UNIVERSITY OF NAIROBI

DETERMINATION OF SURFACE AND GROUNDWATER INTERACTION OF THE KILIMANJARO AQUIFER SYSTEM USING ISOTOPE HYDROLOGY TECHNIQUES

BY

Thomas Maina Kang'ethe

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF GEOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN HYDRO GEOLOGY AND GROUNDWATER MANAGEMENT IN THE UNIVERSITY OF NAIROBI

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DECLARATION

This project is my original work and has not been presented for a degree in any other university.

Signature……………………………… Date…………………………

Thomas Maina Kang'ethe

The Project report has been submitted for examination with our approval as university supervisors

Signature …………………… Date……………………….

Prof. N. Opiyo Akech

Signature ………………… Date……………………….

Dr. C.M. Gichaba

Signature …………………… Date……………………….

Dr. J.K Mulwa

DECLARATION OF ORIGINALITY FORM

University of Nairobi

Name of Student	Thomas Maina Kang'ethe
Registration Number	I56/83675/2015
College	College of Biological and Physical Sciences
Faculty of Science	School of Physical Sciences
Department:	Department of Geology
Course Name	Master of Science in Hydrogeology and Ground Water Management
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ABSTRACT

Sustainable management of the available water resources is the goal of any institution charged with the mandate of water resource management. However, several knowledge gaps exist that hinder the sustainable management of these resources. These knowledge gaps have greatly hampered the allocation and conservation of water resources. There is need to preserve and protect the available water resources, both surface and groundwater. The use of emerging technologies, and in particular isotope hydrology, have been practiced for quite some time to address various gaps in ground water hydrology, which cannot be solved by use of the conventional methods. Isotope hydrology techniques are also becoming more refined with time.

This research attempted to use the emerging technologies and in particular environmental stable isotopes (^{18}O and ^{2}H) to compliment the conventional methods in addressing these gaps. The author used isotope hydrology techniques to compliment the conventional methods of hydrogeology, hydrology, and hydrochemistry investigations. Existing data on hydro geological surveys, discharging wells, exploration wells as well as water quality was also used in this research. Water sampling from rivers, lakes, shallow wells, boreholes and springs was done for hydro chemical and isotope data analysis including insitu measurements of physical parameters. Borehole water rest levels were also measured to assist in modeling groundwater flow direction.

The research established that there is ground water- surface water interaction and also identified areas and altitude of recharge for the various water sources in the project area. The relationship between Lake Chala and the surrounding springs was also established, together with two types of mixing i.e. mixing of water types based on their chemical composition and mixing of water sources. The research also established the sources of salinity of water sources in the south of the project area and specifically Lake Jipe and Orkungu borehole. These sources are nature controlled and are due to evaporation and dissolution of gypsum as a result of the geology of the area.

Ground water flow is from the highest point which is Loitokitok Town and varies in magnitude towards the other areas. Increase in flow magnitude was noted in the lower levels from 950 Masl, which could be an indication of regional groundwater flow.

In conclusion, groundwater resources in the Kilimanjaro Aquifer System are recharged at different altitudes and locations.

The waters of Mzima Springs and the springs from Mt. Kilimanjaro do not interact since they are recharged by different rainfalls regimes with different isotopic signatures and at different altitudes of recharge. The altitude of recharge for the waters from the Kilimanjaro ranges between 1550-2000Masl while that of the Chyulu, where Mzima is located is 1350-1450Masl. There is mixing of both water types and water sources. Relatively fresh waters are also mixing with mineralized waters from the Kilimanjaro. The observed groundwater interaction between boreholes and springs implies that over exploitation of groundwater resources from any of the boreholes will directly negatively affect these other sources.

However, Mzima springs is only affected by mixing in terms of water types and not water sources. Therefore, interbasin transfer from this source will not adversely affect the other water sources and biodiversity along the waterways associated with it as long as the exploitation is done sustainably.

Salinity in some water sources is as a result of evaporation and dissolution of gypsum as controlled by the geology of the area.

Groundwater flow direction is from the highest point generally towards the easterly and south easterly directions as dictated by the Piezometric levels. There is also a high flow magnitude emerging at the lower altitudes and in particular between 750- 700 Masl towards the East and 950-850 Masl in the East and South East directions.

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LIST OF ABBREVIATIONS

As	Arsenic
B	Boron
CAS	Chyulu Aquifer System
^{0}C	Degrees Celsius
CITES	International Convention on Endangered Species
Cl	Chlorine
CNESTEN	National Center for Nuclear Energy Science and Technology
Cs	Cesium
GDP	Gross Domestic Product
(pH),	Potential of hydronium ions
EC	Electric Conductivity
DO	Dissolved Oxygen
ENG	Engineer
F	Fluorine
Fe	Iron
Ge	Germanium
GMWL	Global Meteoric Water Line
GPS	Global Positioning System
H	Protium
^{2}H	Deuterium
^{3}H	Tritium
HDPE	High Density Poly Ethylene
I	Iodine
ICS	Ion Chromatography System
IGRAC	International Groundwater Resources Assessment Centre
KAS	Kilimanjaro Aquifer System
KNBS	Kenya National Bureau of Statistics
<LD:	Less than the Detection Limit
Li	Lithium

LMWL	Local Meteoric Water Line
<LQ:	Below the Quantization Limit
MASL	Metres Above Sea Level
mg/L	Milligrams Per Litre
Mn	Manganese
Mo	Molybdenum
MY	Million Years
N	Nitrogen
Na	Sodium
NM	Nanometers
^{16}O	Oxygen 16
^{18}O	Oxygen 18
pH	Potential of Hydrogen Ions
Rb	Rubidium
RMWL	Regional Meteoric Water Line
S	Sulphur
Sb	Antimony
SO_4	Sulphates
Ta	Tantalum
TDS	Total Dissolved Solids
U	Uranium
UNESCO	United Nations Environmental, Scientific and Cultural Organization
UNICEF	United Nations International Children Education Fund
µS/cm	Microsiemens Per Centimeter
W	Tungsten
δ	Delta

CHAPTER 1: INTRODUCTION

1.1: Background Information

The use of emerging technologies in water resources management is gaining importance as more challenges continue to face the water sector. Isotope hydrology has emerged as one of the important technologies whose use in water resource management can help address the various gaps that the conventional methods have not been able to solve. This study focused on the Kilimanjaro Aquifer System (KAS) in the south Western part of the country and used isotope hydrology techniques to address some of the gaps associated with water resource management in the region. The study also provided valuable information for the management of water resources in other areas and the country at large.

