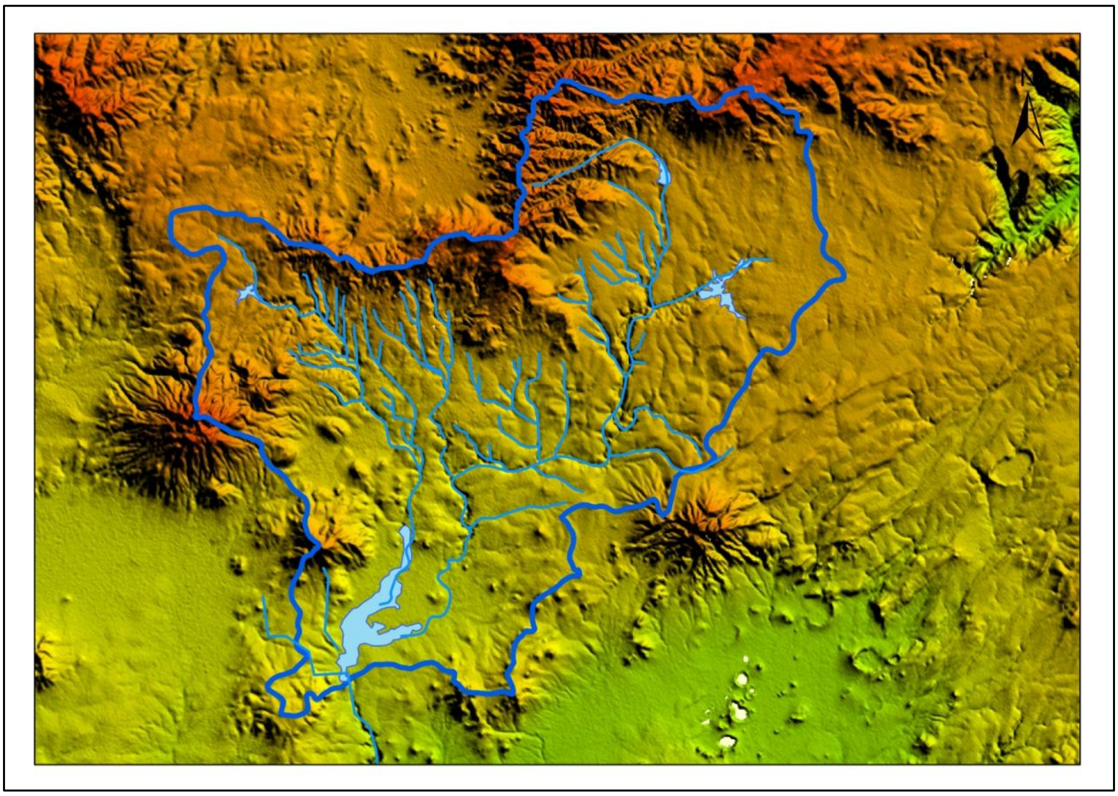
ADDIS ABABA UNIVERSSITY

SCHOOL OF EARTH SCIENCES

COLLEGE OF NATURAL SCIENCES

APPLICATION OF REMOTE SENSING AND GIS FOR THE ASSESSMENT OF GROUNDWATER QUALITY AND VULNERABILITY IN AKAKI CATCHMENT, ADDIS ABABA



By

EYERUSALEM GEZU

May, 2014

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APPLICATION OF REMOTE SENSING AND GIS FOR THE ASSESSMENT OF GROUNDWATER QUALITY AND VULNERABILITY IN AKAKI CATCHMENT, ADDIS ABABA

A Thesis Submitted To the School of Graduate Studies of Addis Ababa University In Partial Fulfillment of the Requirement For The Degree of Masters In Remote Sensing And GIS

By

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ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

This is to certify that the thesis prepared by Eyerusalem Gezu entitled: *Application of remote sensing and GIS for the assessment of groundwater quality and vulnerability in Akaki catchment, Addis Ababa* and submitted in partial fulfillment of masters of Science in remote sensing and Geographic information system compiled with the regulation of the university and meets the accepted standards with respect to originality and quality.

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Chair of department or graduate program coordinator

D E C L A R A T I O N

I hereby declare that the dissertation entitled "**Application of Remote Sensing and GIS for the Assessment of Groundwater Quality and Vulnerability in Akaki Catchment, Addis Ababa"** has been carried out by me under the supervision of Dr. K. V. Suryabhagavan, School of Earth Sciences, Addis Ababa University, Addis Ababa during the year 20013-2014 as a part of Master of Science program in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Addis Ababa

Date: May 30, 2014

(Eyerusalem Gezu)

C E R T I F I C A T E

This is to certify that the dissertation entitled **"Application of Remote Sensing and GIS for the Assessment of Groundwater Quality and Vulnerability In Akaki Catchment, Addis Ababa"** is a bona fide work carried out by Eyerusalem Gezu under my guidance and supervision for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University.

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Dedicated to

My Lovely Husband Meseret Addisu

‘Who encourages me to Success’

ABSTRACT

Remote sensing and GIS tools are an advanced and effective technologies used to assess both surface and groundwater quality. Using spatial analyst extension, This study indicated the spatial distribution of groundwater parameters in the Akaki catchment. Water samples collected from boreholes passes through a physic-chemical laboratory analysis and the results can be used to generate groundwater quality map and to estimate water quality index. Groundwater parameters such as Sodium (Na^+) ,Chloride (Cl^-), Electrical conductivity (EC), Ammonium (NH_4), Nitrate (No_3^-), Fluoride (F^-),Calcium(Ca^{2+}), Magnesium (Mg^{2+}), Sulfate (So_4^{2-}), Potassium (K^+) were selected for this purpose. Overlay analysis of each parameter maps were applied to generate groundwater quality map. Estimation of water quality index (WQI); the technique of rating water quality were made using equations and based on maximum allowable limit of WHO (World Health Organization) for drinking water which in this paper is related with land-use and land-cover of the area. The value of WQI ranges from 73.81 to 1.08 which was then classified in to excellent, very good and poor for drinking purposes. DRASTIC model was constructed to indicate vulnerability of the area to groundwater pollution potential. Hydro chemical map were generated which is used to determine the water type. Water Quality Index (WQI) was calculated to determine the suitability of water for human consumption and suitable recommendations to prevent further deterioration of water quality suggested.

Keywords: *DRASTIC model, Groundwater quality, hydrochemistry, interpolation, WQI.*

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ACRONYMS

RS	Remote Sensing
GIS	Geographic Information System
WQI	Water Quality Index
MERS	Main Ethiopian Rift System
NW	North West
EW	East West
NE	North East
SW	South West
SE	South East
GPS	Global Positioning System
WHO	World Health Organization
LULC	Land Use Land Cover
IDW	Inverse Distance Weighted
Mg/l	Milligram per liter
µs	Micro Siemens
EC	Electrical conductivity
K	Hydraulic conductivity
DEM	Digital Elevation Model
AAWSA	Addis Ababa Water and Sewerage Authority
Meq %	Mili equivalent
asl	Above sea level
TDS	Total dissolved substance
FAO	Food and agricultural organization

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is a natural resource which is important to all life forms on Earth. There are surface water and ground water bodies. These water bodies need to be protected from contamination for the safety of human life, aquatic life and the environment. Ground water occurs in many geological formations which can be drawn for domestic use, irrigation and industrial purpose. The water bodies in Ethiopia have been polluted due to increasing population, urbanization and poor sanitation sites.

Tanneries, oil, soap, food, beverage factories and others are found to be established at the river banks of Little Akaki and Big Akaki. The other factories are also found in a short distance from the river. In this part of the catchment crops are also grown by irrigating the river water. The irrigation system also extends towards the farming field of Akaki in the lower catchment. The water management is very poor and some of the traditional irrigation schemes located in the river course face frequent over flooding during the heavy rainy season (Tadesse Bekele *et al*., 2003). As factories dump waste product to the river directly without treating; fresh vegetables irrigated with waste water are causing health problem.

Ground water quality is the process of estimation of the physical, chemical and biological nature of the water by using different techniques such as a conventional method or GIS and remote sensing technologies. Remotely sensed data, GPS & GIS technology are the major tools for assessing water quality.

There are two main source of ground water pollution. These include natural sources and anthropogenic sources. The natural source of pollution in the Akaki catchment is Fluorine which is dominant in rift system. The anthropogenic sources are by human activities like wastes from industries and septic tanks. Ground water is said to be contaminated when it is unfit for intended purpose. Ground water quality parameters were compared with WHO standard values to check the suitability of water for drinking purpose. Water quality index (WQI) was calculated to find the suitability of ground water for drinking.

A GIS based DRASTIC modeling is a standard system for evaluating ground water pollution potential to prevent further pollution of an area (**http://elsevier.com/locate/apgeog**).

In conclusion remote sensing and GIS technologies with computer modeling are useful tools in providing a solution for water resource management and formulating policy related to water quality.

1.2 Statement of the Problem

As Akaki catchment is the major waste disposal area it is important to consider the side effect of waste to the ground water quality, human health, and aquatic life. Therefore, studying the causes, consequences of pollution and mitigation methods on that area is necessary. Water quality can be assessed by using GIS and remote sensing techniques. The application of these tools is the best method for estimating spatial distribution of ground water quality parameters. This research focuses on the application of recent technologies for groundwater quality evaluation and to enhance these techniques for future applications. This technology has to be used widely in developing countries.

It is observed that at the sides of Akaki River that runs through the center of Addis Ababa there are many industrial establishments among which most of them are discharging their effluent directly to this river. Farmers harvest infected products in that area.

Flush toilet users connect their sewage system either to the centralized system, storm water drainage system or to separate septic tanks. Pit latrine users are estimated as 56.3% of the total population among which 17 % use private and the remaining use shared and communal pit latrines. From the shared ones about 40% are estimated to be in bad physical conditions and full to-overflow (AAWSA, 2000 and Ferezer, 2012).

In Ethiopia ground water is useful for domestic use, irrigation and industry. The literature survey indicates that earlier researchers have made studies on ground water issues using data obtained from open wells and bore wells in the area. It is observed that there is less considerable work undertaken to use GIS on mapping of the ground water quality. Rapid industrialization and improper toxic waste disposal in the area can lead to the degradation of ground water. Application of GIS based modeling can help on protecting ground water from further pollution by indicating vulnerable areas to pollution potential.

1.3 Objective

1.3.1 General Objective

Preparation of Hydro chemical and Ground water quality maps of the area were major objectives of the study in Akaki catchment.

1.3.2 Specific Objective

- To map the spatial distribution of ground water quality parameters
- To produce map of water quality index
- To relate water quality index with the Land-use/Land-cover
- To assess vulnerability of the catchment to ground water pollution

1.4 Significance of the study

Further detailed research is necessary in the area using GIS–based modeling for ground water quality assessment. The community will be benefited from a research applicable to reduce pollution for clear water good for human health and the environment. The purpose of this paper is to indicate the use of remote sensing and GIS technique for assessing groundwater quality. Advancement of geographical information system and spatial analysis help to integrate the laboratory analysis data with the geographic data and to model the spatial distribution of water quality parameters accurately. As Akaki area is a site for waste disposal and many industries this research work will help to show if the groundwater is potable. This study evaluate ground water quality, relates it to the land use /land cover and maps the concentration of the ground water parameters of Akaki area.

Some of the limitation of the study was lack of necessary literature which was made on the area describing the percentage given for weighted overlay to the maps.

1.5 Thesis layout

In this thesis six chapters with headings and subheading are included starting from the introduction to the conclusion and recommendation. In chapter one the statement of the problem and the objective of the study are clearly described. The second chapter is all about the literature review concerning the research. Chapter three includes the materials used for the research, description of the study area, the methodology and analysis of the data. Chapter four describes the result obtained by the research work and discussed on chapter five. Conclusion and recommendation were given on the last chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of key terms

Groundwater quality is the physical and chemical characterization of groundwater which measures its suitability for human and animal consumption, irrigation and other purposes (Ordookhani *et al*., 2012).

Remote sensing is a technique of deriving information about objects from the surface of the earth without physically coming in to contact with them. This process involves making observations using sensors like cameras, scanners radiometer, radar etc mounted on platforms aircraft and satellites which are at a considerable height from the earth surface and recording the observation on a suitable medium, images on photographic films and videotapes (Ramachandran, 2003).

A Geographic Information system (GIS) is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling and display of geo-referenced data to solve complex problems regarding planning & management of resources (Subramani *et al*., 2012).

Water quality index (WQI) allows "good" and "bad" water quality to be quantified by reducing a large quantity of data on a range of physic-chemical and biological variables to be a single number in a simple, objective and reproducible manner (Singh and Khan,2011).

Drastic model is a standardized system for evaluating groundwater pollution potential. Seven parameters are included; **D**epth to water table, **N**et Recharge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of vadose zone & **H**ydraulic Conductivity (Rahman, 2008).

2.2. The role of remote sensing (RS) and Geographic information system (GIS)

Remote sensing and GIS technique is an effective tool than the conventional water quality assessment method which cannot give a spatial and temporal scale of the water quality trends especially for a geographically large country. And is also reported that the integration of remote sensing and GIS are helpful with in situ water sampling for effective water quality assessment with good accuracy (Naithani and Pande, 2012)

The integrated use of RS data, GPS and GIS are helpful for resource managers to develop a policy (Jerry *et al*., 2003). This paper used statistical relationships between measured spectral/thermal properties and measured water quality parameters.

The water quality status in Malaysia using GIS and remote sensing technologies were studied. The equation used to estimate suspended sediments;

$Y=A+BX$ OR $Y=AB^X$

Where Y is the RS measurement (i.e. radiance, reflectance, energy) and X is the water quality parameter (i.e. suspended sediment, turbidity etc) A and B are empirically derived factors, this value are gained from statistical relationship which determined from spectral reflectance value and between the insitu water quality parameters. From the spectral reflectance it can give the information about the band or wavelength suitable for the water quality parameter. On this paper the spatial distribution of each ground water parameters of the area are not mapped (Usali and Ismail, 2010).

RS technique is important in water quality assessment. Atmospherically corrected Land sat ETM^+ imagery is used to monitor water quality using stepwise multiple linear regression analysis. In this paper mean, standard deviation and correlation coefficient of reflectance values from lakes are calculated. (http://intechopen.com).

Spatial variation of groundwater quality parameter map were integrated and groundwater quality map was created using GIS application in coonoon, Taluk (Subramani *et al*., 2012).

Remote sensing with its advantage of spatial, spectral and temporal availability of data covering large area with short time become a very useful tool for assessing groundwater resources. In this study ground water prospect sites identified based on remote sensing and GIS techniques. Thematic maps were digitized using ArcGIS 9.2 software. Groundwater prospect map prepared considering major controlling factors which influence the water yield and quality of groundwater (Kumar and Uday, 2010).

Prediction of groundwater vulnerability using an integrated GIS-based Neurofuzzy techniques were applied in this research. The neurofuzzy model was developed in JAVA using four parameters (soil hydrologic group, depth of soil profile, soil structure, soil horizon and land use).This study is the first step toward incorporation of neurofuzzy techniques, GIS ,GPS and remote sensing in the assessment of ground water vulnerability from non-point source contaminants (Dixon, 2004).

2.3. Previous Works

As Nwankoala and Ananthakrishnan, (2012) the water samples collected from boreholes are analyzed in the laboratory for different group water parameters and was subjected to statistical analysis in order to determine the mean, range and standard of each parameters using SPSS. The suitability of ground water quality for drinking purpose through water quality index was investigated for different bore wells. The result shows WQI greater than 100, that are above the standard limits according to WHO.

The ground water quality parameters for drinking purpose were analyzed using WHO limit. But there is no application of GIS and remote sensing technologies applied for the research work. Conventional methods were implemented (Ackah *et al*., 2011).

Kumar et al. (2013) used GIS to study the spatial variation in ground water quality. Samples analyzed for physic-chemical parameters and maps were prepared using spatial and geostatistical analysis of ArcGIS 9.3. Spatial interpolation technique through inverse distance weighted (IDW) is applied by ILWIS to delineate the distribution of water pollutants.

Ground water contamination with Vinyl (VC) and precursor volatile organic compounds (VOC) studied by use of a geographical information system. The kriging method was used as interpolation procedure for the spatial estimation of the concentrations in the study as it delivers the best linear unbiased estimator and takes in to account the variogram as well as the sample point pattern. It is shown that GIS including geostatistical interpolation tools is a valuable support for dealing with this task. The point information could be mapped for comparison purpose and kriging being implemented (Kristemann, 2008).

GIS was used to assess and map the spatial distribution of ground water quality of Dhankawwadi, India. After the laboratory procedure IDW has been used to estimate the spatial distribution of ground water parameters, index map prepared with the help of WQI map. The results of WQI are interpreted with respect to the LULC. The ground water parameters highly varied depending on the population density of the area. The good point of this paper is that it related the LULC with WQI (Khan *et al*., 2011).

A study on ground water quality and its suitability for domestic and irrigation purpose using GIS in coastal lands of Parisian undertaken. Using inverse distance method (IDW) on Arc-GIS software, ground water quality maps were prepared and classified by spatial analysis tool (Ordookhani *et al*., 2012).

Leta Gudissa (2010) studied subsurface contaminant transport in Akaki well field. As surface and ground water are intimately linked to each other, there might be leakage from the highly polluted Akaki river. The contaminants may inter in to the aquifer system through porous and permeable materials.

Ground water quality in Lucknow evaluated using remote sensing and Geographic information systems(GIS).The study monitors ground water quality relating it to Land-use/Land-cover and different water quality parameters are interpolated.WQI was calculated on the basis of WHO standards (Verma et al., 2013).

Al-Adamat et al., (2003),studied groundwater vulnerability and risk mapping for the basaltic aquifer using GIS, remote sensing and DRASTIC.GIS has used to create a groundwater vulnerability map by overlying the available hydro geological data and integrated with land use map. In this research hydraulic conductivity from the final DRASTIC calculation was excluded.

Impact assessment of land-use change on groundwater quality using remote sensing and GIS were studied. Groundwater samples were analyzed for various physico-chemical analysis in the laboratory to produce attribute data. Spatial distribution of water quality parameters are prepared using GIS software. Water quality index is calculated to determine the suitability of ground water for drinking (Venkateswarlu *et al*., 2014).

Ermias seyoum (2007), On his paper the use of advanced technologies like GIS and remote sensing are not included but physic-chemical analysis of samples and GPS were used. Using WHO standards the suitability of drinking water were assessed in river Baressa, North Shoa.

Spatial interpolation through IDW was used to map the distribution of each parameter. Finally ground water quality map is produced using overlay analysis. WHO standard were used to know if the water is potable or non-potable. On this study groundwater quality and sample location mapped using GIS technique (Blakrishnal *et al*., 2011)

Numerical groundwater flow simulation of Akaki river catchment was studied using groundwater flow modeling software, MODFLOW. Construction of a conceptual model used to simplify field problem. GIS software applied to map hydraulic conductivity, sample location and aquifer thickness. The results are briefly indicated using flow chart, tables and graph for comparison (Ebasa Olijira, 2006).

Groundwater quality map using GIS through geostatistical analyst were generated. Interpolation technique through kriging used to obtain spatial distribution of groundwater quality parameters (Nas and Berktay, 2010).

RS and GIS technique for evaluation of groundwater quality in India were studied. Thematic maps prepared by visual interpretation of Toposheets, physic-chemical analysis of groundwater samples spatial distribution map of each parameter produced and water quality index was calculated. This paper correlated water quality with Land-use/Land-cover (Asadi *et al*., 2007).

Alema Tesfaye (2009), studied steady- state groundwater flow and contaminant transport modeling of Akaki wellfield and its surrounding catchment.GIS used to determine recharge, develop conceptual model used to simulate the ground water flow under steady state conditions. DEM plays a key role in defining of the model boundary.

A new methodology assesses the vulnerability of ground water in the uppermost aquifer to the vertical downward movement of non- specific contaminants from the ground surface in Scotland. The new methodology includes the type of aquifer, type of recharge, characteristic of pathway and vulnerability classification. A Further difference in the mew method is that soils data have been integrated in to the classification of superficial deposit permeability rather than simply overlain (Dochartaigh *et al*., 2012).

2.3.1 Drastic modeling

Derege Nigusse (2007) made assessment of aquifer vulnerability to pollution using DRASTIC system with GIS there by to prepare vulnerability index maps. The DRASTIC index values were then classified in to low, moderate, high and very high in Akaki catchment.

Rahman found out the ground water vulnerable zones in shallow aquifers in Aligarh and its surrounding areas, which is one of the fastest growing big cities of North India. DRASTIC modeling is applied for this work. This model is based on the seven data layers gathered from Government agencies. i.e. (Depth of water, net recharge, Aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity).ILWIS 3.0 and Arcview3.2 software were used to find out the water vulnerable zones in shallow aquifers. The GIS technique has provided an efficient tool for assessing and analyzing the vulnerability to ground water pollution. This study suggested that this model can be an effective tool for local authorities who are responsible for managing ground water resources. The good point of this paper is that presents how GIS combined with other software to do ground water modeling (Rahman 2008).

Study describes a groundwater contamination risk assessment method that integrates hazards, intrinsic vulnerability and groundwater value. GIS technology was essential in completing the assessment work. The DRASTIC model is easy to implement and provide groundwater vulnerability to contamination. The model uses seven parameters to assess vulnerability; Depth to water table, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity and linear combination of all factors.

DI= Dr Dw + Rr Rw + Ar Aw + Sr Sw+ Tr Tw+ Ir Iw+ Cr Cw. r and w indicate rating and weights respectively (Junjie *et al*., 2012).

Groundwater vulnerability assessment is one of the major techniques used to assist the development of groundwater protection strategies. This study applied DRASTIC model to assess groundwater vulnerability. One of the main drawbacks of DRASTIC is its subjectivity in rating and weighting the model parameters. Intrinsic groundwater vulnerability map was produced. Arc GIS and surfer 8 were used. Parameters of DRASTIC model are each mapped and described (Farjad *et al*., 2012).

2.3.2 Water quality index (WQI)

Rao & Nageswararao (2013), Assess groundwater quality using water quality index.WQI is a method to express water quality that offers a simple, stable and reproducible unit of measure and give information to the policy makers.

