.89	-0.95	
1260	84.94	0.03	
1320	84.97	0.01	
1380	84.98	0	
1440	84.98	-84.98	

Annex 3.6 b Bulesa BH Recovery Pumping Test data sheet

Time since Recovery started, min	Water Level(m)	Residual Draw Down(m)
1	70.52	2.43
1.5	68.09	1.11
2	66.98	1.23
2.5	65.75	0.68
3	65.07	0.53
3.5	64.54	0.49
4	64.05	0.38
4.5	63.67	0.14
5	63.53	-0.1
6	63.63	1.56
7	62.07	0.52
8	61.55	0.44
9	61.11	0.34
10	60.77	0.62
12	60.15	0.5
14	59.65	0.38
161	59.27	0.32
18	58.95	0.3
20	58.65	0.54
25	58.11	0.53
30	57.58	0.18
35	57.4	0.2
40	57.2	0.17
45	57.03	0.13
50	56.9	0.15
55	56.75	0.15
60	56.6	0.2
70	56.4	0.19
80	56.21	0.19
90	56.02	0.17
100	55.85	0.18
110	55.67	0.17
120	55.5	0.3
140	55.2	0.1
160	55.1	1.1
180	54	0.02
210	53.98	0.28
240	53.7	0.2
270	53.5	53.5

Annex 3. 7 Gunde BH Pumping Test Raw Data Sheet

Annex 3.7 a Gunde BH Constant Pumping Test data sheet

Time since pumping started, min	Water Level(m)	Draw Down(m)	Discharge Measurement Q(l/s)
0	57	0.5	5.2
1	57.5	0.4	
2	57.9	0.35	
3	58.25	0.48	
4	58.73	0.82	
5	59.55	0.45	
6	60	0.69	
7	60.69	1.3	
8	61.99	0.32	
9	62.31	0.72	
10	63.03	1.17	
12	64.2	0.63	
14	64.83	0.57	
16	65.4	0.55	
18	65.95	1.25	
20	67.2	1.2	
25	68.4	1.19	
30	69.59	1.35	
35	70.94	1.29	
40	72.23	0.27	
45	72.5	0.33	
50	72.83	0.66	
55	73.49	0.99	
60	74.48	0	
70	74.48	0.98	
80	75.46	0.99	
90	76.45	0.95	
100	77.4	1.33	
120	78.73	1.26	
140	79.99	1.02	
160	81.01	1.09	
180	82.1	1.32	
210	83.42	1.02	
240	84.44	0.58	
270	85.02	0.73	
300	85.75	0.32	
330	86.07	1.33	
360	87.4	1.43	
420	88.83	0.27	

480	89.1	0.9	
540	90	0.7	
600	90.7	0.2	
660	90.9	0.5	
720	91.4	0.63	
780	92.03	0.99	
840	93.02	1.03	
900	94.05	0.95	
960	95	1.1	
1020	96.1	1.3	
1080	97.4	0.83	
1200	98.23	0.77	
1320	99	0.87	
1440	99.87	-99.87	

Annex 3.7 b Gunde BH Recovery Pumping Test data sheet

Time since Recovery started, min	Water Level(m)	Residual Draw Down(m)
0	99.87	9.7
1	90.17	1.9
2	88.27	1.36
3	86.91	0.25
4	86.66	0.25
5	86.41	0.19
6	86.22	0.22
7	86	0.3
8	85.7	0.11
9	85.59	0.16
10	85.43	0.23
12	85.2	0.29
14	84.91	0.26
16	84.65	0.18
18	84.47	0.32
20	84.15	2.05
25	82.1	2.09
30	80.01	0.51
35	79.5	0.43
40	79.07	0.96
45	78.11	0.98
50	77.13	0.93
55	76.2	0.87
60	75.33	3.24
70	72.09	2.02
80	70.07	0.86

90	69.21	0.68
100	68.53	0.87
120	67.66	2.53
140	65.13	2.54
160	62.59	0.86
180	61.73	0.73
210	61	0.5
240	60.5	0.85
270	59.65	0.58
300	59.07	0.57
330	58.5	0.57
360	57.93	57.93

