



# **Causes and Effects of Groundwater Depletion in Akaki Well Fields and Catchment Water Supply**

By

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This is to certify that the proposal prepared by Yimer Mekonnen Entitled: Causes and Effects of Groundwater Depletion in Akaki Well Fields and Catchment Water Supply Submitted in Partial Fulfillment of the Requirements for the Degree of Masters of Science (Water Resource Management) complies with the regulation of the University and meets the accepted standards with respect to originality and quality.

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## **Abstract**

The study focuses on causes and effects of groundwater depletion of the well fields in the Akaki catchment. The catchment is known for its sources of many deep well water extraction areas developed for the purpose of providing potable water supplies for the residents of Addis Ababa city. However, research shows that due to high levels of water extraction, groundwater depletion, poor land use and land cover practices in the Akaki catchment, the city is exposed to problems associated with a serious shortage of water supplies.

The aim of this research is to identify the causes of ground water depletion and understand its impacts in the catchment. By assessing geomorphology, vegetation, land use, land cover, urbanization, population dynamics, temperature and precipitation.

The study uses qualitative and quantitative research methodologies. In particular, descriptive type of research design and statistical trend analysis will be one of the main methods of this research to identify the major causes of ground water depletion in the study area. The supply conditions of the study area were assessed using interviews the people and professional's, who works in water sectors.

Groundwater extraction greater than the replenish capacity of the well is one of the main factors that affects the groundwater potential of the Akaki catchment. In addition, the study identified that changes of land use land cover LULC, temperature increase, precipitation variability, urbanization and population density are among other causes of exacerbating ground water depletion the area. From the land use land cover (LULC) analysis, it can be concluded that Akaki catchment had experienced a significant change in land use and land cover over the past three decades. The analysis shows that the rapid conversion of forest, grassland and cultivated land covers to urban settlement

The two primary causes of depletion of water table identified in this study are deforestation and over-pumping of groundwater. Despite the continuous decline in ground water level, there is no ground water management policy and proper system of water conservation practices in the country. Finally the study indicates there is a significant ground water scarcity in the catchment requiring immediate actions

**Keywords:** Groundwater Depletion, Water Supply, LULC, Ground water recharge, Water scarcity, Akaki well field

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# Table of Contents

<b>ABSTRACT .....</b>	<b>I</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>II</b>
<b>TABLE OF CONTENTS.....</b>	<b>III</b>
<b>TABLES AND FIGURES.....</b>	<b>VI</b>
LIST OF TABLE .....	VI
LIST OF FIGURES .....	VI
<b>ACRONYMS AND ABBREVIATIONS .....</b>	<b>VII</b>
<b>CHAPTER 1: INTRODUCTION.....</b>	<b>1</b>
1.1. BACKGROUND TO THE STUDY .....	1
1.2. STATEMENT OF THE PROBLEM.....	3
1.3. RESEARCH QUESTIONS.....	4
1.4. OBJECTIVES.....	4
1.4.1. General Objective .....	4
1.4.2. Specific Objectives .....	4
1.5. SCOPE OF THE STUDY: .....	4
1.6. SIGNIFICANCE OF THE STUDY .....	5
1.7. THESIS OUTLINE.....	6
<b>CHAPTER 2: LITERATURE REVIEW .....</b>	<b>7</b>
2.1. GROUND WATER HYDROGEOLOGY .....	7
2.2. IMPORTANCE OF GROUND WATER.....	7
2.3. Groundwater Depletion.....	8
2.4. Causes of Groundwater Depletion .....	9
2.5. Effects of groundwater depletion.....	10
2.8. SOLUTIONS TO GROUNDWATER DEPLETION .....	11
2.9. STRATEGIES FOR QUICKENING WORLDWIDE PROBLEM OF GROUNDWATER DEPLETION .....	13
2.10. GROUND WATER MANAGEMENT AWARENESS IN ETHIOPIA.....	13
2.11. OVER GROUNDWATER EXPLOITATION IN ANOTHER COUNTRY EXPERIENCE.....	14
2.12. GROUNDWATER MINING .....	15
2.13. PREVIOUS WORKS ON THE HYDROGEOLOGY OF THE STUDY AREA .....	15
<b>CHAPTER 3. MATERIALS AND METHODS.....</b>	<b>17</b>
3.1. THE STUDY AREA .....	17
3.1.1. Location and climate.....	17
3.1.2 Climate.....	18
3.1.3. Rainfall and precipitation .....	18
3.1.4 .Temperature.....	20
3.1.5. Topography and Geo morphology .....	21
3.1.6. Geology .....	23
3.1.7. Hydrogeology of the area.....	23
3.1.8. Drainage .....	25

3.1.9. Demography of the Study Area .....	26
3.2. METHODOLOGY .....	27
Field work includes:.....	27
3.3. STUDY DESIGN .....	28
3.4. MATERIALS .....	28
3.4.1. Source of data .....	28
3.4.2. Equipment used.....	29
3.5. DATA COLLECTION .....	29
3.5.1. Data collection techniques.....	29
3.6. SAMPLING METHOD.....	29
3.6.1. Sample size and selection.....	31
3.7. DATA ANALYSIS AND CODING .....	32
3.10. LAND USE, LAND COVER .....	33
<b>CHAPTER 4. RESULT AND DISCUSSIONS.....</b>	<b>35</b>
4.1. WELL MONITORING DATA ANALYSIS.....	35
4.2. Population growth as the causes of over exploitation.....	43
4.3. CAUSES OF AKAKI GROUNDWATER DEPLETION .....	44
4.4. Overexploitation of Akaki groundwater.....	46
4.5. CITY SETTLEMENTS AND CONSTRUCTION OF ROADS CAUSES OF AKAKI WELL FIELD GROUNDWATER DEPLETION.....	48
4.6. RECHARGE AREA OF AKAKI CATCHMENT WELL FIELDS.....	50
4.7. ENCRUSTATIONS DUE TO THICK ALLUVIAL AND BASALTIC LITOLOGY OF THE AKAKI WELL FIELD .....	57
4.8. GROUND WATER DEPLETION IMPACTS ON THE CATCHMENT WATER SUPPLY .....	58
4.8.1. Economic influence of water shortage on the people.....	58
4.9. THE MEASURES TAKEN BY THE STAKEHOLDERS ABOUT GROUND WATER SUSTAINABLE USE.....	61
4.9.1. Policy adjustments .....	63
4.9.2. Connecting land use plans and groundwater management.....	64
4.9.3. Policy for the role of private sectors .....	64
4.9.4. Support for regulation.....	64
4.9.5. Regulatory stipulation.....	65
<b>CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>66</b>
5.1. CONCLUSIONS .....	66
5.2. RECOMMENDATIONS .....	68
<b>REFERENCE.....</b>	<b>VIII</b>
<b>APPENDICES .....</b>	<b>XII</b>
APPENDIX - I .....	XII
<b>ADDIS ABABA UNIVERSITY .....</b>	<b>XII</b>
QUESTIONNAIRE WILL BE RESPONDED BY INDIVIDUALS (HOUSEHOLDS AND OFFICER) .....	XII
<b>GENERAL DIRECTION .....</b>	<b>XII</b>
<b>PART I.....</b>	<b>XII</b>
<b>PART II .....</b>	<b>XIII</b>

1.11 low effectiveness water resources management.....	xiii
<b>PART III.....</b>	<b>XIV</b>
APPENDIX -II .....	xv
INTERVIEW GUIDE QUESTIONS TO BE MADE WITH HOUSEHOLD MEMBERS .....	xv
APPENDIX III .....	xvi
<i>Guide for Focus Group Discussion</i> .....	<i>xvi</i>
APPENDIX. V WORK SCHEDULE.....	xvii
BUDGE .....	xviii
APPENDIX VI .....	
<i>CHECK LIST</i> .....	

# Tables and Figures

## List of Table

TABLE 1: NATIONAL ATLAS OF ETHIOPIA 1981.....	18
TABLE 2: POPULATION GROWTH FROM 1961-2007.....	26
TABLE 3: AKAKI CATCHMENT LC 2003 SCHE IMG.....	53
TABLE 4: AKAKI CATCHMENT LC2008 SCHE 31 IMG.....	53
TABLE 5: AKAKI CATCHMENT LC 2013 SCHEME IMAGE.....	53
TABLE 6: COMBINED LAND USE LAND COVER OF 2003 AND 2008.....	54
TABLE 7: COMBINED LAND USE LAND COVER OF 2008 AND 2013 ATTRIBUTE DATA.....	56
TABLE 8: RESPONSES ABOUT PURCHASING WATER OTHER PLACES.....	58
TABLE 9: RESPONSES ABOUT DISTANCE TRAVEL FINDING WATER.....	59
TABLE 10: RESPONSES ABOUT SANITATION PROBLEM.....	60
TABLE 11: RESPONSES ABOUT LACK OF SANITATION, HEALTH PROBLEM.....	60
TABLE 12: PERCEPTION OF SAMPLE RESPONDENT ABOUT THE STAKEHOLDER MOVEMENT TO ALLEVIATE THE WATER SHORTAGE PROBLEM.....	61
TABLE 13: PERCEPTION OF SAMPLE RESPONDENTS ABOUT WATER USE IN LAW ENFORCEMENT.....	63
TABLE 14: WORK PLAN OF THE RESEARCH.....	XVII
TABLE 15 BUDGET.....	XVIII

## List of Figures

FIGURE 1: GROUNDWATER WELL LOCATION IN AKAKI WELL FIELD.....	17
FIGURE 2: MONTHLY RAIN FALL RECORDINGS THE YEAR 2017 FROM ADDIS ABABA OBSERVATORY STATION.....	19
FIGURE 3: MONTHLY AVERAGE TEMPERATURE RECORDINGS FROM AKAKI AND INTOTO OBSERVATORY STATIONS OF THE YEAR 2018.....	20
FIGURE 4: DIGITAL ELEVATION MODEL FOR THE STUDY AREA.....	22
FIGURE 5: ANNUAL AVERAGE DISCHARGE AND WATER LEVEL FOR 18 AKAKI WELL FIELDS.....	35
<b>FIGURE 6: SPATIAL DISTRIBUTION OF AKAKI GROUNDWATER WELLS.....</b>	<b>36</b>
FIGURE 7: GROUNDWATER LEVEL AND FLOW DIRECTION MAP OF THE STUDY AREA.....	37
FIGURE 8: WELL ID WF01-PW2 Q, L/S.....	46
FIGURE 9: WELL ID WF01-PW2 STATIC WATER LEVEL.....	46
FIGURE 10: WELL ID WF01-PW6 Q, L/S.....	47
FIGURE 11: WELL ID WF01-PW6 STATIC WATER LEVEL.....	47
FIGURE 12: WELL ID WF01-PW11Q, L/S.....	47
FIGURE 13: WELL ID WF01-PW14 STATIC WATER LEVEL.....	48
FIGURE 14: WELL ID WF01-PW2 DISCHARGE GAUGE STATION.....	48
FIGURE 15: IMAGE TAKEN NEAR AKAKI WELL FIELDS.....	49
FIGURE 16: ROADS SETTLEMENT AND IRRIGATED AREA NEAR WELL FIELDS.....	49
FIGURE 17: LAND USE LAND COVER MAP OF THE STUDY AREA.....	50
FIGURE 18: LAND USE LAND COVER MAP OF THE STUDY AREA (2008).....	51
FIGURE 19: LAND USE LAND COVER MAP OF THE STUDY AREA (2011).....	52
FIGURE 20: COMBINE LAND USE LAND COVER MAP (2003-2008) OF THE STUDY AREA.....	54
FIGURE 21: COMBINED LAND USE LAND COVER MAP (2008-2013) OF THE STUDY AREA.....	56
FIGURE 22: GEOLOGICAL LOGGING WELL ID WF 01-pw11.....	57
FIGURE 23: RESPONSE ABOUT PURCHASING COST OF WATER.....	58

## Acronyms and Abbreviations

AAWSA	Addis Ababa Water and Sewerage Authority
BOS	Bottom of screen
EGMA	Ethiopian Geo spatial and Mapping Agency
EGS	Ethiopian Geological Survey
EMA	Ethiopia metrological agency
EPAE	Environmental protection agency of Ethiopia
GW-MATE	Groundwater Management Advisory Team
LULC	Land Use Land Cover
MENA	Middle East and North Africa
MER	Main Ethiopian Rift Valley
MOS	Middle of screen
MoWE	Ministry of Water and Energy
MoWR	Ministry of Water Resource
OWRB	Oromia Water Resource biro
TOS	Top of Screen
USGS	United State Geological Survey
WWDS	Water Works Design and Supervision

## **Chapter 1: INTRODUCTION**

### **1.1. Background to the study**

Groundwater is the largest source of usable, fresh water in the world. In different parts of the world, especially where surface water supplies are not available, domestic, non-domestic, agricultural, and industrial water needs can only be met by using the groundwater (Tularam, 2009).

In Akaki catchment there are many deep well water extraction areas developed for the purpose of providing potable water supplies for Addis Ababa city dwellers. However, multiple studies show that the quality and quantity of the groundwater supplies in the catchment are drastically deteriorating due to multiple anthropogenic factors that include population growth, urbanization and pollutions.

This research overseas causes of groundwater depletion in Akaki well fields. The study, comprehend from the data about its depth Akaki well field has got its recharge is regionally because those well are deep wells so the researcher try to see or guess scientifically the area of the recharge is how/when it has to be the causes of ground water depletion of the Akaki well field. Recharge occurs whenever precipitation or surface water infiltrates downward through the soil to the water table. Recharge can also from the subsurface lateral flow that reaches the aquifer (National research center , 1997). Ground water is usually found in subsurface formations known as aquifers, which may be a significant hydrological component of watersheds and basins (National research center , 1997). This study thinks drilling materials, like bit types, bit inches, because the well narrowing and widening is having its impact and well developed problem during drilling, in addition to this the study concerned that Pumping water out of the ground at a faster rate than its replenished capacity over the long-term causes similar problems. Groundwater depletion is primarily caused by continuous groundwater pumping, and mainly unplanned water use.

Accordingly, in Addis Ababa city in particular, and in the Akaki catchment in general, water supply problem is happening due to depletion of ground water Akaki well field, therefore, the study tries to dig out the causes of ground water depletion in the study area and its impact on the catchment supply.

Groundwater resource is an additional source of water supply for many countries in the world. Likewise groundwater is used as a source of potable water in the City of Addis Ababa, in addition to surface water resources.

The groundwater of Akaki is, as we know under immense pressure as it is being heavily used for drinking as well as for other activities that require water, resulting in a decline of its water level because the current water system is not reliable from a quality or quantity standpoint. Many wealthier users have developed their own water systems. Pumping supply of water mains or their own wells and storing water in rooftop tanks or underground cisterns (underground tanks) (Wagena, 2011). The municipality withdrawal groundwater resource to provide the city dwellers in addition to surface water resources. Potential groundwater resources in the area available but the resource needs wisely uses. And the study area wells needs strong supervision and conserving the environment of recharge area. To improving quality of fresh water, human beings have increasingly turned to groundwater, and advances in drilling and pumping technology that have made it suitable and economical to do so. However, groundwater tapping requires large and sustainable natural reservoirs where its sustainability ultimately depends on balance withdrawals with rates of recharge. (Sah, 2001)

## **1.2. Statement of the Problem**

The extraction of groundwater resources in well fields of Akaki catchment is currently not based on adequate understanding of drawdown levels and availability of potential groundwater resources in the area. Meanwhile, this mismanagement of groundwater resources and over exploitation in the Akaki catchment has continued. The study area is characterized by lack of strong supervision of water wells and inadequate knowledge management practices that was frequently observed during the drilling process. The problem was further exacerbated year to year due to population growth, enlargement of settlements, deforestation and land degradation increases. The groundwater recharge mechanism has complex systems, variations in a wide range of catchments and also governed by the rainfall distribution, topography, land use and geology. The major recharge to the aquifer comes from precipitation and river channel losses. The main direct recharge is assumed to take place in all areas except where low permeable lacustrine soils exist (Ayenew T. , 2006).

Provision of safe and sufficient water supply and adequate sanitation services are indispensable components in the sustainable development of Akaki catchment socioeconomic well-being. At present, most of the population does not have adequate and safe access to water supply and sanitation (WSS) facilities. As a result, over 70% of the contagious diseases in the study area are water borne diseases. The source of most of these diseases could be traced back to inadequate WSS facilities (seied, 2009). Unable to Providing access to clean and adequate WSS facilities due to shortage of water and less improvement of the performance of this sub-sector couldn't reduces the morbidity rates. Here even the catchment uses surface water resources in addition to ground water, but the depletion Akaki well field ground water brings shortage of water for the catchment.

In this context, the Ministry of Water, Irrigation and Energy requested support of the World Bank in supporting the enhancement of a strategic framework for managing groundwater development, with special attention for areas of intensive groundwater development, in particular for the Addis Ababa Area (groundwater management team 2011). Because there is a gap in Akaki well field like Mismanagement of the good knowledge gaps during extraction of ground water lack of conserving the recharge area. An expansion of urbanization and population growth, brings over exploitation of

the study area ground water beyond replenishing capacity, There are a large number of organizations those activities have a bearing on the sustainable use of groundwater – from regulation, abstraction, recharge and quality point of view. It is encouraging that groundwater has already moved into the realm of land use planning – opening the scope to manage groundwater beyond the water domain, yet there is no organization that masterminds the management or development of groundwater (Ministry of water resource, 2011).

### **1.3. Research Questions**

- 1) What are the major causes for contributing ground water depletion in Akaki well field Addis Ababa?
- 2) What are the consequences/ impacts of ground water depletion around Akaki catchment dwellers on water supply?
- 3) What types of administrative measures were taken by the stakeholders to minimize the risk in the study area?

### **1.4. Objectives**

#### **1.4.1. General Objective**

The overall objective of the study is to identify the causes of Akaki well field ground water depletion and impacts on water supply Akaki catchment households or the dwellers in social, economic and health aspects.

#### **1.4.2. Specific Objectives**

- 1) To assess the causes of natural, meanwhile anthropogenic factors that contributes to the depletion of ground water.
- 2) To evaluate the impacts of ground water depletion on water supply systems
- 3) To examine the required measures taken by the key stakeholders in the catchment.

### **1.5. Scope of the Study:**

The study focus on causes of ground water depletion in the catchment and its impact on the water supply as well as economical and health impact to the society. It would

also emphasize on the assessment of factors of the anthropogenic and natural phenomenon that can aggravate ground water depletion of the study area and the catchment water supply.

Even if, the problems of water shortage existed in the city of Addis Ababa, the planned water resource study is very much limited to the area of Akaki catchment which is considered to be one of the most ground water resource storage areas and informally populated areas in the city. Akaki well field is located in Akaki Kality sub-city of Addis Ababa and Oromia region near to Akaki sub city border. Its estimated location is found around Akaki area, the road from the stadium that leads to the Debrzite. So the study is delimited only in Akaki area of the city and Oromia region near to Akaki Sub city border.

### **1.6. Significance of the Study**

The study could help to estimate the causes of the ground water depletion and the extent of impacts of ground water depletion on the community of Akaki catchment. And shows that what would be the community role to keep sustain this precious resource and it would help for policy making on the administrative part and to create public awareness and shows solution to conserve and use sustainable the ground water of the study area.

It helps for efficiency, equity and sustainability of existing groundwater and surface water use. Able to decide how to safeguard enforces the priority to basic drinking water supply for minimizing the ground water depletion of the Akaki well field.

Able to balance increased resource demands with the needs to maintain the environmental functions of groundwater, helps cross-sectoral integration in policy development if the study clearly identified the causes of ground water depletion.

Represent groundwater interests in land-use management and vice versa, and able to connect macroeconomic policies, broader socioeconomic and environmental goals and the strategy for groundwater management and use if the causes of ground water depletion identified in the study area.

Give stakeholders a voice and a role and special attention to drive in management in the river basin approach as the key planning unit for water resources management (Desta, 2000) for the benefit of keeping in sustainable Akaki ground water.

## **1.7. Thesis outline**

The research is subdivided into five chapters and the contents are summarized briefly as:

Chapter 1: discusses about the introduction of the research that include the problem statement, the objective of the research and research questions, in which; the research tries to answer on the basis of the available data.

Chapter 2: literature review that assesses different articles and books, helping for this research previous works are also discussed in this chapter.

Chapter 3: Methods, This chapter give an idea about the study area geology, Hydrogeology, Geo morphology, climate, Temperature, precipitation and demography of the study area. And how to apply the research

Chapter 4: Discussion and describes characteristics of the well field, and analyze the data that can help to reach the research to result. Describes monitoring data of the groundwater wells and those will be the causes of ground water depletion like, over exploitation, land use land cover, population growth and encrustation

Chapter 5: Conclusion and recommendations discuss the result of the groundwater depletion and impact estimated by different methods. In this final chapter, matters which cannot be addressed are also recommended to be implemented in the future

## **Chapter 2: LITERATURE REVIEW**

### **2.1. Ground Water Hydrogeology**

Groundwater is part of the natural hydrological cycle. When the rain falls onto the land surface some the water infiltrates more deeply, eventually accumulating above impervious bed, saturating the available floor space and forming an underground reservoir. This water now called ground water and the rocks that can store and transmit ground water are called aquifers (Gleeson, 2012). Groundwater occurs at different depth in varying geological unit of hydro geological basin. All three classes of rocks (igneous, sedimentary, and metamorphic) can hold ground water at different scale depending upon pores space and features in the rocks. The rock properties determine how much ground water can be stored and how productive an aquifer is the porosity of rocks related to the proportion of voids. When pores and feature are interconnected the rocks are said to be permeable and water can flow easily. The main features essential for groundwater existence in crystalline rocks are weathered zones (regolith) and fractured zones. The weathered layer, also called regolith, developed on intact volcanic and sedimentary rocks is an important source of groundwater, for the rural and urban water supply in studying an area (Merrey, 2013).