$Wi=wi/\sum^{n}_{i=1} wi$

Where, Wi is relative weight, wi is the weight of each parameter and n is the number of parameters. The calculated WQI values are classified in to five type “excellent water” to water “unsuitable for drinking”. On this paper assessment of salt water intrusion are also made.

Assessment of groundwater quality status by using WQI method in India considered the standard for drinking purpose as recommended by WHO. The results have been described by graphs and WQI categories of samples in various seasons are shown on this paper (Reza & Singh, 2010).

GIS is used to create raster maps of the spatial distribution of the parameters. The suitability of WQI values for human consumption is rated as very good, good and unfit. Results were explained in the form of bar charts (Raikar *et al*., 2012).

Venkateswarlu *et al*., (2014), studied impact assessment of land use change on groundwater quality using RS and GIS. Curve-fitting method in GIS software used to prepare map of selected parameters. Estimation of Water quality index was through equations which are rated in to excellent, good, poor, very poor and unfit for human consumption. The paper related the WQI with the land use change.

Groundwater quality related with land-use/ land-cover map using RS and GIS.WQI was calculated in this paper. It is categorized and correlated with land use/ land cover distribution. This study best describes the methodology and database creation (Asadi *et al*.,2007).

2.3.3 Hydrochemistry

Conventional hydro chemical analysis indicated a very dilute Ca-HCO3, Ca-Na-HCO3 type water in the north (Intoto range) draining the Intoto silicics; Ca-Mg-HCO3, Mg-Ca-HCO3 type water draining the Addis Ababa basalt in the central sector and the Bishoftu basalt aquifers in the south and Na-HCO3 type water of the 'Filwuha' thermal system, which have rock dominated hydrochemistry. While a Ca-NO3 and Ca-Cl type water circulating in the central sector of the catchment is a result of anthropogenic influences, demonstrating pollution (Tenalem ayenew *et al*., 2009).

Water chemistry data can be used to infer groundwater flow directions, to define intended use of water, to indentify sources and amount of recharge and to define local and regional flow system. The quality of groundwater first depends on the composition of the recharge water, the interactions between the water and the soil, soil gas and rocks with which it comes in to contact in the unsaturated zone, and the residence time and reactions that take place within the aquifer(Alema Tesfaye, 2009).

Water samples analyzed for different physic parameters and used to assess the effects of industrial wastes and sewage to the river. Plots showing the variation of parameters are described for different seasons. Hydrochemical analysis of surface and groundwater quality of Yamuna River was studied (http://www.jmaterenvironsci.com).

Hierarchical cluster analysis of hydrochemical data as a tool for assessing the evolution and dynamics of groundwater across the Ethiopian rift were studied . Hydrochemical data have been used to categorize the water in to different classes using Q-mode statistical cluster analysis. Scatter and piper plots of water samples were indicated. Hydrochemical map of the area were generated which showed the different water type. The rift waters are Na-HCO3 type with very high TDS and fluoride. On the contrary highland waters are Ca-MgHCO3 type with very low TDS (Tenalem Ayenew *et al*., 2009).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The Akaki catchment is located in central Ethiopia along the western margin of the main Ethiopian rift. The catchment is geographically bounded between latitude 8° 46' 57"–9° 13' 00"N and longitude 38° 35' 00"–39° 05' 00"E covering the total area extent of 1500 km^2 (Fig. 3.1). There are two sub-catchments: The Big Akaki that drains the eastern part of Addis Ababa area and little Akaki river that drains the western part of Addis Ababa.The two rivers form one of the biggest tributaries of the awash river called Akaki river which finally enters Abba Samuel Lake. The entire catchment is bounded to the north by the Entoto ridge system, to the west by Mt Mengesh 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 center (Ferezer Eshetu, 2012).The northern part of the catchment is characterized by ragged topography and steep slopes which resulted in rapid and a high runoff coefficient (Habtamu Haile, 2007).Daily average temperature range from 9.9^{o}C to 24.6^{o}C and annual mean rainfall is 1254 mm as measured at Addis Ababa observatory. Elevation ranges from 2060 m to 3,228 m asl.

The land-use pattern in the area categorized in to four; Settlement, crop land, forest and water body. The reservoirs in the study area include Aba Samuel, Legedadi, Gefersa and Dire. Volcanic rocks of age ranging from Quaternary to Miocene and clay soils are dominant in this area. The rocks are fractured and are the major groundwater supply. Scoria is the high productive aquifer; fractured basalt and ignimbrite have secondary porosity and permeability (AAWSA, 2000).

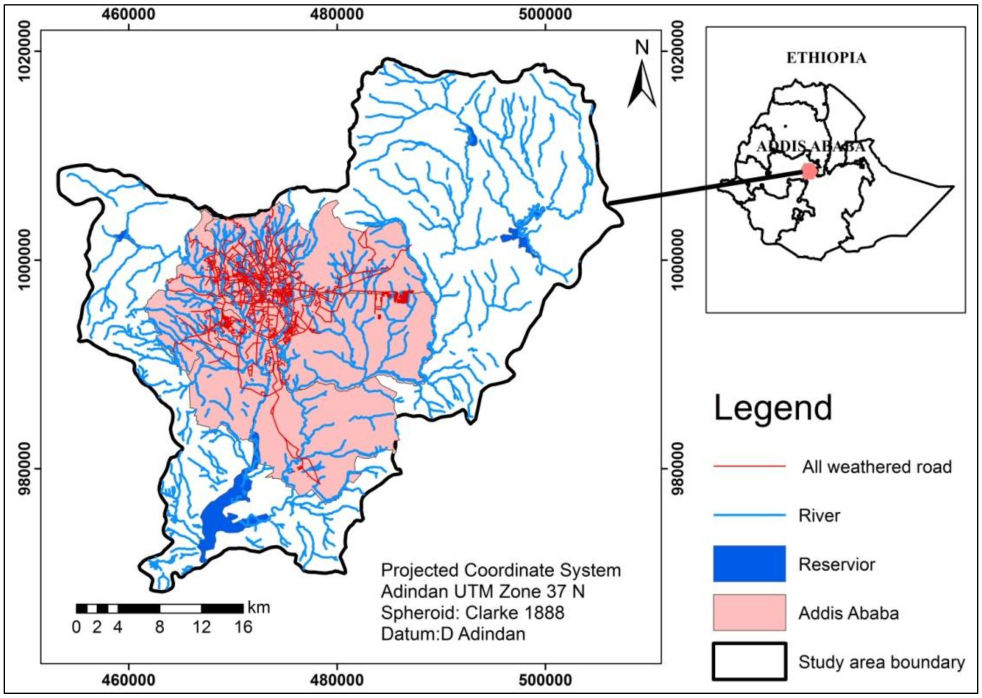

Figure 3.1 Location map of the study area

3.1.1 Regional Geology

Volcanic rocks of different ages cover the largest part of the country. The central and southern part of Addis Ababa area is overlain by younger basaltic rocks. The north and northeastern area are covered with trachyte and rhyolites. The Akaki catchment lies at the upper western margins of the main Ethiopian rift system. Therefore it is highly affected by tectonics and faults having similar trend as that of the rift (NE-SW). The main Ethiopia Rift was the result of extensional tectonics that trends in NNE- SSW. It started to develop in the Miocene (Ebasa olijira, 2006).

The main aquifer systems where groundwater occurs in Akaki catchment are volcanic rocks and minor alluvial sediments that occur both along Big Akaki River and Little Akaki River. These volcanic aquifers have primary and secondary porosities where groundwater circulation occurs (Habtamu Haile, 2007).

Basic and pyroclastic rocks which include basalt, ignimbrite, tuff, ashes and scoria are dominant in the catchment. Igneous rocks are also found on western and northern margins (Fig 3.2).

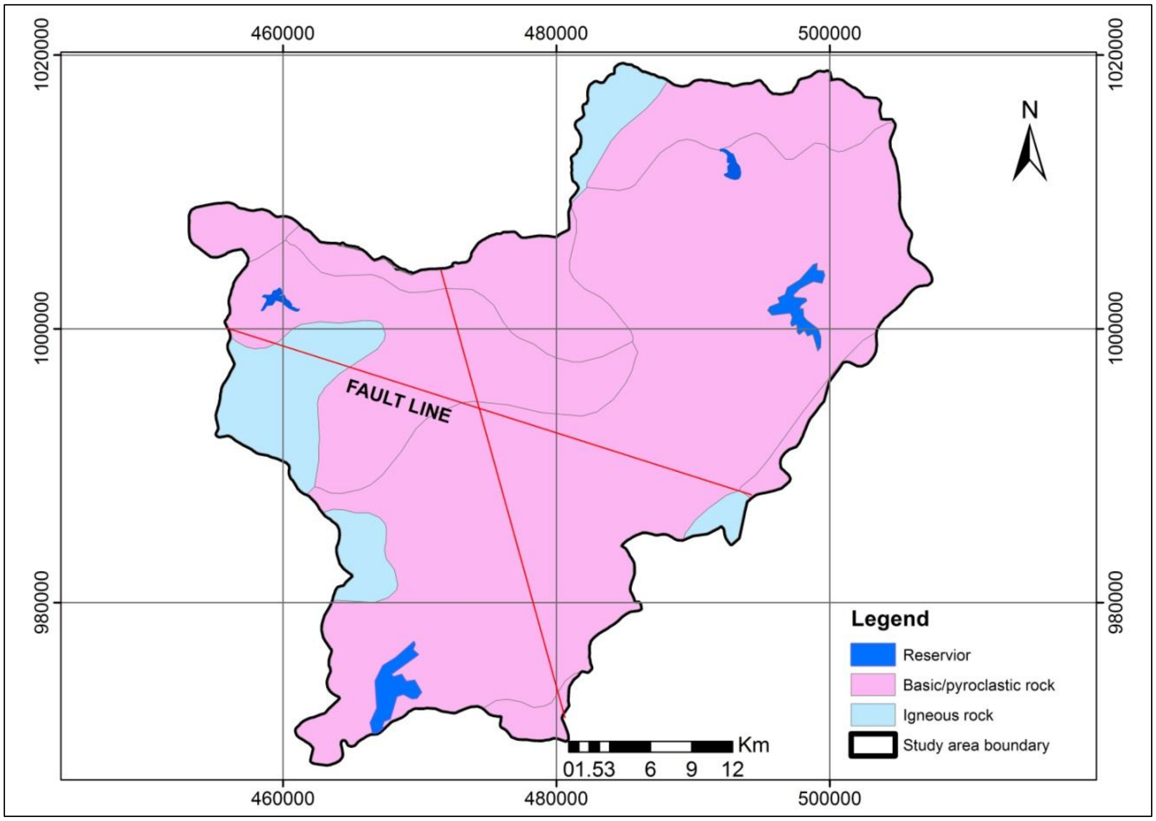

Figure 3.2 Geology of the study area.

3.1.2 Local Geology

From the several studies that are made in the region the following lithostratiraphic units in the catchment are taken from (Alema Tesfaye, 2009).

Alaji Formation

Rhyolites, trachytes, tuff, agglomerate and aphianitic basalt which dominates the northern and central parts of the study area. It is further subdivided in to Alaji Rhyolites and Intoto silicics. The Intoto trachyte overlies the Alaji basalt (Alema Tesfaye, 2009).

Addis Ababa basalts

This unit overlays the Intoto silicics and covers the central and southern part of Addis Ababa. Usually individual flows are easily observed; paleosoils and scoraceous horizons are common in many places (Alema Tesfaye, 2009).

Intoto silicics unit outcrops mainly occur in the Intoto Mountain, central Addis Ababa, along Akaki River course (south) in the vicinity of Legadadi dam to the north of Lake Gefersa and southern part of the city. Their composition can be porphyritic olivine basalt, porphyritic feldspar basalt & Aphanitic basalts (Habtamu Haile, 2007).

Younger volcanic

This unit include Nazareth group and Bishoftu formations. The Nazareth group rock dominates south of the Filwuha fault composed of Aphanitic basalt, welded tuff, ignimbrite, trachytes and rhyolites. It is overlain by Aphanitic basalt and underlain by porphyritic basalt. Bishoftu formation which forms major aquifer of the region is overlain by scoria, gravel and tuff (Alema Tesfaye, 2009).

Recent deposits

Alluvial, lacustrine deposit and residual formations are included overlain by clay soil. Alluvial deposit are found along the little and Big Akaki river especially south and southwest of the capital city. Residual soils occur in southeast, northeast and western areas. Thick Alluvial deposit occurs in the area between Akaki town and Abba Samuel Lake (Ebasa Olijira, 2006).

3.1.3 Geological Structures

Akaki catchment is located at the margin of the Ethiopia Rift System where there is rift tectonics manifested by major and minor fault systems. Most of the faults show NE-SW orientation but some with east-west and northwest-southeast. Joints occur in different rock units in north central part of the catchment is NNE-SSW. Basaltic lava and cinder cones are concentrated along the NE-SW trending fault system as it probably has erupted through these fractures (Ebasa Olijira, 2006). As the area is located in the rift system it is affected by tectonics. Due to this the flow direction of the groundwater is towards south and southeast. Filwoha fault is one of the results of the rift tectonics in which thermal activity is observed. The groundwater occurrence is related with the fault fractures. (Fig 3.3) shows the direction of the major fault line; NE-SW direction.

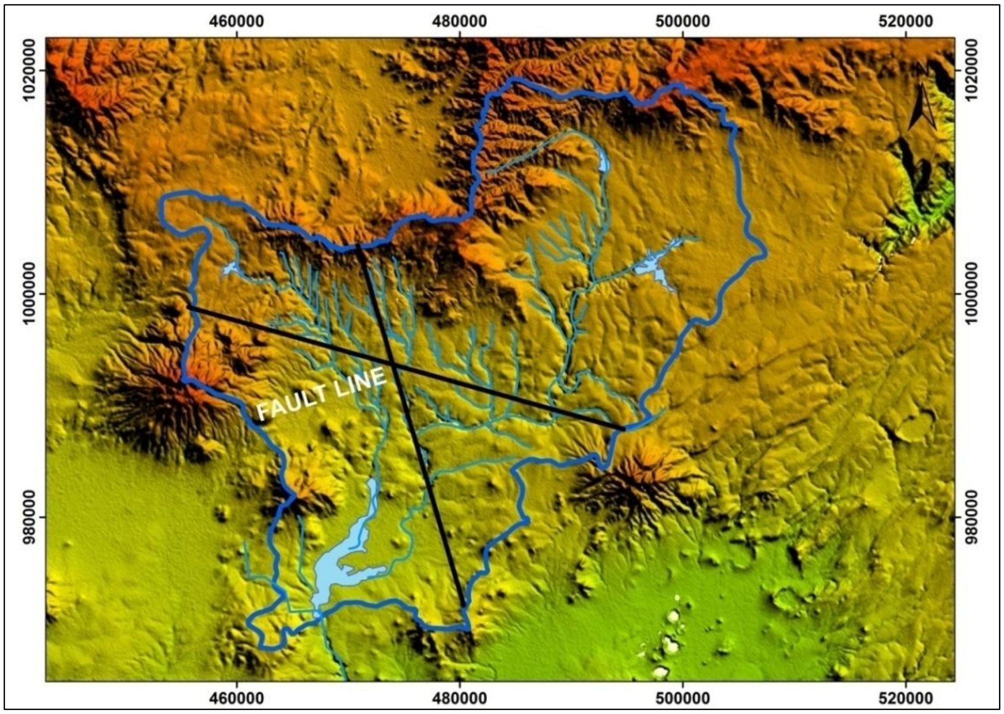

Figure 3.3 Fault line of Akaki catchment

3.1.4 Slope

The slope map indicates the northern part of the catchment has a steep slope and the southern part with gentle slope. As slope increases vulnerability decreases, contaminants are more likely to runoff than infiltrate. Steep slope areas have less residence time for water. Gentle slope is the factor for groundwater storage causing infiltration.

The steep slope of the area is due to the tectonic activity that forms the plateau. Mountain bounds the catchment and the landform changes within small distance due to the complex geology. The highest elevation is Wechecha Mountain (3391 m), Mt. Bereh (3,228 m), Mt. Intoto (3200 m), Mt. Furi (2839 m) and Mt. Yerer (3100 m) and the minimum is around Aba Samuel Lake (2060 m) (Ebasa Olijira, 2006).The slope map was classified in to five parts based on the slope range (Fig 3.4).

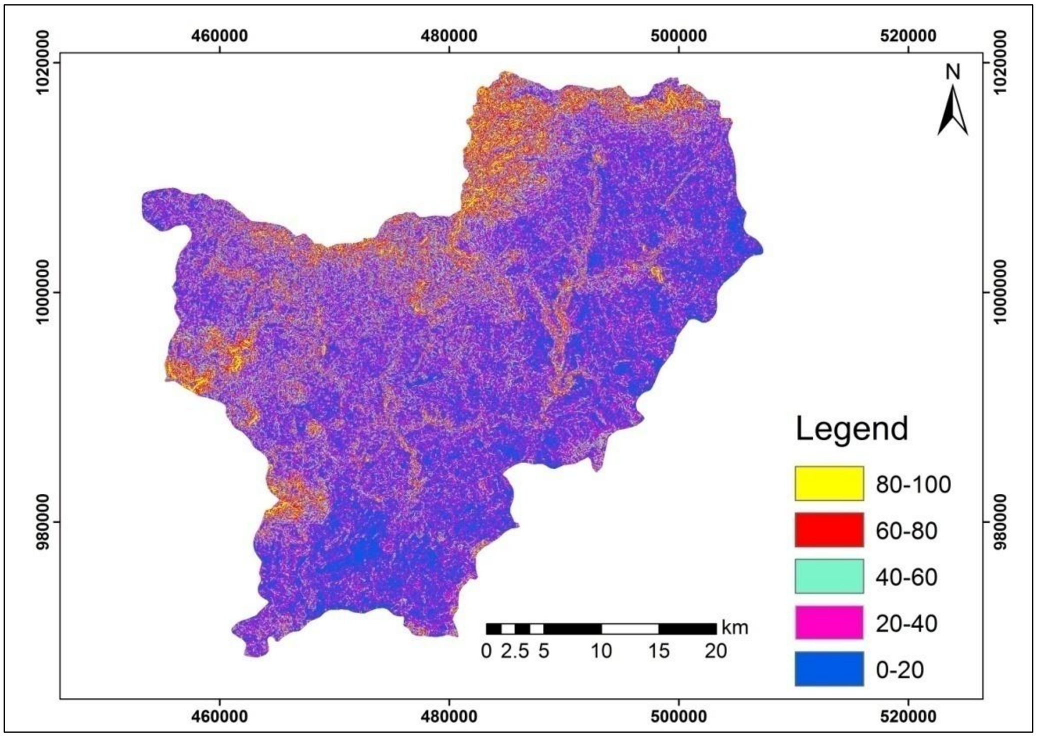

Figure 3.4: Slope map.

3.1.5 Soil

The soils are highly eroded forming thin soil cover. Clay is the dominant composition of the soil in the Akaki area. The Alluvial sediments have high porosity and permeability which constitute one of the potential aquifers in the Akaki area. Soil classification here made based on FAO 1998. Vertisols and Nitosols are the major soil type of Akaki area. Cambisols occur in the highland of Addis Northwest and Northeast of the catchment and Nitosol is located in the Northwest which is good for agriculture. The northern part of the catchment is covered by luvisol. Vertisols cover large are of the central and southeast of the catchment (Fig 3.5).

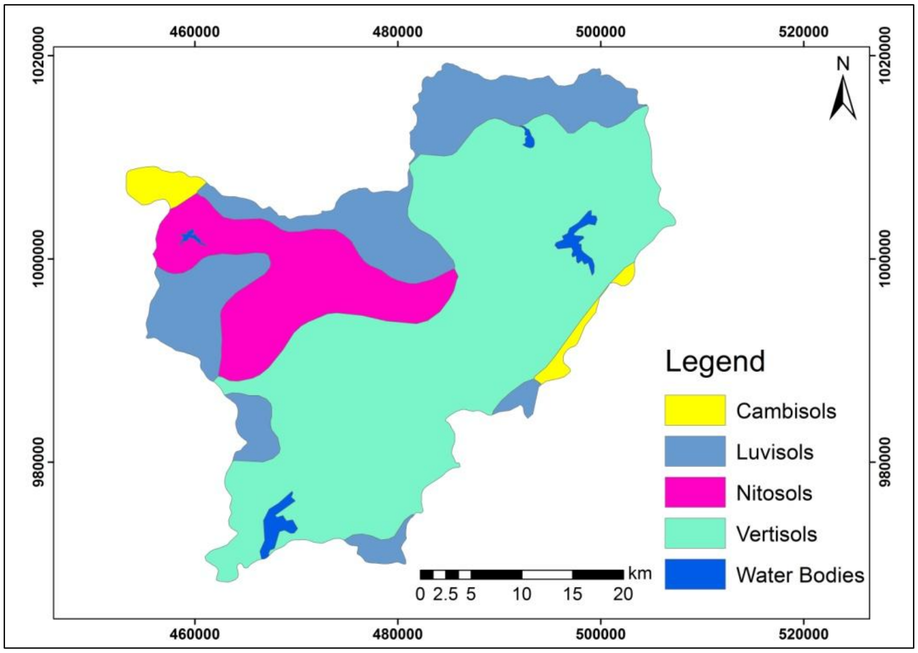

Figure 3.5 Soil Map

3.1.6 Hydrogeology

As Akaki catchment is dominated by volcanic rocks the volcanic aquifer are a major drinking water sources. Geological formation of an area determines the hydrological property of water.

The regional flow direction of groundwater is towards south and southeast due to the structural control. The Akaki catchment has a major NE-SW trending fault which is parallel to lineaments E-W, N-W and NE-SE. Groundwater circulation is associated with porosities, fracture and fissures (Ferezer Eshatu, 2012).

The origin, flow and chemical constituent of groundwater is controlled by the type of litho logy and structure of hydro-geological units through which it circulates. According to previous study the main aquifers in the Akaki catchment can be categorized in to shallow, deep and thermal aquifer (Alema Tesfaye, 2009).

3.1.7 Climate

The climate of the area is warm temperate. Based on rainfall the climate of the area is categorized in to dry and wet season. Seasonal variation of rainfall distribution in 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 easterly and most equatorial westerly across the catchment (Ebasa Oljira, 2006). Daily average temperature range from 9.9^{o}C to 24.6^{o}C and annual mean rainfall is 1254 mm as measured at Addis Ababa observatory.