Annex 3. 8 Dongora Kebado BH Pumping Test Raw Data Sheet

Annex 3.8 a Dongora Kebado BH Constant Pumping Test data sheet

Time since pumping started, min	Water Level(m)	Draw Down(m)	Discharge Measurement Q(l/s)
0	20.67	19.3	
0.5	24.35	0.8	
1	25.48	0.78	
2	27.33	0.52	
3	28.67	0.5	
4	29.34	0.36	
5	30.35	0.39	
6	31.10	0.39	
7	32.15	0.98	
8	32.75	0.53	
9	33.32	0.47	
10	34.05	0.04	
12	35.27	0.16	
14	36.31	0.41	
16	37.95	0.6	
18	38.61	0.59	
20	39.20	0.54	
25	40.90	0.49	
30	42.80	0.4	
35	44.60	1.18	
40	45.95	0.77	
45	47.33	0.88	
50	48.70	0.6	
55	49.40	0.74	
60	50.20	0.63	

70	52.20	0.75	
80	54.75	0.34	
90	56.30	1.16	
100	57.80	0.65	
120	60.15	0.85	
140	62.52	0.85	
160	64.70	0.23	
180	66.50	1.07	
210	69.32	1.35	
240	72.10	0.96	
270	75.50	0.77	
300	78	1.27	
330	83.05	1.4	
360	87.27	0.55	
420	90.60	0.85	
480	92.98	0.95	
540	95.20	0.44	
600	96.30	1.21	
660	98	0.9	
720	100.40	0.9	
780	102.50	0.93	
840	102.65	1.47	
900	102.65	0.47	
960	102.65	0.99	
1020	102.65	0.99	
1080	102.65	0.75	
1200	102.65	0.95	
1320	102.65	0.74	
1440	102.65	0.79	

Annex 3.8 b Dongra Kebado BH Recovery Pumping Test data sheet

Time since Recovery started, min	Water Level(m)	Residual Draw Down(m)
0	81.95	3.01
1	78.94	0.64
2	78.3	0.6
3	77.7	0.22
4	77.48	0.8
5	76.68	0.93
6	75.75	0.27
7	75.48	0.53
8	74.95	0
9	74.95	0.36
10	74.59	0.35
12	74.24	0.6
14	73.64	0.62
16	73.02	0.56
18	72.46	0.49
20	71.97	0.44
25	71.53	0.36
30	71.17	1.39
35	69.78	0.65
40	69.13	1.13
45	68	0.78
50	67.22	0.9
55	66.32	0.82
60	65.5	0.79
70	64.71	-0.26
80	64.97	1.6
90	63.37	-0.45
100	63.82	1.51
120	62.31	0.49
140	61.82	2.2
160	59.62	1.19
180	58.43	0.48
210	57.95	0.43
240	57.52	0.38
270	57.14	0.3
300	56.84	0.3
330	56.54	56.54

Annex 4 Lithological Log of the Wells

Annex 4 a Lithological log of the well site Aletawondo BH-1

		Lithological Description
From	**To**	
0	9	Red clay soil
9	12	Ash
12	15	Res clay
15	30	Fractured basalt
30	39	sand
39	48	lacustrine deposit
48	54	Red cay
54	60	sand
60	69	fractured and weathered ignimbrite
69	72	tuff
72	75	fractured ignimbrite
75	78	lacustrine deposit
78	81	fractured ignimbrite
81	90	lacustrine deposit
90	99	tuff
99	129	pumice
129	144	pyroclastic deposit
144	152	tuff

Annex 4 b Lithological log of the well site Aletawondo BH-2

		Lithological Description
From	**To**	
0	6.77	Red clay soil
6.77	12.77	Dark Color clay with some fine sand
12.77	15.77	Coarse sand
15.77	18.77	Deposit of rock fragment originate from trachyte, ignimbrite
18.77	27.77	weathered ignimbrite
27.77	30.77	pyroclastic deposit of ash
30.77	42.77	Clay
42.77	48.77	Ignimbrite
48.77	51.77	Weathered pyroclastic deposit of ash
51.77	54.77	Weathered pyroclastic deposit of tuff
54.77	63.77	pyroclastic deposit ash with a dominant quartz
63.77	66.77	weathered pyroclastic deposit of ash
66.77	69.77	Scoraceous basalt
69.77	78.77	pyroclastic deposit ash
78.77	81.77	Weathered pyroclastic deposit of tuff
81.77	87.77	ignimbrite
87.77	90.77	trachyte
90.77	93.77	trachyte basalt
93.77	99.77	pyroclastic deposit of ash
99.77	103.77	Weathered pyroclastic deposit of tuff
103.77	162.77	Fractured basalt