The project area is served by groundwater resources from the Kilimanjaro Aquifer System and these resources are also transferred to near and far counties as well as Mombasa City at the Coast for both domestic an Industrial use.

The Kilimanjaro Aquifer System is the general name given to various aquifers which have Mount Kilimanjaro at their centre and besides Mount Kilimanjaro; it includes aquifers emanating from the slopes of Mount Meru in Tanzania and the Chyulu Hills in Kenya. The Chyulu Hills in turn are a major recharge area for several springs emerging at their foot and feeding into the Tsavo and Athi Rivers. One of the largest of these springs is Mzima Springs (Grossmann, 2008). Mzima Springs supplies 360 million litres of water per day to about 2.5 million people, including Mombasa City. The coastal area of Kenya, along which Mombasa City is located, is rather densely populated with the latter having a population of 1.2 million people (UNICEF, 2015). The city itself is important to the country, being the only international seaport, as well as a centre of transportation, trade, manufacturing and tourism. Some areas of Taita Taveta County as well as Mombasa City depends on Mzima Springs for its domestic as well as economic activities. Together with other areas to the North of Mombasa, water is supplied from the Mzima Pipeline and other systems where Mombasa City alone receives an estimated 35000m^3 of fresh water against an estimated demand of 70,000m^3 per day. The problem has been compounded by the ever-increasing population as evidenced by frequent public outcry for fresh water shortage in the city and the coastal region generally. Attempts to bridge this gap with boreholes and shallow wells has not been successful. (Ochiewo, 2001).

Sections of Kajiado, Makueni and Machakos Counties depend on Nolturesh Springs while Taveta urban and peri urban depend on water from Njoro Kubwa Springs. Figure 1.1 below shows the project area in relation to the areas served by water resources from the Kilimanjaro Aquifer System.

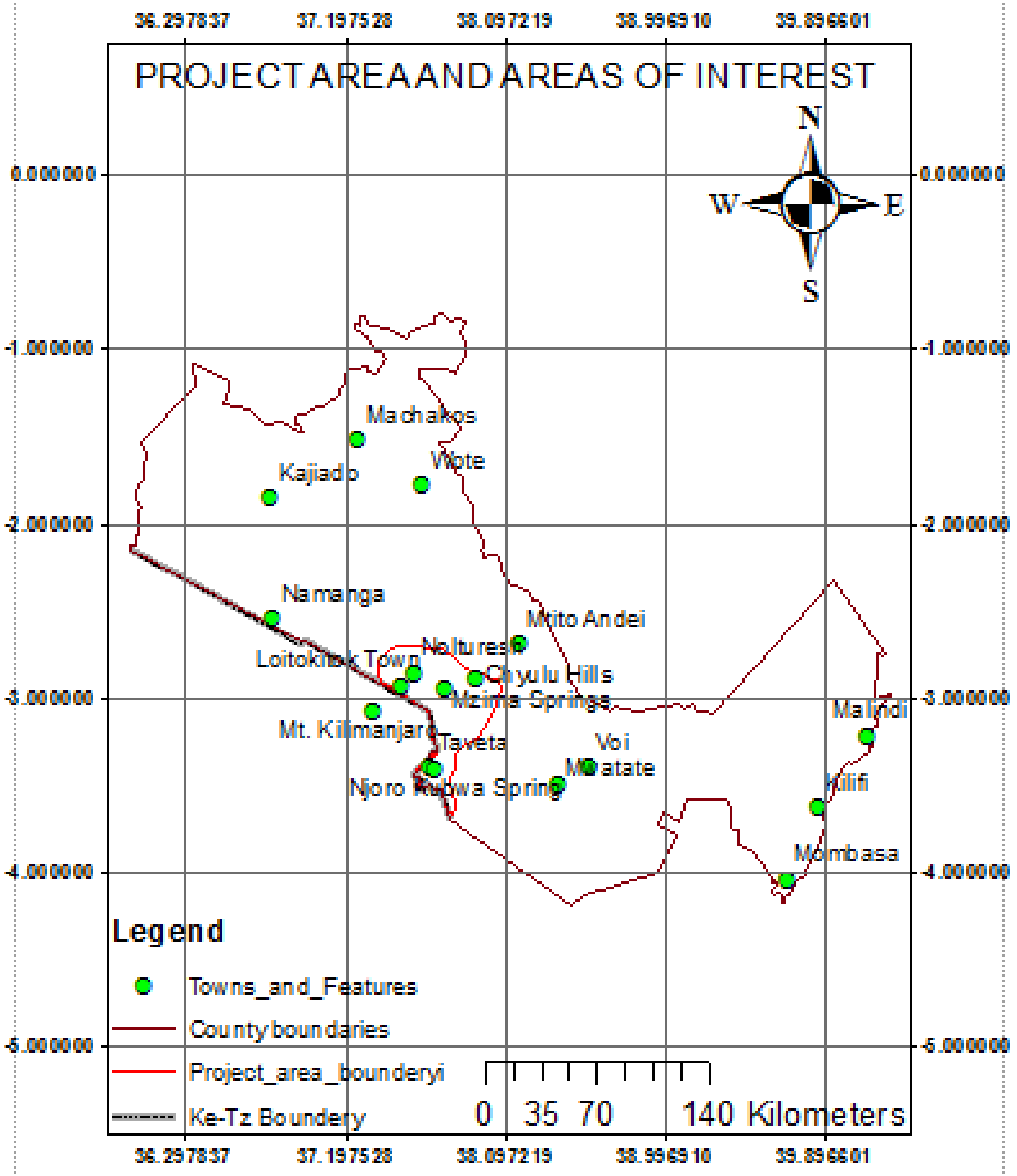


Figure 1.1: Project area in relation to areas of interest

However, these areas have inadequate water supply and experience a chronic water shortage (Ochiewo, 2001). The main challenge is that water resources are unevenly distributed in time and space, which is a factor of the variability of rainfall patterns. In addition, extreme weather events during droughts and floods have become more frequent and affect water availability. The region therefore, just like the rest of the country, faces challenges related to water resources including low freshwater endowment, rapid population growth leading to increased water demand for both domestic use and for food production and industry, and highly variable rainfall leading to prolonged droughts and flooding.