3.1.8 Land-use/Land-cover

The land-use/land-cover class of the catchment is classified in to cropped area (47.45%), water body (1.68%), forest (6.26%) and settlement (44.61%) (Fig 3.6). Agriculture covers large part of the area in the south, southwest and east direction. Gefersa I, Dire, Legedadi and Abba Samuel are the reservoirs in the area. Forest covers northern part of the catchment on Intoto Mountains. Residential town include Sendafa, Akaki and Burayu.

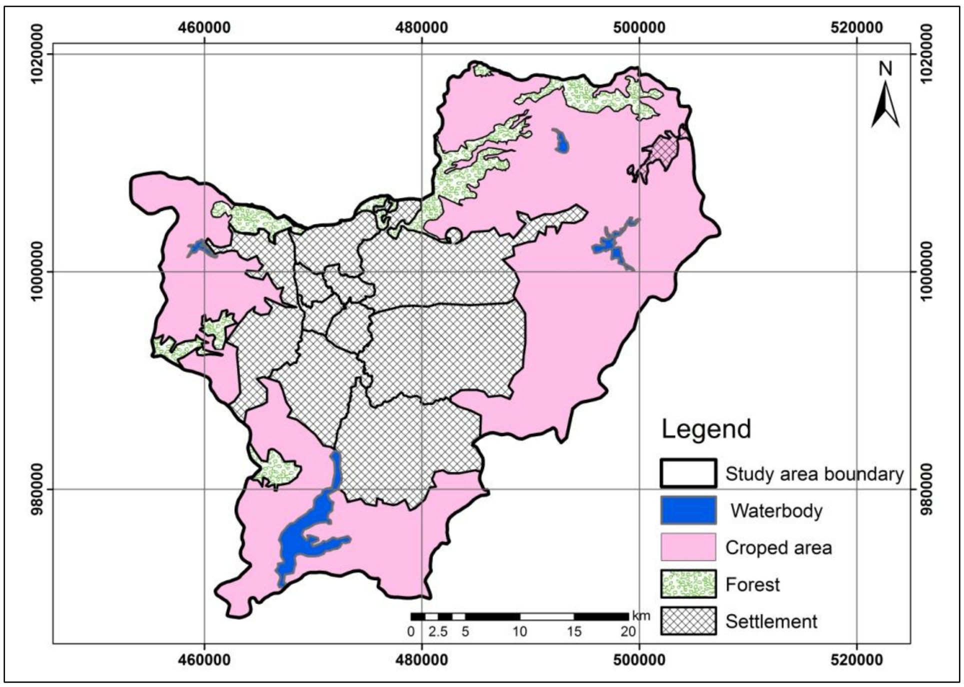

Figure 3.6 Land-use/land-cover map.

3.1.9 Drainage

Dendritic drainage pattern describes the study area. Akaki River catchment contains many small rivers. The drainage of an area is affected by rainfall, slope, vegetation, rock type etc. In the northern part of the catchment the drainage forms steep narrow gorges which facilitate runoff. The drainage in the area is oriented from north to south (Fig 3.7).

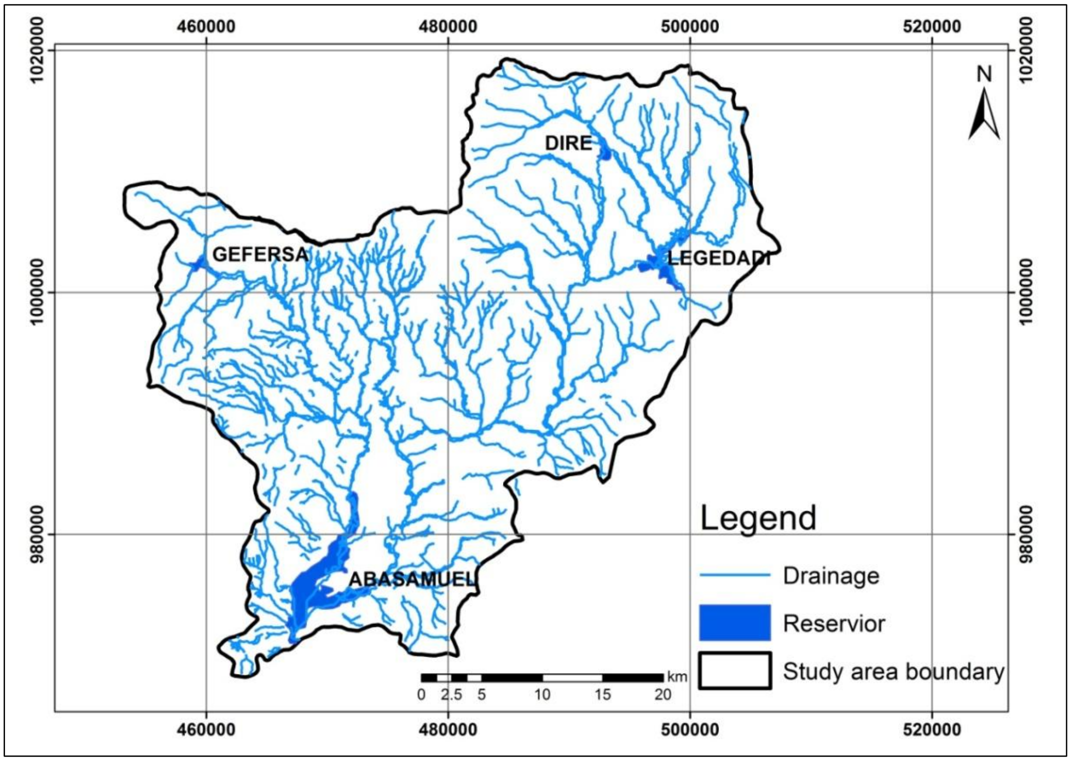

Figure 3.7: Drainage map.

There are many types of drainage patterns. Among them the dominant one in Akaki catchment called dendritic pattern is a common form of drainage system. Here there are many contributing streams which are then joined together in to the tributaries of the main river following the slope of the terrain.

3.2 Materials Used

Groundwater samples were taken from the Akaki catchment and pass through physic- chemical analysis to get quantitative description of the parameters. And it was available for this research as secondary data. Sample data from 145 boreholes, GIS software, Toposheet and satellite images were used to attain the objective in this paper (Table 3.1 and Table 3.2).

Table 3.1 Description of material used in the study

No	Materials	Purpose
1	Toposheet; 0838B1 0838B2	Georeferencing
2	Satellite Images	Extraction of information
3	ERDAS Imagine 9.2, ArcGIS 10	Image processing and analysis
4	Arc hydro tools	To extract drainage pattern
5	AQUACHEM 4.0	To determine water type

Table 3.2 Description of the satellite image used in the study

Satellite	Sensor	Path/row	Bands	Date of acquisition	Spatial resolution
LANDSAT 8	ETM^+	P168/R054	2,3,4,5,6,7	2013	30 m

3.3 Methodology

Data is an important part of a research paper. It can be collected in different ways according to the purpose of the research. After collecting the data database was created. Groundwater quality parameters of Akaki catchment which is a secondary data forms attribute database. The toposheet on a scale 1:50,000 and a Landsat 8 of 2013 form the spatial database. The detailed methodology was presented in (Fig 3.8).

The satellite imagery preprocessed and classified. Land-use/Land-cover map of the study area prepared from the image using ERDAS Imagine software. Thematic maps are generated from the Toposheets and the image. DEM with 30m resolution used to prepare the drainage map.

Groundwater quality data used to produce a Hydro chemical map of Akaki catchment and for a spatial distribution map of the parameters using ArcGIS software. After the evaluation of WQI using a formula it was mapped. Raster maps of the groundwater quality parameters were overlain to produce groundwater quality map of the catchment. All the data were integrated and ground water quality of the area described.

Land use/Land cover map is useful for the analysis of the impact of land use change on ground water quality. To map the spatial distribution of the ground water parameters spatial interpolation through Kriging by using Arc GIS software were applied. Map of the sampling points were produced. Water quality index results classified according to WHO standards for drinking purpose.

Data necessary for preparing a DRASTIC model, the seven parameters were mapped. These can describe the vulnerability of the area to pollution. Here a mathematical formula is applied. Using these methodology and data analysis the results were discussed and then conclusion given.

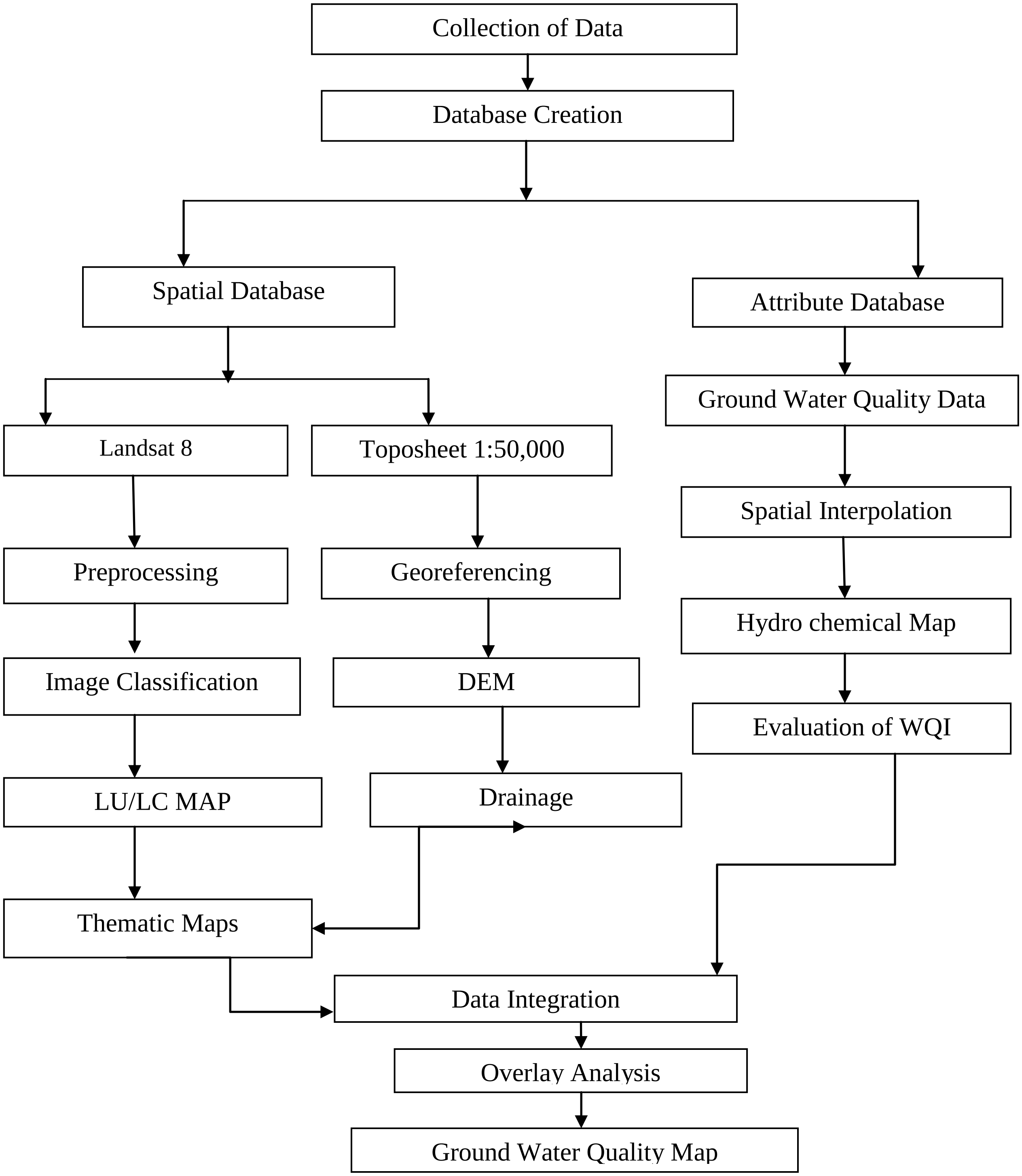

Figure 3.8 Flow chart of the methodology.

3.4 Data Analysis

In this paper the data is analyzed by using remote sensing and GIS techniques. Various studies reported on the usefulness of remote sensing as tools in monitoring of water quality. Remote sensing can be defined as a science and art of obtaining information about an object, area or phenomenon under investigation. Remote sensing for monitoring water quality started in the early 1970's. Insitu measurements are often restricted to selected sampling points. But by remote sensing data it provides the synoptic view of the water body; obtain to measure the characteristic of an area rather than a point. An intensive in situ sampling programmed can validate the remotely sensed products as well as provide information about unobserved things from space such as changing biota, substrate and chemical makeup. These advanced technologies are simple, time saving and accurate. GIS is a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems. The data obtained from satellite systems are input to a GIS for analyses, modeling as well as for preparing different maps, a conversion from raster data to vector data is necessary. Remotely sensed data used to extract information from satellite imageries after the preprocessing, georeferencing and conversion of raster data to vector data. Integrating it with other databases it can be useful as an input to GIS. Thus, the technologies such as remote sensing and GIS are very useful as a tool in evaluating and monitoring water quality.

In this paper after the data which has been necessary for the research was collected spatial and attribute database were created.

1. ***Spatial database***

Landsat8 layer stacked, preprocessed, georeferenced, rectified then supervised classification is done. Same band resolutions of 30m are selected (2, 3, 4, 5, 6, and 7). Band 8 is excluded which is panchromatic (15m) and band 1 is useful for coastal processing; ArcGIS resources (www.blogs.esri.com).

Image enhancement is a method of enhancing the visible interpretability of an image. Image classification is the process of sorting pixels into finite number.

Of individual classes or categories based on their DN values. Two popular classifications are in use namely supervised and unsupervised. In supervised classification, the user will select pixels representing different classes in training sets based on ground truth data. Therefore user can control the classification more closely than in the unsupervised classification. Later, the computer software identifies the pixels of similar characteristics and classifies the entire image using the data set fed by the user.

DEM: Digital Elevation Model forms the basis for contour line, slope and further analyzed through GIS technology to define watersheds and stream networks. Data for high resolution (30 m) DEM used to delineate the study area boundary extract geologic structures (fault) and delineate drainage patterns of the study area on Arc Map 10 using Arc hydro tools.

Topographic map of 1:50,000 are georeferenced, mosaic ked and rectified. These maps were geo-referenced to common reference point in the UTM plane co-ordinate system. Thematic (LULC, geological, regional, topography, slope, soil, drainage) map are prepared and interpreted.

2. Attribute database

The collected ground water samples subjected to a physic-chemical analysis in the laboratory for the water quality data estimation. Some ground water quality parameters for Akaki catchment were imported to ArcGIS to generate spatial interpolation map through Kriging.

3. Surface Interpolation

Point features are used as an input to be interpolated as a surface raster. It is used to delineate the spatial distribution of the selected ground water quality parameters using a selected sample points estimating the output grid cell value.

WQI map were produced by kriging in ArcGIS software after the application of a formula. The final ground water quality map of the study area is prepared by overlaying the spatial interpolation map of the ten parameters. Groundwater samples were taken from 145 boreholes which were useful data for the generation of the spatial distribution maps of the parameters (Fig 3.9).

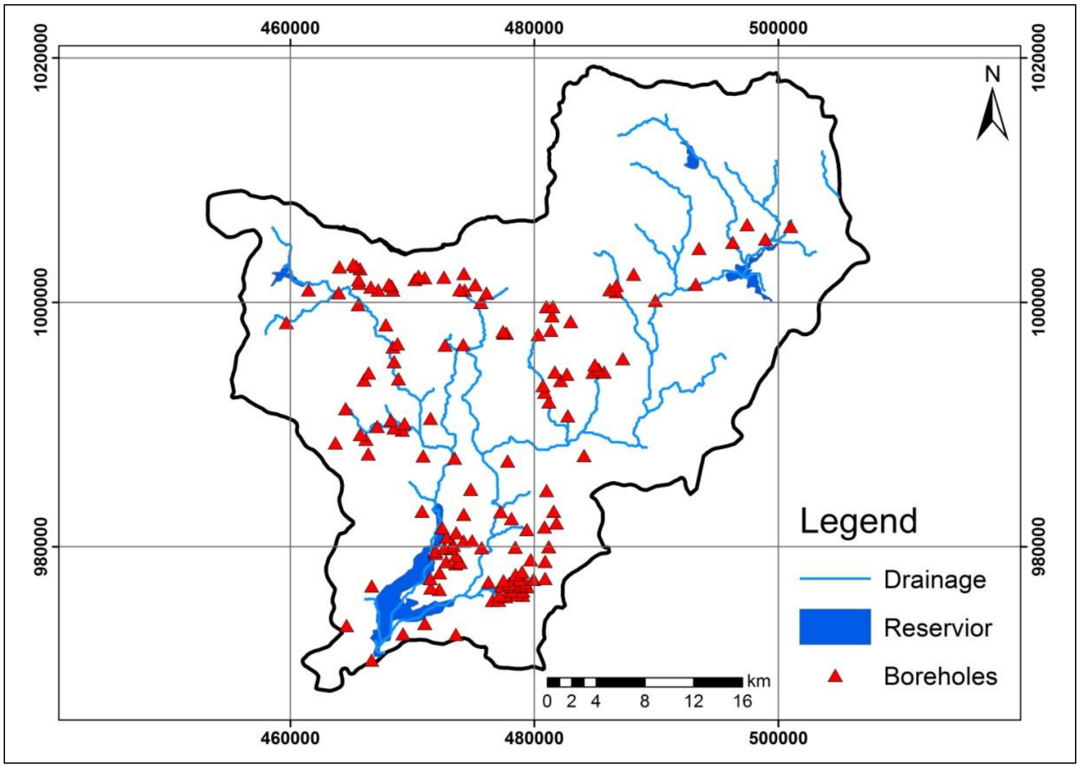

Figure 3.9 Borehole location map.

4. Hydochemical map

The groundwater quality parameters are useful for the generation of hydrochemical map using ArcGIS to determine water potability and its type. The data was imported to AQUACHEM software which is developed for graphical and numerical analysis of water quality data. Piper diagrams are widely used for interpretation and classification of water.

5. Estimation of WQI

Water quality Index (WQI) is defined as a technique of rating. It reduces the large amount of water quality data to a single numerical value. Ten groundwater quality parameters namely K, EC, Mg, Na, NH_4, Ca, Na, NO_3, F, Cl were considered for computing WQI by using the following formulas.

$$\text{WQI} = \text{Antilog}\left[\sum_{i=1}^{n} w_i \log_{10} q_i\right]$$

Where wi=weight age factor of i^{th} parameter qi=quality rating of i^{th} parameter

wi=K/Sn

$$\text{Where } k = \text{constant} = \frac{1}{\frac{1}{vs_1} + \frac{1}{vs_2} + \ldots\ldots \frac{1}{vs_n}}$$

$$q_i = \left(\frac{v_a - v_i}{v_s - v_i}\right) \times 100$$

Where va = actual value obtained from laboratory analysis of i^{th} parameter

vs = standard value of i^{th} parameter

vi = ideal value (pH=7 and 0 for all parameters).

Sn=standard value of i^{th} parameter.

There is also link between the WQI and the land use/land cover of the area. Dense residential areas and sparse residential areas can have different water quality. The value of the WQI interpolated and its map were produced which described the water quality as excellent; very good and good.

<u>6. DRASTIC Modeling</u>

It is a standard system for evaluating ground water pollution potential. Seven parameters are used as an input which can be obtained from various government agencies (Fig 3.4).

- Depth to water
- Net recharge
- Aquifer media
- Soil media
- Topography
- Impact of the vadose zone
- Hydraulic conductivity

The above seven DRASTIC parameters are mapped. The vulnerability map is based on DRASTIC index (Di); sum of the seven layers.

Di = DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw

Where D, R, A, S, T, I, and C are the seven parameters, r is the rating value, and w the weight assigned to each parameter.

This map shows the areas which are vulnerable to pollution by High, Medium or Low classification

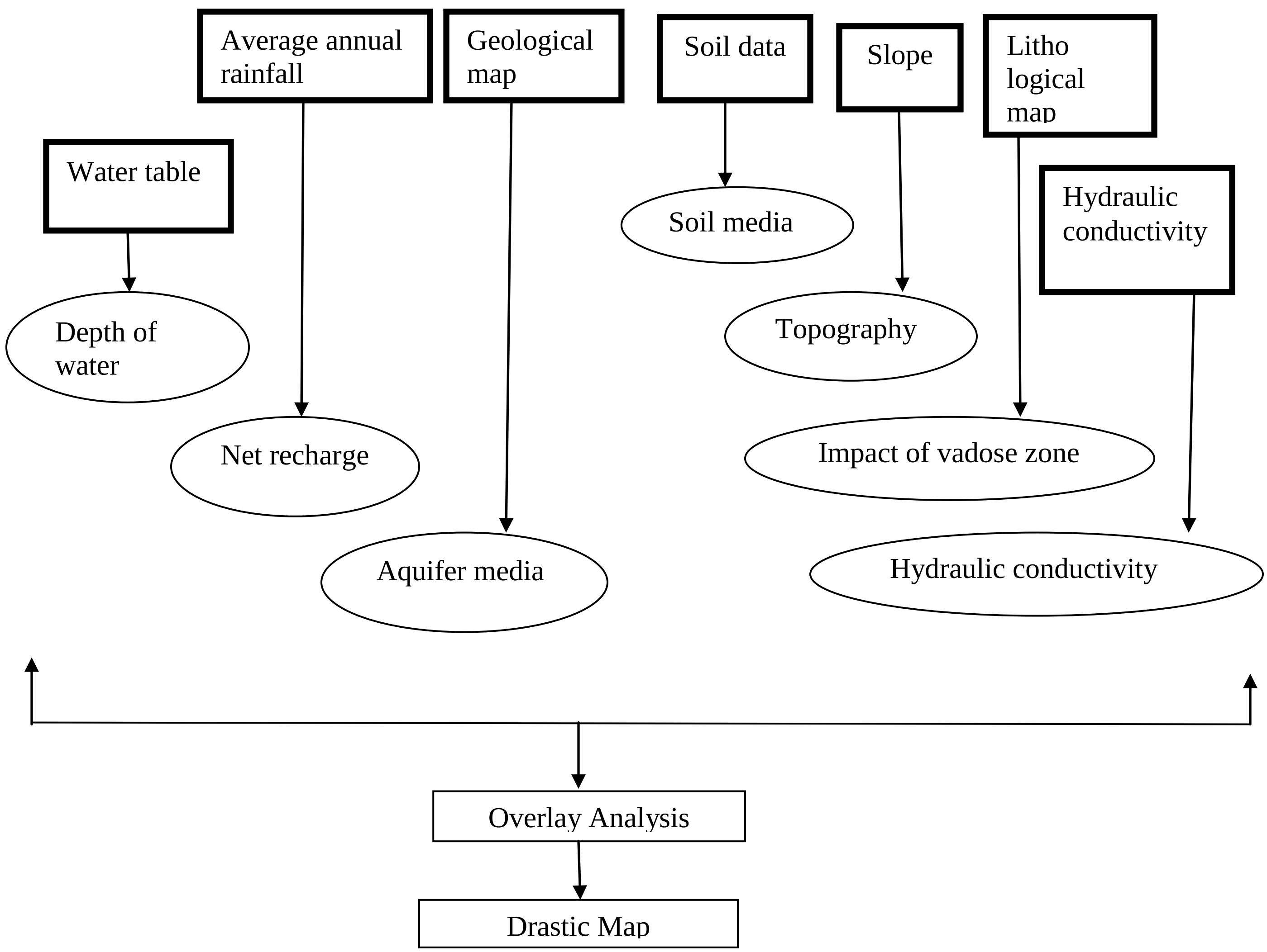

Figure 3.10: Flow chart of the methodology for DRASTIC model

Definition of the terms which were applied for Drastic map are given below;

Depth to water is depth from ground to water table, deeper the water table lesser will be the chances of pollutants to interact with ground water.