### **2.2. Importance of ground water**

Groundwater is the main resource for life and growth and development of the country. Hence, relying on the groundwater has increased greatly. Accordingly, extensive increments in the groundwater withdrawals have occurred in almost every part of the country (Leonard & Eloise, 2005). One of the most fundamental condition for the growth and development of the nation is certain to fulfill its urgent water needs, hence, along with this are demanded good scientific and technical capabilities for the assessment and substantial development of the country for water resource potential particularly for the groundwater. (Merrey, 2013). Ground Water is a significant natural resource for living things to exist on the earth and it is a pillar of civilization. The resource is used for irrigation, industries, and domestic purpose. It is also one of major source, which contributed a lot to the world water demand. Groundwater is very important and most broadly distributed resource on earth and distinct any other mineral resource it gets in annual replenishment from meteoric precipitation. At the present one

fifth of all water used in the world is obtained from the ground resource (Fetter, 2018). Groundwater plays important role in Ethiopia as a major source of water for domestic uses, industrial and Agricultural uses. (Merrey, 2013)

### **2.3. Groundwater Depletion**

Groundwater depletion is a serious threat to the environment. The majority of our bodies and the Earth are made up of water. We may see the beautiful, flowing surface waters that make up the oceans, lakes and rivers, but this water is not always safe for consumption and is much more difficult to filter than groundwater. Consequently, water from the ground is especially valuable (Margat, 2013).

Groundwater is something that we need all over the world. Humans and animals need water in order to survive as our bodies could not function without it. We also need water to assist us in growing crops, powering equipment, and to keep us comfortable. Societies require much more clean water than we are afforded from precipitation and surface water, which is why groundwater is used so frequently (Leonard & Eloise, 2005).

If you were to see groundwater moving, you'll likely find it interesting that so much water lies beneath us. From a bird's eye view, you may even feel that there is more than enough water to go around. While we know that groundwater shortage is a serious issue, we should also know how water naturally finds its way into the aquifers we extract it from (Leonard & Eloise, 2005). Nature goes through a unique process to provide us with groundwater. The surface water that we can see is heated by the Sun and goes into the atmosphere as evaporation. Water vapor then creates precipitation, water that falls from the sky as rain and snow. Once the water falls from the sky and onto the ground, it is absorbed into the Earth and is then stored as groundwater in aquifers.

Groundwater plays a major, if often unrecognized, role in both hydrology and human systems. (Giordano, 2009) The majority of the world's drinking water probably comes from groundwater, and in the last half century, there has been an amazing, if largely ignored, boom in agricultural groundwater use that has provided improved livelihoods and food security to billions of farmers and consumers. However, increased use of groundwater has also created problems, and there are fears sometimes challenged that the boom may soon turn to bust (Giordano, 2009). Groundwater depletion is a serious threat to the environment. The majority of our bodies and the Earth are made up of water

(Rodell, 2009). We may see the beautiful, flowing surface waters that make up the oceans, lakes and rivers, but this water is not always safe for consumption and is much more difficult to filter than groundwater. Consequently, water from the ground is especially valuable (Rodell, 2009). In our country case we use surface water for water supply, especially in Addis Ababa in addition to surface water, use ground water resources in the catchment. So, the research knows even though, ground water depletion not only Akaki well field problem, but also its worldwide difficulties, the writer of this research tries to oversee the causes of the area ground water depletion and impacts on the catchment water supply.

#### **2.4. Causes of Groundwater Depletion**

Groundwater depletion most commonly occurs because of the frequent pumping of water from the ground. We pump the water more quickly than it can renew itself, leading to a dangerous shortage in the groundwater supply. As a growing world with a population that continues to rise, the more we pump water from the ground at a rapid rate, the more difficult it is for the ground water to provide us with the amount of water that we need. We continuously pump groundwater from aquifers and it does not have enough time to replenish itself (Leonard & Eloise, 2005). In Akaki well field the same thing happens; moreover, expansion of Addis Ababa city and construction of concrete asphalts and buildings reduces rainwater infiltration. Deforestation of the recharge area is the other causes of ground water depletion Evaporation are another major climate variable that influences groundwater changes. Water flows freely through the saturated rocks known as aquifers. There are large and small aquifers, and they are the underground water reserves that absorb water and hold it, enabling us to pump it for use.

The amount of water that aquifers hold is beyond impressive and can provide us with billions of gallons of water per day. While this amount of water seems plentiful, groundwater is a major contributor to the Earth's fresh water supply and is responsible for providing up to 40% of freshwater in the world. Therefore, it doesn't have the ability to recollect quickly enough to be continually sourced for our use (Zengyun, 2019). Groundwater tables are falling at phenomenal rates, often more than one meter per year, in many parts of the world. Formerly perennial rivers and streams whose base flow was supplied by groundwater are becoming seasonal or disappearing all together. Wetlands are drying up. (Giordano, 2009) Groundwater depletion most commonly occurs because of the frequent pumping

of water from the ground. We pump the water more quickly than it can renew itself, leading to a dangerous shortage in the groundwater supply. As a growing world with a population that continues to rise, the more pump water from the ground at a rapid rate, the more difficult it is for the ground water to provide with the amount of water that the peoples need (Giordano, 2009). So, when connect it to the current study case it means not only lack of conservation the recharge area, but also, over extraction of water because of ever growing population and urbanization, lithology of the area, supervision problems during drilling and lack of proper water development, monitoring problem during production. This all problems bring the Akaki well field ground water depletion. This ground water depletion as the study findings and AAWSA professionals believed to bring water supply problems in the catchment

## **2.5. Effects of groundwater depletion**

As the world's largest distributed store of fresh water, ground water plays a central part in sustaining ecosystems and enabling humans to improve resilience to climate variability and change. The strategic importance of ground water for the global water and food security will undoubtedly intensify in future due to rising global temperatures and population growth. Groundwater depletion will force us to pump water from deeper within the Earth. The more we extract groundwater right below the Earth's surface, the further down, we have to go in order to get more. As we have to extract water from deeper within the Earth, we find that there is less water available. Consequently, we will have to use even more resources to develop alternative methods to reach further into the ground (Levermann & Payne, 2013). In our country context, this use full resource, especially the study area is under risk because of the Akaki catchment over population, expansion of the city and deforestation

## **2.6. Groundwater depletion, environmental effects**

Reduction of water volume in streams, lakes and wetland environments. Plants and animals that depend on streams and lakes for food, water and habitat are adversely affected reducing biodiversity and deteriorating water quality. Crop production decrease from lack of water availability and here in Akaki catchment shortage of drinking water happens (Leonard & Eloise, 2005).

## **2.7. Groundwater depletion socioeconomic effects**

If intensive pumping from an aquifer continues, and then adverse effects may occur, water-well problems, declining ground-water levels have three main effects on water wells. First, as the depth of water increases, the water must be lifted higher to reach the land surface. As the lift distance increases, so does the energy required to drive the pump. Thus, power costs increase as ground-water levels decline. Depending on the use of the water and the energy costs, it may no longer be economically feasible to use water for a given purpose. Second, ground-water levels may decline below the bottom of existing pumps, necessitating the expense of lowering the pump, deepening the well, or drilling a deeper replacement well. Third, the yield of the well may decline below usable rates. (Bartolino, 2003). Many countries are over pumping aquifers as they struggle to satisfy their growing water needs, including each of the big three grain producers— China, India, and the United States. These three, along with a number of other countries where water tables are falling, are home to more than half the world's people (Leonard & Eloise, 2005). Where excessive groundwater pumping here In Akaki catchment to supply water the community of the catchment rapidly shrinking.

The cost of water to the consumer rises and sanitation problem happens to the dwellers of the Akaki catchment. This is due to the water table lowering so the city administration needed more energy to pump further down. Once the depth of extractable water falls below 300 meters, it becomes uneconomical for most companies to recover.

## **2.8. Solutions to Groundwater Depletion**

As individuals, one of the things we can do to make a difference is to use less water for luxury purposes. We must all address the issue of groundwater depletion. Considering the impending crisis of a mass water shortage, everyone should do their part to use less water whenever possible.

We should reduce our use of chemicals and dispose of them properly. Many people are not paying attention and are simply unaware of how important it is to keep pollution from occurring beneath the ground. The water from businesses and private residences that run into the streets and sewage systems are commonly laden with chemicals. These chemicals find their way into larger bodies of water and absorb into the ground,

poisoning animals and the soil. By using less chemicals and discarding of them carefully, we keep them from adding toxic materials into our water supply (Konikow, 2005).

More comprehensive research and additional funding can help with groundwater depletion. The best way to approach the topic of groundwater depletion and to find a solution is to think on both a personal and government level. Laws that are in place for the pumping of groundwater should be more strict and follow specific regulations.

There are many scientists, researchers, and sustainable companies that remind us how vital it is to know the amount of groundwater we actually have. They also believe that many of the policies we have should be changed with the consideration of saving groundwater in mind instead of treating it like an endless resource (Aeschbach-Hertig & Tom, 2012).

One of the most helpful ways to address the issue of groundwater depletion is to find alternative sources of water. Alternative water sources can be used to help replenish aquifers. Deriving water from other sources would also give aquifers time to refill instead of pumping too much water from them at once.

The pumping of groundwater should be regulated. If we don't have a better understanding of our groundwater supply, then we can simply use much more than we should. Understandably, more funding should be granted towards researching our groundwater supply instead of just pumping the water, so that we can set limits and better pace our usage. Additional funding should be given to support initiatives that not only study the supply of groundwater we have, but also seek to find sustainable ways to use less of it (Aeschbach-Hertig & Tom, 2012).

**Groundwater depletion can also occur naturally.** The problems we would face with fresh water shortage is sure to cause problems in every aspect of our lives. The activities that lead to groundwater depletion come mostly from humans, but a portion of it also comes from changes in our climate and can speed up the process (Aeschbach-Hertig & Tom, 2012).

## **2.9. Strategies for quickening worldwide problem of groundwater depletion**

Groundwater the world's largest freshwater resource is critically important for irrigated agriculture and hence for global food security. Yet depletion has been widespread in large groundwater systems in both semi-arid and humid regions of the world. Excessive extraction for irrigation where groundwater is slowly renewed is the main cause of the depletion, and climate change has the potential to exacerbate the problem in some regions. But its impacts on water resources are more obvious at the regional scale, for example, in agriculturally important parts of India, China and the United States. Food production in such regions can only be made sustainable in the long term if groundwater levels are stabilized. At this conclusion, a transformation is taken in how we value, manage and characterize groundwater systems. Technical approaches, such as water diversion, artificial groundwater recharge and efficient irrigation have failed to balance regional groundwater budgets. They need to be complemented by more comprehensive strategies that are adapted to the specific social, economic, political and environmental settings of each region. (Gleeson, 2012)

## **2.10. Ground water management awareness in Ethiopia**

Lack of qualified and community consciousness about the sustainable use of groundwater resource made gaps in ground water management. Ground water management systems may be expected to incorporate a set of economic regulation and ethical levers that functioned by markets regulatory or state in situations and user associations. Groundwater acts as the primary buffer against the impact of climate variability and spatial variability in drought. Effective institutional approaches need to be aware of these socio –economic realities surrounding ground water use. In most situations ground water is a common property resource with extremely high use value. The country has enormous surface water and ground water resources (Merrey, 2013). The occurrence of ground water is not uniform because it depends on various environmental and geological factors. Ground water used is also poorly monitored relative to surface water use. These reduce the information available to determine sustainable ground water extraction regimes. According to Harvey large scale metering of bores has only considered (Harvey, 2002). Ground water is easily extracted through

wells and how much can be extracted depends on water level or how much storages available (Saudi National Water company, 2005). Agriculture can flourish in some deserts, but only with water either pumped from the ground or imported from another area (Fetter, 2018). In Ethiopia ground water is available in sediments, sandstone, alluvial and karstic limestone (Awulachew, 2007). The shortage of fresh drinking water for human and livestock population and for agriculture is known in the lowland, in some highland areas of Ethiopia found essential to explore water resource for sustainable water supply and food self-sufficient (Awulachew, 2007). Ground water management is the planned and coordinate management of a groundwater basin with a goal of long term sustainability of resources. The management of groundwater resource is more complicated than that of surface water supply on the basis of the mode of occurrence (Fetter, 2018). Ground water is one of the natural resource which is the determinant resource for everyone that lives on this earth.

### **2.11. Over groundwater exploitation in another country experience**

In this article over-exploitation refers to the multi-impact exploitation of groundwater with undesirable consequences (Salameh, 2008) such as increasing cumulative draw down, continuous deterioration in water quality detrimental to users of aquifers, and among others, reduced spring discharges. It does not only refer to the hydrologic concept of unbalanced exploitation based on a water balance of recharge and discharge.

The over-exploited, non-equilibrium state of the groundwater resources of Jordan is used as an example of the groundwater situation in most Middle East and North Africa (MENA) countries, to demonstrate the water supply situation in these countries are heading towards. In the following elaborations, continuous water level declines and increasing groundwater Salinities will be illustrated by examples of the major aquifers in the country which have resulted in ceasing or reduction in spring discharges, loss of agricultural productivity and accordingly, loss of investment and jobs with all their subsequent socioeconomic impacts. Last, the limits of aquifer productivity will be discussed to indicate the situation that future generations will be facing concerning their water supplies. (Salameh, 2008)

## **2.12. Groundwater mining**

The main reason that bottled water is bad for the water system is because of something called water mining. In simple terms, water, mining is the practice of a bottled water company going somewhere, drilling, pumping out groundwater, and then leaving, but it's so much more than that. A more groundwater mining is defined as "The process, deliberate or inadvertent, of extracting groundwater from a source at a rate in excess of the replenishment rate such that the groundwater level declines persistently, threatening exhaustion of the supply or at least a decline of pumping levels to uneconomic depths" 5 Bottled water companies are like any other business in that they're there to make a profit. When they go into a community they've identified as a good place to set up shop, they are there to pump as much water as they possibly can. When they withdraw water, is also called consumptive use, they take groundwater out, but don't put it back. The groundwater is taken out, bottled, and then shipped all over the country or the world. This water never goes back to where it was taken from. Groundwater depletion impacts everyone and everything in the area who uses water; farmers, businesses, animals, ecosystems, tourism, recreation, and the regular guy getting his water from a well (Hassan, 2016)

## **2.13. Previous works on the hydrogeology of the study area**

Concerning hydro geology of the Addis Ababa region, different papers have been written that concerned about surface and groundwater potential of the catchment, ground water hydrochemistry and geology, of the catchment, how to affect ground water. Hydro geological study of Akaki catchment with special emphasis on the problems of groundwater recharge has been carried out by (Dmlie et al, 2007). Previously detailed hydro geological investigation has been also carried out by (Girma, 1994) in his master's thesis "Hydrogeology of Akaki Area". As cited in a thesis, many geoscientists like (Corti, 2009), (Ayen, et al, 2008) (Visentiet et al, 1979), have discussed the geology of the Addis Ababa in their studies discussed the volcanic stratigraphy of rock units out crop pininat the vicinity of the Addis Ababa- Nazareth area. Regarding surface and ground water potential of the Addis Ababa region, (Wohnlich, et al, 2006) have conducted valuable works. Assessments to assure the feasibility of surface and groundwater as a source of water supply in Akaki Area have been carried out by (AAWSA, 2000). The geology and Hydrogeology of Akaki

(Sekelo) sub basin with particular emphasis to its hydrochemistry and interaction between the surface and ground water have been investigated by “Water Quality and Ground Water/Akaki River Interaction in the Sekelo Basin Lower Akaki River (Shaqa, 2010). Specific references to water well drilling, Construction, Pumping test data, water quality data, Geological and geophysical logs in Akaki well field is included in the water well construction report by AAWSA as a client and WWDE (Water Well Drilling Enterprise) as a contractor in 1996. Similar activities have been carried out for 25 water wells drilled in the Akaki well field for the supply of Addis Ababa by AAWSA as a client and COMPLANT as a contractor in 1997.

In Addis Ababa, and its neighboring areas, both surface and groundwater resources have been inspected in terms of potential, and vulnerability (Tekle-Haimanot, 2006) by a relatively good number of investigators such as); (AAWSA & SEURECA, 2000) (A, 2008); and surveyed pollutant the three river surveyors of the Addis Ababa City (Alemayehu, 2001). These studies, although they vary in scope and degree of geological and geochemical information, have stressed that the quality of surface water is often affected by uncontrolled waste disposal of domestic and municipal wastes and industrial effluents. They further indicated that these would have a potential impact on the quality of groundwater of the region. The recharge in the area and he stated that recharge takes place over the entire surface area, major recharge takes place within the Intoto sector of the catchment, serving as a so-called mountain block recharge (Dmlei et al, 2007).

Moreover, hydro chemical and environmental isotope data indicated additional recharge sources of wastewater, leakage from the mains and reservoirs. In addition to that, did aquifer vulnerability of the whole Akaki catchment and water quality assessment.

## Chapter 3. MATERIALS AND METHODS

### 3.1. The study area

#### 3.1.1. Location and climate

The Akaki Catchment is located in central parts of Ethiopia along the western margin of the main Ethiopian Rift Valley (MER). The catchment is situated in the northwestern Awash River basin between 8°46'–9°14'N and 38°34'–39°40'E. It is bounded to the north by the Intoto ridge system, to the west by Mt Menagesha and the Wechecha volcanic range, to the southwest by Mt Furi, to the south by Mt Bilbilo and Mt Guji, to the southeast by the Gara Bushu hills and to the east by the Mt Yerer volcanic centre. The Akaki catchment has an area of about 1500 km<sup>2</sup>. Addis Ababa is located at the centre of the catchment (Figure 1). Surface water reservoirs located within the study area include Legedadi, Gefersa, Dire and Abasamuel (Demlie et al 2007). The elevation varies from 2060 m.a.s.l in the south around the Akaki well field to 3200 m.a.s.l in the northern Intoto Mountains. The southeastern, central and eastern parts are flat and undulating lands covered with thick Quaternary alluvial and lacustrine deposits (Ayenew et al 2011)

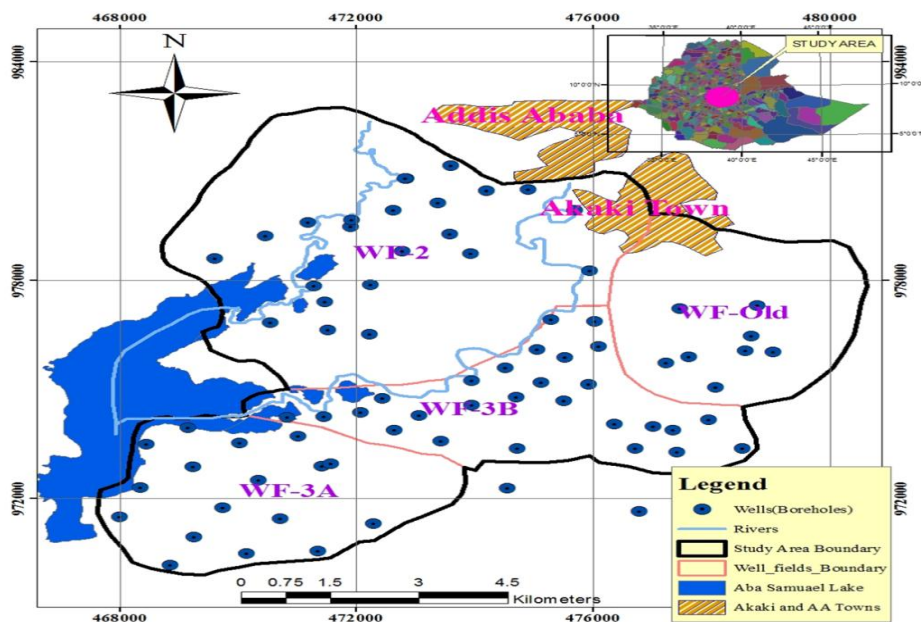


Figure 1: Groundwater well location in Akaki well field

### 3.1.2 Climate

The climate of the Akaki catchment is characterized by two distinct seasonal weather patterns. The main wet season, locally known as '*Kiremt*', extends from June to September. A minor rainy season, locally known as '*Belg*', contributes moisture to the region from mid February to mid April (Berga, 2011). Such climates which are characterized by alternating wet and dry seasons may favour. This seasonal variation of rainfall distribution within the study area is due to the annual migration of the inter-tropical convergence zone, a low-pressure zone marking the convergence of dry tropical easterlies and moist equatorial westerly's across the catchment (Ebasa, 2006). The climate is warming temperate to humid. The study area receives rainfall from Atlantic Equatorial Westerly during the main rainy season and from the Gulf of Aden and Indian Ocean during March and April months. There is low to negligible amount of rainfall in the other months. Addis Ababa is located in the region where the rainy months are closely distributed weathering (Ebasa, 2006).

### 3 .1.3. Rainfall and precipitation

According to Alemu E. L (2014) the following table shows the 1981 National Atlas of Ethiopia.