Urbanization and the increasing population have led to groundwater being increasingly recognized as an important water source for both urban and rural areas to address these emerging challenges. It is therefore imperative that exploiting the full potential groundwater sources for these areas is vital for water allocation and supply. However, this exploitation should be carried out in a manner that ensures sustainability of the biodiversity within the water courses.

In view of the above, a second pipeline from Mzima Springs is planned to augment water supply to the city in an effort to meet the growing demand. The water stress in the project area as well as the benefitting counties has called for the use of emerging technologies in the exploitation of available groundwater resources of the Kilimanjaro aquifer system (KAS).

The project area lies within 37^{0}22'23·70" East and 38^{0}04'13·56"East and -2^{0}41'55·31" South and -3^{0}40'11·98" South as shown in Figure 1.2 below. The approximate population of the area is 205,161 and holds approximately 46,061 households (KNBS, 2016). Among the factors that influence the distribution of human beings are water availability and proximity to social amenities. The population density in the study area averages 42 persons per square kilometre. Higher population densities have however been observed in the while lower densities have been observed in the lowlands. (Githaiga et al., 2003). The parks have the least density. The area is about 230 kilometres from Nairobi City via Nairobi-Mombasa Highway (A109) to Emali and then Emali to Loitokitok (C2) and from Mombasa City the area is 264 kilometres via Mombasa – Nairobi Highway (A109) to Voi and Voi –Taveta (A23).

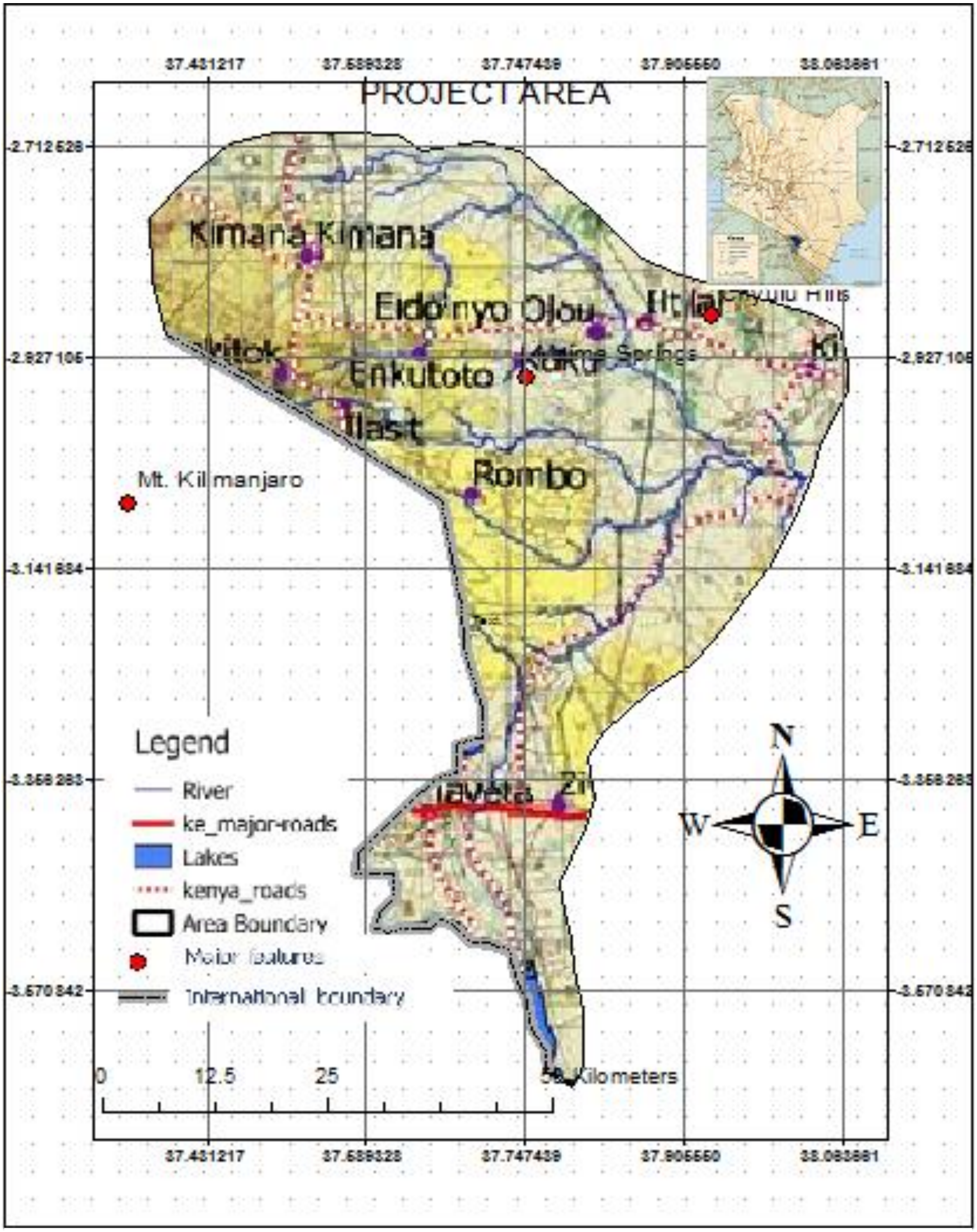


Figure 1.2: Map of the project area showing the main features

1.2: Problem Statement

Sustainable management of the available water resources is the goal of any institution charged with the mandate of water resource management. This includes exploiting the full potential of the resources while at the same time putting into consideration the needs of the future generation as well as those along the water courses.

The project area is endowed with adequate groundwater resources and scarce surface water resources. However, in spite of this, frequent water shortage outcries are common, which is an indicator of underutilized resources. Among the reasons for water resource underutilization in this area are the existence of several knowledge gaps, that hinder the sustainable development and management of these water resources. These knowledge gaps have greatly hampered the allocation and conservation of water resources. There is need to develop, preserve and protect the available water resources, both surface and groundwater. To do this, it is important to identify areas and altitude of groundwater recharge, identify and control points of pollution and identify areas of surface water ground water interaction. If these issues are addressed, this can go a long way in assisting the managers of the resource in the project area and beyond in ensuring full exploitation and sustainability of the available water resources.

This research attempted to use the emerging technologies and in particular environmental stable isotopes (^{18}O and ^{2}H) to compliment the conventional methods of hydrology, hydrogeology and hydrochemistry in addressing some of the above gaps.