Net Recharge is the amount of water/unit area of land that penetrates the ground surface and reaches the water table.

Aquifer media is the potential area for water storage.

Soil media is the uppermost and weathered part of the ground which influence the surface and downward movement of contaminants.

Topography refers to slope or steepness of the area.

Impact of vadose zone is the ground portion found between the aquifer and the soil cover in which pores or joints are unsaturated.

Hydraulic conductivity refers to the ability of the aquifer formation to transmit water; an aquifer with high conductivity is vulnerable to contamination.

Interpolations through kriging in ArcGIS software and overlay analysis were the major tools in this paper to produce the necessary maps. Point data in excel were exported as input to the ArcMap and interpolated using spatial extension tool. Then the maps were extracted by the study area using extraction by mask. These methods were then important for producing the groundwater quality and vulnerability map.

CHAPTER FOUR

RESULTS

4.1 Spatial distribution of groundwater quality parameters

4.1.1 Calcium

It is the most common mineral that make water hard. (Fig 4.1) shows the spatial distribution of calcium in Akaki catchment. It ranges from 91.40 mg/l to 3.52 mg/l which is within the acceptable limit of drinking water. For high concentration of calcium in the southern part of the catchment, rock-water interaction is responsible in that while groundwater flows from the highlands to the low elevation, it reacts with rock material and more calcium is included in the water. All the groundwater with respect to calcium is in an acceptable limit of WHO standards for which the highest allowable limit is 200 mg/l.

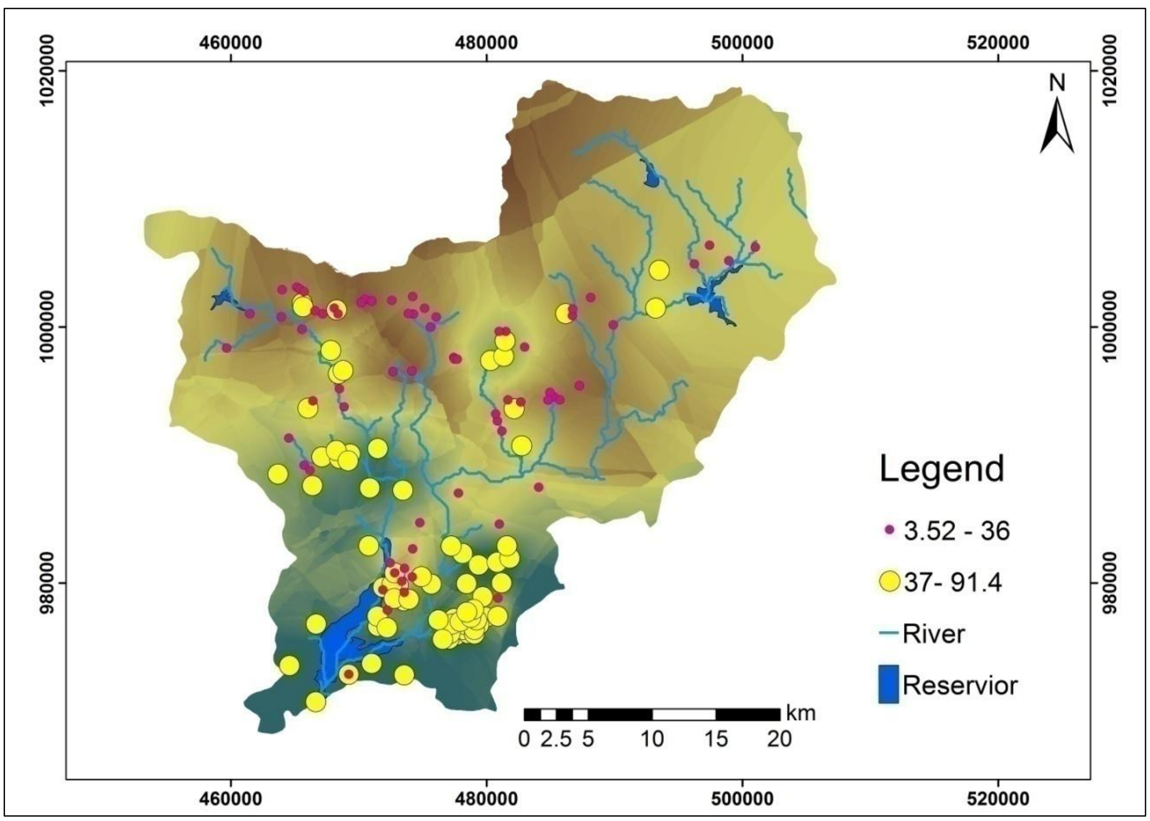

Figure 4.1 Spatial distribution map of calcium.

4.1.2 Chloride

Health problem of chlorine contamination in drinking water include Anemia and effect on nervous system. High concentration of it gives a salty taste to water. In this area it ranges from 1 mg/l to 131 mg/l. According to WHO standards the maximum allowable limit for chloride is 250 mg/l. The value shows that chloride is within the acceptable limit in the area. (Fig 4.2) indicates some areas of chloride with range above 32 mg/l. For the High values of Chloride in the downstream part of the catchment, in addition to rock-water interaction, some industries like tannery contribute chloride to the groundwater system on condition that the rocks are fractured.

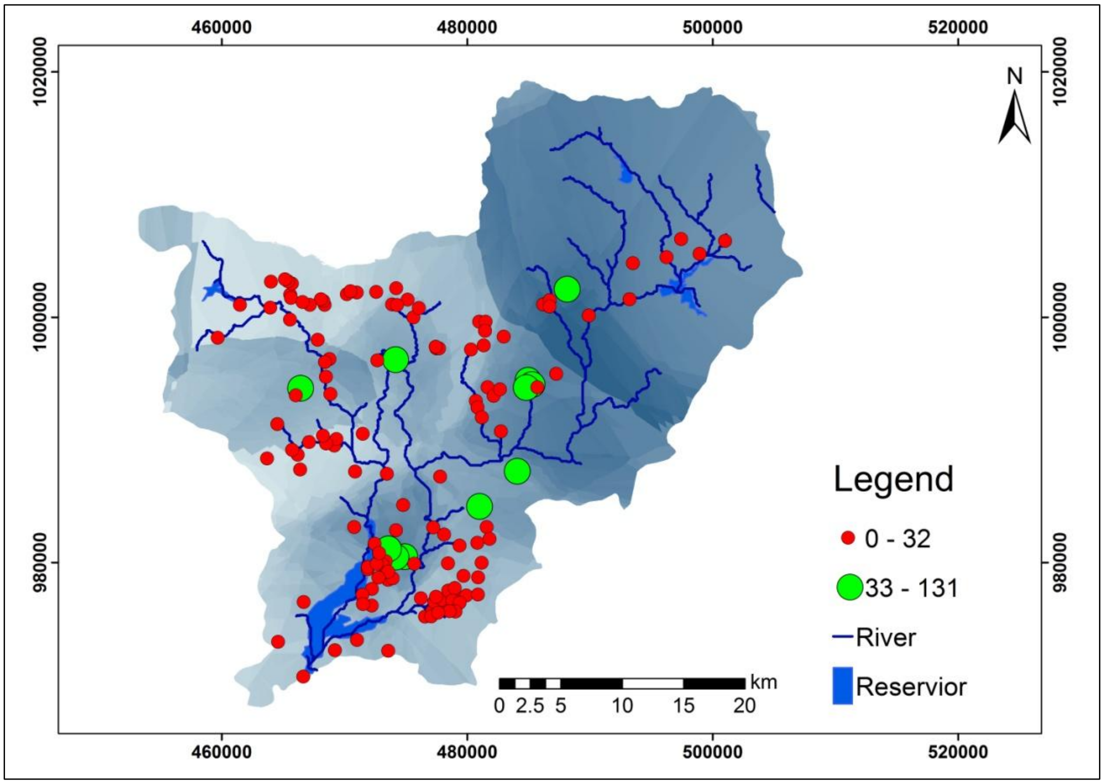

Figure 4.2 Spatial distribution map of chloride.

4.1.3 Nitrates

Nitrate in the area ranges from 0.1 mg/l to 52.6 mg/l which is above the standard value of WHO(45 mg/l). The high and medium concentration of nitrates are at the lower catchment. The values between 26-45 mg/l are shown at the lower catchment and some near legedadi reservior at the north (Fig 4.3). These areas may become beyond the limit with nitrates if the pollution increasses. Sewerage leaking and industrial polution from the area can be the cause for the high concentration shown in the downstream part of the area. High nitrate amount in the water causes shortness of breath and others.

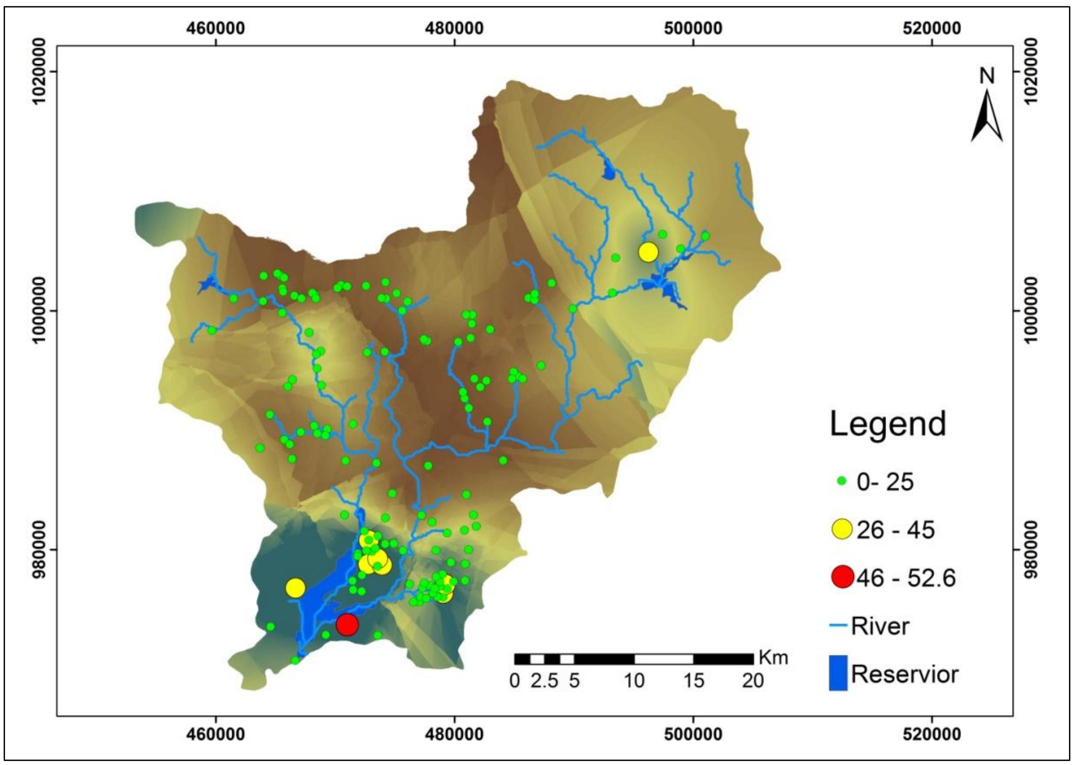

Figure 4.3: Spatial distribution map of Nitrates

4.1.4 Electrical Conductivity

It is the capacity of aqueous solution to carry electrical current which is directly related to the concentration of ionized substances in the water. In the study area EC value ranges from 135µs/cm to 3359 µs/cm. The higher value indicates high concentration of ionized substance in that area. EC directly relates to TDS (Total dissolved substances). The lower value indicates low concentration of ionized substances in the water. The maximum allowable limit for EC is 1500 µs/cm as WHO standard. For parameters that are above the limit were classified in to three to show the medium value areas that can go beyond the limit if prevention couldn't take place. High EC values are observed in the southeast. The medium range is from 1001µs/cm-1500µscm near Legedadi Nas food factory (Fig 4.4). The high EC values are attributed to the thermal groundwater zones along the Ambo-Filwuha fault line. Anthropogenic inputs have little contribution to the high values as they are observed in areas away from the river courses and fractured rocks.

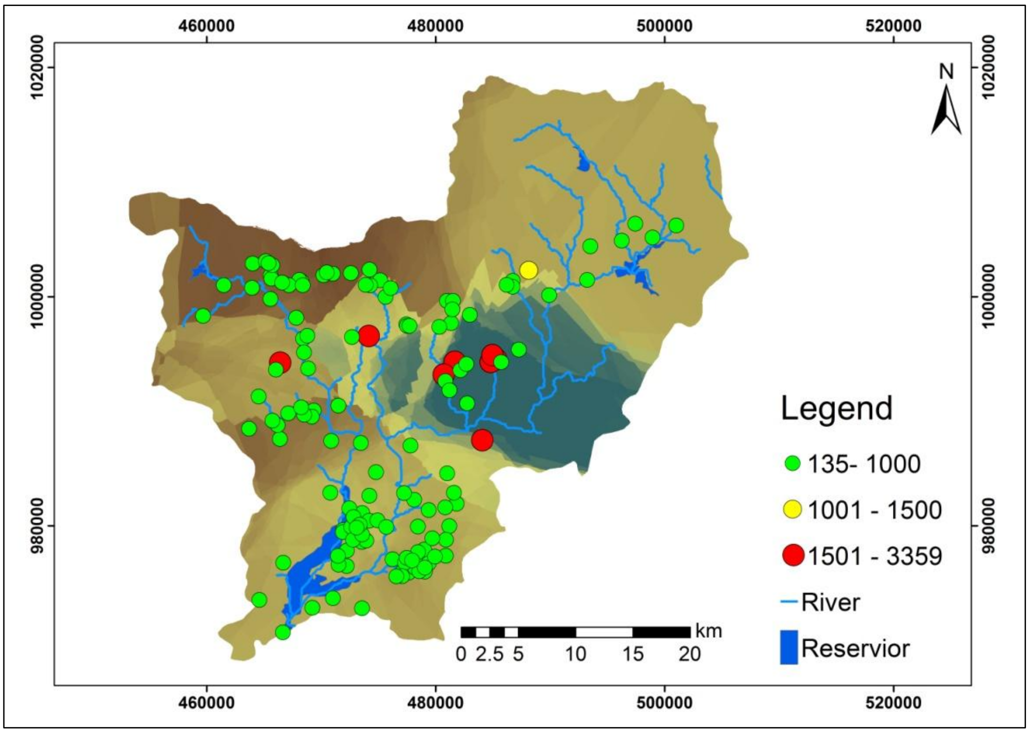

Figure 4.4 Spatial distribution map of electrical conductivity.

4.1.5 Fluoride

Found naturally in much water and if it is low it can be added to bring the concentration to recommended level. High amount of fluorine concentration can cause tooth decay and bone problems. In this area the value of fluorine ranges from 0.1 mg/l to 21.1 mg/l (Fig 4.5). According to WHO standards the allowable limit for fluorine is 1.5mg/l. which some part of this area shows a value above the allowable limit along the fault system that runs from Ambo to Yerer Mountain. The high concentration can be due to the acidic rock types in the area which contain high fluoride ions and associated to the thermal zones. High value of fluoride ion occurs in the rivers of rift system.

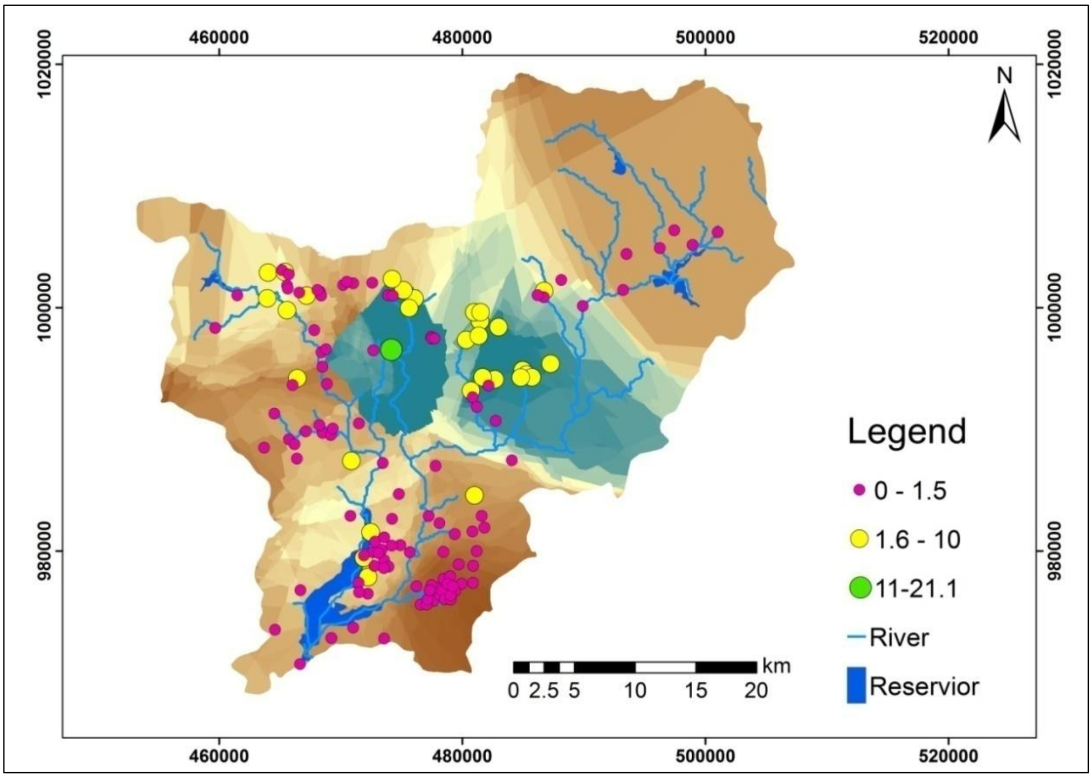

Figure 4.5 Spatial distribution map of Fluoride.

4.1.6 Potassium

In addition to rock-water interaction, the high or low concentration of potassium relates with the degree of human and industrial activities. As it is seen on the (Fig 4.6) In this area it ranges from 1.3mg/l to 55.44mg/l. According to WHO standards the allowable limit for potassium is 200mg/l in which this area shows a value within the acceptable limit of drinking water. The high potassium concentration in the central part would rather show thermal effect that causes fast rock water interaction.

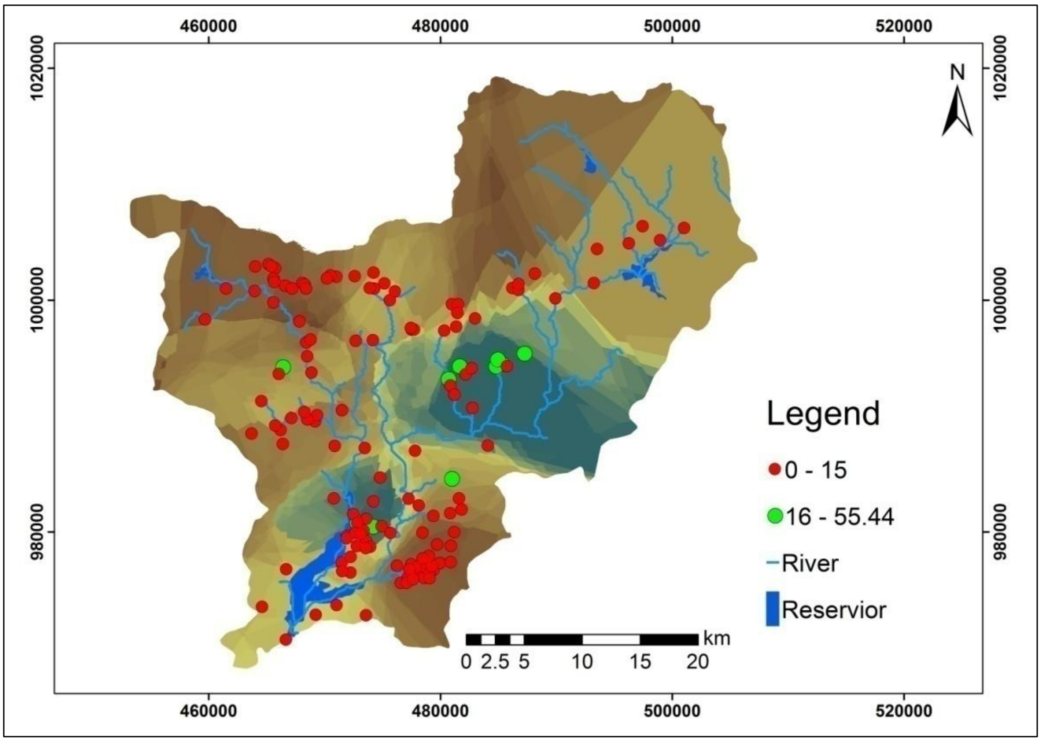

Figure 4.6: Spatial distribution map of potassium.