Table 1: National Atlas of Ethiopia 1981

No.	Climatic Zone	Altitude (above esea level ASL)	Rainfall/Precipitation/
1	Alpine " <i>Kur</i> "	3000 m ASL	900-2200 mm
2	Temperate ' <i>Dega</i> '	2300m - 3000m	900- 1200mm
4	Sub tropical ' <i>Weina- Dega</i> '	1500-2300m	800-1200mm
5	Tropical ' <i>Kolla</i> '	800-1500	200-800mm,
6	Desert ' <i>Berha</i> '	Less than 800	Under 200mm

Source: Adapted from Alemu E. L, (2014)

Accordingly, the climate of the Addis Ababa area is typically characterized by two distinct seasonal weather patterns: the wet season, which extends from June to September, contributing about 70% of the annual rainfall, and the dry season which covers the period from October to May with a minor rainy season in March and April well known for its failure. Such climates which are characterized by alternating wet and dry seasons may favor. This seasonal variation of rainfall distribution within the study area is due to the annual migration of the inter-tropical convergence zone, a low-pressure zone marking the convergence of dry tropical easterlies and moist equatorial westerly's across the catchment. The climate is warming temperate to humid. The study area receives rainfall from Atlantic Equatorial Westerly during the main rainy season and from the Gulf of Aden and Indian Ocean during March and April months. There is low to negligible amount of rainfall in the other months. Addis Ababa is located in the region where the rainy months are closely distributed weathering (Alemu E. L., 2014).

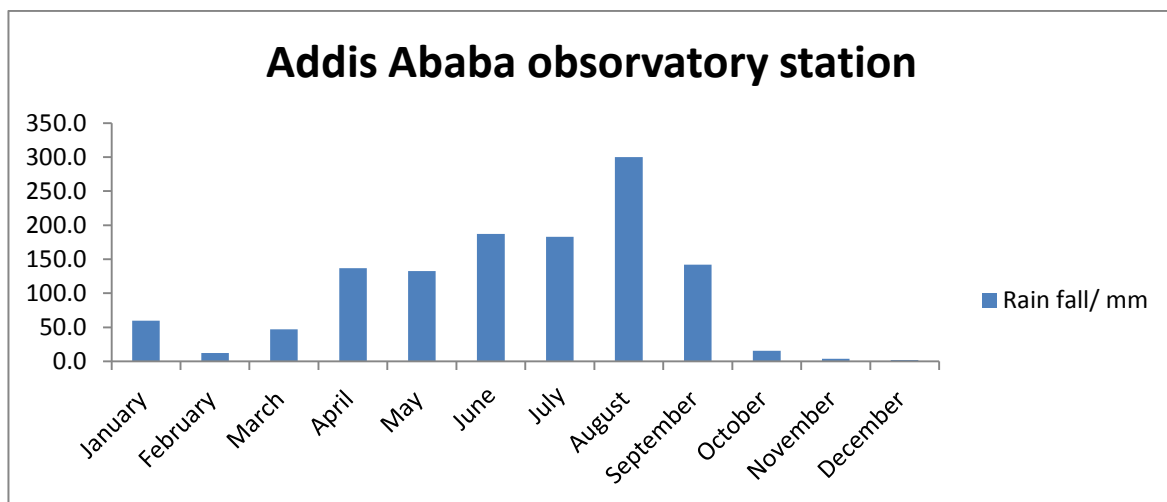


Figure 2: *Monthly Rain fall recordings the year 2017 from Addis Ababa Observatory Station*

As shown here in (figure 2) dry season of the catchment extends from October to February and the minor rainy season starts from March ends April only two months, and the main rainy season starts from June extends to September.

The variation in the seasonal distribution of rainfall in Ethiopia can be attributed by the reference to the position of the Inter-Tropical Convergence Zone (ITCZ), the relationship of between upper and lower air circulation, the effects of topography and the role of local convection currents and the amount of rainfall (Tesfye, 2009)

According to Tesfye (2009) indicates that, classification of Ethiopia's rainfall region, Addis Ababa is located in the region where the rainy months are contiguously distributed. In this region there are seven rainy months from March to September/and the small rains occur from March to May. The big rains are from June to September. High concentration of rainfall occurs in July and very high concentration in August. As shown above in( figure 2)

The Ethiopian meteorological agency has rainfall measurement devices in different places inside Akaki catchment those charts under each station shows the variability of Akaki catchment average precipitation of consecutive year till 2017GC

### 3.1.4 .Temperature

As Alemu (2014) indicated that under normal conditions, air temperature decreases with increasing altitude at a mean rate of  $0.7^{\circ}\text{c}$  for every 328 feet according to Fetcher ( 1998).

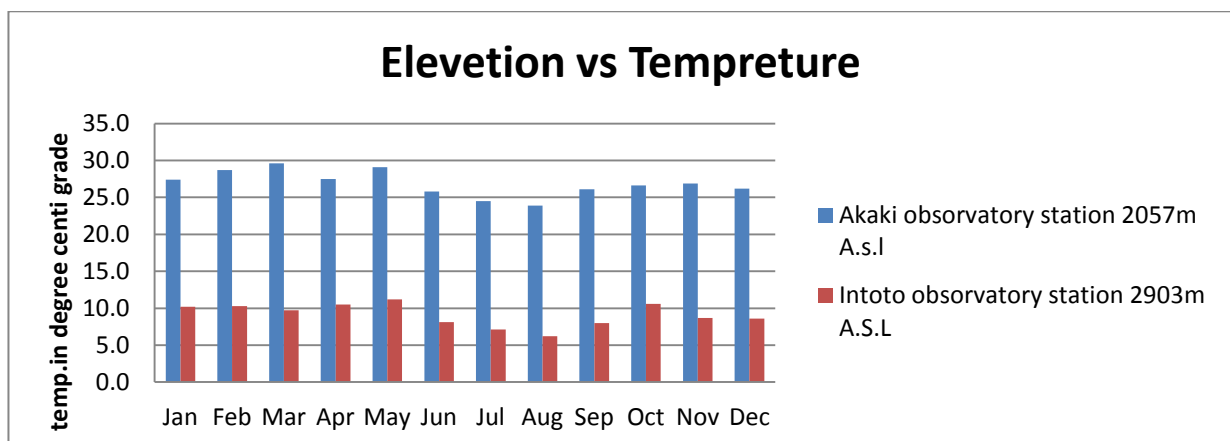


Figure 3: *Monthly average temperature recordings from Akaki and Intoto observatory stations of the year 2018.*

This works also in Ethiopia, where temperature decreases with increasing elevations. The maximum temperature of Addis Ababa ranges between  $20^{\circ}\text{c}$  (in the wet season) to  $25^{\circ}\text{c}$  (in dry season), while the minimum falls between  $7^{\circ}\text{c}$  -  $12^{\circ}\text{c}$  in the year.

And the student comprehend from the above (figure 3) easily by taking Akaki observatory station that has the lowest elevation of the catchment and Intoto observatory

station that have the highest elevation of the catchment, 2057m a.s.l and 2903m ASL so temperature recordings of the year 2018 respectively show that when the elevation increase the temperature decreases.

But all stations in the catchment many recorded show that not to reduce but the temperature increasing year to year.

### **3.1.5. Topography and Geo morphology**

Overall, the site ranges in elevation from 2050m in south and central part to 2180m in the northeastern corner. It is drained from northwest, north, and northeast towards the southeast and into Akaki River, in places losing itself among extensive seasonal swamps, but eventually discharging into the Awash River. (Leta, 2014) The area can be divided into three major physiographic regions. These are: (1) The Furi Ridge, (2) The eastern and (3) Akaki plain physiographies regions. The Furi ridge physiographies region, the southeastern part of the Furi volcano, is drained from northwest to southeast into the Akaki plain, part of the radial drainage of the Furi volcano. The creeks finally lose themselves in the extensive Akaki seasonal swamp area. The Furi Mountain rises from the surrounding area by about 700m. It is built of mainly trachytic flows and minor associated pyroclastics (WWDSE, 2011). The northwestern, northeastern and southeastern areas are underlain by Quaternary age basaltic flows. These areas gradually slope due west into the south central part. This is a large and relatively little modified basaltic shield of recent origin. This large mound has been built by voluminous outpouring of basalt flows from east–northeast trending central fissures, now marked by speckles of numerous well preserved cinder and basalt cones. There are scattered cinder and basalt cones sticking out of the surrounding surface, forming conspicuous topographic features in the site area. (Leta, 2014). The south central part of the site is a sediment deposition site, a NE–SW trending sort of Graben structure now filled with recent alluvial sediments. It presents a flat lying not yet modified topography. The featureless alluvial plain is completely devoid of bedrock exposed and lies in elevation between 2060 and 2080m.

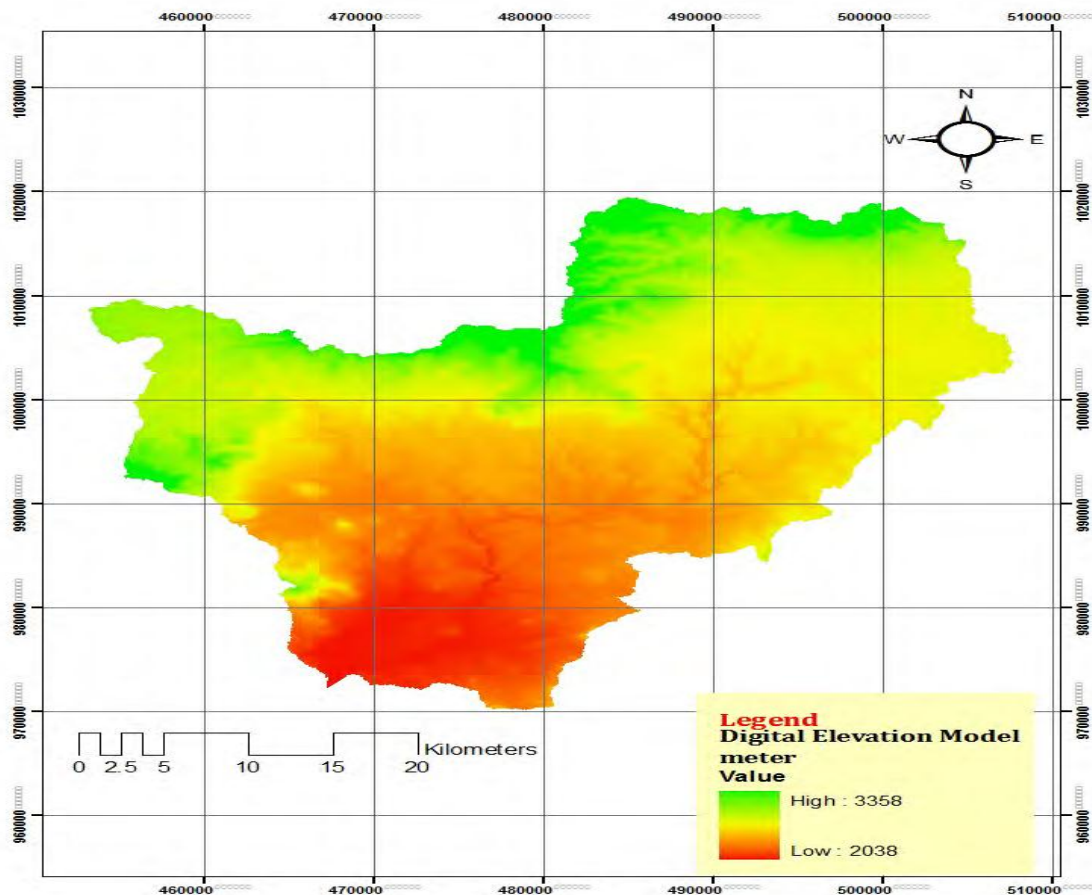


Figure 4: *Digital Elevation Model for the study area*

Akaki River meanders southeastward across the plain, in places losing itself among extensive seasonal swamps, but eventually discharging into the Awash River outside the site area. The river meanders through the alluvial sediment eroding its own depositions. Generally, the geomorphology of the study area is flat plain Graben with scoria and vesicular basalt hills which is bounded by mountains NW and SE directions. According to Abraham Brega (2011) study the catchment found at the southern flank of the Entoto ridge (3199m a.s.l.) and expanded in all directions. This ridge marks the northern boundary of the city following the east-west trending major fault (Ambo-Kassam). According to AAWSA, AAU,(2003) other prominent volcanic features surrounding the City are Mt. Wochacha in the west (3385m a.s.l.), Mt. Furi (2839m a.s.l.) in the southwest and Mt. Yerer (3100 a.s.l.) in the southeast.

The topography is undulating and form plateau in the northern, western and southwestern parts of the city, while gentle morphology and flat land areas characterize the southern and southeastern parts of the city (Abdurhaman, 2011)

### **3.1.6. Geology**

The north and northeastern area (the Entoto Mountain, the northern and northeastern Addis Ababa) is covered with trachytes, rhyolites, basalts and several episodes of pyroclastic materials of older volcanism occur in the upper part and foot hillsides of Entoto ridge. Overlying these, younger basaltic rocks (Addis Ababa Basalt) are found covering the central and southern part of the city. Outcrops of ignimbrites north of the Bole area (Eastern Addis) and Lideta area (Central Addis) have been observed underlying the Addis Ababa basalt. Younger volcanic of trachy-basalt, trachytes, ignimbrites and tuff Belonging to the wochecha, Furi and Yerer volcanoes are recognized overlying un-conformably on the Addis Ababa basalt in the western, southwestern and eastern part of the catchment (Abdrhaman, 2011)

### **3.1.7. Hydrogeology of the area**

The total catchment area of Akaki is divided into two sub-catchments. These are Big Akaki According to Alemu (2014) Akaki area groundwater prospective site is part of Aadaa-Becho plains groundwater system which is found at the margin of the western part of the Ethiopian Rift Valley. The general hydro geological set up of the basin is governed by the lithologic stratigraphy and tectonics of the area. In the city scale for Addis Ababa, studies characterized the rocks by ways of fracture porosity and interstitial porosity they exhibit(Leta, 2014). And accordingly categorized the main aquifers into three groups:

- a) Shallow aquifers: made of weathered volcanic rocks and alluvial sediments along the river courses,
- b) Deep aquifers: made of fractured volcanic rocks that tap fresh groundwater, and
- c) Thermal aquifers: those are located in the depths greater than 300m.

According to WWDSE (2008) the prospective site is recharged from large areas (Abay plateau and Upper part of the Awash River basin). Part of the groundwater flow path of the groundwater basin pass through Akaki is a prospective site (SWAWF) and this makes the potential of the site prospective. The Oligocene-Miocene Tarmaber basalts that cover the recharge zone of the groundwater basin, the pyroclastic rocks that cover

most parts of the surroundings of Addis Ababa, the young basalt flows and scoria deposits that cover the surroundings of Akaki, the alluvial deposits along Akaki river flood plain and the fault lines which are all associated with the Ethiopian Rift system are the major geological phenomenon that are governing the hydro geological conditions of the region in general (WWDSE, 2011).

A previous report (Shaqa, 2010) had identified regional groundwater flow direction which is assumed to be north-south from Addis Ababa towards the Akaki well field. (Wang, et al, 2001) Assumed groundwater flow direction in the well field is from the NE towards the SW. The groundwater flow system can be schematized with depth into two major categories: a shallow zone of active fast flow and a deeper zone of relatively slower flow and longer residence time. The shallow systems are confined to the upper permeable soil, sediment, and weathered rock zone (usually less than 50 meters). This zone is considered to be the phreatic near surface aquifer with high permeability supplying water to hand dug wells, low-discharge springs, and river base flows. Below this zone, there exists a fractured rock zone and volcano clastic deposits in places interbedded with paleosols (up to a maximum of 230 m depth). This zone is a major aquifer of the catchment dominantly confined in central and southern Addis Ababa. In the highlands, groundwater reserve is limited due to the absence of large faults and the existence of non-fractured massive volcanic forming the mountainous areas along the watershed boundaries. According to Tenalem Ayenew et al (2008) High flow exists in and around the Akaki well field where scoria and fractured basalts provide the most productive aquifer. The groundwater flow direction within the prospective site do not flow along the Akaki River's flow direction, it flows almost perpendicular to the river's flow direction (WWDSE, 2011). Groundwater in Akaki are a prospective site exists in fractures of vesicular basalts and scoraceous basalts and in the pores of scoria.

The aquifers of the Akaki Well Field and its surrounding, the study area, are also of volcanic origin, largely related to processes of lava flow and tectonic fractures. Volcanic deposits of scoria, scoriaceous and vesicular basalts are the predominant rock types in the area. Tectonic activities in the region developed intensive and network fracturing/fissuring, which resulted in favourable conditions for groundwater circulation. In the study area and its surrounding, (Girma, 1994) showed that there are four types of aquifers in the Akaki area. The first aquifer type, which is highly productive, is

constituted by scoria deposits, scoracious basalt and alluvial sediments. The second type of aquifer comprises of highly fractured and fissured basalt while the third aquifer is of a salts with moderate productivity having fractures, vesicles and sparsely spaced joints, ignimbrite and agglomerates. The scoria cones and surge deposits from the last group of aquifer, which has low productivity.

### **3.1.8. Drainage**

The Akaki River catchment comprises of abundant small rivers. The leading ones are the big Akaki, which drains the eastern part of the catchment area, and the Little Akaki that drains the western part of the catchment; and their respective tributaries. The two rivers form one of the biggest tributaries of the Awash River called Akaki River that enters Abba Samuel Lake, leaves the lake and passes through a gorge up to 100m deep which extends for about 8km before it joins the Awash River. Almost all the streams in the catchment originate from the northern part of the catchment big Akaki suffers a total drop of about 600m in a river length of 95km from its origin to its confluence with the Awash River near Dodota, 1800m above sea level AAWSA 2000.

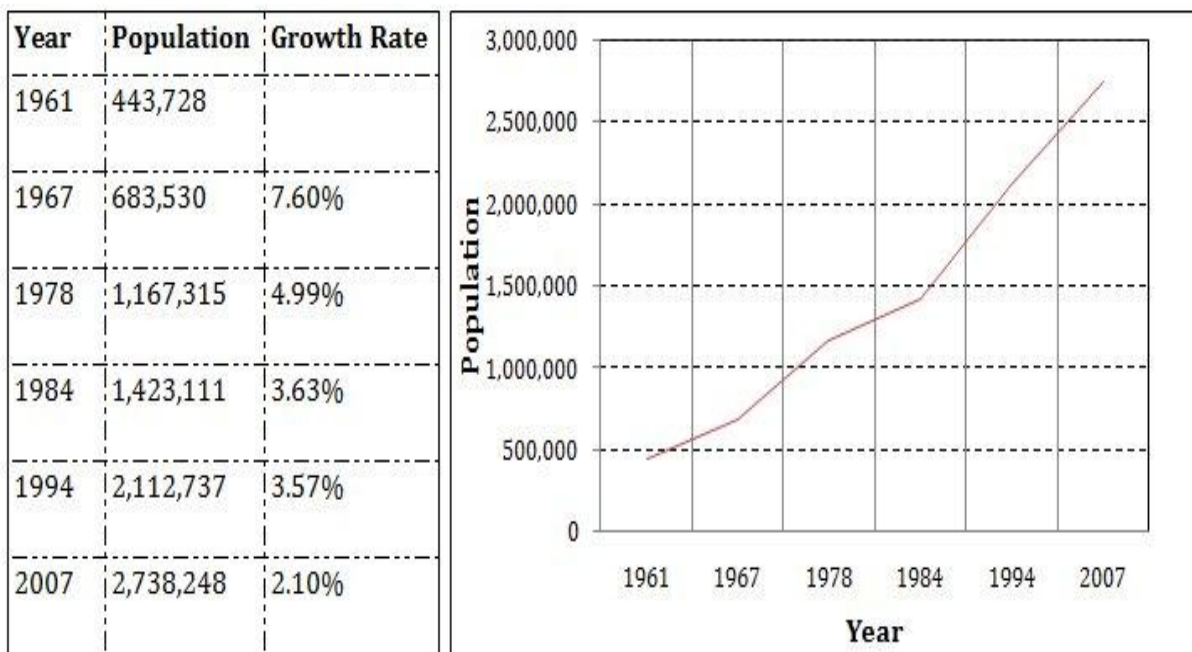
Intoto Mountain range in the northern forms the surface water divides between the Blue Nile and Awash River basins. The drainage of an area is affected by numerous factors among which, rainfall, slope, vegetation, rock type and tectonic activity, infiltration capacity, soil types and thicknesses, are some. In the northern part of the catchment the drainage forms steep, narrow gorges (facilitates runoff) which can be attributed to high rainfall.

Dense vegetation cover and high topographic elevation (>2800m). Where there are volcanic ridges /domes, drainage radiates in all directions forming radial or parallel drainage system. It is clear that areas with higher permeability have a lower drainage density that in turn may decrease the surface runoff. These can be observed from the topographic map of the area that in areas with high elevation and that are not covered with vegetation have a higher drainage density compared to flat lying areas and areas that are covered with vegetation (increases permeability). Generally, the drainage in the catchment is oriented nearly from north to south following the regional slope.

### 3.1.9. Demography of the Study Area

According to Abdurrahman Berga (2011) Central Statistical Agency of Ethiopia (CSA) 2007 reported that Addis Ababa has a total Population of 2,738,248, of whom 1,305,387 are men and 1,434,164 women. This report also shows that the population of the city grows at an average rate of 2.1 percent than that of the 1994 Census, even some people do not believed 2007 census its correctness. Those people estimated more than this number at that time, so this change has occurred due not only to natural increase, but continues attraction between 90,000 to 120,000 new residents every year. In general, it appears that much of this growth (probably up to 70 percent of the total), taken place in the slums and without permission (squatter) settlements of the city (UN-Habitat., 2012).