1.3: Aim and Objectives

1.3.1: Main Objective

The main objective of this research work was to gain an in depth understanding of surface water ground water interaction of the Kilimanjaro aquifer, Chyulu Hills and Mzima Springs area. In order to achieve this objective, it was important to narrow down to the following specific objectives.

1.3.2: Specific Objectives

- To establish the relationship between surface and groundwater resources in the Kilimanjaro, Chyulu and Mzima springs area.
- To determine the quality of water in the project area.

- To determine the groundwater flow direction in the project area.

1.4: Scope of the Research

This research entails the use of isotope hydrology to compliment the conventional methods of hydrogeology, hydrology and hydrochemistry to address knowledge gaps and assist in better management of the available water resources in the project area. Therefore, any adverse change in the ecosystem in question may have reverberating negative impacts on the other sectors, which can be felt by those near as well as those far from the project area.

Water as a resource is a key driver to the social and economic pillars of the Kenyan economy and seeks to improve the quality of life for all Kenyans. As far as the project area is concerned,

there is a need for improved water service provision and also to other far areas that rely on water sources from the project area, without destroying the ecosystems in which these waters are derived. Having the knowledge of the water resources available in an ecosystem as well as the surface water ground water interaction is important in its better management.

The researcher introduces the purpose of the research followed by description of the study area in order to acquaint the reader with both the intention of the research and the settings of the area where it is being carried out. Literature review on previous isotope, hydrogeology, hydrology and hydrochemistry of the project area is carried out extensively in order to appreciate the works of previous researchers and identify gaps .Methodology in carrying out the research work is introduced and involves field campaign and sampling of all the major springs, boreholes, shallow wells rivers and lakes in the project area followed by analysis of physical , chemical and isotopic data. Measurement of physical parameters is done insitu while chemical and isotopic analysis is dome in the laboratory. The results are discussed followed by conclusions and recommendations in the last chapter of the research work.

1.5: Justification and Significance of the Research

Sustainable water resource management requires that the full potential exploitation of the available resource is achieved while at the same time conserving it for future generations. With the effects of climate change evidenced by long dry spells and almost always followed by flooding, it is imperative to put in place measures that will mitigate against the effects of this. However, knowledge gaps on the interaction of surface water and ground water, which is important in planning, hinders these efforts. This research therefore attempts to bridge these gaps and enhance sustainable management of the available water resources.

With better understanding of the surface water –groundwater interactions, it will be possible to map out areas of recharge for catchment preservation, the groundwater flow direction, understand altitude of groundwater recharge, understand areas of mixing as well as comparison of evolution and water quality of the different types of water.

CHAPTER 2: LITERATURE REVIEW

The use of emerging technologies, and in particular isotope hydrology, have been practiced for quite some time to address various gaps in ground water hydrology, which the use of the conventional methods cannot solve. Isotope hydrology techniques are also becoming more refined with time.

In a paper titled 'Hydrological studies using isotopes' (Kumar, 2013) the author explains isotopes and their various applications in hydrology.

Isotopes are atoms of an element having the same atomic number but different mass numbers. Isotopes found in nature are known as environmental isotopes. They can either be radioactive or stable. There are three different types of applications of isotopes in hydrology. These are:

i. Stable and radioactive isotopes may be used as tracers. In general groundwater is usually isotopically heavier than water that is recently percolated into an aquifer from a particular precipitation event.
ii. Making use of differences brought about by isotope fractionation. Isotope fractionation is described as the enrichment of one isotope relative to another in a chemical or physical process. Therefore, observing differences in the stable isotope concentration ratios gives particular information on Geophysical or Geochemical processes that took place. Some of the processes produce visible effects which may include: Latitude effect, continental effect, Seasonal effect, amount effect and altitude effect.
iii. Radioactive decay. This gives possibilities on determining water age provided that the conditions under which the determination is carried out are suitable for the purpose.

The author lists some particular applications of isotopes making use of the various application methods of isotopes as groundwater age using Tritium and Carbon 14, groundwater recharge estimation, Surface and groundwater interaction and identification of recharge zones of springs especially in mountainous areas (Kumar, 2013)

The observed isotope effects in precipitation events which are also applied in isotope hydrology studies have been identified by Mook in the book titled 'Environmental Isotopes in the Hydrological Cycle' to include:

a) Latitude/annual temperature effect

Isotope fractionation which accompanies the evaporation process is one important factor in the variability of isotopic composition within the water cycle. The Craig – Gordon Isotopic evaporation model also called the Langmuir linear-resistance model is used to quantify the variabilities putting them in a manner easy to interpret. The model makes the assumptions that there is an equilibrium condition at the air/water interface, that there is no divergence or convergence in the vertical air column and that no isotopic fractionation during a fully turbulent transport takes place. The successful application of this model; relies on two processes

i. The formation of atmospheric vapour by evaporation in regions with the highest surface ocean temperatures;
ii. The progressive condensation of the vapour during transport to higher latitudes with lower temperatures.

The equations from this model combined with observed data have resulted in a *Global Meteoric Water Line (GMWL)*, which is useful in isotopic data interpretation on a global scale. Regionally and for certain periods (such as seasons) a *Local Meteoric Water Line* (LMWL), is used instead of GMWL depending on the conditions for forming the local water source of each region.

b) The seasonal effect

The dependence of the isotope variations on the local temperature (or the closely related parameter of the precipitable water content) portray a seasonal change in the isotopic composition of the precipitation. These variations are correlated with the temperature in most cases. At tropical islands, on the other hand, where the vapour source region essentially coincides with the region of precipitation, the temperature dependence is not very noticeable. The most pronounced factors which determine the seasonal effect magnitude are:

i. Different source characteristics of the moisture, either due to the seasonal change of the meteorological conditions over the ocean, or different location of the source regions. This produces different meteoric water lines, for each of the seasons.

ii. Evaporative enrichment in the falling droplets beneath the cloud base, effective during warm and dry months when rain amounts are small. This partially evaporated rain is characterized by relatively higher ^{18}O values.

c) Oceanic and Continental precipitation

Precipitation over the ocean has the characteristics of a first condensate of the vapour. The continental effect also referred to as the distance-from coast effect, produces a progressive depletion in ^{18}O in precipitation with increasing distance from the ocean. It varies considerably from area to area and from season to season, even over a low relief profile. It is also strongly correlated with the temperature gradient and depends both on the topography and the climate regime.

d) Altitude effect

As a rule, the isotopic composition of precipitation changes with the altitude of the terrain and becomes more and more depleted in ^{18}O and Deuterium at higher elevations. This has enabled one of the most useful applications in isotope hydrology, namely the identification of the elevation at which groundwater recharge takes place. This altitude effect is temperature-related, because the condensation is caused by the temperature drop due to the increasing altitude. This is because increasing altitude results in decreasing pressure (Mook,2000).