4.1.7 Magnesium

It is also the major contributor to water hardness like calcium. The major source of magnesium in water is the chemical weathering of rock such as dolomite and also silicate mineral which are found in igneous rocks. High concentration of magnesium can cause health problems. The value ranges from 1.08 mg/l to 29.2 mg/l which is in the acceptable limit of drinking water. According to WHO standards the maximum allowable limit for magnesium is 150 mg/l. From the (Fig 4.7) maximum value occurs at the lower catchment due to rock-water interaction and runoff from highlands.

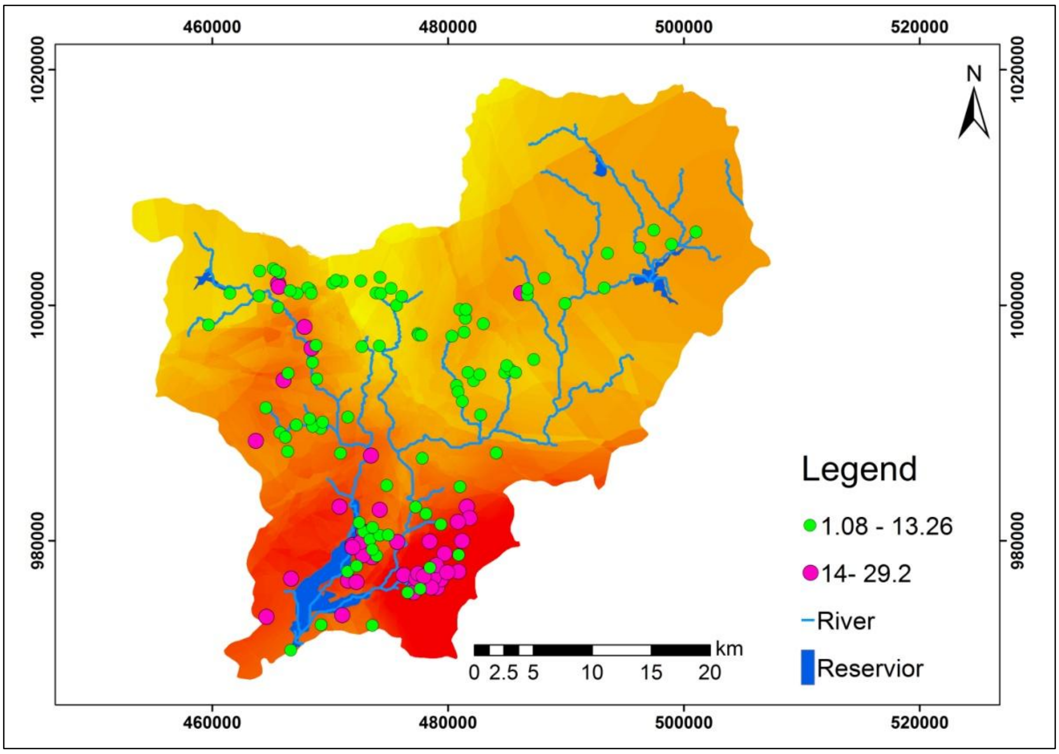

Figure 4.7: Spatial distribution map of magnesium.

4.1.8 Sodium

Presence of sodium in water is important for health, agriculture and soil with its limit. The value of sodium in the area ranges from 0.01mg/l to 840 mg/l which is above the allowable limit of WHO standards (200mg/l).The high concentration is due to the use of sodium chloride salt for hair removing and pickling activity by the tannery industry and discharge of sodium ion content to the river. The high values are in the southeast (Fig 4.8). The high values of sodium in the central part are attributed to the prevailing thermal nature of the groundwater in the area.

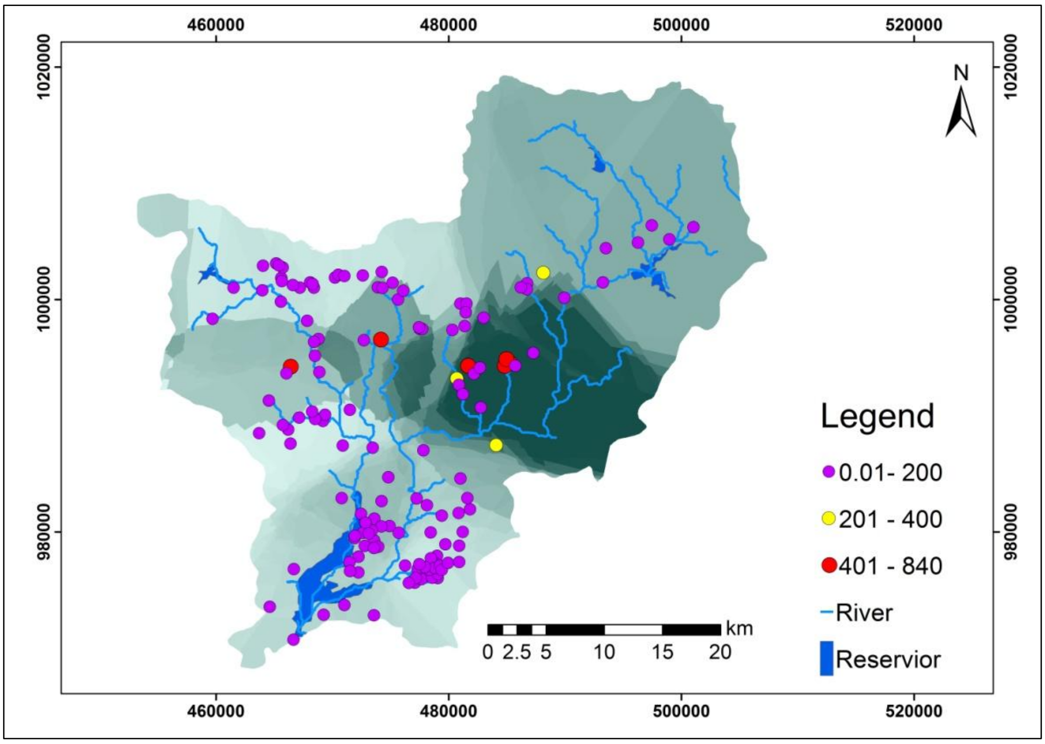

Figure 4.8: Spatial distribution map of sodium.

4.1.9 Sulfate

This occurs in the chemical industry. They are discharge in to water from industrial wastes. Increased concentration found in the central and lower catchment (Fig 4.9). High sulfate concentration can lead to diarrhea and other health problem. The value in this area ranges from 0.1mg/l to 99.5 mg/l which is in the acceptable limit of WHO standards (400 mg/l). The high values may be due to deep seating sedimentary rocks contribute sulfate in the central part of the study area but in the downstream part industrial wastes contribute sulfate.

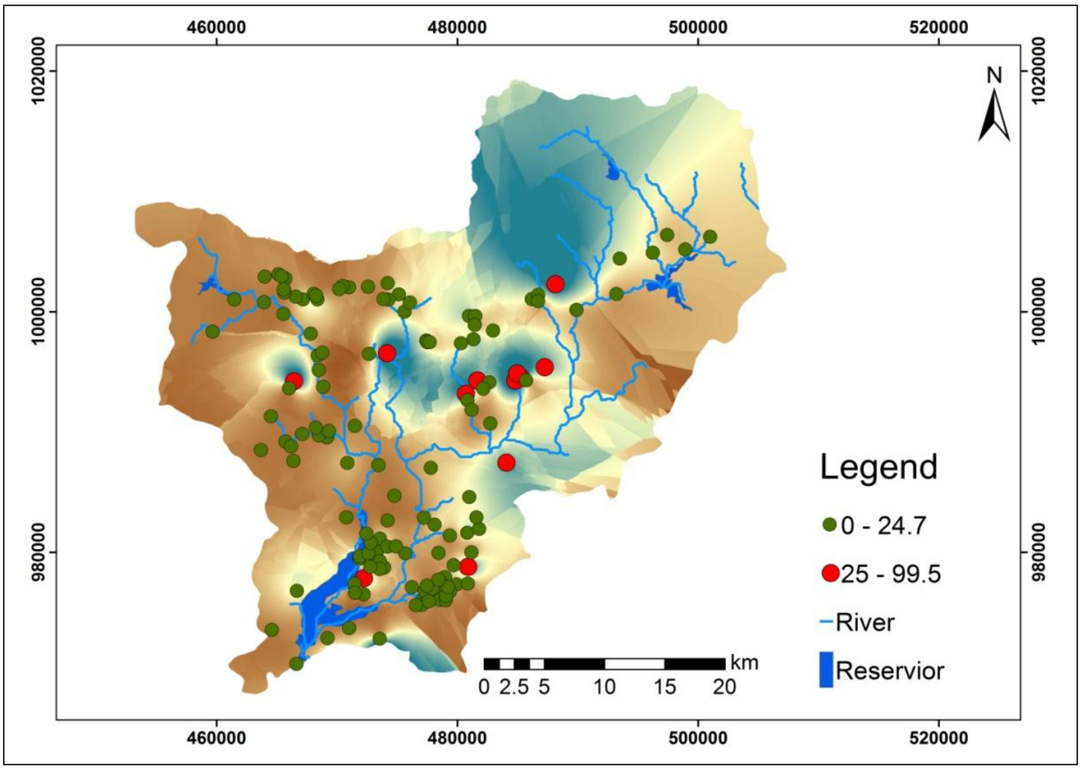

Figure 4.9: Spatial distribution map of Sulfate.

4.1.10 Ammonia/Ammonium

Maximum allowable limit of WHO standards for ammonia is 1.5mg/l. In this area it ranges from 0.1 mg/l to 2.71 mg/l which is above the standard. Industrial pollution increases the amount of ammonia which is formed by bacterial decay of nitrogenous organic wastes. Low concentration of ammonia in the area indicates low rate of nitrification process. The catchment is in good range of ammonium except the area near Batu tannery above 1.5 mg/l (Fig 4.10). It shows low contribution for the quality of water in the area.

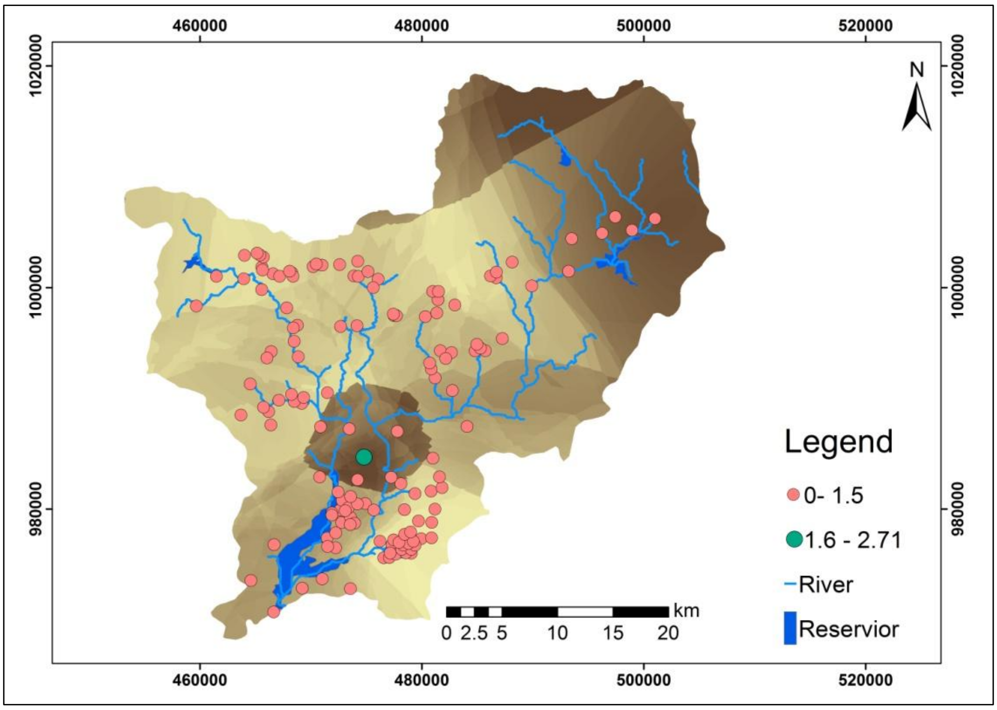

Figure 4.10: Spatial distribution map of ammonia.

4.2 Groundwater quality map

Final groundwater quality map for drinking purpose was created by overlying the ten parameters raster maps which were produced by kriging in ArcGIS spatial analyst extension. This map is useful to classify the areas with excellent, very good and good groundwater quality. From the ten groundwater parameters EC can represent all dissolved parameters so the highest weight is given (50) and as the area is close to the rift system it can be highly affected by fluoride (30). Nitrate and sulfate which are the next parameters which affect the groundwater quality of the catchment have a weight of 18 and 2 respectively.

Generally groundwater at the central and southeast catchment is very good and good in small parts of the area. The other parts of the south and the north have excellent groundwater quality (Fig 4.11). High surface run-off occurs from the steep slope area of the northern part. Groundwater flow direction of the catchment is from north to south. Water can infiltrate easily in to the ground in the lower catchment as it is dominated by fractured volcanic rocks and vertisols which are clayey soils with deep wide cracks. Domestic wastes from the settlement area, wastes from factories and fertilizers are the major cause for pollution.

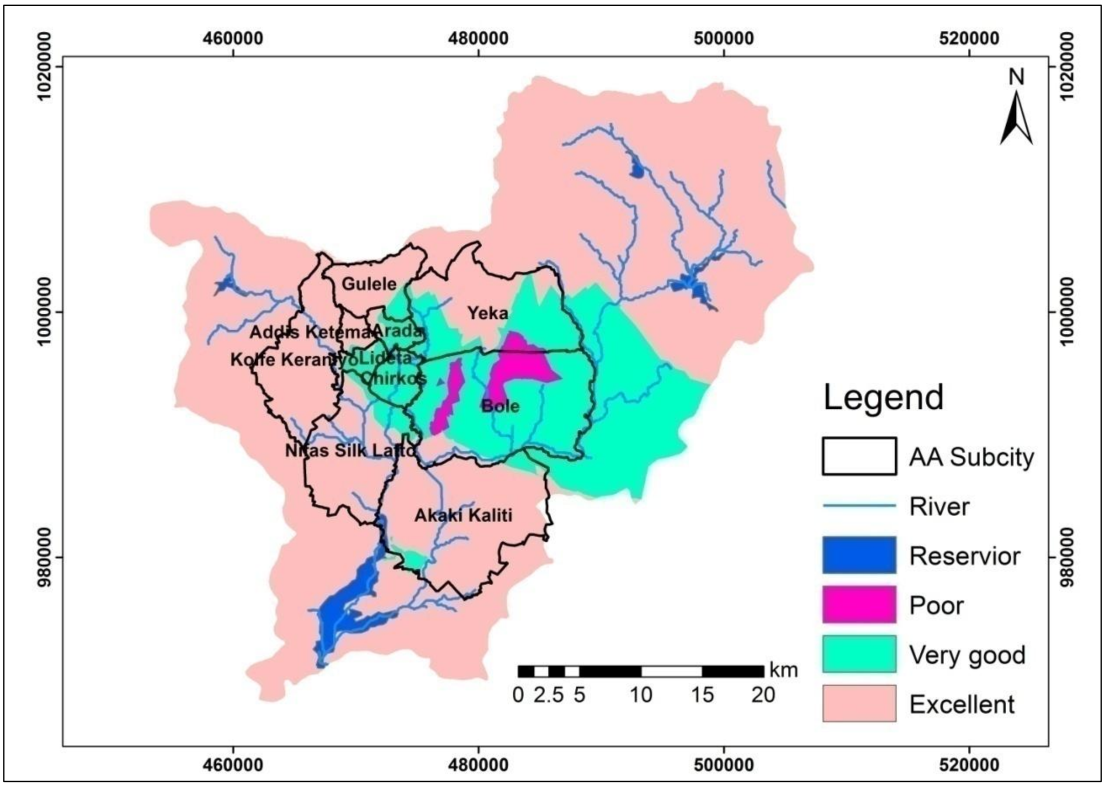

Figure 4.11: Ground water quality map.

4.3 Water Quality Index (WQI)

The values of selected groundwater parameters were used for calculating WQI which shows the role of various physico-chemical parameters on the overall quality of drinking water. The following formulas are applied for the calculation.

WQI=Antilog [$\sum^{n}_{i=1} W_i \log10 q_i$]…………………. eq (1)

Wi= K/Sn………………………………………. .eq (2)

K=1/1/vs_1+1/vs_2…1/vs_n……………………………eq (3)

q_i=[Va-Vi/Vs-Vi]*100……………………………. ..eq (4)

Where; K=constant

Sn/Vs=WHO/DEDWS standard value of the parameters

Wi= weghtage factor

qi= quality rating

Va= actual value of the parameters obtained from laboratory analysis

Vi= ideal value of the parameters, PH=7 and 0 for other parameters

The estimated WQI were compared with the land-use/land-cover of the area using tables. Table 4.1 describes the standard and weightage of the parameters.WQI integrates complex data and generate map and describe water quality status by reducing large quantity of data in to a single number. The results from laboratory for the parameters are listed in table at the end in the appendix.

Table 4.1 Water quality parameters, their standard and weightage

Parameters	**Standard (Sn &Vs)**	**1/Sn**	**K**	**Weightage(Wi)**
EC	1500	0.0006	0.72	0.00048
Sodium	200	0.005	0.72	0.0036
Potassium	200	0.005	0.72	0.0036
Calcium	200	0.005	0.72	0.0036
Magnesium	150	0.006	0.72	0.0048
Chloride	250	0.004	0.72	0.0028
Fluoride	1.5	0.66	0.72	0.481
NH_4	1.5	0.66	0.72	0.481
NO_3	45	0.022	0.72	0.016
Sulphate	400	0.0025	0.72	0.001
		Total 1.38		**1**

All units are in mg/l except Electrical conductivity (EC), µs/cm.

Table 4.2 Water quality index and status of water quality

Water quality index	**Water quality status**
0-45	Excellent
46-55	Very good
56-75	poor

(Source: Singh & Khan, 2011).

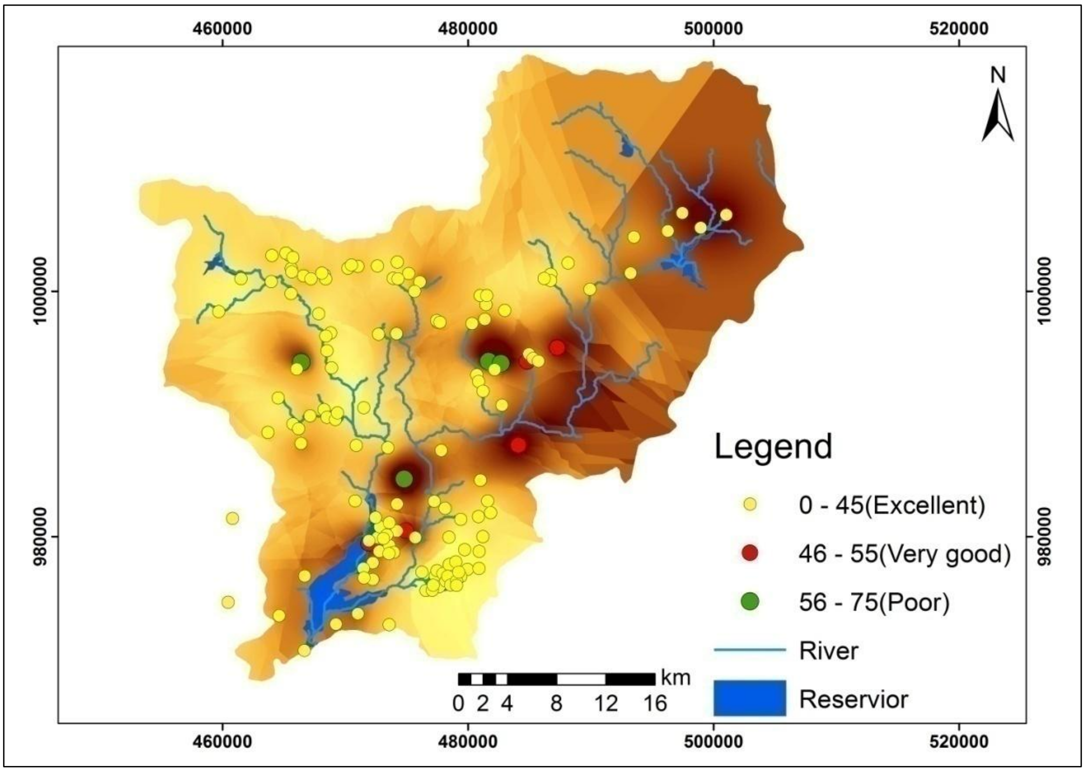

Figure 4.12: Water quality index map.

As indicated in (Fig 4. 12) the water quality index map of the area classified in to Excellent, very good and poor range based on the value of water quality index (Table 4.2). It ranges from 1.08 to 73.81.

4.4 Correlation of water quality index with land-use/ land-cover

Groundwater samples collected from 145 boreholes in Akaki catchment shows different value of water quality index which was calculated to determine the suitability of the water for drinking purpose. The study area is categorized in to four land use classes (Fig 4.13). Most of the groundwater samples were collected from the settlement and cropland areas. The correlation indicates there is a linear correlation of the extent of water quality contamination with the land-use/land-cover. Water quality index values revealed that the groundwater at 141 location of the study area is of excellent and very good quality with WQI ranging between 0-45 and 46-55 respectively which can be used for human consumption. 4 samples are of poor quality with WQI ranging between55-75 and cannot be used for drinking.