Table 2: *population growth from 1961-2007*



Source: Adapted from Abdurrahman Berga (2011)

Even, CSA report says Population number 2007, 2,738,248 but Addis Ababa is the heart City Ethiopia. It is also the biggest city in the country by population, with a total population of 3,384,569 according to the 2007 census. However, it is believed that this number was inaccurate when recorded and underestimated the city's population. The city has through recent years seen a strong annual growth rate, and population counts as of 2017 are growing closer to 4 million. The next census is arranged for the 2018 to 2019, as it was delayed by security concerns between 2017 and 2018. Addis Ababa is a

chartered city and as such, is considered both a city and a state. It is the largest city in the world located in a landlocked country. Population in the near future is expected to grow to exceed 6.5 million residents. The annual growth rate of the city has been estimated in recent years to be 3.8%. In prior years, growth has been as much as 8%.

### **3.2. Methodology**

In order to achieve the objectives, the study a number of steps has been followed. These included reviewing different previous works, not only geophysical works (on groundwater exploration and identification of geological structures) but also geological and hydro-geological data of the study area. Finally, different geophysical, geological and hydrological reports of WWDSE were collected study area and analyzed, by spss and Microsoft Excel Consequently graphs, charts are produced and interpreted to achieve at the objectives of the study, satellite images are analyzed using appropriate software like, GIS and AutoCAD.

In order to fulfill the objective of the study, the authors of this study follow three methodologies namely pre-field work, field work and post-field work.

Pre-field work: this study includes:

- Collection of different literatures and relevant data (hydrogeological, geological, topographic maps, and satellite imageries,
- Data preparation and interpretation in order to meet the overall objective of the current study
- Interpretation and analysis in order to meet the three specific objectives
- Identification of data gap that couldn't elaborate the causes of ground water depletion of the study area

Field work includes:

Field observation and reconnaissance survey primarily field observation and reconnaissance survey done through observation using checklists. A checklist having questions prepares for assessing the area, handling system of nature that helps the ground water recharge, and other basic environmental condition of the study area

Understanding the hydro geological & geological setup, collection of well completion and pump test data, data preparation for analysis, land use land cover data and meteorological data

Post-field work includes:-

- Analysis and interpretation of collecting, monitoring hydro geological, geological and meteorological data
- Collection of additional data from different source.
- Processing satellite imagery and DEM data for understanding changes of LULC and geographical features Akaki catchment comparing by calculating area difference of different unique values within the satellite image change using combined image analysis.

The main approach to this study was to make a closer evaluation of the existing Akaki well field groundwater resources situation to gain an understanding of the causes of Akaki well field groundwater depletion and impacts on the catchment.

### **3.3. Study Design**

The study uses qualitative and quantitative research methodologies. The research trying to explain groundwater depletion and impact in the catchment. In particular, descriptive type of research design and statistical trend analysis would be one of the main methods of this research to identify the major causes of ground water depletion in the study area by analyzing samples taken from well data during drilling, during taken different tests and analyzing monitoring data. The study focuses on describing the impacts of water supply shortage of community. The supply conditions of the study area were assessed using, interview the people and professional's works in water sectors.

### **3.4. Materials**

#### **3.4.1. Source of data**

Primary data were obtained from field observation, checklists, interviews, photos and well monitoring data from selected production well monitoring data. Well lithology collected and analyzed what the effect on the ground water depletion. Secondary data were collected from published and unpublished row data from the AAWSA, MOWR, WWDS, EMA, GSE and EGMA.

### **3.4.2. Equipment used**

Photo camera , GPS that can use for locating the study area and find the wells, and deep meter to measure the current water level to compare previous consecutively monitored data and use computers to analyze the data with the help of different software like GIS, AutoCAD, spss, excel etc.

## **3.5. Data collection**

### **3.5.1. Data collection techniques**

In order to achieve the objectives of this study a comprehensive literature review was collected from published and unpublished sources. Collected 18 wells, ground water monitoring data from Akaki well field and the recharge area and well field area assessment about its geological feature by studying the area out crops and previous lithological data. And over sees the extent of the recharge and the study area natural coverage by using different maps, reconnaissance survey and Google maps and assess how urbanization contribute the study area ground water depletion by using arc GIS processing satellite image. And assesses precipitation, temperature condition of the catchment by collecting daily and monthly ppt. And temperature from Ethiopian meteorological agency (EMA) through soft copy format. And About the impact data collected through interview Informal discussion by preparing and collecting data. Beside this, Information was also collected through photographic observation. And there was discussion FGD with different community group, about impacts of water shortage, interview with the professionals who are responsible in the city administration like, AAWSA, WWDS, the ministry of water and energy and community of the study area.

Due to increased demand of water as the population is increasing day to day. And also due to global warming, which increases the temperature and in turn water level goes down. And also, we do misuse of water and do not conserve it, that's why all this happens so population data in Addis Ababa collected Ethiopian statistics agency and different websites.

## **3.6. Sampling Method**

Purposive sampling strategy was used in this study. It is possible to make the study both quantitative and qualitative using open and closed ended questions regarding

water resources management and consequently to have an appropriate unit of analysis to get the attitude of the target population. Further, this sampling strategy allowed me to use, flexible interpretations with regard to the type of respondents to choose (Hoggart, 2002) A non-probability sample is a type of sample in which elements are selected in a nonrandom manner on the basis of convenience, and every element in the population does not have a non-zero probability of being included in the sample (Shively, 2011)

A non-probability purposive sample is often used in applied social research where circumstances to do the selected sampling technique is feasible, practical or theoretically sensible (Bornstein & Jager, 2013) This is used primarily when there are a limited number of people that have expertise in the area being researched. This type of sampling method is often used in qualitative research and relies on one's experience and knowledge of theory and previous research findings. Therefore, respondents are selected that are considered to be representative of the population being studied. Compared to probability samples, non-probability sampling is considerably more advantageous than doing probability sampling in applied social research

➤ Advantages of Non-probability Samples

- Costs less than probability (cheaper)
- Can be conducted more quickly
- Produces samples that are reasonably representative
- Used when sampling frame is not available
- Useful when the population is so widely dispersed that cluster sampling would not be efficient
- Often used in exploratory studies
- Some research is not interested in working out what proportion of

Population gives a particular response, but rather in obtaining an idea of the range of responses on ideas that people have.

Based on the above mentioned advantages, a non-probability sampling framework

was applied in order to obtain a sample that was appropriate for the study. Given that the interest of the research is specific to the utilization and management of water resources around the Akaki sub-city of Addis Ababa, using purposive sampling can be very useful to reach a targeted sample quickly and to get the opinions and interests of the target population. Further, in order to apply the researcher's knowledge about the study area and to identify the major problems such as access to potable water and reliability, and ground water resource problems of the area, a purposive sampling method was necessary. For this, descriptive evaluation with a non-probability sampling approach was adopted because it was an appropriate strategy for asking 'what, how and why' questions.

It required no control over behavioral events and had a contemporary focus (Tellis, 1997). The result may not be generalized to other places of the country, but; it intends to reflect the Akaki Catchment management practices and the water use pattern of the catchment. Substantial information was required for the use of resources and management practices.

### **3.6.1. Sample size and selection**

In order to ensure homogeneity in the grouping of households in the selected Akaki Sub-City, Woreda 01 was subdivided into three groups (sex, age and marital status) households through the sampling technique used on the basis of two principles: conformity with the stated objectives and theoretical approach. This grouping helps the study to identify who are the most affected due to shortage of water.

If we want to get information about a large group of individual people or things, it is normally impossible to get all of them to answer our questions or to examine all the things that would take a long time and be far too expensive. The solution is to just ask or examine some of them and hope that the data we get are representative (or typical) of all the rest. If the data we collect are as identical as we would expect from the rest, then we can draw conclusions from those answers that we can relate to the whole group. This process of selecting just a small group of cases from out of a large group is called sampling as Nicholas (2011), explanations.

To conduct this study, the researcher randomly selected 1 Woreda using the lottery method from the total of 11 Wordas in Akaki sub city that is known as word 01, which

has a total population of 13,972 based on the source data obtained from Akaki Kality sub city Atlas (2006/2014), first edition.

With respect to households, worda (01) has totally no of 1746, households. To select the respondent of households in the selected word, the researcher used simple random sampling technique in order to remove bias and to get correct information.

### **3.7. Data analysis and coding**

Statistical trend analysis is one of the main methods of this study to identify the causes of ground water depletion by comparing timely changes of monitoring ground water level data and the changes of land use land cover of the recharge area. Supervised classification was done on the different period satellite images of 2003, 2008 and 2013. Image data collected from Ethiopia mapping agency where department of remote sensing. The field data were used for reclassification of the image using the maximum likelihood classifier. Based on this classification method above ten major land use and land cover types were identified. The above image 2003 combined from the image 2008 to identify the change.

Neuman (2000) explains that data analysis involves transferring data from questionnaires to a format that is suitable for statistical analysis. The information collected in the local study is basically quantitative; therefore, it was analyzed using the SPSS Statistical Package. Neuman (2000) defines coding as “the hard work of reducing mountains of raw data into manageable piles allows a researcher to quickly retrieve relevant parts...” The quantitative data collected from the survey were presented in statistical form of tables and graphs. The qualitative data gathered through involving key informant interviews, observation and assessments of the studies were written up in a narrative.

### **3.8. Assumptions**

To evaluate wellness issues and well pump test results made for the analyses, consecutive years monitoring data making statistical trend analysis. Additional data and analysis would be required to address some of these limitations, and to enhance the analysis with more realistic approximations.

- All wells analyzed for impacts related to well depths are still in service;
- Well construction data in the study area can be grouped into statistical distributions;

### **3.9. Data**

Potential impacts of groundwater elevation decline on well operations and monitoring were evaluated. Most wells were in the Akaki and Akaki border Oromia region. Well completion reports were obtained from the WWDSE. These reports contain well history, geological and hydrological settings of the well and different well development test result.

A geologic log of the stratigraphy, will use classification, provided sufficient information for this analysis. The data set included 18 wells that are uses water supply of the catchment or the city of Addis Ababa in addition to surface water supply or miscellaneous public use. Well characteristics obtained from well logs included relative elevations from ground level to screened intervals, particularly top of the screen (TOS), middle of the screen (MOS), and bottom of the screen (BOS). Data from the well completion reports were spreadsheet.

### **3.10. Land use, land cover**

To prepare land use/Land cover map for that can show the change of the catchment year to year. Arc GIS 10.3 Software was used to perform image analysis and image classification. This analysis was done to provide information on LU/LC trends and for generation of land cover scenario changes of the area within the time.

The five land cover classes were considered, namely; Forest land (scarce and dense), land Grassland, cultivated land, Settlement (urban) and Water body.

Forest Land: Area with a high density of trees which include deciduous forest land, evergreen forest land, mixed forest land and plantation forests that mainly are eucalyptus, junipers and conifers.

Grassland: Area covered with grass that is used for grazing and that covered for a considerable period of the year (half of the year).

Water body: Area which remains water logged throughout the year,

Cultivated Land: Areas used for both annual and perennial crop cultivation

Settlement (Urban): areas where there is a permanent concentration of people building, and other man-made structures and other activities. Here the Land Use Land Cover (LULC) helps the study to estimate how affect the recharge of Akaki catchment groundwater by comparing different years land use, land cover of the catchment change by analyzing three different years satellite image

Various approaches were used to quantify the impacts of LU/LC changes on groundwater recharge and quality. The different approaches complement each other in providing a comprehensive evaluation of LU/LC changes on groundwater quantity and quality at varying space and time scales

Assessing how the catchment dwellers have exerted large scale of changes on the terrestrial biosphere, primarily through urbanization, industry and agriculture practices of the catchment. However, such changes on the hydrologic cycle are poorly understood. The catchment of Akaki, reflected on supply.

The purpose of this study is to show the causes of groundwater depletion Akaki well field, therefore, land use and land cover change on the subsurface portion of the hydrologic cycle by changing groundwater recharge. To analyses these changes in the catchment area and spatial pattern over the time, a set of satellite images were obtained for the years 2003, 2008 and 2013. Years LULC of the catchment especially vegetation cover and settlement, so the purpose of the current study was to evaluate the impact of LU/LC change on groundwater recharge of the Akaki well field. The study considers a range of LU/LC settings that includes a natural range land ecosystems, urban settlement area trends of these elements are presented in the following way.

## Chapter 4. Result and Discussions

### 4.1. Well monitoring data analysis

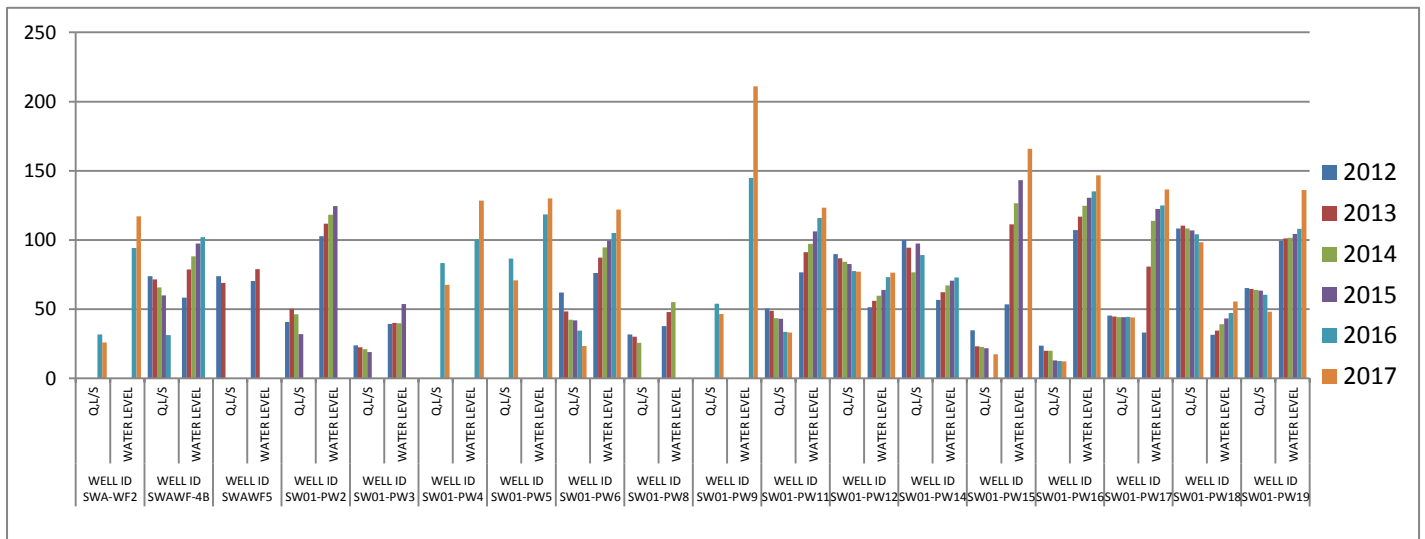
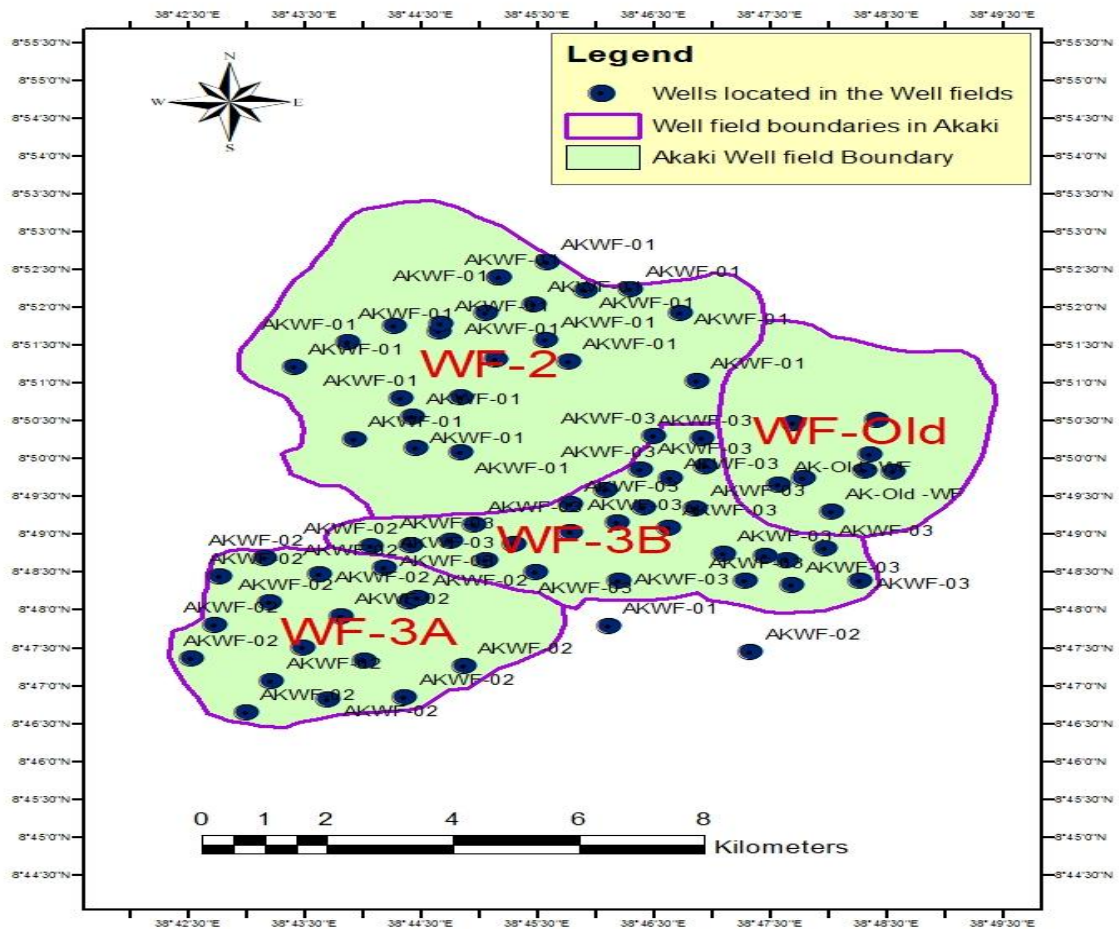


Figure 5: annual average discharge and water level for 18 Akaki well fields

This chart shows different year average discharge and water level taken from each well when monitored different consecutive years.

Weekly monitoring data for 18 deep wells of Akaki collected from Water Works Design and Supervision (WWDS) and Addis Ababa Water and Sewerage Authority (AAWSA) data like weekly static water level (SWL) and discharge (Q) collected in a soft Copy format, and in order to analyze easily those well monitored data changed to a yearly average as shown the above chart that yearly average water level and discharge monitored from above a year.



**Figure 6:** *Spatial distribution of Akaki groundwater wells*

The above (figure 6) shows that the spatial distribution of Akaki groundwater wells as shown on the above figure, this study concern the 18 well that includes WF-2 areas in the Akaki well field

And (figure 7) that show under are groundwater flow direction and ground water levels in the study area. As the student comprehend in this contour map ground water flow direction of the area to south.

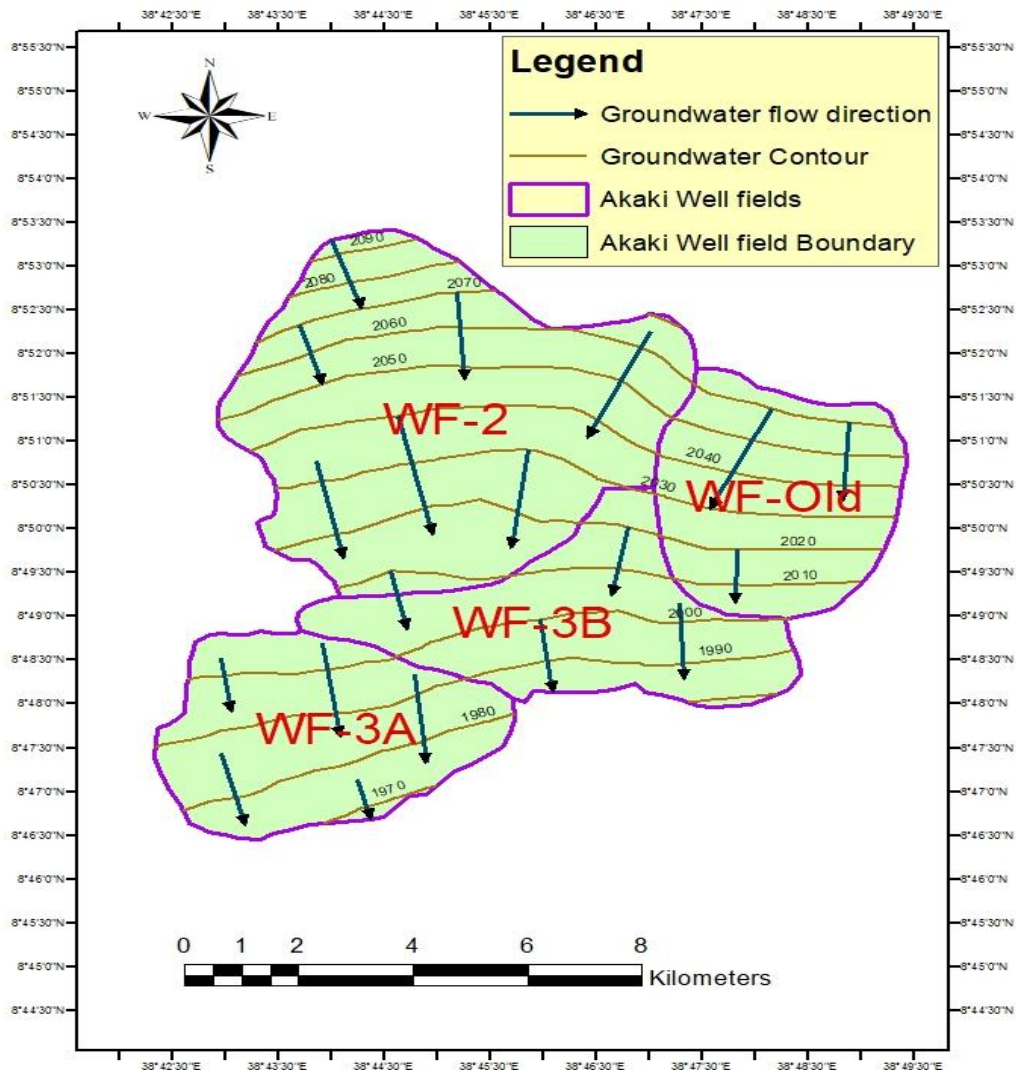


Figure 7: Groundwater level and flow direction map of the study area

Well id SWAWF2 located at a coordinate of UTM E475697 and N979915, and Point Elevation of 2062m.a.s.l. Drilled from 2008-2009.