In a paper on the variability of stable isotopes in Lake water, (Shi et al., 2017) the authors ventured to study the roles that lakes in high elevations play in seasonal and annual water balances especially for glacier run off systems. Lakes can either increase seasonal stream flow by recharging local and regional groundwater sources or decrease seasonal stream flow by increasing evaporation. Since Lakes are surficial integrators of surficial information, they can be good sources of information on climate change. In this paper the authors were able to determine the spatial variations and influencing factors of stable isotope composition, the vertical distributions of isotopic compositions and quantitatively evaluated the water balance in a Lake (Shi et al., 2017).

Isotope studies have also been used in studying groundwater pollution sources. The intention being to protect water quality for human consumption. In a study carried out in Spain in a region called Sierra de Canete, the authors made use of hydro chemical and isotopic tools to identify pollution points and pathways. This would make it possible to suggest Groundwater Protection Zones to maintain water in a state that is suitable for human consumption. Consequently by making use of the isotopes of Sulfate, the authors were able to determine the sources of pollution as the Triassic evaporates and sulfate fertilizers used in the Olive orchards (Jiménez-Madrid et al., 2017). In Chyulu hills aquifer which is considered a natural lysimeter, isotope studies have been used to study the relationships between spring discharge and rainfall, groundwater residence times, and the extent to which percolation of rainwater differs in the various areas of the hills. A lysimeter is a hydrological instrument for measuring the percolation of water through soils and for determining the soluble constituents removed in the drainage. Chyulu hills consist of highly permeable and porous lavas and pyroclastics leading to very little surface pounding or runoff, making for good infiltration conditions. As a result of Chyulu Hills overlying impermeable basement rocks, the relatively high rainfall which falls over the region results in the discharge of some important spring complexes on the range periphery hence the hills act as a huge natural lysimeter. The pre-Quaternary topography of the basement has led to the springs being concentrated on the eastern side and at the southern end of the hills with a major one on the south western foot slopes of the hills. The natural discharge is directed towards the Athi River but several of the springs are used for water supply, the most notable being the Mzima Springs. Large quantities of water are piped to the city of Mombasa from Mzima springs. Isotope hydrology techniques were also applied in identifying sources of water to the Nolturesh wetlands to the south west of the hills in this particular study.

This study weighed in on the debate about the origin of springs in the swampy areas of the lower Nolturesh River which are suspected to originate from the Kilimanjaro uplands to the south west. Previous stable isotope data has pointed to the Chyulu Hills as a probable source of recharge (Darlin, W.G., 1999).

Other authors have attempted to quantify groundwater discharge by use of ^{222}Rn. The idea hinges on the principle that ^{222}Rn can be used as a tracer. An additional tracer, Xenon in this case is added to help determine the degassing constant which will then lead to the calculation of discharge rate.

Headwater basins are recognized as being critically important for generating runoff that is captured in reservoirs and used for irrigation and municipal water supplies. As climate change progresses, precipitation in subalpine regions will occur more frequently as rain rather than snow, which could have drastic impacts on stream flow and on groundwater recharge.

Snowpack in the Sierra Nevada of California where this study was carried out allows for slow melting and gradual groundwater recharge in basins; however, as more precipitation occurs as rain, more limited opportunity for groundwater recharge is likely due to increased run-off as overland flow. Groundwater is essential to the area as it provides base flow to streams during the dry summer months, thus maintaining stream ecosystem health. Groundwater discharge to streams also moderates stream temperature, especially in the late summer and fall, which is essential to the viability of the fish population in the streams. For better management of this resource then quantification of groundwater influx is important. However, quantification of groundwater influx to streams is not simple. Geochemical methods then offer the best alternative to physical measurements like stream gauging and to modeling methods that may be associated with high uncertainty. Some studies have made use of physical parameters such as flow measurements, temperature, or electrical conductivity in addition to ^{222}Rn to better constrain locations of groundwater inflow. A multi technique approach gives a more complete picture of the interaction between groundwater and surface water thus lowering prediction error for groundwater inflow. The introduction of Xenon as a tracer in this study allowed for direct quantification of the degassing parameter. In this study, two independent methods were used to determine the groundwater influx i.e. geochemically (using ^{222}Rn as a tracer) and physically (using measured stream discharge) (Avery et al., 2018).

Lakes and reservoirs are critical water resources for local ecosystem conservation and socioeconomic development, especially in arid and semi-arid regions. The Lake Hulun in China is one such important Lake, which supports a unique wetland ecosystem that includes many endangered species. It is also a Ramsar Wetland of International Importance included within UNESCO’s World Network of Biosphere Reserves. It has of late however, suffered from low water inflows resulting in a rapidly shrinking lake size leading to the Lake becoming endorheic (i.e., lacking any surface water outflow). This has in turn led to the lake water salinity increasing significantly, and visible eutrophication occurring, thus impacting on its ecological function.

Concern over the declining lake water levels and deteriorated water quality prompted research where isotopes were applied and a paper titled ‘Understanding the Role of Groundwater in a Remote Tran boundary Lake (Hulun Lake, China)’ published.

The authors list lack of hydrologic and geologic information as one of the challenges in their studies. They however noted that, stable isotopes of water can provide good insight into lake water balances and associated processes. Isotopic investigations are also widely acknowledged as powerful approaches to study the hydrologic cycle in ungauged or poorly gauged watersheds. The authors then applied a combination of hydro chemical tracers and stable isotopes approaches to provide insight into hydrological processes. It was then possible to apportion between water sources (including groundwater contribution), and their contribution to lake water balances. They incorporated the increase in the values of stable isotopes in water ($\delta^{2}H$ and $\delta^{18}O$) with the increasing extent of evaporative losses into the isotope-mass balance determinations thus quantifying water balances. They also made use of chloride, a conservative ion, to provide an independent line of evidence to estimate evaporative loss assuming increased chloride concentrations resulted from evaporation only (Gao et al., 2017).