Annex 4 c Lithological log of the well site Gidibo BH

		Lithological Description
From	**To**	
0	2.5	Compacted clay
2.5	7.5	Dry boulder
7.5	22.5	Slightly fractured basalt
22.5	42.5	sandy soil
42.5	60	Slightly fractured ignimbrite
60	62.5	Slightly fractured trachyte
62.5	67.5	pyroclastic deposit
67.5	85	Slightly fractured ignimbrite
85	122.5	moderately fractured ignimbrite
122.5	137.5	Slightly fractured trachyte
137.5	147.5	moderately fractured ignimbrite
147.5	160	Slightly fractured trachyte
160	182.5	moderately fractured ignimbrite
182.5	185	Slightly fractured ignimbrite
185	202.5	moderately fractured basalt
202.5	217.5	Massive basalt
217.5	220	Slightly fractured basalt

Annex 4 d Lithological log of the well site Sheyicha BH-1

		Lithological Description
From	**To**	
0	5	compacted clay
5	15	dry boulder
15	25	Basalt with sand
25	30	clay with basalt
30	55	slightly fractured amygdaloidal basalt
55	80	highly fractured Basalt
80	85	slightly fractured amygdaloidal basalt
85	90	slightly fractured ignimbrite

Annex 4 e Lithological log of the Well site Balesto BH

		Lithological Description
From	**To**	
0	10	Red Clay Soil
10	17.5	Highly weathered clay
17.5	50	clay with quartz
50	55	Fine clay
55	70	clay with sand
70	82.5	Slightly weathered rhyolite
82.5	105	Coarse sand
105	115	Ignimbrite
115	120	Fractured basalt
120	130	Sand
130	135	Sand with Clay
135	145	Fine Clay layer

Annex 4 f Lithological log of the Well site Bulesa BH

		Lithological Description
From	To	
0	2.5	Red Clay
2.5	25	Yellowish clay
25	37.5	Grey clay weathered ignimbrite
37.5	50	Fractured ignimbrite
50	55	Red Clay
55	62.5	Yellowish clay
62.5	70	Fractured basalt
70	75	Sticky Clay
75	85	Slightly weathered ignimbrite
85	97.5	Fresh ignimbrite
97.5	105	Fractured Weathered ignimbrite
105	110	Weathered Sand
110	115	Sticky clay with weathered ignimbrite
115	125	Highly ignimbrite rocks
125	130	Highly weathered fractured ignimbrite
130	140	Fractured weathered pyroclastic
140	150	Highly fractured trachyte basalt
150	152.5	Bolder ignimbrite with clay
152.5	155	Bolder pyroclastic rocks
155	157.5	Fractured weathered ignimbrite
157.5	165	Black weathered fractured ignimbrite
165	185	Highly Weathered bolder ignimbrite
185	195	Clay

Annex 4 g Lithological log of the Well site Gunde BH

		Lithological Description
From	To	
0	2.5	Black cotton soil
2.5	10	Silt sand /red color
10	25	Sand with clay
25	42	Weathered ignimbrite
42	47	Tuff
47	50	Weathered basalt
50	57.5	Weathered and Fractured basalt
57.5	60	River basaltic gravel
60	70	Gravel with sand
70	72.5	Gravel
72.5	77.5	Tuff
77.5	85	Andesite rock
85	87.5	Ignimbrite
87.5	100	Tuff
100	115	Gravel with sand
115	140	Highly weathered and fractured basalt
140	165	Fractured ignimbrite
165	190	Intercalation Ignimbrite with tuff
190	210	Tuff

Annex 4 h Lithological log of the Well site Dongora Kebado BH

		Lithological Description
From	**To**	
0	5	Top Red soil
5	50	sand with clay
50	70	Highly weathered tuff with sand
70	80	Fresh andesite rocks
80	82.5	Slightly weathered basalt
82.5	85	Stick clay with basalt
85	92.5	Highly weathered andesite
92.5	97.5	clay with andesite
97.5	100	Fractured basalt
100	105	Clay with sand
105	115	Fresh andesite rocks
115	130	Highly weathered tuff with gravel
130	150	Highly weathered basalt
150	155	Highly fractured basalt
155	170	Highly weathered basalt
170	172	Highly weathered ignimbrite