During that time its static water level was 9.45m and its discharge was 54.45l/sec the depth of the well was 448m. After seven years later during 2016 and 2017 monitoring as shown above on (figure 5) the discharge (Q) going down the water level depth increasing down. When comparing to the discharge and water level recorded year 2009 and a year 2017 have had huge difference during 2017 the water level descended down to 117m the discharge going down to 25.9l/sec. The major water bearing rocks is fractured Basalt and Scorseous

basalts in addition to this, as water supervision description of drilling cuttings of SWAWF2 table 0-8m Reddish brown clay, 8-30 highly weathered and fractured basalt almost decomposed to the soil.

Well id SWAWF4B located at a coordinate of UTM E474204, N980459, and point elevation of 2077m.a.s.l. This well monitored for five consecutive years for seven days difference, but this chart shows year average discharge (Q) and water level the well has 21.23m static water level depth 250m. The major aquifer units at this site are Scoria, Scoraceous basalt and fractured vesicular basalt and the discharge was 62.5 l/Sec as well 38m depth from the top is clay. Drilling Construction & Pumping test operations were carried out from Jun 29, 2009-to-July 08, 2010 after two years later from 2012-2016 for four years monitored when the last monitoring taken in 2016 the water level going down to 101.95m and the discharge reduces to 31.2l/sec as shown above on (figure 5) so the discharge decreases when the water level depth increases down.

Well id SWAWF 5 also monitored for two years by seven days difference and (figure 5) shown above is year Average discharge and water level. The site is located at coordinates UTME 472779, UTMN 978788, and point Elevation 2183m. a. s. l. The well was drilled up to 486m and its static water level was 9.69m. and discharge was 90l/sec drilling carried out 2009 after three years later 2012 and 2013 this well monitored the discharge at this time Decreased from 90l/sec during 2009, reached 69l/sec during 2013 and the water level during 2013 decreased to 78.8m. The major aquifer at this site is Scoria, Scoraceous basalt and fractured basalts. Thick black cotton soil 0-10, black to dark with clay 10-48 and Friable light volcanic Tuff so these Shows there have been thick alluvial features of the well

Well id SWF01-PW2 This well monitored for four consecutive years for seven days difference, but the above chart (figure 6) shows year average discharge (Q) and water level to help us easily analyzed. Drilling, Construction & Pumping test operations were carried out from Jun 29, 2009-to-July 08. The total drilled depth is 250m below ground. The site is located at a coordinate of UTM E474204, N980459, and point elevation of 2077m.a.s.l. The well has 21.23m static water level. After drilling reached to the depth of 250m during the pumping test was conducted with 62.5 l/sec discharge. But during 2015 monitored data shows the water level amazingly descended down to 124.5m and the discharge decreases to 32l/sec. The major aquifer units at this site are Scoria, Scoraceous basalt and fractured

vesicular basalt. The depth from 0-22 unconsolidated black cotton and Friable light brownish clay.

Well id WF01-PW3 monitored for four consecutive years within seven day gap the chart (figure 6) shows changed yearly average discharge (Q) and water level. The site, located at a coordinate of UTME 474918, UTMN 980486 and at a point elevation of 2081 m.a.s.l. The well is drilled up to 481.6m and its static water level is 21.83m. Discharge is taken during pump test 28 l/Sec. Drilling operation was carried out from July 07, 2009-to-Dec 21, 2010 after to years later from 2012-2015 monitoring report the discharge rapidly decreases and the water level increases its depth down during 2015 records the water level decreases to 53.7m and the discharge reduces 18.9l/sec. Here again The major aquifer at this site is Scoria, Scoraceous basalt and fractured & weathered basalt and its unconsolidated top soil thickness reached up to 10m.

Well id WF01-PW4 This well also monitored per seven days difference for two consecutive years, but the researcher changed the data to yearly average in this study. The well site is located at a UTME: 475585 and UTMN: 9779580 with point elevation of 2061m.a.s.l. The well drilled up to 500m depth. During pump test the water level was 71.68m and the discharge of this wells 122 l/sec discharge after Drilling, Construction & Pump test operations were carried out from 26/12/2013 to 14/02/2014 monitoring starts after two years later 2016 and 2017 as the like other well its discharge decreases and the water level depth increasing down so during 2017 monitoring 128.4m water level and 67.7l/sec discharge recorded. The depth from 0-70m different clay types and the water bearing aquifer weathered scoracious basalt.

Well id WF01-PW5 this well show two consecutive years monitored data year average discharge (Q)and water level taken by seven days difference but for this study taken to yearly average ,the well located at UTME:470434 and UTMN: 979201 with point elevation of 2058 m.a.s.l. The well was drilled up to 510m when pumping test conducted 140 l/sec discharge recorded and static water level 110.48m. Drilling, Construction & Pump test operations were carried out from 03/08/2013 to 01/10/2013 after three years later 2016 and 2017 monitored this well This monitoring data shows that discharge decrease to 70.93 l/sec and water level depth increases down ward to 129.98m as shown on (figure 6) above. The most water bearing aquifer here was slightly weathered fractured basalt and from 0-60m Brownish clay.

Well id -WF01-PW6 This well monitored for six years from 2012-2017 within seven days difference and (figure 6) shows above changed yearly average discharge (Q) and water level. The site is located, at UTME: 472630, UTMN: 979912, and point elevation of 2096m.a.s.l. The well has a static water level of 8.35 meters. The well was drilled up to 600m when the pumping test was conducted the discharge was 78.78 l/Sec, the major aquifer systems for this well are Scoria and highly weathered & fractured Basalt and the well from 0-54m black cotton soil, salty clay and sandy clay. Drilling, Construction & Pump test operations were carried out from Jan 21, 2010-to-Oct 25, 2010 monitoring starts 2012-2017 this monitoring clearly put on the chart above indicates that the discharge going down to 23.5l/sec, and the water level depth is increasing down to 121.95m.

Well id WF01-PW8 The site is located at coordinates UTME 472779, UTMN 978788 and point elevation 2062m.a.s.l. The well was drilled up to 483.7m and its static water level is 17.5m. Pumping test was conducted with 50 l/s discharge but after some years latter the static water level descended down 55m and the discharge decreases to 25.7l/sec The major aquifer units at this site are Scoraceous basalt and fractured basalt and the well had been thick top soil and clay 0-8 and 8-36 consecutively, so the well WF01-PW8 Drilling, Construction & Pumping test operations were carried out from April 11, 2009-to-Feb 4, 2010 after two years latter monitoring study for three years from 2012-2014 the water level of this well depth increasing down and the discharge also decreases year to year ( figure 5) shows above is try to show this.

Well id WF01-PW9 This well has two years monitored data that had taken within seven days difference and the (figure 6) shows yearly average discharge (Q) and water level. The site located at UTME:470470 and UTMN: 979206 with point elevation of 2049m a.s.l. The well was drilled up to 514m when the pump test conducted the discharge records 70 l/s and the static water level 130m. But 2017 monitoring data the discharge decreases to 46.5l/sec and the water level goes down to 210.9m. Drilling, Construction & Pump test operations were carried out from 12/06/2012 to 16/08/2013 as shown he (figure 6) Monitoring yearly average data 2016 and 2017 are the discharge decreases and the water level deepen. The study analyses the well lithology in this well the major aquifer unit is Weathered scoracious basalt and it has thick Black to brownish clay the depth range reached 0-30m.

WELL id WF01-PW11 this well monitored for six years per seven day gap and the (fig 5) show year average discharge (Q) and water level. The site location is at UTME: 472245,

UTMN: 977865, and point elevation of 2048m.a.s.l. The well was drilled up to 500m and its static water level is 27.53m and the discharge when the pump test conducted was 62.15 l/sec. The major aquifer systems are Scoria, Scoriaeous basalt and fractured basalts and this study try to analyze how to contribute to deplete the water level this well from 0-4 Black cotton top soil, 4-34 Light colored friable clay, 34-42 Gravel with the clay, 42-72 Gravel with coarse sand and Ash. Drilling, Construction & Pumping test operations were carried out from Nov 02, 2009-to-Jun 21, 2010 after two years later from 2012-2017 monitored by wwds as shown (figure 6) Discharge decreases continuously and water level depth going deep down year to year, the discharge descended down to 33.2l/sec and the static water level decreases to 123.4m.

Well WF01-PW12 monitored for six years, starting from 2012-2017 per seven day gap and this data changed to yearly average discharge and water level as shown (figure 5) the site located at UTME: 471476, UTMN: 977396 and point elevation of 2048m.a.s.l. The well was drilled up to 480m and its static water level was 34.10m. When the pumping test conducted the discharge was 100 l/sec Drilling, Construction & Pumping Test operations were carried out from March 27, 2010-to-Nov 11, 2010 this well monitored by wwds from 2012-2017 for 6 years the discharge decreases continuously and water level increases its depth down, that the discharge decreases to 77.2l/sec and the water level go down to 76.4m. The major aquifer at this site is Scoria, weathered & fractured Scoriaeous basalt and fractured basalt. The top 38m of the well has been alluvium.

Well id WF01-PW14 The well monitored for five years from 2012-2016 weekly. The (figure 5) show yearly average discharge (Q) and water level this well located at UTME: 470778, UTMN: 976165, and point elevation of 2061m.a.s.l. The well has a static water level of 39.79 meters. The well was drilled up to 552m during pump test conducted the discharge recorded 76.32 l/sec. but after a years later the discharge decreases to 61.11/sec and the water level down to 73m. The major aquifer systems for this well are weathered, fractured Basalt and Scoriaeous Basalt. The top part of the well was 0-20 Black cotton Top soil Clayey soil (brownish color) consecutively Drilling, Construction & Pump test operations were carried out from April 14, 2010-to-April 13, 2011 after one years later the water works design and supervision enterprise starting monitoring five 5 years it's also shows clearly discharge going decrease and water level increasing its depth down.

Well id WF01-PW15 this well monitored for six years from 2012-2017 (figure 5) shows yearly average discharge and water level of the well this site located at UTME473944, UTMN978720. The well was drilled up to 492.1m and its static water level is 28.40m. Pumping test was conducted with 40 l/sec. discharge. The major aquifer units at this site are scoria, scoraceous and fractured basalts. this well top part from 0-40m depth contains Black cotton soil Silty clay consecutively. Drilling Construction & Pumping test operations were carried out from 24/02/10 to 24/11/10 and water works design and supervision enterprise (WWDSE) started monitoring from 2012-2017 for six years the monitoring data shows that on (fig 6) discharge decreases year to year and water level also increases its depth down so 2017 monitoring data shows the discharge decreases to 17.5l/sec and the water level goes down to 166m.

Well id WF01-PW16 The site is located at UTME: 473386, UTMN:980122, and point elevation of 2065m.a.s.l.The well was drilled up to 549.73 meter and its Static water level is 11.38 meter below ground level and its discharge 83 l/sec recording during water level conducted. The major aquifer systems are weathered & fractured Basalt and Scoracious Basalt. The top part of well lithology from 0-40 Black Cotton Top soil Brownish Silty clay. Drilling, Construction & Pump test operations were carried out from Oct 13, 2010-to-Feb 12, 2011 and after one years later WWDSE started monitoring this well for six consecutive years from 2012-2017. When monitoring the year 2017 the discharge goes down to 12.2 l/sec amazingly and the water level deepen to 146.64m

Well id WF01-PW17 the site located at UTME: 472460, UTMN: 981553, and point elevation of 2080m.a.s.l. This well is an Artesian well of an overflow discharge 21.5 l/sec and it was drilled up to 505m. When pumping test conducted the discharge was 48.75 l/s. The major aquifer systems at this site are weathered & fractured Basalt and Scoraceous basalt & fractured Trachyte. Top part of well was covered from 0- 4m black top soil, Drilling, Construction &

Pump test operations were carried out from Jun 20, 2010-to-May 13, 2011 one year after monitoring the well started so the monitoring data indicate that this well again like other well drastically decreases its discharge to 43.9l/sec and increasing its water level depth down to 136.4m.

Well id WF01-PW18 the site located at UTME: 471918, UTMN: 979657, and point elevation of 1969m.a.s.l. The well was drilled up to 272m. When the pumping test conducted the discharge was 140 l/s. The static water level 3.68m. Drilling, Construction & Pump test operations were carried out from Jun 09, 2011 to April 16, 2012 monitoring starts after months for six consecutive years, even the result that monitored 2017 the discharge decreases 98.3l/sec and the water level deepen 55.6m the same as the other and shows on the (figure 5). The major aquifer system is slightly weathered & fractured scoriaceous basalt. Top clay soil (brownish) ranges to 4m.

Well id WF01-PW19 located at UTM Zone: 37(Adindan) 47286 Easting, 971308 Northing. There was drilled to the final depth of 550 m. Static water level is 26.7 meters and the discharge was 71.5l/Sec. The major aquifer units penetrated by the well are well, moderately Fractured & weathered Basalt. And the top layer of the well from 0-4 was top dry clay soil Drilling & Construction & Pumping test operations were carried out from 13/07/11 to 24/11/1. And monitoring carried out from 2012-2017 all year result indicated for this study discharge continuously decreases with water level depth increases down. 2017 monitoring shows the discharge decreased to 48.1l/sec and the water level deepen down to 136.1m

## **4.2. Population growth as the causes of over exploitation**

Addis Ababa population growth one of the cause of this over exploitation Akaki well field ground water. The population is rapidly increasing, therefore municipality of the Addis Ababa City administration needs more water for the resident of the City. Due to inadequacy of the existing surface water, Akaki ground water gets into the City water system. Everyone needs water as it is a basic necessity; the city's government is headed by the mayor and the city council. The city is considered the safest in Ethiopia. In terms of the economy, Addis Ababa is very diverse. Trade and commerce are the most popular industries, followed by manufacturing and industry, homemaking, and civil administration. Tourism is a growing industry in the area as more shopping centers, restaurants and attractions are built (world review, 2019). The researcher does not forget here in addition to direct water use of industries virtual water uses too, increases water demand of the city.

Population in the near future is expected to grow to exceed 6.5 million residents. The annual growth rate of the city has been estimated in recent years to be 3.8%. In prior years, growth has been as much as 8%. The city is a thriving urban area in Ethiopia, and the jobs

available in Addis Ababa, the availability of clean drinking water and plumbing, and the many shops and businesses ensure that growth will continue to be steady in this capital city well into the future (world review, 2019).

### **4.3. Causes of Akaki groundwater depletion**

The first objective was to analyze the causes of ground water depletion in the Akaki well field. After analysis, the main causes of ground water depletion for the catchment were; over exploitation of ground water, geological /lithology of the well that can contribute incrustation, land use land cover change, precipitation variability, and temperature increment year to year.

The study shows that excessive exploitation of groundwater, population growth, vast settlement in the catchment, road and other construction, changes the groundwater hydrology of the study area. Akaki well field groundwater uses mainly for domestic purposes of the city of Addis Ababa in addition to surface water supply, but the population growth of the city and widening of the settlement every time and life style change, increases domestic water needs highly so, ground water extraction increasing highly. See below, (table 8), Addis Ababa Water and Sanitation Authority (AAWSA) THE New -CT wells daily report on the day 5/7/2011. Their planed and current extraction of water has been great difference some Akaki wells included in this report.

Table 2: the new -CT well daily report AAWSA 5/7/2011

I/M	Name of wells	Location / project name	Q in l/s	Production per m <sup>3</sup> /hr (Current)	Planned Working hours/day	Current Working hours/day	Planned Water Production /m <sup>3</sup> /day	Current Water Production /m <sup>3</sup> /day	Operating	Not operating	Unproduced water	Reason for in operation
1	SWAWF-2(PW2')	Akaki	32.28	116.208	22	24	2556.576	2788.992	√			
2	WF-01 PW-2	Akaki	25.19	90.684	22	24	1995.048	2176.416	√			
3	WF-01 PW-3	Akaki	10	36	22	24	792	0		√	2217.6	EM, Motor burnt.
4	SWAWF-4B	Akaki	35.19	126.684	22	24	2787.048	3040.416	√			
5	WF-01 PW-4(NEW)	Akaki	62.06	223.416	22	24	4915.152	5361.984	√			
6	SWAWF-5B	Akaki	72.11	259.596	22	22	5711.112	5711.112	√			GW, 2 hrs has been reduced to keep up the recovery time.
7	WF-01 PW-5(NEW)	Akaki	75	270	22	24	5940	6480	√			
8	WF-01 PW-6	Akaki	50	180	22	24	3960	4320	√			
9	WF-01 PW-8	Akaki	12.78	46.008	22	24	1012.176	1104.192	√			
10	WF-01 PW-9(NEW)	Akaki	50.78	182.808	22	24	4021.776	4387.392	√			
11	WF-01 PW-10/18	Akaki	101.19	364.284	22	22	8014.248	8014.248	√			GW, 2 hrs has been reduced to keep up the recovery time.
12	WF-01 PW-11	Akaki	50	180	22	22	3960	3960	√			GW, 2 hrs has been reduced to keep up the recovery time.
13	WF-01 PW-12	Akaki	65.58	236.088	22	24	5193.936	5666.112	√			
14	WF-01 PW-13	Akaki	19.44	69.984	22	22	1539.648	1539.648	√			GW, 2 hrs has been reduced to keep up the recovery time.
15	WF-01 PW-14	Akaki	68	244.8	22	24	5385.6	0		√	6019.2	Motor failure
16	WF-01 PW-15	Akaki	26.39	95.004	22	24	2090.088	2280.096	√			
17	WF-01 PW-16	Akaki	19.19	69.084	22	24	1519.848	1658.016	√			
18	WF-01 PW-17	Akaki	50.97	183.492	22	14	4036.824	2568.888	√			GW, 10 hrs has been reduced due to water level drop.
19	WF-01 PW-19											
(NEW)	Akaki	40.06	144.216		22	24	0		√		Motor failure	
20	WF-01 PW-20											
(NEW)	Akaki	6.94	24.984		22	24	599.616		√		EM, Motor failure	
	Total water production in m <sup>3</sup>						<u>69,153</u>	<u>61,657</u>			17,863	

So we can estimate how those well over exploited more than planned for one day monitoring only. And simple technical problem makes the well couldn't operate as we see (table 2) above, this type of technical failure aggravate the shortage of water supply of the catchment. The wells work 24 hours every day

#### 4.4. Overexploitation of Akaki groundwater

The well were included in this studies almost all from WF2 except stop operation due to motor failure and technical problem, pumping the water for 24 hours. Overexploitation of the groundwater resource leads to lowering of groundwater levels in the study area. Even the city not depend entirely on the groundwater resources for all, but; all water resources that are surface and ground water not able to adequately for the city water needs. In order to determine groundwater level decline, water level measurements were collected from 18 observation wells over the period 2012 to 2017 monitored by WWDSE so those monitored data result shows discharge and its water level decreases as the graph shown below.