In another paper published in Mexico the authors had the objective of defining a reliable Local Meteoric Water Line (LMWL) and establish groundwater recharge sites in an alluvial aquifer. Oxygen and hydrogen isotopes ($\delta^{18}O$ and $\delta^{2}H$) can be used to determine the source of groundwater and surface waters. In nature, there is a similar systematic isotopic fractionation of stable hydrogen and oxygen, thus, their behavior in the hydrologic cycle is also similar. This similarity rises to a covariance between the stable hydrogen and oxygen isotopic concentration; the covariance was defined by Craig as follows:

$\delta D = 8\ \delta^{18}O + 10$ (1)

This relation defines the Global Meteoric Water Line (GMWL), and was obtained by using a linear regression method derived from the isotopic analysis of precipitation, snow water, and river water from all over the world; most of the precipitation in the world follows this relationship. The slope and the intercept of this equation are useful in understanding the systematic isotopic fractionation controlled by the hydrologic cycle. The slope and intercept of the “Local Meteoric Water Line” (LMWL) for precipitation from a specific region can be different from the GMWL. The intercept, which is usually called the deuterium excess parameter (d-excess, or d), has been used to describe different Meteoric Waterlines (MWLs), such that:

$d = \delta^2H - 8\delta^{18}O$ (2)

In Mexico, there have been several studies reporting different values for $\delta^{18}O$ and δ^2H. This study would therefore establish a LMWL that could be relied upon for further research work. In arid areas some aquifers may hold fossil water. This study was also used to establish the recharge sources of major aquifers in Zacatecas State, Mexico (González-Trinidad et al., 2017).

In another Mexican study, a Hydro chemical study was carried out to assess the flow dynamics of groundwater by using the combination of statistical and geochemical methods in an active volcanic system. Water groups and factors that control the groundwater chemical processes were identified using a cluster and principal component analysis. Environmental tracers were also applied in assessing chemical evolution.

Active volcanic systems are frequently accompanied by an intense hydrothermal circulation, which is controlled by the exchange of mass and energy between groundwater systems, magmatic fluids and hot rock. The characterization of such hydrothermal systems helps to quantify its geothermal energy potential and to assess volcanic related risks. In such systems hot springs, mud deposits, fumaroles, vaporization and degassing soils give initial clues about subsurface hydrothermal conditions. The chemical characterization of fluids and groundwater has been used as an indicator of the subsurface structure and the origin of released fluids when hydro geological information is scarce. Hydro chemical data, such as high electrical conductivity (EC), high temperatures and elevated concentrations of As, B, Br, Cl, Cs, F, Fe, Ge, I, Li, Mn, Mo, Na, Rb, Sb, Ta, U and W denote the presence of hydrothermal fluids in groundwater. However, hydrothermal volcanic systems are sometimes difficult to analyze due to the fact that groundwater is a mixture of fluids from various sources, sometimes consisting of shallow meteoric waters from recent infiltration, seawater and hot water rising from deep hydrothermal reservoirs. The combination of different environmental tracer techniques helps elucidate the groundwater's origin, recharge, flow velocity and direction, residence or travel times, connections between aquifers, and surface and groundwater interrelations. Radioactive tracers like tritium (^3H) are relatively accessible methods to estimate groundwater ages and characterize groundwater flow systems. Relatively few studies attempt to quantify mixing between different hydrothermal and cold fluids. This particular study was carried out in the Atemajac–Toluquilla aquifer system (ATAS) which underlies the metropolitan area of Guadalajara, the second most populated city in Mexico. It is located in a complex neo tectonic active volcanic system in the Tepic–Zacoalco Rift. Several survey wells were drilled up to 3 km deep at La Primavera to explore the potential for geothermal energy. Temperatures between 80 and 300 ^{o}C were registered in these wells, and temperatures higher than 40 ^{o}C were also measured in adjacent springs. The hydrothermal fluids and springs were characterized by high concentrations of Na, Cl, SiO2, HCO3, B, F, and TDS (total dissolved solids). A mixture of hydrothermal fluids and meteoric-derived water was identified in the springs of La Primavera. While it was assumed that this caldera influences the aquifer system underneath the metropolitan area, the proportion of hydrothermal fluids and cold water is not clear. Moreover, nitrate contamination was related to exogenic processes induced by anthropogenic activities. The diversity of the chemical results from previous studies contributed to the difficulty in clearly evaluating the relationship between the fluids. This study aimed at understanding the flow dynamics of groundwater by using the combination of statistical and geochemical methods as earlier mentioned (Hernández-Antonio et al., 2015).

In an attempt to find out human impact on groundwater and groundwater flow processes, environmental tracers were applied in a study carried out by (Mahlknecht et al., 2018). Groundwater chemistry and isotopic data from 40 production wells in the Atemajac and Toluquilla valleys, located in and around the Guadalajara metropolitan area, were determined to develop a conceptual model of groundwater flow processes and mixing. Stable water isotopes (δ^{2}H, δ^{18}O) were used to trace hydrological processes and tritium (^{3}H) to evaluate the relative contribution of modern water in samples. Multivariate analysis including cluster analysis and principal components analysis were used to elucidate distribution patterns of constituents and factors controlling groundwater chemistry. Based on this analysis, groundwater was classified into four groups: cold groundwater, hydrothermal groundwater, polluted groundwater and mixed groundwater. Cold groundwater was characterized by low temperature, salinity, Cl and Na concentrations and was predominantly of Na-HCO3-type. It originated as recharge at “La Primavera” caldera and was found predominantly in wells in the upper Atemajac Valley. Hydrothermal groundwater was characterized by high salinity, temperature, Cl, Na and HCO3, and the presence of minor elements such as Li, Mn and F. It was a mixed-HCO3 type found in wells from Toluquilla Valley and represented regional flow circulation through basaltic and andesitic rocks. Polluted groundwater was characterized by elevated nitrate and sulfate concentrations and is usually derived from urban water cycling and subordinately from agricultural return flow. Mixed ground waters between cold and hydrothermal components are predominantly found in the lower Atemajac Valley. Twenty-seven groundwater samples contained at least a small fraction of modern water. The application of a multivariate mixing model allowed the mixing proportions of hydrothermal fluids, polluted waters and cold groundwater in sampled water to be evaluated. This study would help local water authorities to identify groundwater contamination zones (Hernández-Antonio et al., 2015) .