Annex 4 i Lithological log of the well site Bargo BH

		Lithological Description
From	**To**	
0	24	Plastic red clay
24	30	Clayey sand
30	36	Plastic Clay
36	90	Basalt with varying degree of weather & fracture, effect at different depth
90	96	Massive Basalt
96	120	Basalt with varying degree of weather & fracture, effect at different depth
120	126	Massive Basalt
126	160	Basalt with varying degree of weather & fracture, effect at different depth

Annex 5 Deep Wells Water Point data of the Study Area

Annex 5 a Deep Wells data in Kola River Catchment

No	Woredas	Kebeles	X/Easting/	Y/Northing/	Z/Elevation/	Depth/m/	SWL (m)	DWL (m)	Discharge (L/s)
1	Aleta Wondo	Dongora Elmete	431532	734626	1779				
2	Aleta Wondo	Belesito	433426	730767	1873	145	51.05	77.14	11
3	Aleta Wondo	Gordama	441511	732719	2079		45		10
4	Aletawondo	Sheyicha	437784	731357	1904	90	10	33	31
5	Aletawondo	Gidibo-1	435267	733773	1843	150			13
6	Aletawondo	Shallow well 1	434069	732919	1895	60			1.9
7	Aletawondo	Shallow well 2	433431	733745	1874	50			2
8	Aletawondo	Gidibo-2	435239	733918	1822	220			20
9	Aletawondo	Homacho	432414	725818	1889	150	10.7	94.26	7
10	Aletawondo	Bargo	445564	736415	2380	160	50	55.45	18
11	Aletawondo	Town Water Supply BH	434766	729519	1908				
12	Aletawondo	Town High School BH	436309	730865	1913				
13	Aletawondo	Korke town	426114	732875	1786	123	22.3	47.03	4.4

Annex 5 b Shallow wells Data in Kola River Catchment

No	Woredas	Kebeles	Villages	X/Easting/	Y/Northing/	Z/Elevation/	Yield L/s
1	Aleta Wondo	Shoicha	SULEKETO	437584	730334	1955	0.5
2	Aleta Wondo	Huletegna Mogisa	HAMENTO	439032	729120	1994	1.5
3	Aleta Wondo	Dongora Elmete	1stWUMERIR A	433238	735493	1858	
4	Aleta Wondo	Dongora Elmete	KOCHO	433596	735795	1857	0.2
5	Aleta Wondo	Dongora Elmete	GUNUFA	430402	734865	1800	0.12
6	Aleta Wondo	Hebeja	HOMBISA	438497	732147	1960	1
7	Aleta Wondo	Dande	RASE	433828	727054	1904	0.2
8	Aleta Wondo	Dande	JAGESA	437240	724366	2060	0.14
9	Aleta Wondo	Belesito	GISHENETO	433071	730574	1888	0.1
10	Aleta Wondo	Belesito	ALELECHO	433961	731665	1886	0.2
11	Aleta Wondo	Gidibo	DOLEMA	432831	733527	1847	
12	Aleta Wondo	Dobe	Sedeka	433838	735512	1864	1
13	Aleta Wondo	Dobe	Woyiba	435535	734864	1872	1
14	Aleta Wondo	Dobe	Ketela	436926	733999	1896	0.2
15	Aleta Wondo	Dobe	Gesa	436765	734418	1859	0.5
16	Aleta Wondo	Dobe	Bankeno	437736	733785	1912	1
17	Aleta Wondo	Dobe	Jema	436072	733884	1842	0.2

18	Aleta Wondo	Bulesa	Sodecha	431646	733307	1836	0.1
19	Aleta Wondo	Guwadamo	Chewita	433828	727054	1904	0.2
20	Aleta Wondo	Guwadamo	Wolako	433264	726394	1927	0.1
21	Aleta Wondo	Hankesa	Hodana	443004	734004	2183	2