Well id WF01-PW2, WF01-PW3, WF01-PW6 taken for this study to show how water level and discharge decreases their level the remaining monitored wells are decreasing the same pattern like these three wells

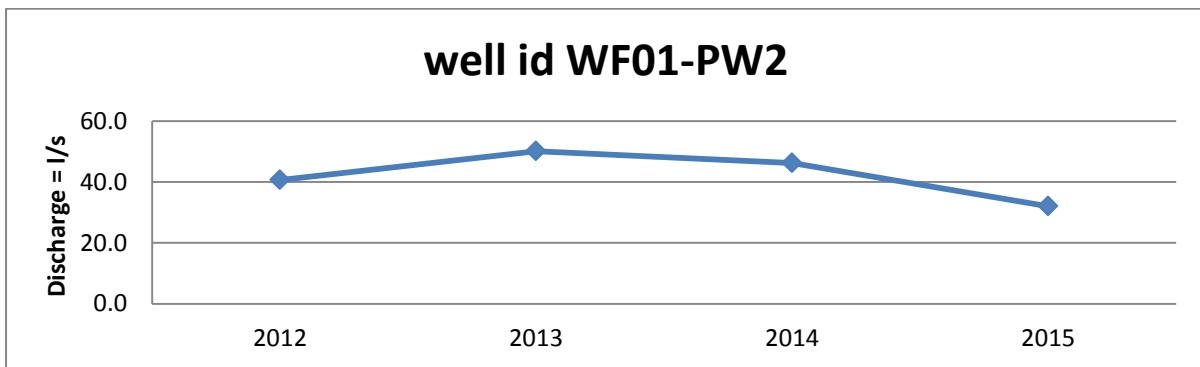


Figure 8: well id WF01-PW2 Q, l/s

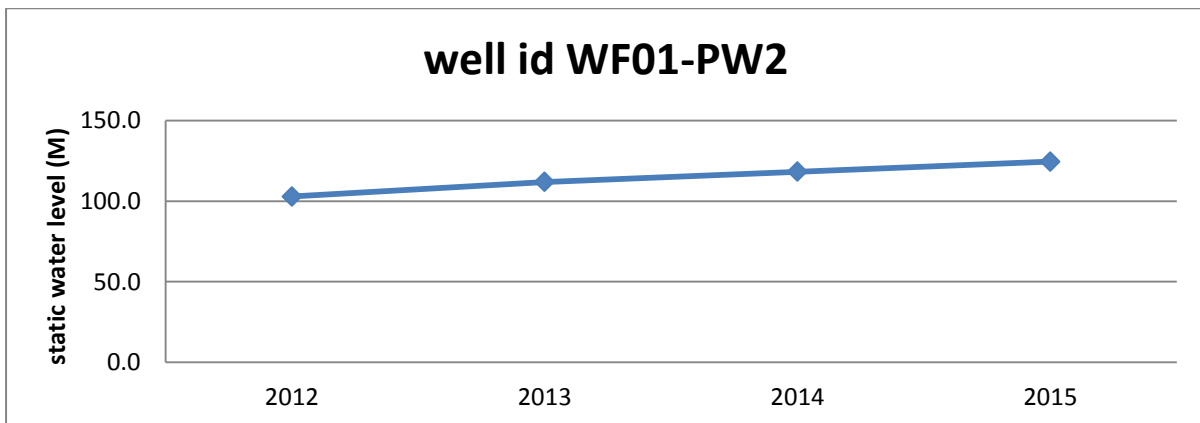


Figure 9: well id WF01-PW2 static water level

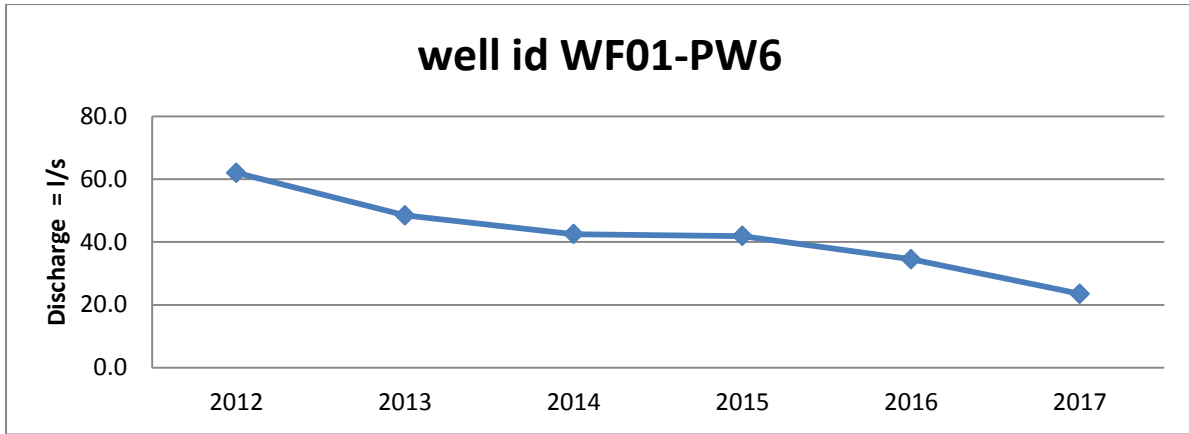


Figure 10: well id WF01-PW6 Q, l/s

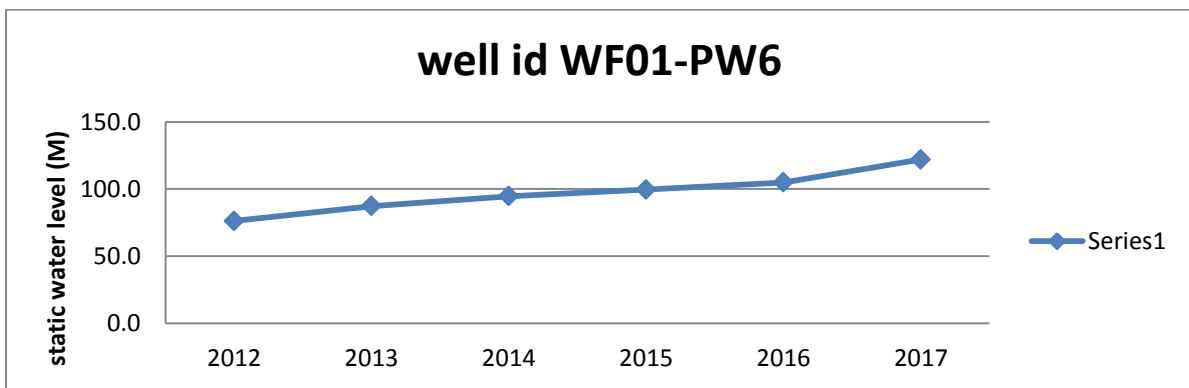


Figure 11: well id WF01-PW6 static water level

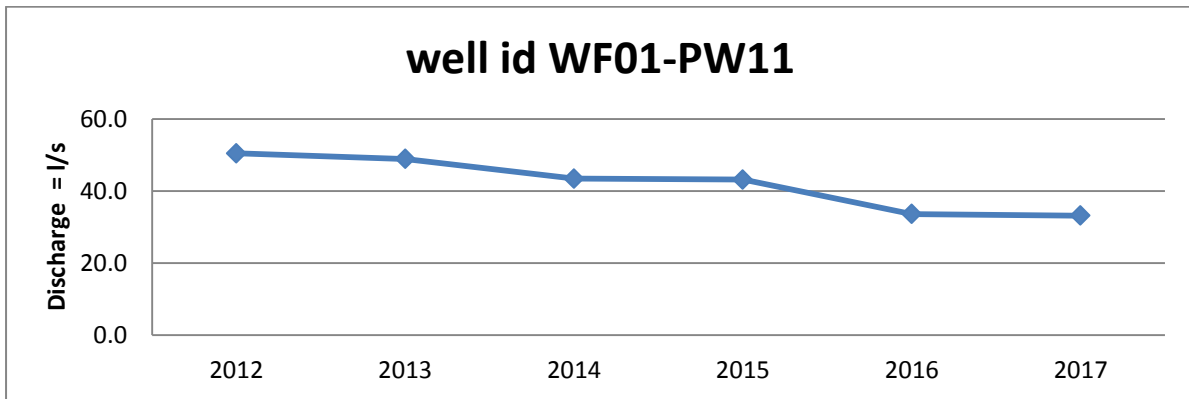


Figure 12: well id WF01-PW11Q, l/s

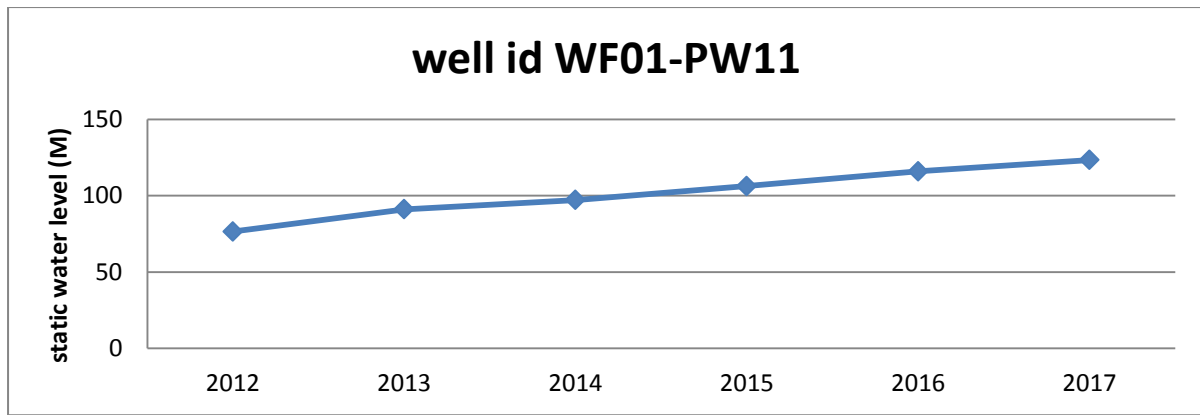


Figure 13: *well id WF01-PW14 static water level*



Figure 14: *well id WF01-PW2 discharge gauge station*

Those the above three figures can represent the other wells, including in this study because the declining water level and discharge has the same pattern in the monitoring years, see (fig 5) . Data taken weekly during monitoring, but for this study suitability the data changes the data yearly average therefore resultant of all the processes that act by increasing the decline in water level and the increase in over-exploitation and in Akaki catchment reported by many researchers

#### **4.5. City settlements and construction of roads causes of Akaki well field groundwater depletion.**

Municipal and institution in the city dig wells and bore wells and extract ground water. Due to concreting of most of the urban areas there is very less rain water percolating into the ground in urban areas.



Figure 15: *image taken near Akaki well fields*



Figure 16: *roads settlement and irrigated area near well fields*

The storm water drains take excess rain water into the river, instead of it getting into the ground. Less replenishment of ground water and more extraction results in deficit. As Addis Ababa road Authority 2013 report Addis Ababa road reached 70 percent and since 1997 Addis Ababa Housing Agency starting construct condominium and Roads around periphery of the city on cultivated land so more area covered by concrete houses and asphalt this duty continuing to this day, that's why this study estimate the situation, one of the causes of ground water depletion of Akaki well field because those road and building construction, that reduces water infiltration and aggravate runoff.

#### 4.6. Recharge area of Akaki catchment well fields

The study assesses again the ground water recharge area of the catchment by processing and comparing three years satellite image of land use land cover of the study area.

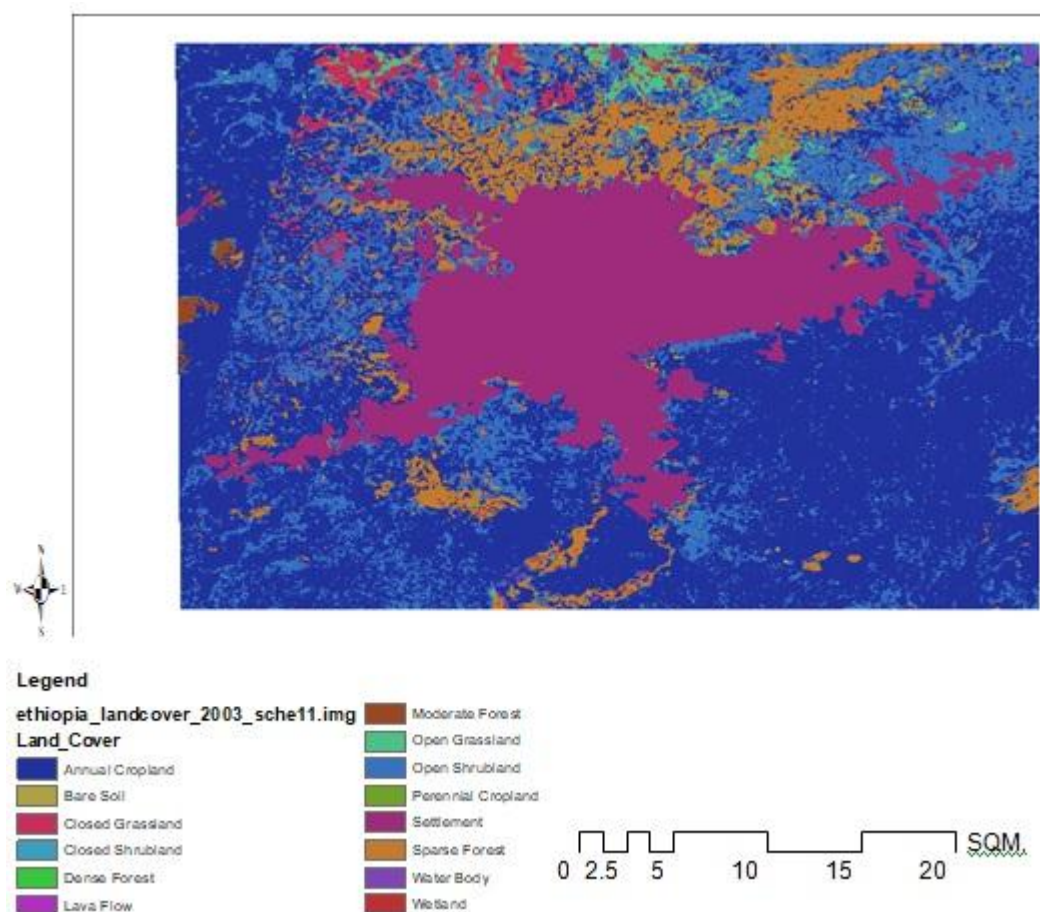


Figure 17: Land use Land cover Map of the study area

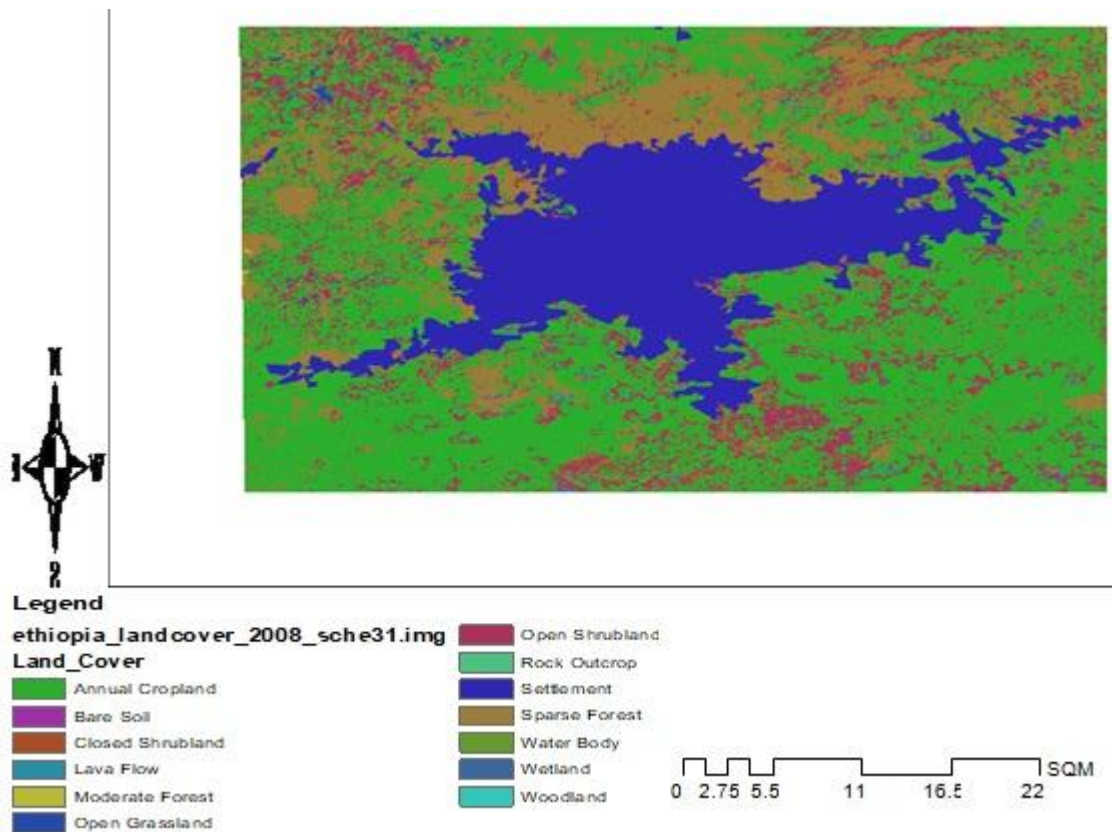


Figure 18: Land use Land cover Map of the study area (2008)

Settlement land and forest land change of Akaki catchment increasing and decreasing consecutively the major changes in the catchment. From the classified map of the 2003, 2008 and 2013, it has been observed that the aggregated area of forest land bush land and shrubby woodland has decreased so this study will show difference by a simple calculation of the area. This image 2008 combined with the next image 2013 again to identify the change.

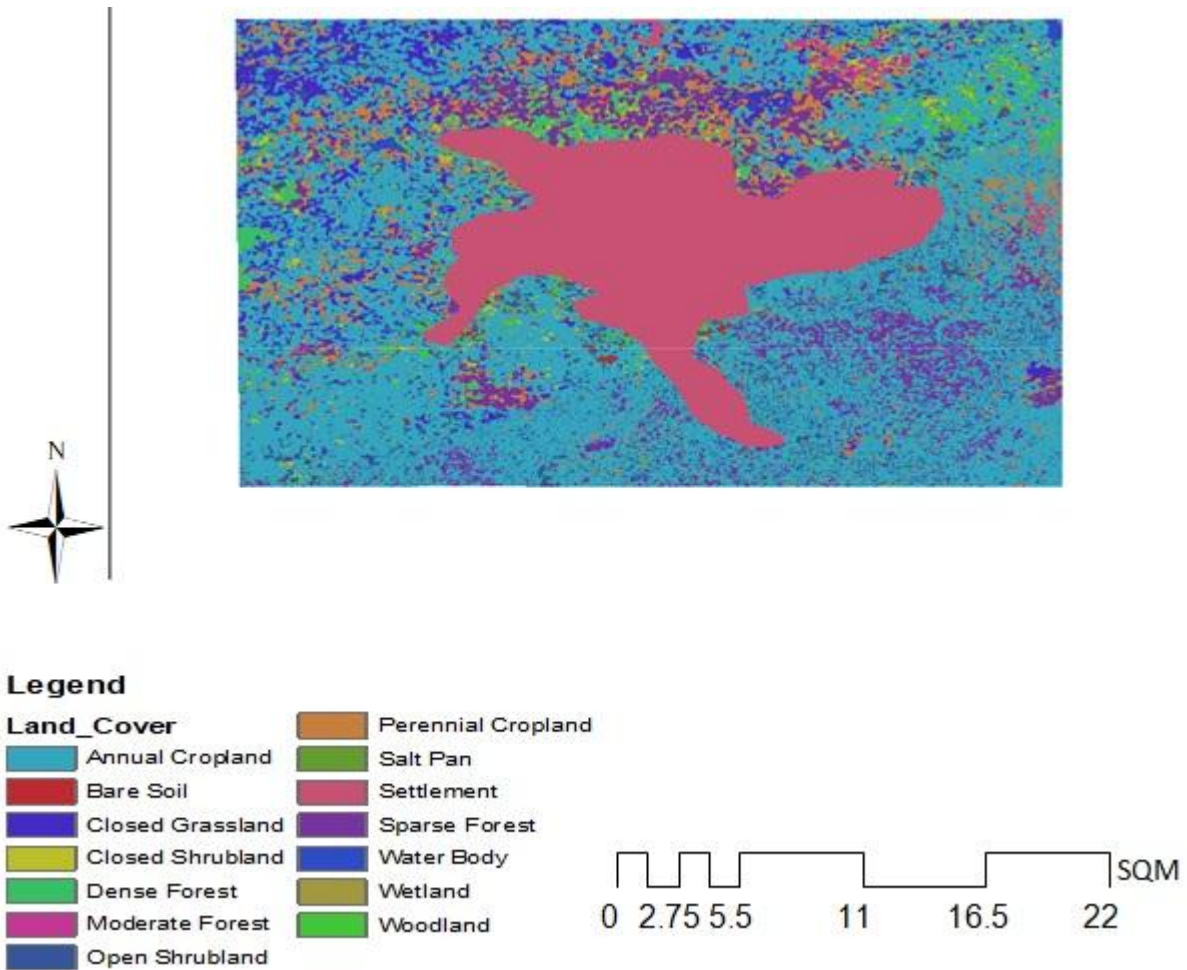


Figure 19: *Land use Land cover Map of the Study area (2011)*

Three tables below are Akaki catchment land use, land cover image 2003, 2008 and 2013 of the above satellite image. It's essential to show the images attribute table after merging and count the area, but before combining the images, that to clear the readers combined images attribute table where come from. The main purpose of these table is to show the change each land cover unique value after combined both images this study concern here mainly on settlement and forest changes of the catchment so see (table 6) the combined 2003 and 2008 image Attribute data

Table 3: Akaki catchment LC 2003 sche img

OID	Value	Land Cover	Red	Green	Blue	Opacity	LC_Code	Area_Ha	Count	area
1	2	Moderate Forest	0	0.68	0	1	2	2375683.11	4389	2375680
2	3	Sparse Forest	0	0.86	0	1	3	7509673.08	152277	7509670
3	5	Closed Grassland	0.8	0.8	0	1	31	852973.02	28484	852973
4	6	Open Grassland	1	1	0	1	32	14607482.67	31201	14607500
5	7	Closed Shrub land	0.62	0.32	0.17	1	33	10559189.61	3393	10559200
6	8	Open Shrub land	0.8	0.4	0.22	1	34	39808235.52	325580	39808200
7	9	Perennial Cropland	1	0.5	1	1	41	42933.78	68	42933.8
8	10	Annual Cropland	1	0.6	0.74	1	42	19609571.52	836899	19609600
9	11	Wetland	0	0.93	0.93	1	51	317228.49	3924	317229
10	12	Water Body	0	0	1	1	52	815571.27	2220	815571
11	13	Settlement	0.58	0.58	0.58	1	61	122303.88	331262	122304
12	14	Bare Soil	1	1	0.73	1	71	8297085.06	690	8297090
13	16	Lava Flow	1	0.79	0	1	73	210924.54	4	210925