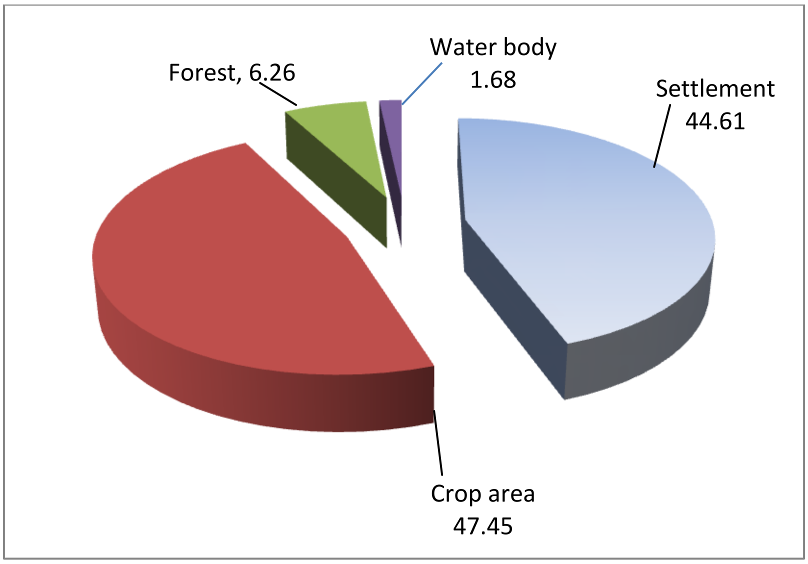

Figure 4.13 Land-use/land-cover distributions.

Table 4.3 Correlation of Water Quality with Land-use/land-cover.

WQI/LULC	Water body	Crop area	Forest	Settlement
Excellent	1	50	0	85
Very good	0	2	0	3
poor	0	0	0	4

One sample taken from the water body of Abba Samuel lake it was rated as excellent (100%). 52 samples were collected from crop areas which were categorized in to excellent (96.15%) and very good (3.85) quality. No samples were taken from forest areas (Table 4.3). The settlement area which is the second dominant land use class of the catchment 92 samples was taken. From these excellent (92.39%), very good (3.26%) and poor (4.35%) water quality was exhibited (Fig 4.14). Most of the area is in excellent groundwater quality except some areas reduced to very good and poor due to natural activity. Even if there is little contribution for pollution from the settlement the fault system contributed greater for the contamination in the Akaki catchment.

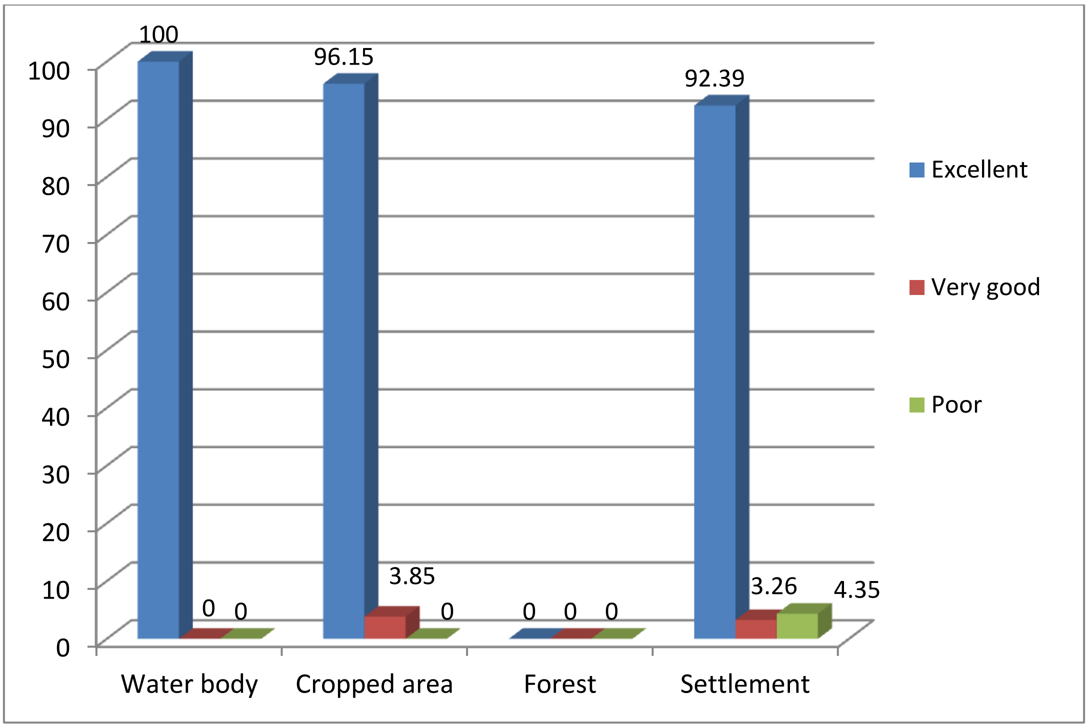

Figure 4.14 Correlation of land-use /land -cover with water quality.

4.5 Hydrochemistry

The spatial distribution of Total dissolved substance (TDS) is directly related with electrical conductivity. TDS is the amount of dissolved substance found in the water. TDS value more than the limit may cause gastro-intestinal irritation. The concentration is lower in the highland areas around Intoto where there is high recharge and short residency time for rock-water interaction. It's higher in the discharge areas of the lower catchment due to runoff from highlands and along fault lines. There is wide range of variation of TDS from 2043.5 to 89.5 (Fig 4.15). Groundwater flow direction of the area is dependent on the topography and geological structure of the area. TDS map can confirm the groundwater flow direction. There exist ion exchange reaction between sodium and calcium due to long residency time and presence of clay soil so that calcium is substituted by sodium. For the variation of water type in an area the litho logy and residency time of the water in the aquifer are the major contributors. In the study area the water quality is mainly controlled by the tectonic activity occurred and presence of volcanic rocks. The chemical composition of groundwater is the result of rock-water reaction. The effect of pollution also influences groundwater chemistry. Maps are useful to show the distribution of water composition and quality. Water chemistry provides information about the processes and environments through which the water circulated.

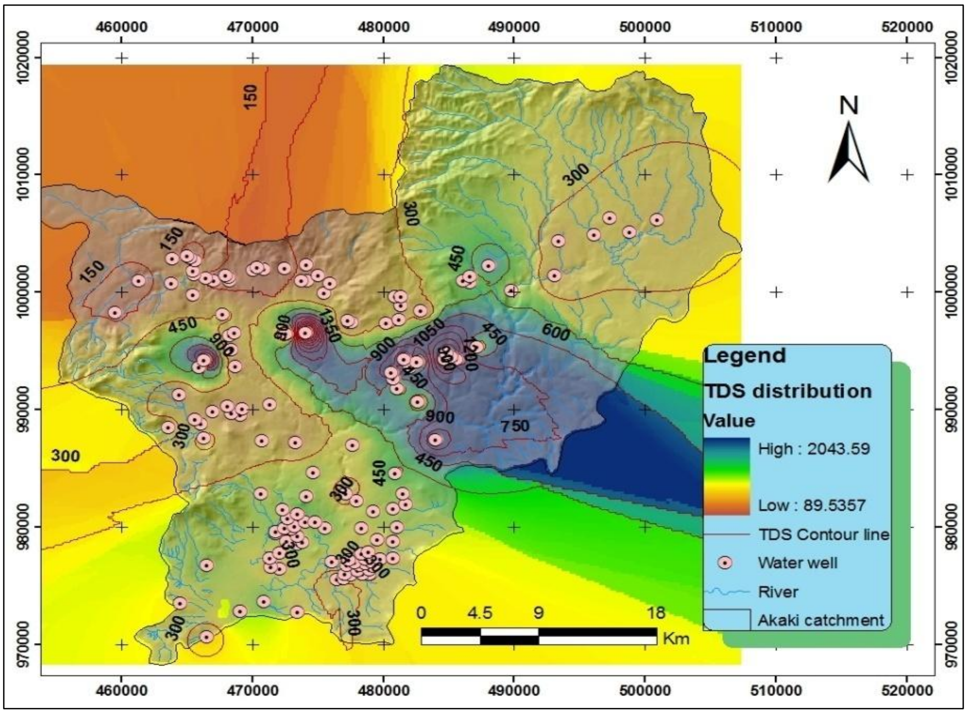

Figure 4.15 TDS distribution map.

Analysis of groundwater chemistry is useful for classification of water type, determine the direction of groundwater flow and recharge/discharge areas. The major cations were calcium and sodium. The major anions were bicarbonates and chorine. Magnesium and potassium are in limited concentration. Fluorine and nitrate are pollutant indicators. The groundwater chemistry uses standard classification scheme. Composition of groundwater is expressed as percentage of concentration of main cations and anions. Concentration of main ion is presented in mili equivalent per liter of sample (Meq/l). The excel data is the input to Aquachem 4.0 software to classify and the final map produced in ArcGIS using interpolation through inverse distance weightage (IDW).

There are three hydrochemical types based on concentration of main ion;

1. Basic type: The concentration of main cation and anion is higher than 50 Meq%.
2. Transitional type: The concentration of the main cation and anion range between 35 and 50 Meq% for one ion only.
3. Mixed: The concentration of cation and anion are not over 50 Meq% and only one ion has its concentration over 35 Meq%.

The water type in the study area is dominated by transitional and basic nature. Ca-HCO_3 basic is the major type in the central and northern part which is dominated by volcanic rocks. Na-HCO_3 type is along the fault line with high TDS value. Na-Cl basic type occurs at some part of the lower catchment due to anthropogenic influences (Fig 4.16).

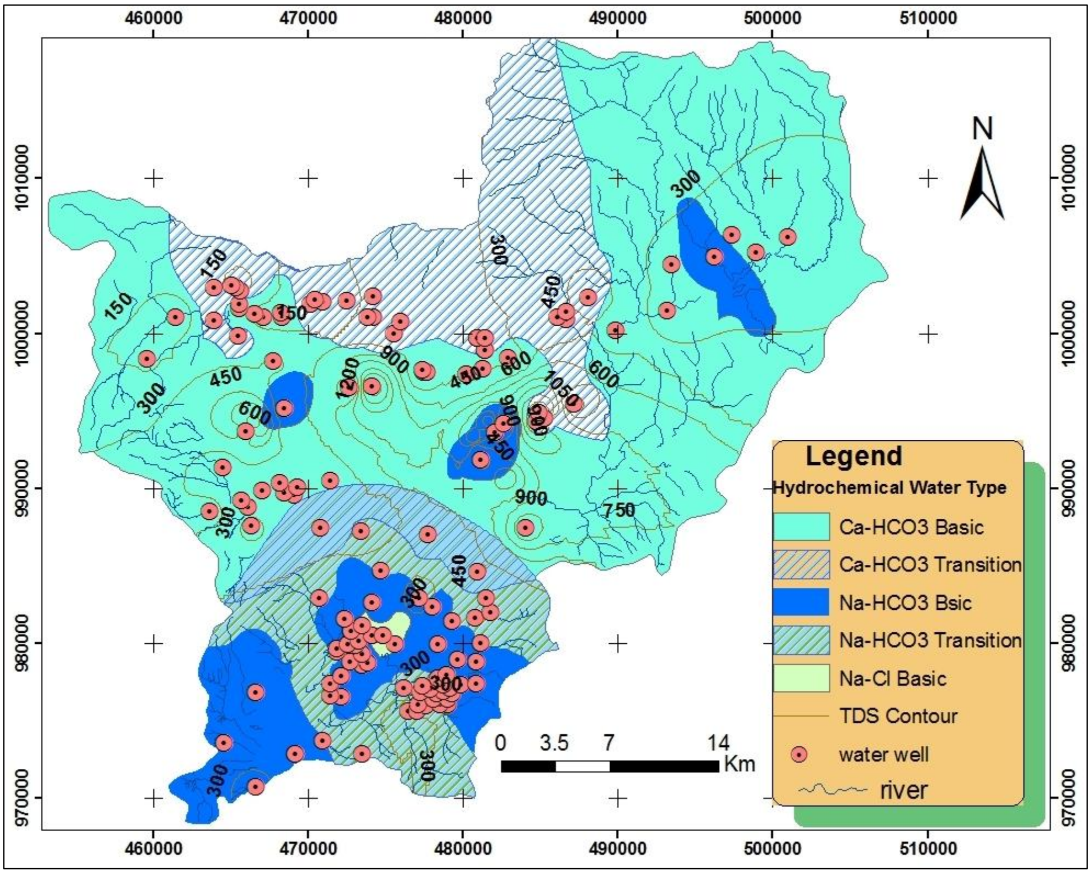

Figure 4.16 Hydrochemical map.

4.6 Drastic Model

The name DRASTIC represent each of the seven input parameters; (Fig 4.17)

- Depth to water table
- Net recharge
- Aquifer media
- Soil media
- Topography
- Impact of vadose zone
- Hydraulic conductivity

DRASTIC model is useful for indicating ground water vulnerability to contamination or the tendency for contaminants to reach the water table after introduction at the ground surface.

Each of the seven parameters is mapped from existing datasets. Each map rated from 1 to 10 (lowest to highest vulnerability) according to their relative ability to protect groundwater from contamination and multiplied by a weighting factor (1 to 5) depending on how important the parameter is for overall vulnerability (Table 4.3). Each of the seven parameters can increase or decrease the vulnerability according to their properties. The weighting system is based on (Rahman, 2008).

As recharge to the aquifer increases, vulnerability will increase. Larger grain size, high fracturing and high permeability are responsible for the increase of vulnerability as contaminants can move quickly through them. The increase of slope can decrease vulnerability as contaminants runoff than infiltrate. The Highest weight 5 has been assigned to depth to water level and impact of vadose zone.

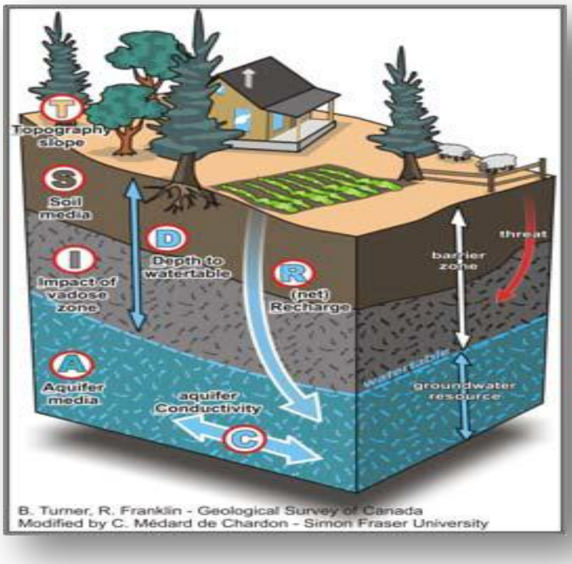

Figure 4.17 DRASTIC parameters.

Source (Liggett *et al*., 2011).

Table 4.4 DRASTIC parameter.

No	**Parameters**	**Range**	**Rating**	**Index**	**Weight**
1	Depth To Water Level	0.3-86m	10	50	5
		87-173m	9	45	
		174-260m	5	25	
2	Net Recharge	<40	3	12	4
		40-80	8	32	
		>80	10	40	
3	Aquifer Media	Clay	3	9	3
		Fractured basalt/ignimbrite	10	30	
		Scoracious	8	24	
4	Soil Media	clay	6	14	2
		Silt loam	5	10	
		Sandy loam	7	12	
5	Topography	0-20	1	1	1
		20-40	3	3	
		40-60	6	6	
		60-80	9	9	
		80-100	10	10	

6	Impact of Vadose Zone	Clay	3	15	5
		Fractured basalt/ignimbrite	10	50	
		Scoraceous	8	40	
7	Hydraulic Conductivity	0.02-30	6	18	3
		31-60	8	24	
		61-90.16	10	30	

1. **Depth to water level**

Borehole point data are interpolated and reclassified in to three categories based on the index value (Fig 4.18). Each Ratings and weight is multiplied to get the index value (Table 4.4). Deeper the ground water level smaller is the rating value. As the distance between the ground surface and the water table determines how contaminants can reach groundwater. Water level located at small distance to the surface is more vulnerable.

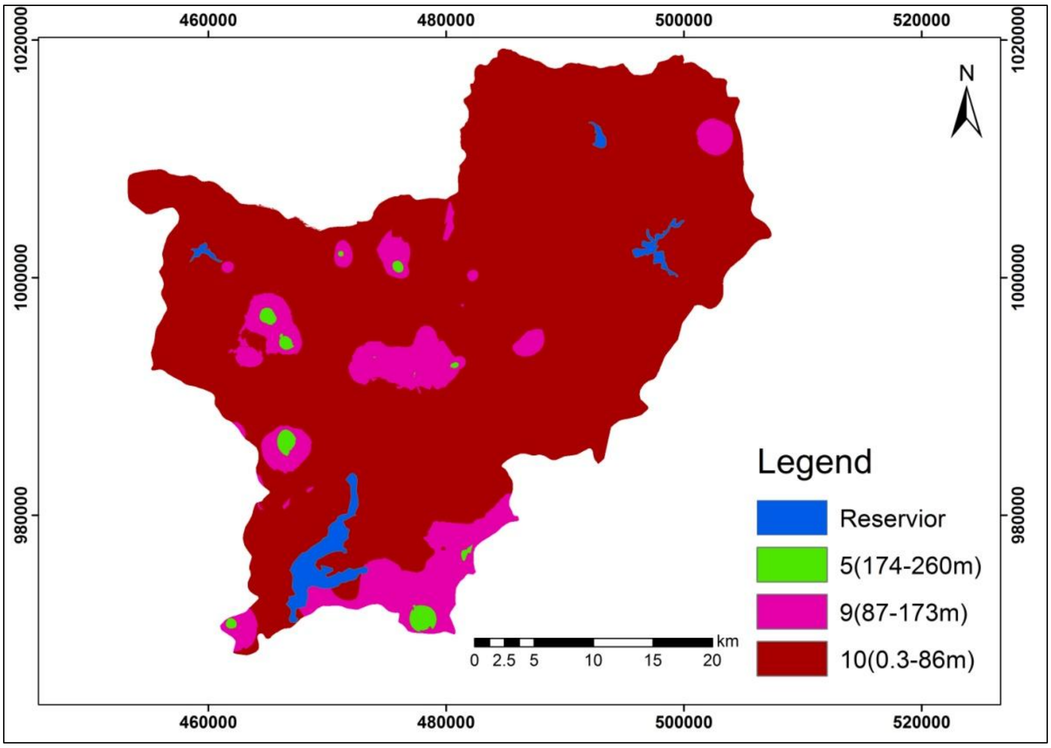

Figure 4.18 Depth to water level map

2. Net recharge

Areas with high groundwater recharge have high rating which is vulnerable to pollution. Recharge water is significant to contaminant transport to saturated zones. The range was given depending on the rock exposure. For fractured ignimbrite and basalt (80 mm) high rating was given (Fig 4.19). For Ash areas (40 mm) low rating was given. The map generated based o the classification on Table 4.4.

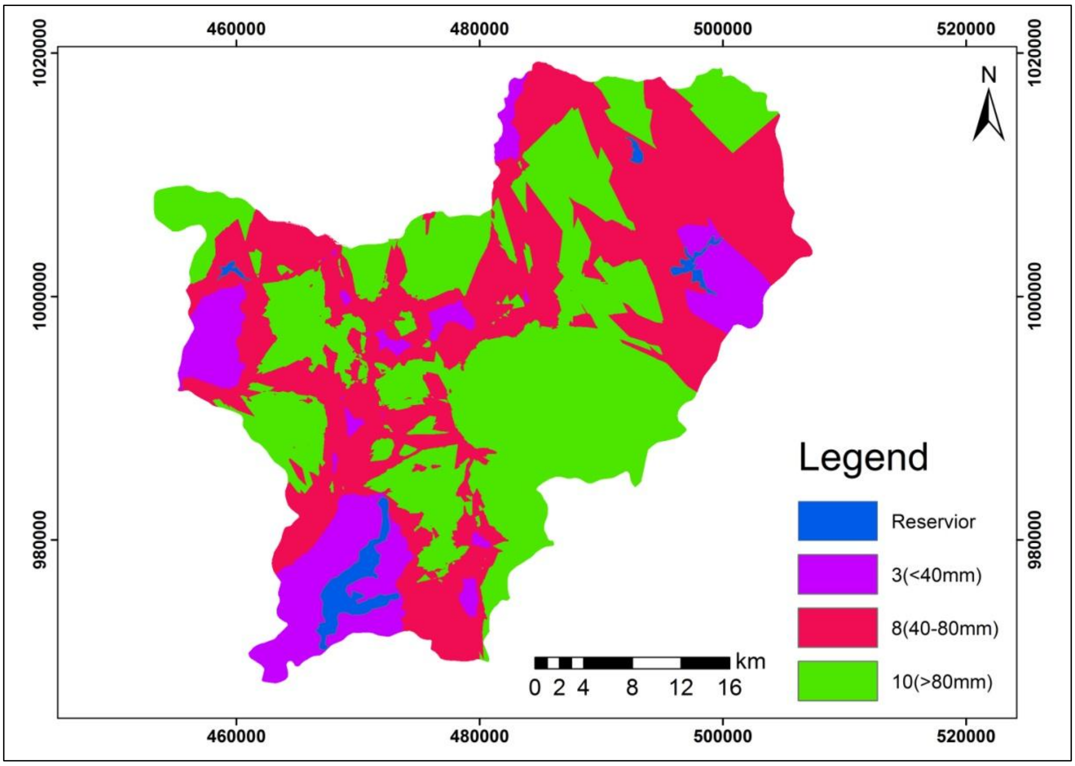

Figure 4.19 Net recharge map

3. Aquifer media

It refers to the unconsolidated or consolidated rock formation which serves as water storage. The larger the grain size and more fractures in the aquifer there will be high permeability which increases the vulnerability to pollution. High rating is assigned to fracture and vesicular rocks (saturated or unsaturated). Clay has low rating and fractured basalt have high rating. (Fig 4.20)

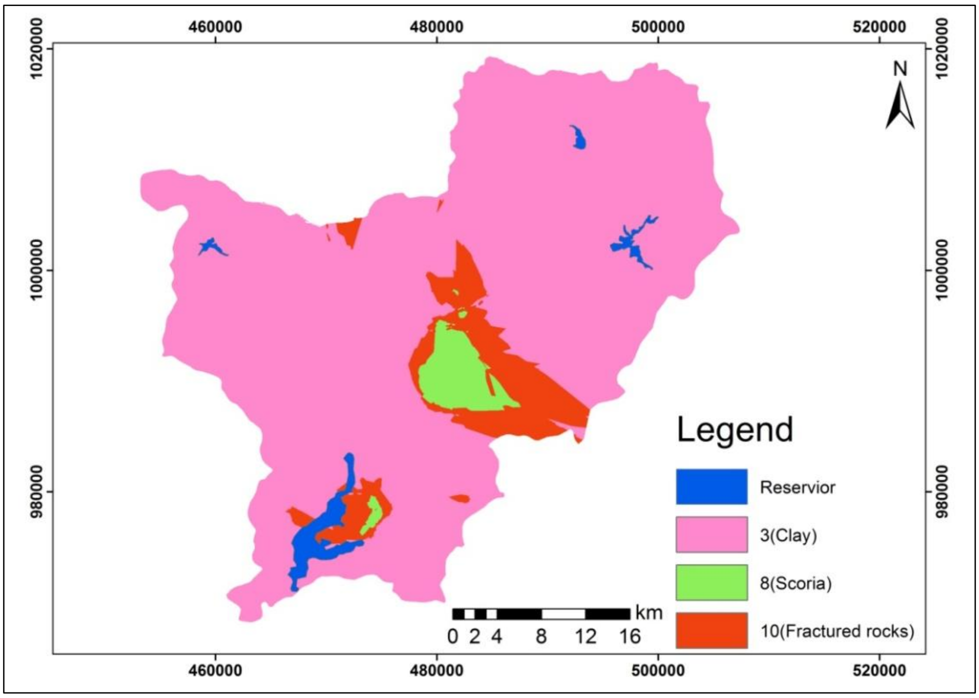

Figure 4.20 Aquifer media map

4. **Soil media**

Fine soil media prevent contaminant migration. Clay soils dominate the study area. Coarse soil medium have high rates than fine soil media. The soil type of the area classified in to clay, sandy loam and silt loam (Fig 4.21). Sandy loam has high rating and silt loam has low rate and low index.