In this study, groundwater interactions of the Kilimanjaro aquifer was studied. The Kilimanjaro Aquifer system includes but not limited to aquifers emanating from the slopes of Mount Meru in Tanzania and the Chyulu Hills in Kenya. Previous studies were based on a delineation of the aquifer as proposed in the International Groundwater Resources Assessment Centre (IGRAC) Database of trans boundary aquifers of Southern Africa (Grossmann, 2008). Water recharge for the Chyulu Aquifer System (CAS) has previously been estimated using soil moisture balance, hydro-chemical data and isotope content. Consequently, the water which enters the permeable parts of the series high up the Chyulu Hills either escapes at the surface as springs or is stored as groundwater (Kiringe et al., 2016). In some instances, the water discharge from some of the springs is large enough to form permanently flowing rivers (Kiringe et al., 2016).

In a paper titled ‘Survey of Water Quality Changes with Land Use Type in the Loitokitok Area, Kajiado District, Kenya’ the authors noted ground water recharge and discharge as one of the diverse and pivotal functions wetlands in arid areas. Water quality is an important aspect of these habitats as they support a high biological diversity contents and also critical in supporting the adjacent arid environments. In this investigation, the authors used data from sampling of both upstream and downstream for purposes of comparison of water quality as a result of land use through irrigation. Spring and channeled flow samples upstream of land use types were obtained and taken as reference samples in assessing any changes in water quality arising from land use type. The results showed that water samples taken at the irrigation or downstream had higher values of nitrate and phosphate concentrations compared to samples taken at the source. The results also found Iron as the only heavy metal found in these water samples at a mean concentration of 0.14 mg/lt. The authors concluded that expansion of irrigated agriculture had the most profound negative impacts on the water quality in that ecosystem.(Githaiga et al., 2003)

In a paper titled "Estimation of The Economic Value for The Consumptive Water Use Ecosystem Service Benefits of the Chyulu Hills Watershed, Kenya'' sort to estimate the economic value of the consumptive water use by the various users. In order to do this, the Chyulu Hills watershed boundary was delineated using 30m Landsat images and the ASTER Digital Elevation Model (DEM). Rainfall data (1954-2013) was analyzed and revealed a significant spatial variation in rainfall with the wetter zone in the north and the drier part in the south. Since most of the rainfall is intercepted by the young porous volcanic rocks, there is minimal or no runoff. This creates a subsurface flow between the volcanics and the basement rocks.
Using ArcGIS 10.3 and overlaying the drainage layer and the watershed boundary, analysis of the watershed network and drainage density was done by use of the Horton's method. Water analysis considered both surface and groundwater resources. Secondary data on water discharge records for springs and rivers was used in mapping of surface water sources while secondary borehole data and data from shallow well was used to establish groundwater resources. Monetization and water use analysis was based on both primary and secondary data (Mwaura et al., 2016).

Darling , in his paper titled "The Chyulu Hills Basalt Aquifer, Kenya: Isotopic Investigations of a Major Natural Lysimeter" used environmental isotope techniques as part of the hydrogeological investigations to look at the relationships between rainfall and spring discharge, groundwater residence times and the extent to which infiltration conditions might differ over different areas of the Chyulu Hills. These techniques were also used in identifying the sources of water that recharge the Loolturesh wetlands located in the South Western side of the hills. The author used monthly isotope data represented by monthly samples from two gauges at elevations of 1280 MASL and 1810 MASL collected from late 1984 to early 1987. The results indicated an altitude effect of -0.32 %c 5^{18}O and -1.7 %c 5^{2}H per 100 m increase in altitude, which was within the range observed worldwide. Also frequently used were stable isotope Chloride balance techniques in obtaining recharge approximation amounts. The Cl contents of several springs were measured and found to be quite consistent over time, but not between springs. The author concluded that for the stable isotope Chloride balance techniques to achieve highly reliable results, the amounts of recharge must change significantly between areas with different rock types, vegetation cover, or both (Darlin,G., 1999).

While discussing the characteristics of Lake Jipe -Lumi River Flood Plain ecosystem and significance to sustainable socio-economic development , the author noted that ,although this ecosystem contributes significantly to socioeconomic development through water supply as well as providing support to many communities, it has been severely affected by management challenges including increasing siltation and accelerated runoff due to bare lands as well as deteriorating lake water quality resulting from rising salinity levels.

The author concluded that Lake Jipe ecosystem required conservation and management policies as it has a higher potential for social economic development. However, lack of adequate scientific information to support policies and conservation was noted and also a solution to the declining lake water quality was not offered (Ndetei, R., 2006).

Mt Kilimanjaro is an important water tower, being the source of several rivers and also a ground water recharge zone. However, the mountain has undergone extensive hydrologic changes over the past century in an area where water resources are critical. This prompted a research on the hydrological effects of these changes. In a paper titled ‘A hydrogeochemical survey of Kilimanjaro (Tanzania): implications for water sources and ages’ the authors used hydrochemical and isotopic synoptic sampling techniques to characterize hydrogeology, hydrology, and water quality of the area. Samples were collected from the summit and southern side of the mountain while sample sources included four glaciers, seven groundwater wells, 12 rivers, 10 springs, precipitation, and a lake. The analyses included major ion chemistry, stable isotopes of water (^{18}O and ^{2}H). Moreover, seven samples were analyzed for tritium. The results for all the analysis indicated that the hydrogeologic system is comprised of both local and regional flow systems, and that regional rivers are receiving significant inflow from shallow groundwater, and at very high elevations the hydrologic system is derived from groundwater, precipitation, and glacial melt water (Mckenzie et al., 2010).In this study geological, hydro geological, hydrological, isotope hydrology methods and water chemistry investigations were used.

From the literature review, the researcher was able to identify issues that have not been addressed by various researchers. These include the use of isotope hydrology techniques to study the interactions of surface and groundwater interactions of the Kilimanjaro Aquifer System.
The following gaps have been identified.

- The groundwater and surface water interaction in the project area has not been adequately established
- The source of salinity for Lake Jipe and the surrounding groundwaters has not been established.
- The groundwater flow direction in the project area has also not been identified.

This research therefore attempted to fill in the identified gaps.