Table 4: Akaki catchment LC2008 sche 31 img

OID	Value	Red	Green	Blue	Opacity	LC_Code	Land_Cover	Area_Ha	Count
1	3	0	0.86	0	1	3	Sparse Forest	9945305.46	300701
2	4	0.48	0.15	0	1	20	Woodland	1551480.57	6
3	6	1	1	0	1	32	Open Grassland	11879335.17	6292
4	7	0.62	0.32	0.17	1	33	Closed Shrubland	11359054.44	8691
5	8	0.8	0.4	0.22	1	34	Open Shrubland	40748302.17	209110
6	10	1	0.6	0.74	1	42	Annual Cropland	20880695.52	842223
7	11	0	0.93	0.93	1	51	Wetland	674518.05	2651
8	12	0	0	1	1	52	Water Body	812501.19	2704
9	13	0.9	0	0	1	61	Settlement	166268.34	334980
10	14	1	1	0.73	1	71	Bare Soil	9910807.92	4498
11	15	1	0.5	0	1	72	Rock Outcrop	5018873.49	19
12	16	1	0.79	0	1	73	Lava Flow	287901.63	8314

Table 5: Akaki Catchment LC 2013 Scheme Image

OID	Value	Land_Cover	Red	Green	Blue	Opacity	LC_Code	Area_Ha	Count
0	1	Dense Forest	0	0.588235	0	1	1	6827125.95	26870
1	2	Moderate Forest	0	0.682353	0	1	2	2728001.43	<b>9123</b>
2	3	Sparse Forest	0	0.862745	0	1	3	6600935.52	137813
3	4	Woodland	0.486275	0.156863	0	1	20	2405635.83	35297
4	5	Closed Grassland	0.803922	0.803922	0	1	31	6984824.76	127325
5	7	Closed Shrubland	0.627451	0.321569	0.176471	1	33	12231406.71	31247
6	8	Open Shrubland	0.803922	0.407843	0.223529	1	34	33860381.13	105584
7	9	Perennial Cropland	1	0.509804	1	1	41	4390663.5	129939
8	10	Annual Cropland	1	0.607843	0.745098	1	42	17002434.42	824514
9	11	Wetland	0	0.933333	0.933333	1	51	415619.91	1868
10	12	Water Body	0	0	1	1	52	811167.3	2325
11	13	Settlement	1	0	0	1	61	173778.12	320992
12	14	Bare Soil	1	1	0.737255	1	71	6235624.08	6512
13	17	Salt Pan	0.584314	0.784314	0.647059	1	74	317666.43	189

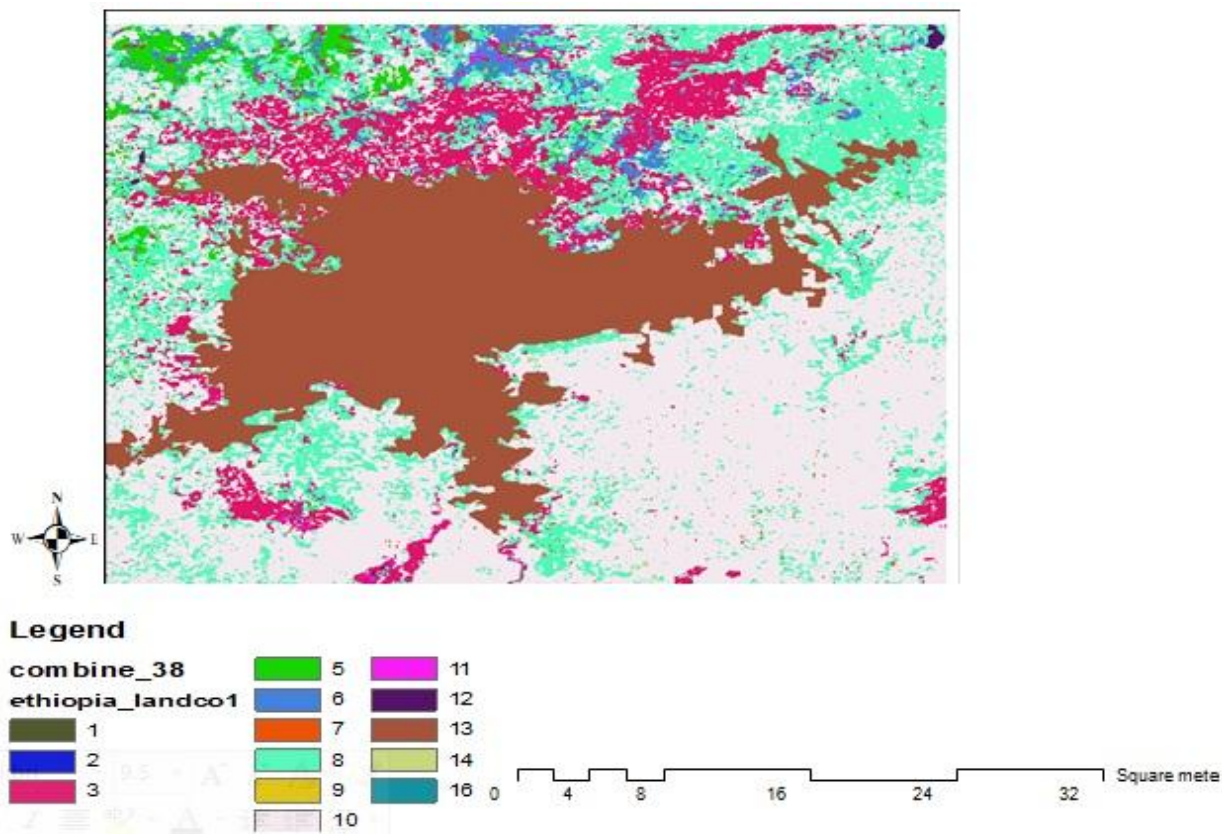


Figure 20: Combine Land use Land cover Map (2003-2008) of the study area

Table 6: combined land use land cover of 2003 and 2008

Row Labels	Column Labels	2	3	4	6	7	8	10	11	12	13	14	15	16	Grand Total
1			114					2		1					117
2		217	3980				20	168			4				4389
3		14	111772		12	682	14075	22688	1334	50	786	348	1	515	152277
5			5819		1330	190	5231	15081	13	34	31	469		286	28484
6			13009		331	106	1916	15489	6		52	87	2	203	31201
7			778			85	585	1915	8		6	13		3	3393
8		33	61827	6	2113	2450	57633	194002	182	1156	2287	876	2	3013	325580
9							24	44							68
10		55	100813		2501	4918	128066	589658	1087	325	2824	2547	14	4091	836899
11			1826			67	415	1437	19		16	7		137	3924
12			59			176	445	297	1	1137	2	70		33	2220
13			697			5	359	1171	1		328970	26		33	331262
14			7		5	12	341	268			2	55			690
16								3		1					4
Grand Total		319	300701	6	6292	8691	209110	842223	2651	2704	334980	4498	19	8314	1720508

Here in the above (table 6) the horizontal row represents 2003 and the column represents 2008 and subtract from 2008 values land cover to 2003 so have got the difference the area, there for; this study concern is to show how the settlement of the catchment widen year to year and misuse the ground water hydrology of the catchment. As shown in (table 6) number 13 is represent settlement so, we will subtract from column 13 to row 13 totals.

$334,980\text{ha} - 331,262\text{ ha} = 3,718\text{ha}$  so during 2008 settlement increased 3,718ha(1.12%) increasing within 5 year difference this indicates that dense forest, shrub lands and sparse forests cultivated land included into the settlement area of the catchment .

And we can compare the next combined image 2008 and 2013 (table7) that can shows how much shrub lands, forest lands and cultivated lands included within 5 years difference.

We again subtracted the column number 13 total and the row number13 total and we get the difference because the row represents 2008 and the column represent 2013.

$334970\text{ ha}, -313807\text{ ha} = 21,163\text{ha}$  here this catchment loose forests and cultivated land, but, in contrary replaces to settlement land 21,163 ha (6.32%), therefore; this study trying to show land use land cover change, how can be able to the causes of akaki well field ground water depletion thus we can understand easily this change of land use land cover affects this catchment ground water hydrology and. Not only settlement widening of the catchment but also drastically negatively changed the catchment wetlands as we have seen on this combined image. Combined attribute table of combined image 2003 and 2008 on (table 7) shows the wetland during 2003 the area reached 3924 ha after five years latter 2008 reduce to 2651 ha, thus this catchment loose wetland 1273 ha (32%) within 5 years.

And then when come to the combined image of 2008 and 2013 loose more wet lands amazingly almost none again see (table 7) in 2008 the catchment had 2651ha wet lands but after five years later in 2013 image shows as the remaining wet lands in the catchment only 2 ha (0.08%) so the catchment loose 2649 ha(99.92%) within five years. The study understands from wet lands disappearance the catchment ground water is declining under water table.

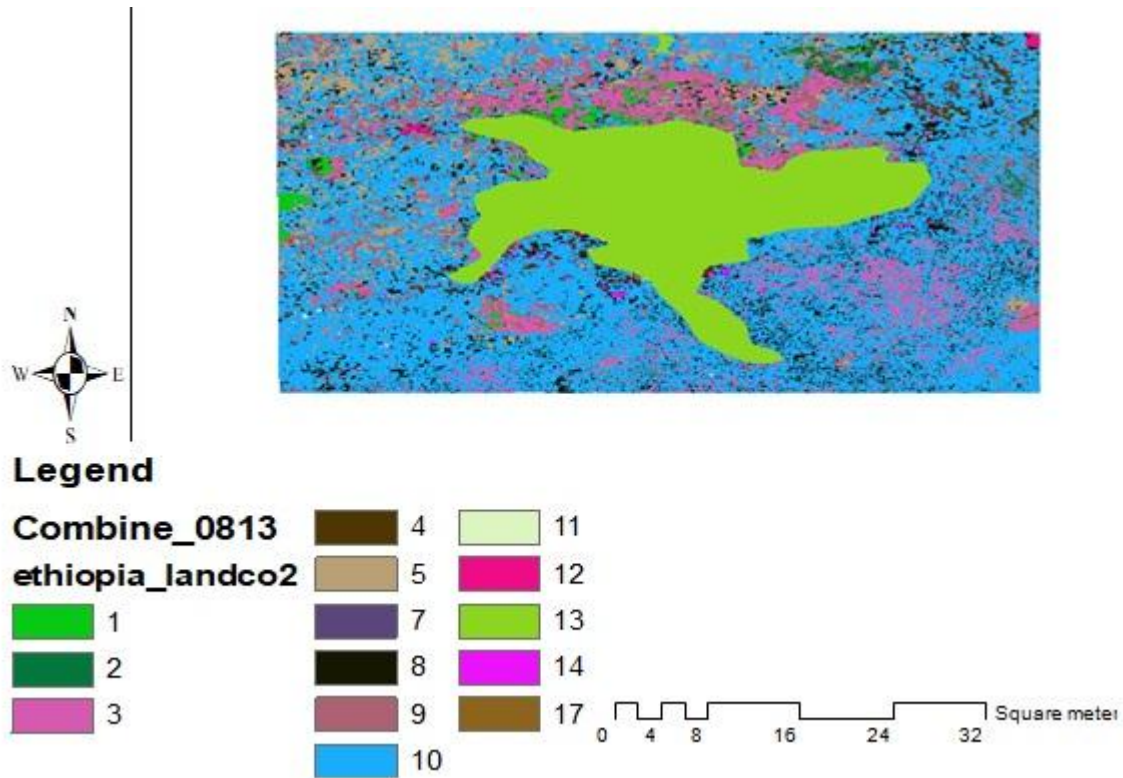


Figure 21: Combined Land use Land cover Map (2008-2013) of the study area

Table 7: combined land use land cover of 2008 and 2013 attribute data

Sum of Count	Column Labels														Grand Total
Row Labels	1	2	3	4	5	7	8	9	10	11	12	13	14	17	Grand Total
2	281		14		4			11	9						319
3	22445	5823	61669	7128	27150	13783	6037	59880	85516	200	64	10864	102		300661
4					2			2	2						6
6			17	5	3507	20	52	408	2264			19			6292
7	18	8	614	310	241	75	1149	316	5096	3		747	114		8691
8	1683	916	10333	6035	22005	4284	17408	14687	119587	99	174	11135	674	43	209063
10	1332	2170	58019	13439	69054	9692	65809	46753	542295	795	112	29860	2575	143	842048
11	82	3	1248	19	59	35	70	477	582	1		75			2651
12	6		21	2	51	8	271	46	335	4	1950		10		2704
13	379		2760	7372	1191	2515	10961	3755	42306	724		260211	2796		313807
14	4		77	47	687	23	881	169	2032	5	2	491	80		4498
15							3	2	13			1			19
16	4	24	178	169	402	138	615	509	5847	2		404	19	3	8314
Grand Total	26234	8944	134950	34526	124353	30573	103256	127015	805884	1833	2302	334970	6370	189	1720236

Finally the study want informed to the readers that the entire combined image done by using arc GIS 10.3 software opening the tool analysis using different tools that helps combine the image

#### 4.7. Encrustations due to thick alluvial and basaltic litology of the Akaki well field

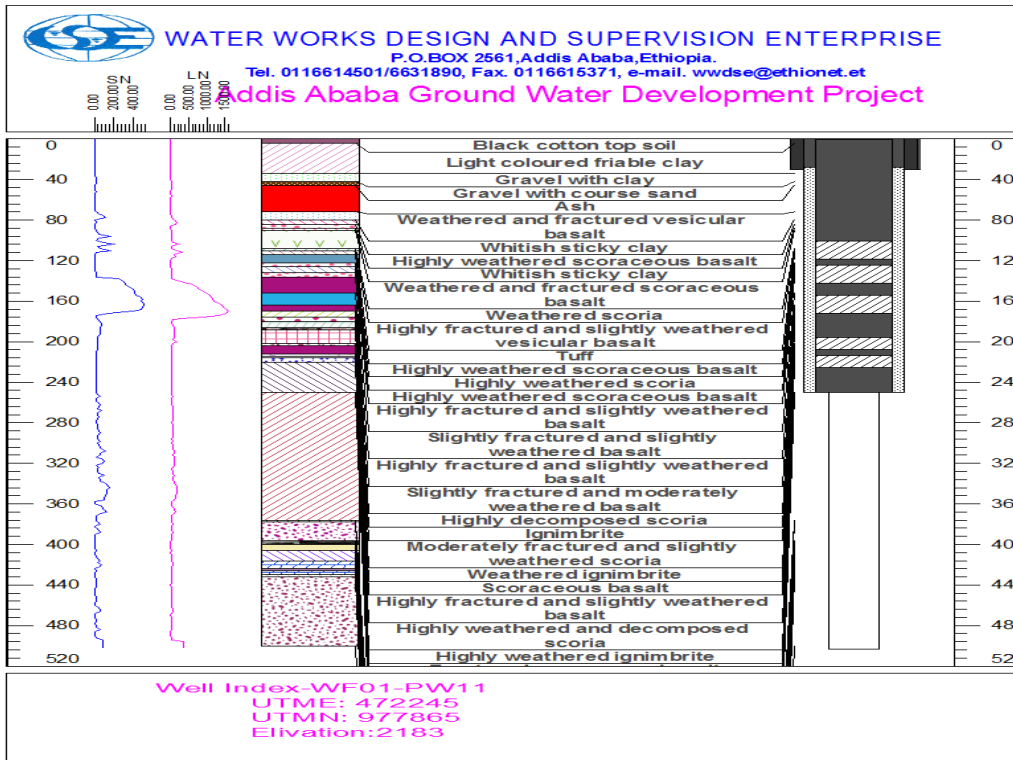


Figure 22: geological logging well id WF 01-pw11

The above fig 22 as an example of the other remaining wells, thick alluvial coating reached 72 meters and more basaltic feature in the lithology so this alluvial sediment, silicate grains (clay and sand), drawn in form the alluvial matrix through the screen slots and The oxidation of iron dissolved in groundwater and subsequent precipitation of the oxidation products on the screens and discharge pipes of water wells that tap aquifers leads to the formation of well encrustations (Brankica, 2015). Dissolved iron may clog the aquifer that is why this study believed encrustation one of the causes of depletion in addition to the other main causes.

## 4.8. Ground water depletion Impacts on the catchment water supply

### 4.8.1. Economic influence of water shortage on the people

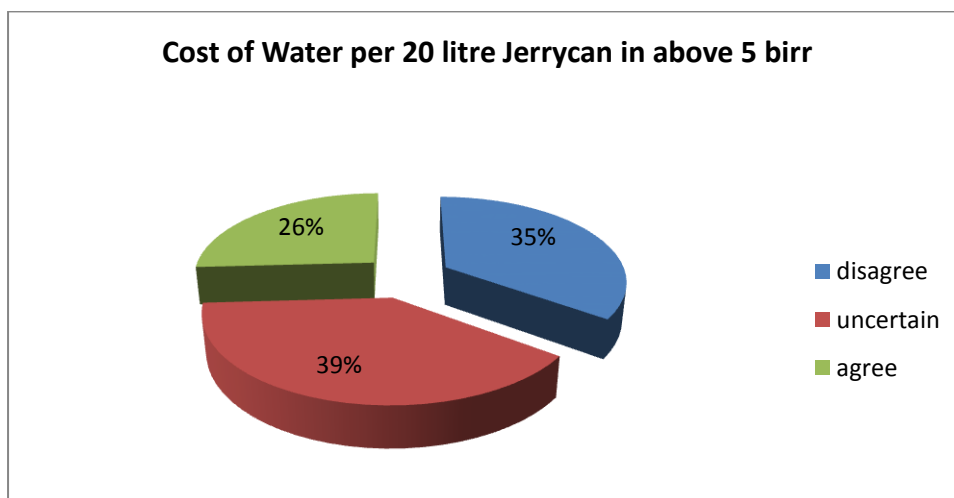
As a result of increase population and the consequent demand for water, creating a shortage of water, that's why this study estimates the purchasing water when the water disappear other place. Purchasing water is an additional expenditure of the people. (Table 8) shows under is may the people

Table 8: *responses about purchasing water other places*

Variables	Disagree of respondent	Frequency	Percent
Purchase water other place when water disappears in your area			
	Disagree	12	8.4
	Uncertain	12	8.4
	Agree	119	83.2

From the table 8: above, 83.2% they agree that Purchase water other place when water disappear, 8.4% respondent show uncertainty and 8.4% respondent said disagree, but still the respondent those are agree are above 75% of the sample size

Figure 23: *response about purchasing cost of water*



From the figure 23 above, 26% of the respondents agreed that they spend 5 bears per 20 liter Jerrycan water, when the water, terminate longer time 39% they did not sure most of the respondents here was male and 35%. Respondents did not agree they may agree below 5birr this implies that most of the households spent money on water depending on the members of the family

Table 9: *responses about distance travel finding water*

Variables	Disagree of respondent	Frequency	Percent
At least a kilo meter you and your family travel to purchase water	Disagree	6	4.2
	Uncertain	37	25.9
	Agree	100	69.9

In table 9 above 69.9% of respondents said agree that they travel finding water when their own pipe water disappear, 25.9% of respondents said uncertain they show uncertainty and 4.2% of the respondents disagree.

As a result of a dramatic increase in population and the consequent demand for water, the government anticipates utilizing local groundwater sources (the Akaki well fields) situated in the vicinity. However, unless strict measures are soon undertaken to improve surface water quality, seepage from the polluted rivers and runoff will ultimately affect the groundwater, which is an alternative potential for supplying clean water in the region. In fact currently the pollution of surface and groundwater is one of the most serious problems affecting the health of the population in and around Addis Ababa According to key informant's poor sanitation because of shortage of potable water and generally poor living conditions. Tamiru (2004). Indicated that diarrhoea in particular was found to be the leading cause of morbidity. According to Fisseha, (2002) Study the observed level of iron were also high enough to raise serious Concern.

Table 10: *responses about sanitation problem*

Variables	Disagree of respondent	Frequency	Percent
There is a sanitation problem because of water shortage	Disagree	18	12.6
	Uncertain	25	17.5
	Agree	100	69.9

In the above (table 10) 69.9% of respondent agree that there are sanitation problem and related diseases, 17.5% of the respondent shows uncertainty and 12.6% of respondent said disagree

Table 11: *responses about lack of sanitation, health problem*

Variables	Disagree of respondent	Frequency	Percent
There is a health problem because of lack of sanitation	Strongly disagree	7	4.9
	Disagree	21	14.7
	Uncertain	16	11.2
	Agree	99	69.2

In the above (table 11) 69.2% of the respondent Agree that there is a health problem because of lack of sanitation and polluted water, 14.7% of the respondent said disagree and 14.7% of the respondent shows uncertainty and 4.9% of the respondent strongly disagree those said disagree and strongly disagree family put water tanker on their home roof.

There are only a few studies that focus on the socioeconomic aspects of the pollution of the Akaki Rivers and depletion of ground water Akaki well field. However, many studies have been conducted on urban poverty and its impacts in the Addis Ababa area. Most of these studies indicate that the most major health complications in the area are related to the lack of clean water. According to the Ethiopian science and technology (2005). Although estimates are not available, in Ethiopia, where government health services are subsidizing the consequent cost incurred by the government due to easily preventable water related diseases is anticipated to be tremendous. As we understand after interviewed the people

where lives Akaki kality sub city worda 01 Water shortage some household member's west their time and money during finding water and purchasing, in addition to this hygiene problem as indicating above one of the causes of health problem.

**4.9. The measures taken by the stakeholders about ground water sustainable use.**

The table below illustrates what is the sample respondent perceive about the activity of different stakeholder, those private and government sectors done to alleviate water shortage

Table 12: *perception of sample respondent about the stakeholder movement to alleviate the water shortage problem*

Variables	Disagree of respondent	Frequency	Percent
There is movement different stakeholders to alleviate the problem	Strongly disagree	6	4.2
	Disagree	61	42.7
	Uncertain	52	36.4
	Agree	24	16.8

In (table 12) 42.7% of the respondent said disagree, 36.4% of the respondent Shows uncertainty, 16% of the respondent said agree that there is a movement to alleviate water shortage problem and creation of awareness and 4.2% of the respondent said disagree. Here many of the respondents said disagree and uncertain this answer comes from lack of information or lack of transparency of government and private sectors.