Annex 5 c Shallow Wells Data in Kola River Catchment

S.No	Region	Woredas	Kebele	Village name	X	Y	Z	Total depth, m	Static water level, m	Yield, L/s	Drilling Year
1	Sidama	Aleta womdo	Siheca 1st	Maki	438135	730601	1971	42.76	21	0.15	2022
2	Sidama	Aleta womdo	Siheca 2nd	Tonto	438587	729870	1949	67	33	0.94	2022
3	Sidama	Aleta womdo	2nd mogsa	Hamnto	440510	729442	2076	42.76	24	0.37	2022
4	Sidama	Aleta womdo	Aw hosiptal	Hosiptal	435229	729424	1923	91.44	48	0.25	2022
5	Sidama	Aleta Wondo	Gidabo 1st	Alecho	434760	732513	1889	48.76	32	0.25	2021
6	Sidama	Aleta Wondo	Gidbo 2nd	Kilto	433960	733664	1870	54.86	29	0.25	2021
7	Sidama	Aleta Chuko	dengora	Gudumale	428804	735847	1800	48.76	17.6	0.94	2021
8	Sidama	Aleta Chuko	Korqe 1st	Gelano	428087	733427	1811	54.86	42.6	0.5	2021
9	Sidama	Aleta Chuko	Korqe 2nd	Boyaseni	428334	732601	1824	42.76	13.7	1.26	2021
10	Sidama	Aleta Chuko	Korqe 3rd	Setamo	428834	732048	1829	42.76	10.66	0.25	2021
11	Sidama	Aleta Chuko	Gunde	Gunde	425258	733955	1752	60.96	37.7	0.32	2021

12	Sidama	Aleta Chuko	Korqe	Gutano	428818	732620	1809	48.8	3.3	1.89	2021

Annex 5 d Springs Data in Kola River Catchment

No.	Woredas	Kebeles	Villages	X/Easting/	Y/Northing/	Z/Elevation/	Yield L/s
1	Aleta Wondo	Shoicha	MIKA	439438	729957	1972	0.25
2	Aleta Wondo	Shoicha	DOLEMA	439232	730559	1955	0.2
3	Aleta Wondo	Agara Sodicha	ADAMIE	446179	732276	2367	0.5
4	Aleta Wondo	Agara Sodicha	ADAMIE	445090	737460	2261	0.25
5	Aleta Wondo	Agara Sodicha	GOWA	445066	731936	2277	0.2
6	Aleta Wondo	Gordama	BABIE	442418	730852	2078	0.2
7	Aleta Wondo	Gordama	DANEGIE	443913	730737	2192	0.16
8	Aleta Wondo	Huletegna Mogisa	DEGASA	440038	729708	2008	0.16
9	Aleta Wondo	Huletegna Mogisa	MADERARE	441018	726865	2006	0.2
10	Aleta Wondo	Huletegna Mogisa	DEGASA	441612	729627	2128	0.2
11	Aleta Wondo	Hebeja	BEREBERO	440430	732928	2029	0.2
12	Aleta Wondo	Hebeja	MALEGA	439533	733153	1936	0.5
13	Aleta Wondo	Gidibo	WALA	435595	733442	1834	0.1
14	Aleta Wondo	Gidibo	SETAMO	433854	732683	1839	0.3
15	Aleta Wondo	Titira	Gutano	431201	729352	1860	0.1

16	Aleta Wondo	Kila hiqicha	Chalaka	446397	730457	2401	0.25
17	Aleta Wondo	Kila hiqicha	Anedegna Eifero	445800	729820	2326	0.16
18	Aleta Wondo	Kila hiqicha	Eifero	445029	730149	2227	0.2
19	Aleta Wondo	Kila henafa	Godicho	443258	729129	2169	0.16
20	Aleta Wondo	Kila henafa	Diella	443748	728750	2241	0.2
21	Aleta Wondo	Kila henafa	Shemurie	443320	729881	2148	0.125
22	Aleta Wondo	Bergo	Gosaluwa	445148	735188	2276	0.25
23	Aleta Wondo	Bergo	Butula	446377	737594	2425	0.2
24	Aleta Wondo	Hankesa	Morega	443140	735667	2201	1
25	Aleta Wondo	Hankesa	Hamitanto	444628	735581	2272	1
26	Aleta Wondo	Hankesa	Hodana	443885	734128	2211	0.5
27	Aleta Wondo	Gordama	Eidewa	442708	731942	2084	0.2
28	Aleta Wondo	Hondoba	Duea	442007	734071	2093	0.25