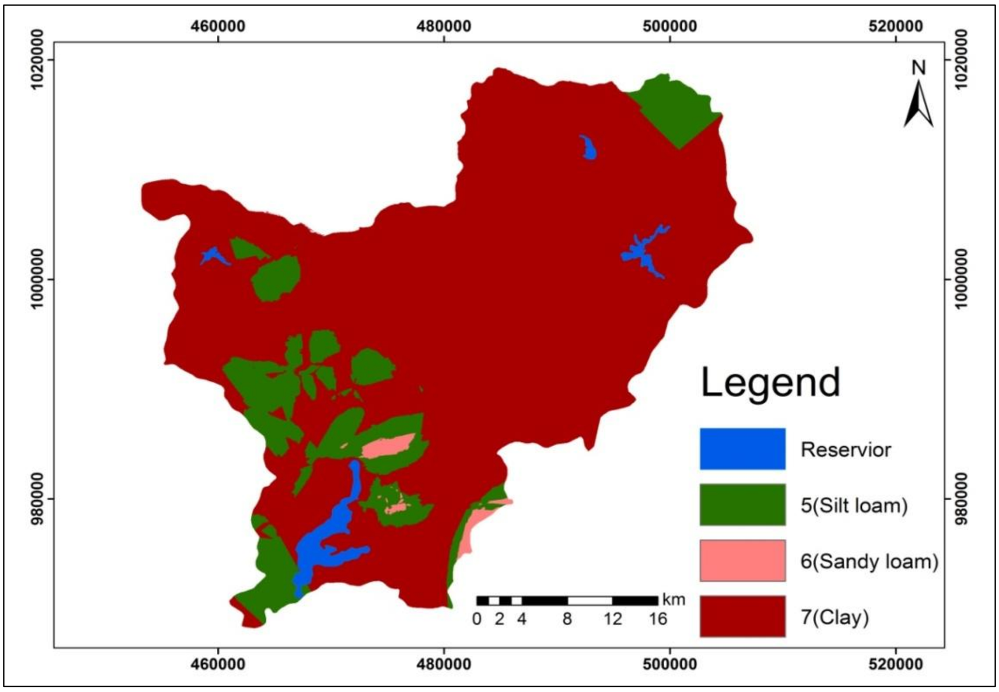

Figure 4.21 Soil media map

5. **Topography**

Topography refers to the slope of the area which is extracted from DEM and divided in to five classes. Flat areas assigned high rate (Fig 4.22) because in flat areas the run-off rate is less so contaminants can infiltrate in to the groundwater. Generally infiltration and contaminant migration increases in lower sloping areas. Least weight was assigned for the slope and high weight was given for the impact of vadose zone and depth to water level.

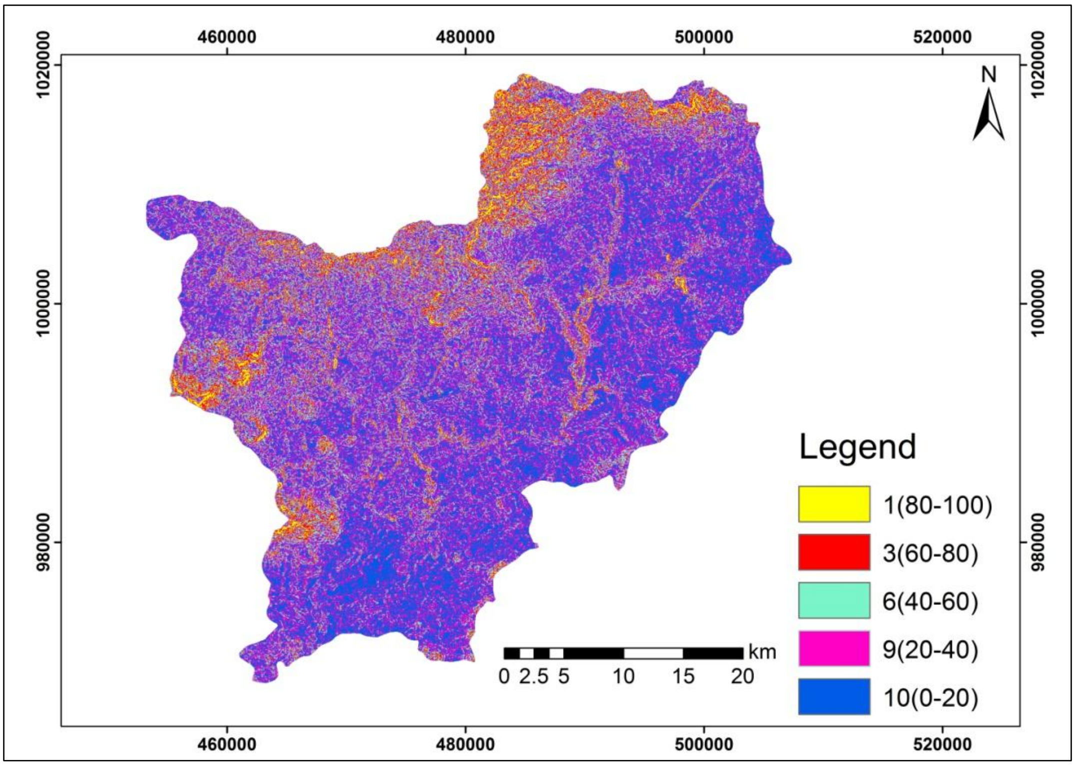

Figure 4.22 Slope map.

6. **Impact of vadose zone**

It has high impact on water movement if it is composed of permeable materials. High rate is assigned for permeable materials in the vadose zone. Fractured rocks porous materials have high permeability with high rating (Fig 4.23).

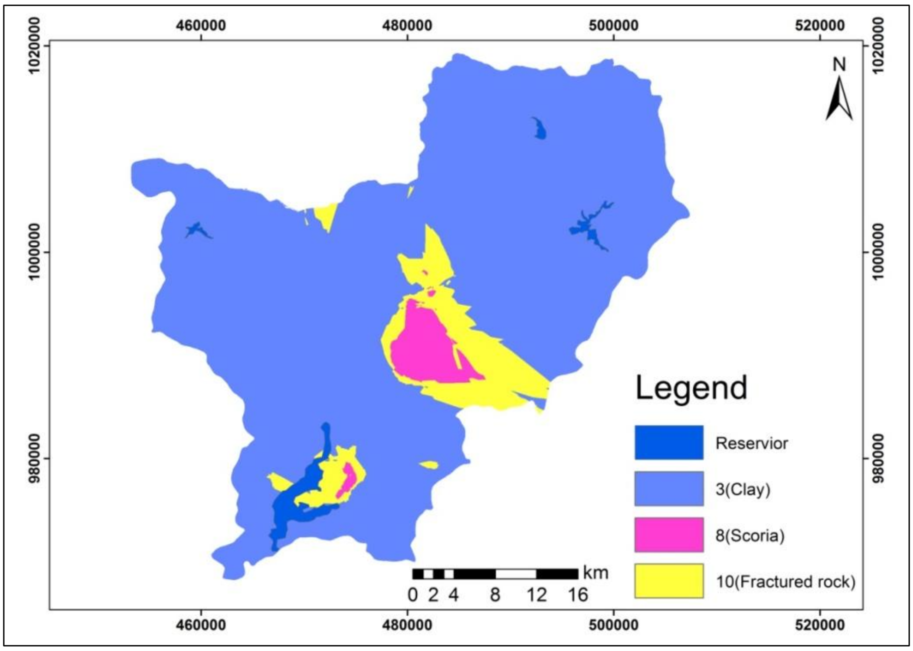

Figure 4.23 Impact of the Vadose zone map.

7. **Hydraulic conductivity**

It is the ability of the aquifer to transmit water. An aquifer with high hydraulic conductivity is more vulnerable to contamination. This is different from an aquifer media in which impermeable materials can conduct water through fractures and for a hydraulic conductivity the materials are rated based on their ability to conduct water through their interconnected pores. High rating is assigned to high conductivity of the aquifer (Fig 4.24).

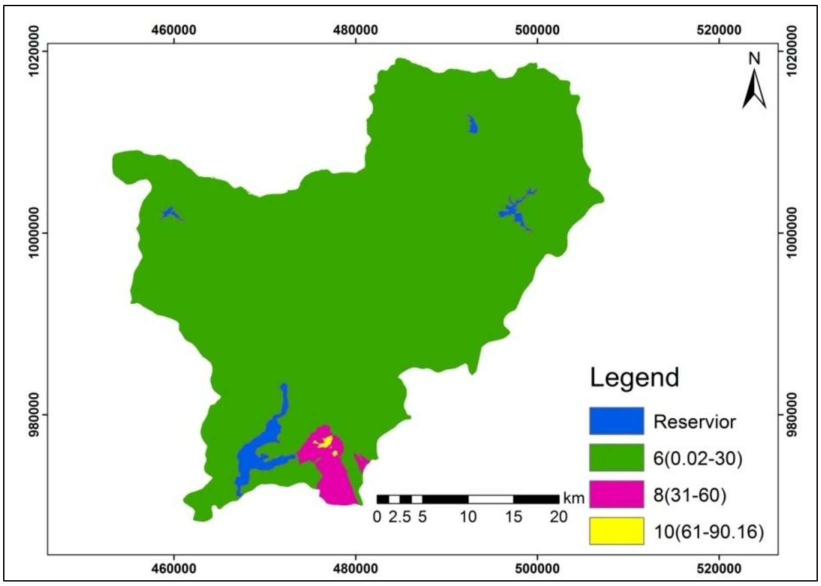

Figure 4.24 Hydraulic conductivity map

Finally, the map of seven parameters was overlaid. The higher the DRASTIC index value is the greater the ground water pollution potential. The range is classified in to five classes (Fig 4.25).

The parameters were prepared by interpolating the point data using ArcGIS software. Thereafter the raster maps were reclassified based on their rating values. The index value ranges from 208 to 92; it is calculated by the weighted sum overlay in spatial analyst tool. The weighted sum allows the calculation of several raster maps being weighted. The final DRASTIC map was classified in to very low (92-115), low (115-138), moderate (138-161), high (161-184) and very high (184-208).

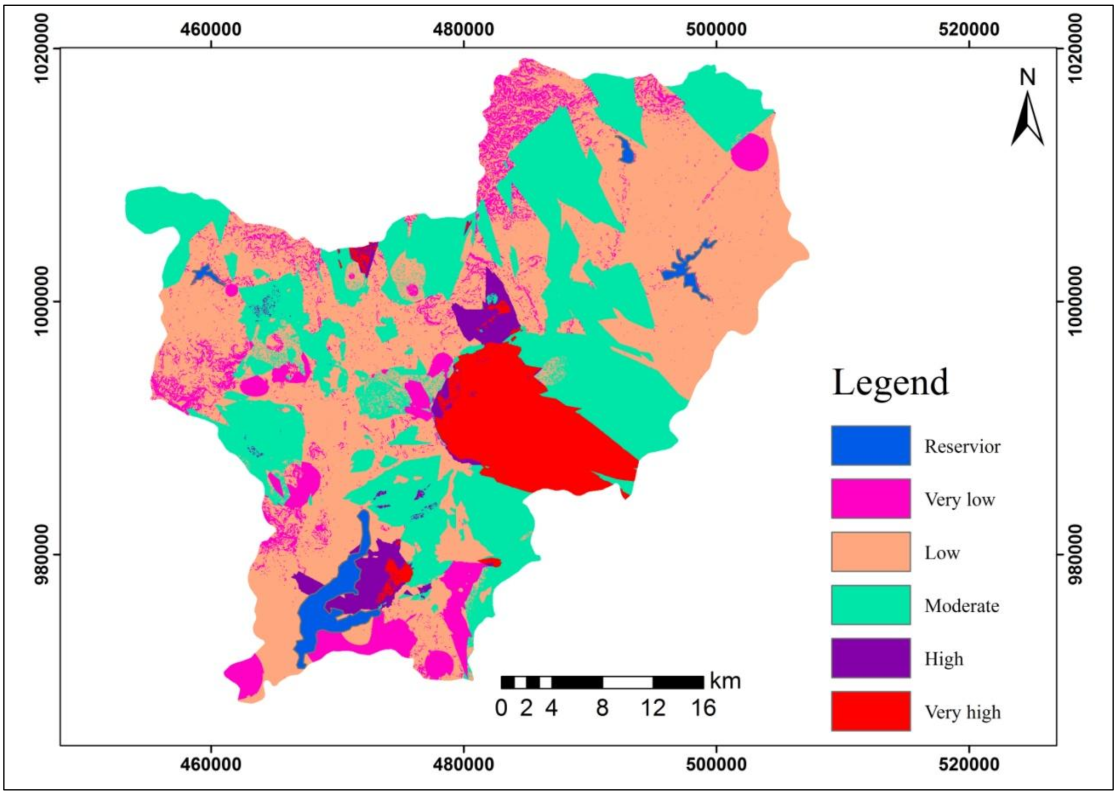

Figure 4.25 DRASTIC model of Akaki catchment map.

Most of the catchment's groundwater is at low and moderate risk in terms of pollution potential. The steep slope having large amount of runoff and low amount of infiltrations are less vulnerable areas. Moderate recharge areas have moderate risk to groundwater pollution as it carries contaminants to the water table Areas with high net recharge and fractured basalt/ignimbrite rocks have very high vulnerability which covers small part of the east and southern catchment. High hydraulic conductivity at the lower catchment is also responsible for a very high vulnerability. Shallow water table made the area to have high risk to pollution.

4.7 Drastic index validation

To check the efficiency of using DRASTIC method to assess groundwater vulnerability nitrate concentration was correlated with the DRASTIC index. Nitrate concentration value was plotted on the vulnerability map (Fig 4.26).

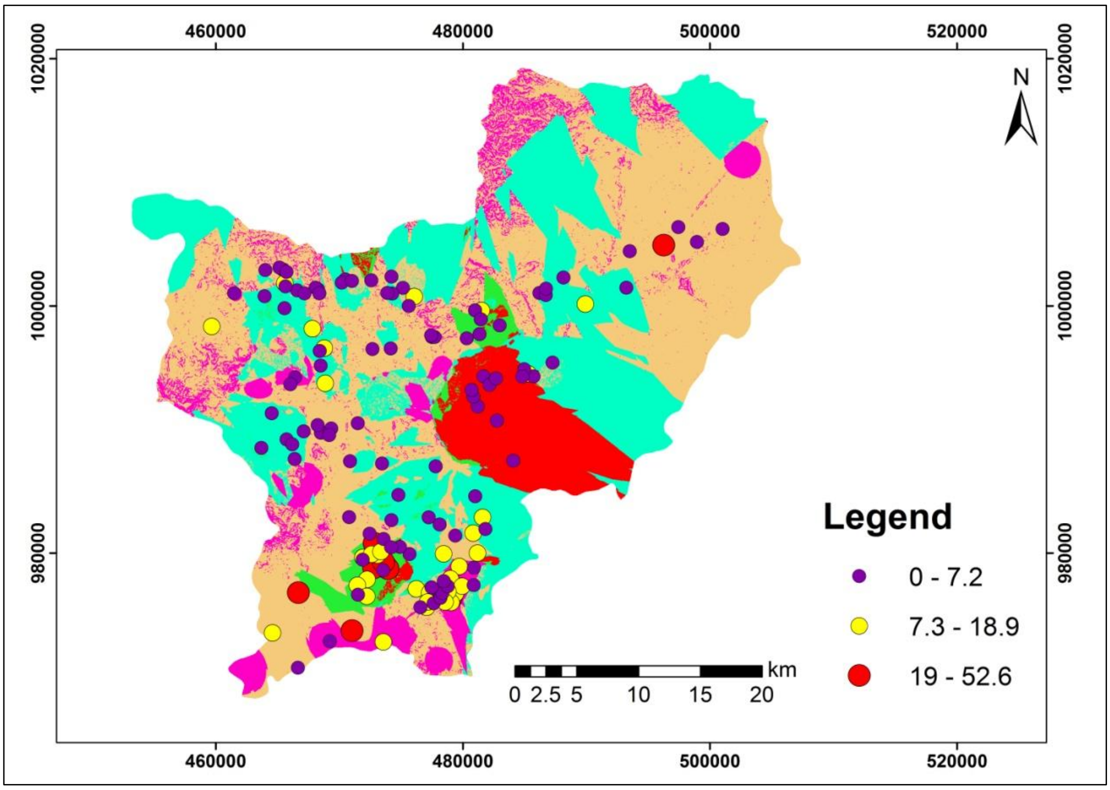

Figure 4.26 Correlation of DRASTIC index with Nitrate map.

High nitrate concentrations are observed in very high, high and moderate groundwater pollution risk areas; Low concentration observed in low vulnerable areas which show good correlation with DRASTIC approach. To the contrary, even if the DRASTIC index shows low risk at some part of the southern and northern part, high nitrate concentration observed. Nitrate can be high because of the agricultural activity in the area and sewage from septic tanks. But the low hydraulic conductivity and recharge water due to the dominance of silt/clay in that area make the groundwater less vulnerable. As the high vulnerable areas at the east central catchment have high hydraulic conductivity, dominated by fracture basalt/ignimbrite and high net recharge; the increment of nitrate concentration or other contaminants can pollute the groundwater. The cause for the increment of any contaminants might be sewage from septic tanks, agricultural activities or industrial wastes.

CHAPTER FIVE

5.1 DISCUSSION

The groundwater flow direction is influenced by the geological structures as the catchment is located where there were tectonic activities. Large mountains and volcanic rocks characterize the boundary. Clay soil dominates the area and the rivers have a dendritic drainage pattern. The land use pattern categorized in to four such as settlement, crop land, forest and water body. Settlements have large coverage area than the others. Groundwater samples were taken from 145 boreholes to assess the groundwater quality of the area. In this study the application of remote sensing and GIS were applied to the groundwater quality and model its vulnerability. Different methodologies and materials used to achieve the objectives of the study.

Groundwater is an important source of drinking water which can become contaminated due to human activities or natural sources. The use of GIS and remote sensing benefited groundwater by estimating its vulnerability to pollution potential and mapping the spatial distribution maps of the parameters. The ten groundwater parameters selected to produce the final groundwater quality map were Ca, Na, K, Cl, NH_4, F, Mg, So4, EC and No_3.Interpolation is the method used to map their distribution. It is the estimation z values of a surface at an un sampled point based on the known z value of surrounding points (Nas and Berktay, 2008). Inverse Distance weightage (IDW) and kriging were the two techniques of interpolation. IDW was used in this study for a hydro chemical map generation and groundwater quality map carried out by the overlapping of the thematic maps produced through kriging. Their values were classified based on WHO standard for drinking purpose where some parameters such as calcium, chloride, potassium, magnesium and sulfate are within the acceptable limit. Nitrate, electrical conductivity, fluoride, sodium and ammonium are above the acceptable limit. Majorly the natural sources due to the fault system and some sewerage and waste from tanneries are the causes.

Usali ad Ismail (2010) suggested that anthropogenic activities in industrial area have effect to water bodies. Domestic wastes and agricultural wastes can lead to deterioration of groundwater quality. Thus the groundwater quality monitoring and assessment is needed to create awareness of the public, the consequences of present and future problem of contamination to groundwater resources. The result in the groundwater quality map is similar with the water quality index value category. Areas of high and moderate WQI have poor and very good water quality respectively. Low WQI shows excellent water quality. So areas of polluted groundwater are indicated in the thermal filwuha areas and very good in the central and eastern parts whereas most parts have excellent quality which can be used for human consumption. Water quality index is one of the most effective tools to get information of the overall influence of the parameters on the quality of water bodies. It is a mathematical equation used to transform large number of water quality data in to a single number (Reza and Singh, 2010). The water quality index in the Akaki catchment was calculated using equations and interpolated to produce the map which was classified in to excellent (0-25), very good (26-55) and poor (51-75) in other studies. Even if there were no previous work on WQI estimation of this area; based on the classification given above and the groundwater quality map of the area this study revised the range in to excellent (0-45), very good (46-55) and poor (56-75). The correlation of this value with the land use pattern indicates some contribution of pollution from the settlement areas due to septic tank leakage.

Groundwater vulnerability map shows groundwater pollution potential of the area. Drastic model is the major method of an overlay and index method to assess groundwater vulnerability. One of the drawbacks of this method is its subjectivity in rating and weighting the model parameters. A region with high vulnerability may not have a source of contamination. A region with low and moderate vulnerability may have high level of contamination (Al-Adamat et al., 2003).