But the study understand from the interview of water sector professionals there are a large number of organizations who activities have an attitude on the sustainable use of groundwater from both regulation, abstraction, recharge and quality point of view (ministry of water resources, 2011).

It is encouraging that groundwater has already moved into the territory of land use planning – opening the extent to manage groundwater beyond the water field, yet there is no organization that masterminds the management or development of groundwater.

At the federal level the main stakeholders are the Ministry of Water Resources, the Federal Environmental Protection Agency, the Ministry of Mines and Energy - in particular the Ethiopian Geological Survey, the ministry of Agriculture (as it concerns land use), the Ministry of Urban Planning and Ministry of Health and in the private sector the Drillers' Association. At regional level the stakeholders are the Oromia Water Resources Bureau, the Addis Ababa Water Supply and Sanitation Authority, the Addis Ababa Environmental Protection Agency, the Oromia Land and Environmental Protection Bureau, Housing Bureaus and Regional Urban Bureaus apart from private sector service providers and users. The activities of all organizations have a bearing on groundwater use and management. Roles should be clarified between federal/regional organizations and between regional organizations as well as the mechanism to coordinate the different interests. Is a proposal for a better definition of roles at national level? The same should be done in the Addis Ababa area.

Several of the organizations mentioned above undertake activities that have a bearing on sustainable groundwater management, but so far have no explicit program in the field is the Practical Framework for Managed Groundwater Development for the Addis Ababa region ( Ministry of water resource, 2011)

In spite of the importance of groundwater now and in the future, institutions in managing ground water are weak in the Addis Ababa Region. This is a point of concern as one would expect in the country Addis Ababa to be a front runner in this field. Even though Monitoring of water levels or water quality is taking place at the moment WWDSE, their data not collected properly. The regulatory framework arrangement concerns mainly well licensing by EPA and the OWRB. The capacity of the EPA in this respect is very limited and in fact the wells that are licensed are the ones developed by AAWSA. With a few exceptions privately developed wells are 'out of sight' A more intensive use of groundwater would require a commensurate development of groundwater management institutions. ( Ministry of water resource, 2011)

Below the approaches in terms of policy adjustments, regulatory provisions and stakeholder engagement are described, as well as the groundwater quality measures and the supply and demand measures and . This leads to priority actions that are described in the next section.

#### 4.9.1. Policy adjustments

The table below shows the sample respondents' perception about the policy that, is there any law enforcement to minimize scarcity of water supply

Table 13: *perception of sample respondents about water use in law enforcement*

Variables	Disagree of respondent	Frequency	Percent
To minimize scarcity of water supply tougher law enforcement	Strongly disagree	51	35.7
	Disagree	55	38.5
	Uncertain	31	21.7
	Strongly agree	6	4.2

In the above ( table 13) 38.5% of the respondent is disagree, 35.7% of the respondent said strongly disagree, 21.7% of the respondent shows uncertainty and 4.2 of the respondents is strongly agree those people said strongly agree have information from governmental water sectors.

If most of sample respondents disagree and uncertain this indicates, for this study there is how much ignorance on the water sectors to be transparent to the people, give the information what the Gov't and other sectors what to do. As the study, comprehend the interview of water sectors professionals said there is collaboration between Addis Ababa and Oromia An encouraging development is the cooperation between Addis Ababa and Oromia Regional State with respect to land use planning and regional development. Cooperation between Oromia Regional, State and the Addis Ababa Administration needs to be further elaborated, since the aquifer is shared between the two regions. The Oromia

Special Zone Surrounding Addis Ababa consists of six woredas surrounding Addis Ababa (Ministry of water resource, 2011)

Part of the land use planning is the preparation of a Green Belt. The Special Zone constitutes a large part of the recharge area for the shallow aquifer. Cooperation between the Addis Ababa Administration and the Oromia Special Zone Administration should be intensified to include the management of surface and groundwater.

#### **4.9.2. Connecting land use plans and groundwater management**

Land use plans are being prepared and near completion of the Oromia Special Zone. In the land use plan prime land is allocated for agriculture and horticulture, whereas land that is less suitable is allocated to industry, housing, quarrying and others. The development of new heavy industry is planned in the South East of the Special Zone, away from the shallow aquifer recharge area. Environmental protection zones are planned around the urban centres, stretching for 3-5 kilometres. Along with perennial and intermittent streams and around reservoirs buffer strips of 50 to 100 meters have been designated. The land use planning could be further expanded to include managing recharge retaining runoff in recharge zones, dovetailing road design and urban design with recharge (Ministry of water resource, 2011).

#### **4.9.3. Policy for the role of private sectors**

As described in the National Framework, where groundwater has taken off it has been through private sector Investment and services. This requires both a facilitating environment and a regulatory regime. There needs to a clear vision on how to engage the private sector in groundwater development and management in the Addis Ababa region, including: Clarity on regulatory procedures, opportunities to develop the private sector role and capacity in drilling, well operation, monitoring fulfillment and communication.

#### **4.9.4. Support for regulation**

The reverse side to enlarged private sector involvement is better regulation. Currently, regulation is weak and has no priority, as is clear to the meager manpower dedicated to it, the logistical means and the political support for enforcement. If groundwater use is to intensify and extent to agree-economic use, regulatory activities need to be better resourced

both in Addis Ababa and in Oromia. This should start by enforcing the regulations that are thereby making the minimum required resources to do so available.

#### **4.9.5. Regulatory stipulation**

Enhancing monitoring capacity: Monitoring even on the Akaki well field is nonexistent up to 2011. Basic information on groundwater levels or total number of functioning wells for instance has not been recorded, making it difficult to make an assessment of the sustainability of groundwater extraction by AAWSA and by other groundwater users during 2011.

But starting from 2012 Water Works Design and Supervision Enterprise (WWDSE) starting monitoring akaki well field it is proposed to develop the monitoring and management of the Akaki well field also to set an example nationally. And AAWSA already has a field unit that records abstraction and sees to it that the estimated safe yield is not exceeded.

Recording water table depths and water quality should be added to its workload. A monitoring plan for the Addis Ababa region should be developed and implemented.

Guidelines for well development It is proposed to develop national well drilling guidelines and the Ministry of Water Resources has made a start of this the urgency of these guidelines is particularly high in the Addis Ababa region where intense exploratory and exploitation drilling is taking place ( Ministry of water resource, 2011).

In the drilling of the test wells a large variation in quality and techniques is observed. The well drilling guidelines would help to set quality standards in well development and to protect the well drilling sector against unfounded complaints. The well drilling guidelines should make use of standardized, well designs – in the case of Addis Ababa in particular the diameter of the wells should be revisited, as the wells that are currently drilled are over dimensioned which add to the cost.

## **Chapter 5: CONCLUSIONS AND RECOMMENDATIONS**

### **5.1. Conclusions**

The aim of the study is to identify the causes of Aakaki well field ground water depletion and impacts on water supplies in the catchment and recommend sustainable use of ground water uses that improves the socioeconomic and the livelihood of the communities. Accordingly, this research identified the core causes and impacts of the depletion of water in Akaki well field that is mainly related to anthropogenic factors, which seriously exacerbate the scarcity or lack of ground water resources.

Water scarcity means lack of sufficient available fresh water resources required to meet water demands. Shortage of water affects the community, environment and overall ecosystems. During the process of this research work, the researcher has identified three major factors essential to be addressed in improving the quality and quantity of the ground water wells that incorporates (1) identification of causes of ground water depletion, (2) assessment of well field impacts on water supply systems, and (3) integrating measures required and to be taken by concerned institutions and stakeholders.

In implementing objective 1 of the research "to assess the causes of natural and anthropogenic factors that contributes to the depletion of ground water" the data analysis of the study indicates that the ground water monitoring shows there is a significant declining of ground water resources in the near future; and this requires immediate action to reinstate the normal situation. Over-pumping of groundwater speeds up in reducing the groundwater level in the catchment. The data collected indicates excessive pumping of well fields are causing a shortage of water supply in the Akaki catchment.

Based on this result, it is highly recommendable to protect the remaining patches of vegetation and apply both physical and biological conservation measures to reclaim the degraded areas.

If conditions go like going to decline as we see on, despite the continuous decline in ground water level, no proper system of water conservation has been developed in the country. Every year, billions of cubic meters of rain water go waste. According to groundwater experts, given the pace water is being exploited in the country, the level of ground water will go further down in the coming years.

Satellite based land use, land cover image of the years 2003, 2008 and 2013 shows a high level of deforestation in the catchments such as clearing of the forest land by cutting the trees and shrubs, and also converting it into a commercial or a residential land, which has an adverse effect both on the water table. There is on-going forests, transport in the catchment that reduces water into the atmosphere via plant transpiration. As the deforestation occurs, there is will be inadequate amounts of precipitation in the area affecting the flow of rivers, and also reduces the infiltration of water into the ground.

Based on GIS based LULC analysis of the study, it can be concluded that Akaki catchment had experienced a significant change in land use and land cover over the past three decades. The two main causes of depletion of the water table are deforestation and over-pumping of groundwater. Secondly, even precipitation and temperature related factors can be considered as the causes of the depletion problem. In addition, rapid conversions of forest, grassland and cultivated land covers into urban settlement are among the main factors that increases the problem.

In application of objective 2 of the research "to evaluate the impacts of ground water depletion on water supply systems" the identified impact was manifested by partial or no satisfaction of expressed demand, economic competition for water quantity or quality, disputes between users, this has socially affected the members of the community irreversible depletion of groundwater, and negative impacts on the environment.

Socioeconomic impacts; intermittent water supply he studies established that a lot of time was spent to collect water mostly by women and children from the sources in terms of distance travelled and queuing to fetch the water. This has negatively affected the development in the area since time meant for other activities is spent to acquire water. There was also water borne diseases due to reduced availability of water. This has affected the health of the individuals and a lot of finances used in the treatment would have been used for development. There were also conflicts related to water.. In the study, females are the most affected members of the community in water collection activities since they are involved in home household tasks. This negatively affects them since they have few chances for decision making and involvement in other development activities.

Optimistic for employment opportunity to people selling water at the private water points and seller; water point owners make a profit from the water sale income generation

In achieving objective 3 of the research " to examine the necessary measures to be taken by the key stakeholders in the catchment" the study identified that strengthening the capacity of the core stakeholders in the catchment that includes governmental, non-governmental, water user communities and private sectors. Moreover, implementation of appropriate use of enforcing mechanisms on water management and conservation, integrated and participatory approaches are among some of the identified findings.

Among main measures outlined in the study, community involvement should be ensured in the fight against ground water pollution through public awareness and capacity building campaign.

Through the implementation of water conservation structures with appropriate designs to offset the ground water resources of the country, efforts should be made to preserve the ground water by restricting the waterfalls in mountainous areas and restricting the indiscriminate construction of bore wells. In order to meet current and estimated water shortages in relation to Demand are more than supply more and more people dig wells and bore wells and extract ground water, climate change strategies should include ground water management

Due to increased demand of water as the population is increasing day by day. And also due to global warming, which increases the temperature and in turn water level goes down. Also, we do misuse of water and do not conserve it, that's why all this happens. And in addition to this due to concreting of most of the urban areas there is very less rain water percolating into the ground in urban areas. The storm water drains take the excess rain water into the sea, instead of it getting into the ground.

In Ethiopia and many developing countries, water is considered as the most important and the biggest natural resources that improves the socioeconomic dynamics and ensures sustainable development of the country that requires due attention by all stakeholders.

## **5.2. Recommendations**

Considering the findings of this research on assessments of causes of groundwater depletion in the Akaki well field and its impact on the catchment water supply, the following recommendations are suggested for sustainability of the groundwater supply resources in the catchment.

- Efficient permit system and management

Water in the Akaki well field is vital for drinking water supply and small scale irrigation. However, hotels and other different organization in the Addis Ababa city are illegally drilling ground water for personal use without any permit from the municipality, which would be creating serious problems in the sustainability of the future water supply and demand management. Therefore, the practice of illegal exploitation of ground water that exacerbates the depletion of the ground water resources should be seriously regulated and/or banned.

- Enrichment of water resources and protection from pollution

The use of appropriate technology for cleaning surface water as an alternative to the use of ground water; conservation and protecting the river systems from pollution; creating awareness of the local people for using water resources in the catchment in a sustainable manner, should be implemented by all stakeholders in the catchments.

- Plantation drives

Appropriate programs, projects, and efficient measures that are acceptable by all stakeholders in the catchment should be deployed to protect the catchment from the anthropogenic threats that causes water pollution, depletion and mainly climate change impacts, by undertaking extensive plantation activities in the catchment.

- Increasing local participation and awareness

Many water scheme's development and conservation activities in the catchment have been conducted mainly by regional and federal government institutions without having adequate consultation and participation with the local community. Therefore, there should be an efficient strategy that increases community participation and awareness that helps to achieve the desired level of the water conservation.

- Optimizing the groundwater recharge mechanisms

Conservation and storage of rain water is not only important in terms of the continuous falling ground water level, but also it can overcome water shortage problems. The catchment receives lots of water in the rainy seasons in Ethiopia mainly called '*Kiremt*'. This water can be collected in small reservoirs and dams in the catchment. For instance the

water collected in Abba Samuel dam is used for irrigation and electricity purpose. The process of rain water conservation should adopt at many levels starting from the houses and public places through development of natural sources such as ponds and wells. For this purpose, first of all, the list of areas should be identified and mapped to indicate where the pools and wells dry out and the water level decreases in the ground in the summer season. Therefore, in such areas, by creating large reservoirs, the depletion of ground water can be reduced, sustained and water can also be systematically provided for irrigation, domestic and industrial uses at optimum level.

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# APPENDICES

## Appendix - I

Addis Ababa University  
College of Development Studies

Center for Environment and Development

Questionnaire will be responded by Individuals (households and officer)

Dear Respondents

The purpose of this questionnaire is to collect data that can serve as inputs to a research entitled as “causes ground water depletion in Akaki well field and its impact on the catchment, and to recommend the reliable solutions for the cause of water supply problem. The people’s lives in the area also to identify the major effect on societal health in Addis Ababa.

General Direction

- Please don’t write your name.
- To make the research more valid and reliable your genuine responses are highly essential.
- Note that there is no right or wrong answer to the items in the questionnaire.
- For question items that require your opinion or comments, please give short answer in the space provided.

Thank you in advance for you cooperation.

## PART I

You are kindly requested to indicate your response by putting “√” in the box provided located in questioner and write your suggestion and/or anything you feel that is not written on the questioner of given at the end.

### 1. Personal Information

#### 1.1 Distance where the Place of living around Akaki area

- |             |                          |
|-------------|--------------------------|
| Very nearer | <input type="checkbox"/> |
| Near        | <input type="checkbox"/> |
| Far         | <input type="checkbox"/> |
| In          | <input type="checkbox"/> |

1.2 Number of persons in the family \_\_\_\_\_

1.3 Sex                      Male                       Female

1.4 Age \_\_\_\_\_

1.5 Marital status

Single                       Married

## PART II

How do you rate the following items that related to causes of water supply problem, the mechanism taken be the community in order to reduce water supply problem to societal health according to your degree of agreement in Addis Ababa specifically in your area Akaki? Where

5- Strongly Agree      4- Agree      3- Uncertain      2- Disagree      1- Strongly Disagree

<i>Items</i>	<i>Degree of response</i>				
	5	4	3	2	1
<b>1.</b> shortage of water supply around 6 kilo					
1.1 Water supply system design problems					
1.2 Reservoir design and leakages of distribution system/pipe line					
1.3 Increasing population					
1.4 water resources management problem					
1.5 Insufficient water resources problem					
1.6 maintenance problem					
1.7 electrical supply for water pump /pump station					
1.8 less price of water per meter cub					
1.9 Industrialization					
1.10 the problem of organized integration among different sector					
1.11 low effectiveness water resources management					
<b>2.</b> How water supply deficient reduces by the community	5	4	3	2	1
2.1 Education (awareness creation)					

2.2 to minimize Scarcity of water supply					
2.3 Tougher law enforcement					
2.4 Redesign water supply in to the system					
2.5 Keep the environment clean					
<b>3. Effect of Water supply deficient with societal health impact</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>
3.1 Health, like as :poisonous drinking water and food					
3.2 hygiene					
3.3 environmental pollution					
3.4 disease such as Typhoid fever ,bacteria and trachoma					
3.5 Stomach sickness in humans					
3.6 Effect of quality packed food					

### Part III

Please write short answer for the following questions based on the current information you have.

1. What do you think are the major causes of water supply problem around the akaki catchment

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## Appendix -II

Addis Ababa University  
College of Development Studies

Center for Environment and Development

### Interview Guide Questions to be made with Household Members

Dear Respondents

The purpose of this questionnaire is to collect data that can serve as inputs to a research titled as “domestic water supply deficient in the Case of Akaki area”, and to recommend the reliable solutions for the cause of water pollution and shortage. The aim of the research is also to identify the major effect of water pollution economy on societal health in Addis Ababa.

#### Guiding Questions

- Can you mention the major impact of water supply deficient in Akaki catchment ( Addis Ababa)?
- What do you think are considered to be the source of water supply deficient around Akaki
- What kind of mechanisms has been taken in order to reduce water supply deficient and its negative impact on societal health and economy?
- What kind of mechanisms will be taken for the future in order to reduce water supply deficient and its negative impact on societal health and economy?
- What are the major effects of water supply deficient on societal health occurred in Akaki Addis Ababa?

## Appendix III

### Addis Ababa University College of Development Studies

#### Center for Environment and Development

#### **Guide for Focus Group Discussion**

The main purpose of the focus group discussion is to gather relevant and pertinent information regarding the major impacts of water shortage and ground water depletion, the mechanism taken by the community to reduce water shortage and ground water depletion and the impact of water pollution and shortage on societal health and economy. Therefore you, as participant of the discussion, are kindly requested to provide the necessary information as much as you can. Any information you provided will be kept confidential and used only for academic purpose.

Thank you

1. What do you think about the major impacts of water supply deficient around in Addis Ababa?
2. What do you think are considered to be the source of water supply deficient in the Akaki catchment?
3. What kind of mechanisms has been taken in order to reduce water supply deficient and its negative impact on societal health and economy?
4. What kind of mechanisms will be taken for the future in order to reduce water supply deficient and its negative impact on societal health and economy?
5. What are the major effects of water supply deficient on societal health economy occurred at Akaki and over all in Addis Ababa?

## Appendix. V Work Schedule Activity Breakdown

The research proposal and research writing need time schedule because time is limited to do various things with in the given period of time. The researchers try to show the time gap to do different functions of research proposal and report writing, data collection, organization, analysis, presentation and interpretation.

Table 14: Work Plan of the Research

R. No.	Actions to be done	Months								
		Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr	May	Jun
1	Proposal writing									
2	Date of proposal submission									
3	Presentation of proposal									
4	Questionnaire development									
5	Writing of review of related literature									
6	Duration of data collection									
7	Data analysis and interpretation									
8	Research report writing									
9	Completion of the first draft									
10	Submission of the first draft									
11	Completion of final report									

## Budge

Any research work needs budget. So the researcher will plan to use budget for research work shown in the blow table.

Table 15 Budget

No.	Item Description	Measurement	Quantity	Unit Cost	Total Cost In ETB
1	Stationary				
1.1	Pen	Pcs	15	5.00	75.00
1.2	Note book	Pcs	8	25.00	200.00
1.3	Typing of questionnaires and thesis	Page	700	2.50.00	1,750.00
1.4	Printing of questionnaires and thesis	Page	1400	1.00	1,400.00
1.5	Cost of binding thesis	Pcs	3	20.00	60.00
2	Travel, Per diem, instrument rent and personal cost				
2.1	Transportation	Trip	16	200.00	3,200.00
2.2	Hand GPS rent	Day	3	150.00	450.00
2.3	Deep meter rent	Day	5	300.00	1,500.00
2.3	Food expense	Day	14	150.00	2,100.00
2.4	FGD	Event	2	500.00	1,000.00
2.5	Training for data collector	Day	10	500.00	4,000.00
2.6	Per diem for supervisor	Person	2	2,100.00	4,200.00
2.7	Per diem for enumerator	Person	10	700.00	7,000.00
2.8	Telephone (mobile card) cost	Pcs	22	50.00	1,100.00
	<b>Sub Total</b>				<b>28,035.00</b>
	Contingency 5%				1,401.75
	<b>Total</b>				<b>29,437.50</b>

## Appendix VI

### CHECK LIST

For the research that will conduct to helping assess the recharge area of the Akaki well field

	YES	PARTLY	NO
➤ I am familiar with the other research that has been conducted in the area I am researching.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I have identify where the recharge area Akaki well field	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I have understand What makes reduce infiltration when ppt. that helps as the recharge of Akaki well field	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I have a clear understanding of the theoretical and practical knowledge about the recharge area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I have a clear understanding of the people that lives the recharge area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I have a well-considered knowledge about the people environmental Understanding	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I have understand the area landscape and forests for the contribution of Akaki well field	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I know that the population growth and urbanization affecting the well fields of Akaki	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I have understand about the geological feature of the recharge area that it contribute for depletion of groundwater for the well fields of Akaki	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
➤ I have considering from history and maps of the previous and current area situation that helps estimate the causes of the depletion of Akaki well field	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>