The Drastic index values in the study area were classified in to five classes. It ranges from 92-208. It was then validated with nitrate concentration of the area. Low nitrate concentration indicates low vulnerability of the area and vise versa. Area in the east and some part at the lower catchment are very high and high to groundwater pollution potential. The high value of Drastic index is due to the fault system except the lower catchment with high Drastic index due to human activities. Most of the area have moderate to low pollution potential. Each of the seven parameters determines the value with different weight. Weighted sum overlay analysis produces the final Drastic map of the area.

The hydrochemical and isotopic signature clearly demonstrates the existence of different water type with indications of groundwater pollution in few places.

Hydrochemical analysis indicates Ca-HCo_3 water type in the north and Na-HCo_3 water type of the filwoha thermal system (Tenalem Ayenew, 2008).

The hydrochemical characteristic of groundwater in Akaki catchment volcanic aquifer reflects the interaction of various natural processes and human activities. With increased residency time and longer flow path, Groundwater interacts with more aquifer material and chemical species (Alema Tesfaye, 2009).

In the study area the lower catchment Na-HCo_3 basic water type is dominant where. Due to the high residency time and longer flow path the calcium is substituted by sodium. Some Na-HCo_3 water type is found along the filwoha thermal system. Ca-HCo_3 is dominant in the northern highland discharge areas.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Generally, remote sensing and GIS is an advanced and effective tool for the protection of natural resources, groundwater. The objective of the study was to map groundwater quality map. The specific objectives were achieved and hydro chemical map of the area were produced. The spatial distribution map of selected groundwater parameters were produced showing the variation in concentration and classified according to WHO standards. Ground water quality map produced by overlay analysis and the water quality index map showed the quality of water in the area. Source of pollution in the area were determined. The hydro chemical map of the catchment revealed that Na-HCO_3 is dominant along the fault system. Vulnerability of groundwater increases at the central and small part of the lower catchment. Recharge areas are more vulnerable to groundwater pollution. The aquifers in the area are fractured basalt, scoria and ignimbrite. The high index values also indicate the precautions that should be taken for groundwater resource management in the catchment. The seven parameters of drastic model were each mapped with their rating and weight given to generate the vulnerability map through overlay. Pie chart and graph were used to relate the water quality index with the land use pattern. More groundwater samples were taken from the settlement and crop land. The point data in excel were the input to produce WQI map which determined the suitability of water for drinking. Large quantity of data can be reduced in to a single value by using an equation of determining the rate and weightage. It is a simple and accurate method to use. The value ranges from 73.81 to 1.08 which was then classified in to three.

Vulnerability is different from pollution risk. Pollution risk depends on the presence of pollutants entering the aquifer. It is possible to have high aquifer vulnerability but no risk of pollution if there is no pollutant. Drastic can be used to prevent further pollution. This study help policy makers as it gives an indication of vulnerability to groundwater contamination.

6.2 Recommendation

Addis Ababa Government Environmental Protection bureau should put rules and regulation in order to prevent the pollution of Akaki River. The regional government should also contribute in the improvement of sanitary facilities to all household. Disconnecting pit latrines from entering the water system and using high technology treatment by blending the contaminated water with clean water is suggested. Continuous monitoring and assessment is the study area through GIS is recommended to update groundwater data. Developing use of advanced technologies such as remote sensing and GIS software's is important. Rules and regulations for industries and public waste disposal should be given. Improved septic tanks are necessary to prevent leakage of wastes to the groundwater. Creating awareness to the public about the cause of groundwater pollution in the future and how to protect this natural resource is important. Further studies are recommended on the application of remote sensing and GIS for groundwater quality assessment and estimation of WQI. The hydro chemical map, Drastic model and its correlation, mapping of the concentration of groundwater parameters in the area can be a sample for further work and investigation in this area.

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References

Appendix-1

	Locality	Easting	Northing	EC	TDS	ToC	pH	NH4	Na	K	Ca	Mg	Fe
1	Tuka Gaditi	441202	937730	344	226.0		7.1	0.4	17.0	6.8	46.6	9.2	0.1
2	Tuka Gaditi	443143	937853	311	174.0		7.0	0.1	8.4	1.8	42.0	12.8	0.0
9	Bantu-Areda Leka	424000	952736	507	312.0	20.0	7.8	0.1	20.0	6.1	68.7	17.5	0.0
10	Bantu	429969	952736	588	376.0	20.0	7.4	0.2	67.0	9.5	41.8	13.8	0.0
18	Muti Dayu	451590	954524	427	276.0	20.0	7.3	0.2	24.0	6.1	67.3	6.1	0.1

26	Sego	464431	961268	196	132.0		6.9	0.1	8.6	4.8	30.3	3.8	0.2
31	Lalise	428566	961644	227	139.0	23.3	8.6	0.3	28.9	5.3	24.1	10.7	0.2
32	Awash Melka	456740	962388	310	189.0		7.9	0.1	26.6	5.5	27.8	6.9	0.1
33	Melkakunture-Awash	456314	962592	188	115.0		7.4		43.4	3.0	16.0	3.9	0.0
34	Awash Sheba Flower	454852	962780	176	107.0	17.3	8.6		38.0		8.0	2.0	0.0
35	LagaDawo	410362	964468	174	106.0		7.2	0.1	23.8	1.3	11.2	3.0	0.1
36	TajabDawo	411878	965587	470	287.0		8.3		30.0	2.5	37.0	9.0	0.6
37	BondeDawo	422468	966195	470	356.0	18.3	8.0	0.1	54.4	11.6	35.3	15.6	0.7
39	AA-Filwuha	473276	966535	375	253.0	20.0	7.9	0.3	23.8	2.8	40.1	6.8	0.1
40	Keta	424094	968971	395	246.0	19.2	7.3		19.0	5.0	42.0	14.0	0.1
41	Kelecho#2	445144	969045	251	163.0		7.2		29.0	3.0	16.0	5.0	0.1
42	Becho	426362	969316	3359	2049.0	25.4	7.5		840.0	15.0	6.0	2.0	0.4
43	kelecha	445354	969451	380	250.0		7.4		7.4	3.2	40.8	15.5	0.0
44	Wasarbi Nadi#1	432820	969800	498	305.0		7.8		45.0	7.7	60.0	7.3	0.0
47	Tita Maru	405640	970310	135	89.0		6.8		11.5	4.6	9.6	3.4	0.2
48	Tikure InchiniAbeyi werabesa	340786	970444	201	130.0		7.8		18.0	4.9	21.6	4.0	0.0
49	Alem Gena-Dika	466662	970715	248	168.0		7.4		14.0	4.3	30.4	6.3	0.0

50	Alem Gena-Geja Dera	461930	970844	1035	595.0		8.8		220.0	2.9	10.4	3.4	0.1
52	Becho	426873	970945	489	298.0		7.5		23.0	3.4	39.0	26.0	0.1
53	Koftu	478007	971121	337	206.0		7.0	0.0	34.0	4.6	56.1	14.6	0.1
54	Haro	374782	971227	459	280.0		7.1		36.0	4.9	45.7	20.0	0.1
55	Asgori	427126	971361	615	400.0		7.7	0.1	49.0	6.3	51.7	28.0	0.1
56	Meti KotichaDawo	412247	971408	545	354.0		7.8	2.7	36.1	9.4	33.3	11.7	0.0
57	SankaleDawo	414991	971562	218	336.0		8.5		19.7	4.9	60.1	15.8	0.1
58	Akaki	471677	971640	240	369.0		7.5		65.5	2.7	36.9	14.6	0.1
59	Alem Gena-Dobi	451420	971692	500	332.0		8.4		23.6	5.5	53.7	16.4	0.1
60	Akaki	469738	971752	652	424.0		7.7		33.6	5.1	60.1	20.0	0.0
61	Merero	473576	972379	171	111.0		7.3		4.1	1.3	14.0	4.0	0.1
62	Kelecho Gerbi	407400	972711	429	279.0		7.5		16.1	6.9	26.4	6.3	0.1
63	weini	345151	972810	540	351.0		7.9	0.5	20.4	4.0	56.1	9.7	0.0
64	TW2 Test well No.2	473576	972821	530	385.0		7.6	0.0	40.8	5.3	67.3	15.6	0.0
65	Gerado	469239	972866	540	380.0		7.4		44.2	4.0	56.1	20.4	0.0
66	Kontome	453850	973096	500	330.0		8.4		78.9	3.4	9.6	8.0	0.1
67	Alem Gena-Debel yohanes	445643	973409	430	362.0		7.4		44.2	4.0	91.4	2.9	0.1
68	Jiduka	423375	973439	397	258.1		7.6		37.4	5.3	54.5	22.4	0.1

69	Alem Gena-Gombobdu	464607	973547	493	301.0		7.3		26.0	4.2	45.7	27.2	0.0
70	Roge	471027	973709	512	312.0		7.3		27.2	3.6	44.9	29.2	0.1
71	Tulumangura	435988	973764	478	292.0				30.6	3.6	48.5	27.7	0.1
72	Mereno	477362	973887	516	315.0			0.1	30.6	4.0	40.0	28.2	0.1
73	Dima Jalewa	413137	973900	476	291.0		7.7		27.2	4.3	60.8	20.4	0.1
74	Alem Gena-Bisrate wengel, Boneya	461900	974300	486	300.0		8.0		27.7	5.3	56.1	24.4	0.1
75	Tikur Inchini town	351977	974551	494	301.0				27.2	3.5	77.6	11.2	0.1
76	Alem Gena-Bonoya	460464	974637	477	291.0		8.1	0.1	40.8	4.3	49.7	23.4	0.1
77	Merero	472446	974756	480	310.0	26.0	7.8	0.1	24.5	4.0	49.7	23.4	0.0
78	Akaki	474653	974776	529	343.0	20.2	7.9		0.0	2.1	43.3	27.2	0.0
79	AA-Water lll Borehole BH01	477972	974859	496	303.0		7.8		36.6	3.3	39.7	23.6	0.0
80	Jiduka	418707	974898	284	182.0		7.3	0.4	29.5	6.4	26.4	4.3	0.0
81	AA-Water lll Borehole BH3b	478713	974977	273	172.0		7.3	0.1	32.0	5.4	25.5	3.2	0.2
83	Wajitu	409122	975187	341	206.0		8.6		76.0	2.6	3.5	1.1	
84	AA-Water lll Borehole BH04	477992	975552	295	194.0		7.7		14.5	5.7	42.2	9.2	0.0
85	Akaki,BH4	477992	975552	309	200.0		7.3		22.0	8.3	37.0	11.2	0.1

86	AA-Water lll Borehole BH02	478399	975589	367	240.0		7.5		27.5	6.3	34.4	10.2	0.2
87	AA-Water lll Borehole BH05b	476574	975607	438	280.0		7.0		13.8	5.2	65.6	10.3	
88	Akaki BH5b	476574	975607	147	98.0		6.9	0.2	12.7	4.1	13.2	2.7	0.5
89	TW3 test well No.3	484475	975622	284	182.0		7.3		29.5	6.4	26.4	4.3	
90	Akaki BH26	477086	975624	280	190.0		8.3		50.0	3.7	14.1	3.2	0.3
91	AA-Water lll Borehole BH26	477181	975680	464	308.0		7.4		62.0	5.0	33.6	8.2	0.1
92	AA-Water lll monotoring well 04	477185	975729	344	226.0		7.1		17.0	6.8	46.6	9.2	0.1
93	AA-Watter lll Borehole BH22	477651	975923	295	194.0		7.7		14.5	5.7	42.2	9.2	0.0
94	Akaki BH22	477651	975923	524	344.0		7.4	0.4	77.0	22.0	16.6	3.2	0.3
95	AA-Water lll Borehole Bh18	478154	975966	209	138.0		7.6		38.0	4.3	9.2	2.0	0.2
96	Akaki BH18	478154	975966	414	272.0		7.2		30.5	3.2	53.8	10.7	0.3
97	AA-Water lll Borehole BH10	479058	976020	213	142.0		6.9		9.8	3.4	27.7	4.6	0.1
98	Dukem MBI	483567	976037	1904	1394.0		6.5		495.0	24.5	25.2	5.6	0.2
99	AA-Water III Borehole BH25-2	477162	976038	194	128.0		6.9		9.0	4.3	25.2	5.1	0.6

100	Akaki BH 25-2	477162	976038	234	154.0		7.7		19.0	7.4	22.7	4.1	0.1
101	AA-Water lll Borehole BH14	478580	976051	181	128.0		7.3		24.0	5.5	12.6	2.0	0.5
102	AkakiBH	478580	976051	528	344.0		7.3		30.0	4.6	52.1	23.0	0.0
103	Gelan	484266	976150	265	174.0		7.0		10.4	4.5	36.1	9.2	0.1
104	AA-Water lll Monitoring well 03	476972	976152	422	282.0		7.4		55.0	4.6	35.3	8.2	0.3
105	Dukem Atlas Hotel	482463	976154	189	126.0		7.4	0.3	22.5	10.5	10.4	2.0	0.4
106	Akaki Mesfin Zelwlew Dairy Farm	481507	976220	440	286.0		7.1		41.0	3.2	54.6	9.2	0.1
107	Sunshine Terminal PLC(Dalota)	483093	976323	333	216.0		7.9		48.5	9.8	18.5	3.1	0.1
108	AA-Water lll Borehole BH17	478199	976361	253	166.0		8.3		37.0	2.6	19.3	2.6	0.1
109	Akaki BH17	478199	976361	295	186.0		7.1		18.0	4.0	37.8	9.7	0.4
110	AA-Water lll Borehole BH08	479061	976370	750	492.0		6.9		123.0	12.9	38.6	6.6	0.2
112	Akaki BH08	479061	976370	192	128.0		7.4		30.5	7.1	8.4	3.6	0.6
113	AA-Water ll monitoring well 02	476523	976374	445	292.0		6075.0	0.2	42.0	5.9	50.4	7.1	0.3
114	AA-Water III	477856	976402	220	140.0		7.3		30.0	4.6	17.6	4.1	0.3

	Borehole BH21												
115	Akaki BH21	477856	976456	498	332.0		7.1		80.0	7.4	33.6	5.6	0.2
116	AA-Water lll Borehole BH13	478694	976490	1908	1246.0		7.0	0.6	465.0	22.0	15.1	6.1	0.2
117	ButuluDawo	406847	976500	2010	1388.0		6.9	0.5	510.0	23.0	15.1	8.7	0.3
118	kotcha	472233	976508	2500	1620.0		6.8		580.0	31.0	26.0	5.6	0.1
119	Hechu	471521	976630	408	260.0		6.8		24.0	4.0	50.4	10.2	0.8
120	AA-Busa-Areda Jawe	415715	976666	490	318.0		7.2		102.0	8.2	5.4	2.0	0.1
121	AA-Water lll Borehole Bh07	479405	976735	552	362.0		7.4		43.0	4.9	66.9	15.1	
122	AA-Water lll Borehole BH16	478347	976752	625	410.0		7.9		132.0	2.4	21.0	7.1	0.1
123	AAWSA/AEA Piezometer No.1	478347	976752	267	182.0		8.2	0.2	41.5	7.0	19.3	2.6	0.1
124	Akaki BH16	478347	976752	1742	1132.0		7.4		380.0	35.5	17.6	8.9	0.2
125	Alem Gena-Ilamu	466690	976790	715	468.0		8.3		180.0	1.9	15.1	4.6	0.0
126	AA-Water lll Borehole BH24	477330	976793	532	344.0		7.7	0.2	66.0	9.3	45.4	8.2	0.1
127	Akaki BH24	477330	976793	492	296.0		7.8		43.0	3.3	57.1	9.7	0.0
128	Bonoya	460950	976800	735	477.0		7.3		128.0	12.1	31.1	7.7	0.2
129	AAWSA/IAEA Piezometer	475402	976807	319	210.0		7.7		35.0	9.1	24.4	3.1	0.1

	No.3(p3)												
130	AA-Water lll Borehole BH12	478808	976867	558	364.0		8.0		53.0	3.9	58.1	18.4	0.1
131	Akaki BH12	478808	976897	478	314.0		7.1	0.2	58.0	6.6	47.0	6.6	0.1
132	Akaki,BH7	479696	976897	381	250.0		7.0	0.2	68.0	7.0	15.1	4.1	0.6
133	AA-Water lll Borehole BH06	479696	976936	385	250.3		8.1	0.0	25.5	4.3	44.9	11.6	0.1
134	AA-Water lll Monitoring well 01b	476454	976951	485	315.3		7.5	0.0	24.5	4.2	45.7	27.2	0.0
135	Stars Business Group,Tana Transport	481205	976968	512	332.8		7.3	0.0	27.2	3.6	48.5	27.7	0.0
136	AA-Water lll Borehole BH20	477945	976985	464	301.6			0.0	27.2	3.6	44.9	29.2	0.0
137	Akaki BH20	477945	976985	508	330.3		8.0	0.0	27.2	4.0	59.3	24.3	0.0
138	Akaki BH20	477945	976985	542	352.6		7.5	0.0	27.2	5.3	56.1	24.4	0.1
139	Dukem NOC	480641	977009	398	258.7		7.5	0.0	23.8	4.6	43.3	13.6	0.0
140	AkakiBH-9	476246	977104	463	300.8			0.0	18.7	4.6	59.3	19.5	0.0
141	AA-Water lll Borehole BH09	479246	977104	476	309.7		7.8	0.0	27.2	4.0	49.7	23.4	0.0
142	Sidamo Awash	479820	977160	494	321.2		7.3	0.0	27.2	4.3	49.7	23.4	0.1
146	sebeta	438871	977181	2480	1580.0	33.0	6.5	0.2	545.0	27.0	22.9	13.0	0.0
155	Busa-Areda Jawe	416140	977209	382	244.0	24.0	7.4	0.2	33.0	6.7	37.4	8.6	0.1

203	AA-Water lll Borehole BH23	477477	977216	366	240.0	21.0	7.9	0.4	32.0	1.4	46.2	6.6	0.1
204	Akaki BH23	477477	977216	507	332.0		7.9	0.1	93.0	3.3	19.3	12.8	0.0
205	Busa-Areda Jawe	415528	977263	595	390.0		6.9	0.3	46.0	8.6	64.7	15.3	0.0
206	AA-Water lll Borehole BH11	478780	977307	518	382.0		7.3	0.2	58.0	7.4	46.2	16.3	0.0
207	Akaki Water Supply Well Ep-4	479942	977322	522	344.0		7.3	0.4	44.0	55.4	13.3	13.3	0.0
208	kotcha	471476	977396	522	346.0		7.5	0.3	47.0	7.1	52.1	16.8	0.0
209	Akaki Beverly Internation	480895	977403	562	330.0	26.0	7.5	0.3	54.0	5.8	53.2	16.0	0.0
210	Akaki Water Supply Well EP-6	479526	977468	582	360.0	30.1	8.2	0.3	69.0	6.9	29.6	14.4	0.1
211	NMWC Spare Parts 7 Hand Tools Factory-2	478462	977506	413	274.0	31.0	7.6	0.2	38.0	9.0	46.4	9.6	0.0
212	Tafki golden Rose#	442842	977555	514	316.0	27.0	7.3	0.2	54.0	8.8	44.0	15.8	0.0
213	AA-ZAF Pharmacutical Akaki	480965	977576	454	300.0	24.9	7.1	0.1	21.5	6.0	57.6	15.8	0.0
214	AAWSA AkakiEP-7	479021	977596	778	542.0	34.0	8.3	0.1	176.0	11.6	11.4	3.6	0.0
215	Akaki Water Supply Well EP-7	479021	977596	618	416.0	32.0	8.0	0.1	98.0	18.0	22.8	7.8	0.0

216	Tefki Golden Rose#2	442811	977625	612	398.0	27.0	8.3	0.5	99.0	14.0	38.0	2.8	0.2
217	Tefki-Golden Rose#1	444000	977700	531	348.0	34.0	8.2	0.1	88.0	8.8	25.1	4.6	0.0
218	AA-Beverage CorpGasv& Crate factory	478462	977721	488	320.0	28.5	7.9	0.2	79.0	11.9	30.4	1.8	0.3
223	Hechu	472245	977865	539	314.0	24.0	7.6	0.1	59.0	6.5	43.3	5.0	0.0
224	Tefki	441366	977899	479	302.0	29.0	8.0	0.1	50.0	10.1	35.7	10.5	0.0
225	Akaki Water Supply Well EP-8	478998	977937	581	346.0	48.1	8.3	0.0	118.0	8.8	5.6	2.9	0.1
226	AA-Water lll Borehole BH03a	480517	977974	640	440.0	22.9	7.3	0.3	31.0	7.1	79.0	20.1	0.0
230	AA-Water lll Borehole BH19	478019	977985	485	310.0	48.0	8.1	0.3	30.0	4.2	69.9	7.4	0.1
232	Tefki	444624	978143	484	308.0	38.9	7.3	0.1	82.0	9.1	24.3	3.7	0.0
233	tefki,WSSA	445000	978200	1571	1026.0	44.5	7.5	0.8	360.0	9.8	29.0	12.5	0.2
234	Akaki Telecommunications	476600	978200	711	460.0	36.3	7.6	0.1	154.0	17.0	13.7	1.8	0.1
238	Akaki city	475936	978248	438	278.0	23.0	7.3	0.6	54.0	7.7	30.4	11.9	0.1
239	Tefki STTW-2	448502	978502	425	260.0	26.4	7.6	0.7	43.0	7.9	34.2	8.2	0.1
240	sebeta	447224	978514	458	298.0	28.5	7.6	0.6	62.0	8.9	34.2	7.8	0.1

241	AA-Water lll testwell-B7	473566	978610	624	410.0	25.0	7.6	0.2	51.0	9.6	60.8	13.8	0.1
245	NMWC Pump Factory	477608	978689	473	286.0	29.8	7.5	0.2	85.0	9.6	15.2	3.2	0.0
246	Akaki	473944	978722	464	308.0		7.4		62.0	5.0	33.6	8.2	0.1
247	Hechu	472779	978788	552	360.0	48.0	7.8	0.2	84.0	12.5	27.4	8.7	0.3

(Source: Tilahun Azagegn, 2008-recent)