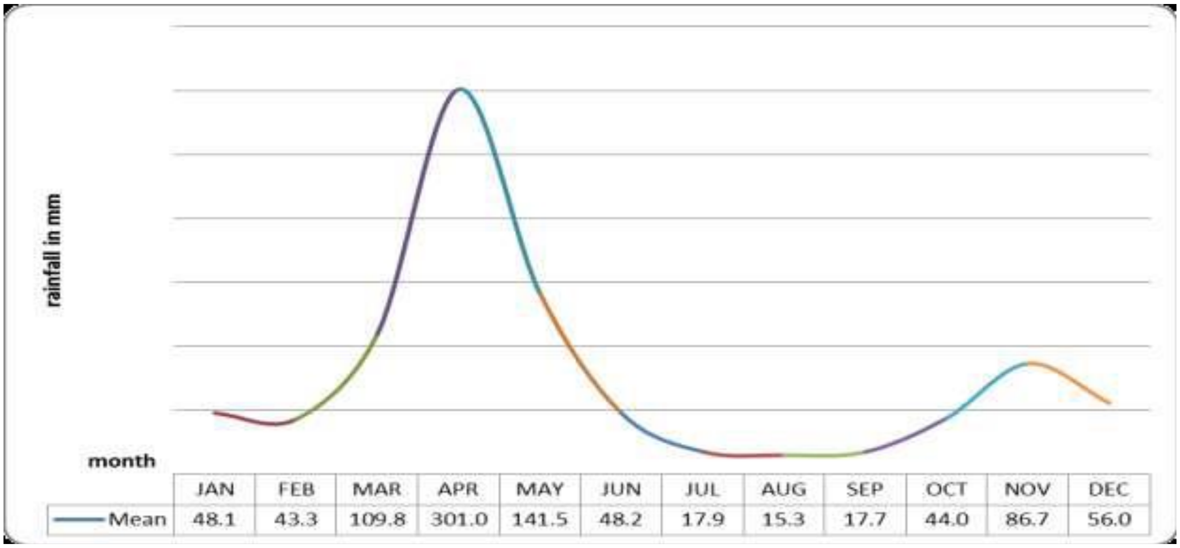
CHAPTER 3: STUDY AREA AND RESEARCH METHODOLOGY

3.1: The Study Area

The study area lies within two administrative units namely Kajiado and Taita Taveta Counties. The area also borders the United Republic of Tanzania along the western and South Western parts. The western side lies on the eastern slopes of Mt. Kilimanjaro while the eastern side covers part of the Tsavo West National Park. The north Eastern side covers a section of the Chyulu Hills game Reserve. The area covers approximately 3650 square kilometres of which 1886.1 is the national park, game reserves and private wildlife sanctuaries.

3.1.1: Climate

Much of the area is basically classified as arid and semi-arid lands (ASAL), except for the high catchment areas in the Chyulu Hills as well as Oloitokitok, which lie on the eastern slopes of Mt. Kilimanjaro. The mean annual temperature is 23^0Celsius (^{0} C) with 30^0C and 15^0C as the mean monthly maximum and minimum temperatures respectively (CWSB, 2018). The coldest period is between June and July while the hottest months are September, October, January and February. The area experiences a bimodal rainfall pattern with the long rains being experienced between March and May (MAM) and the short rains falling between October and December (OND) as shown in Figure 3.1 below. The effects of the south – easterly winds influence the climate of the area. The hilly and mountainous areas have ideal conditions for condensation of moisture, which results in relief rainfall. High rainfall amounts imply the possibility of high groundwater recharge while low rainfall indicates low groundwater recharge, thus low groundwater (Mwega et al., 2013). The annual rainfall distribution is highest on the Chyulu Hills with an altitude of between 1500-2100 metres above sea level (MASL) and ranges between 500-700 milimetres (mm) and lowest amounts of 300-350 is received in the lowlands with rainfall increasing with an increase in the altitude, (Mwega et al, 2013).The annual rainfall on the southern slopes is high and reaches a maximum of 3,000 mm at 2,100 MASL in the forest belt in Tanzania. The northern slopes on the leeward side of Mt. Kilimanjaro, where the study area is located, receive 800–1,200 mm of annual rainfall. Annual rainfall is 400–900 mm in the lowland plains.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	48.1	43.3	109.8	301.0	141.5	48.2	17.9	15.3	17.7	44.0	86.7	56.0

Figure 3.1: Mean Monthly Rainfall for 1950 to 2010. (Source CWSB)

3.1.2: Vegetation

Altitude, soil type, climate, human occupation and utilization of the land have influenced the distribution of natural vegetation in the study area (Githaiga et al., 2003) .The vegetation community consists of woodland, bush land, grassland and forest patches which are scattered in different parts of the landscape . Areas above 1400 MASL are occupied by montane forests and most of the lowlands covered by grasslands. The northern part of the project area is characterized by bush land and scattered trees. The Chyulu Hills occupy the north eastern section of the area while the rest is lowland sloping in a South Easterly direction and characterized by open grass plains. These forest caps sit like desert islands atop a sea of open grassland, their edges so clearly defined it seems there is some invisible boundary which prevents their advance (Sheldrick,N, 2013). From previous studies (Bytebier, 2001), natural vegetation is dominated by several tree species, mainly Acacia tortilis(Forsk) Hayne, Chionanthus mild braedii, Tamarindus indical., Ficus spp., Neoboutonia macrocalyx, Tabernae montana stapfiana, Prunus africana, Strombosia scheffleri, Cassipourea malosana, Olea capensis, Ilex mitis, Erythrina abyssinica, Juniperus procera and the blue-stemmed Commiphora baluensis.

The flat topped Acacia abbyssinica and Acacia mellifera dominate the woodland and buasland. The dominant grasses are Cenchrus ciliaris Enteropogon macrostachyus, Chloris roxburghiana and Eragrostis superb (Bytebier, 2001) .Khaat or miraa (Catha edulis) is also found at higher elevations as well as the East African sandle wood (Osyris lanceolata).This is among the protected species by the International Convention on Endangered Species (CITES).There is also a forest belt along the rivers and the area surrounding Mzima Springs and the associated pools. The heterogeneous nature of the vegetation therefore provides a massive natural sponge which soaks up most of the rainfall which thereafter percolates into the underlying highly porous rocks and emerges as springs and rivers or through shallow wells and boreholes (Kiringe et al., 2016). The vegetation of Tsavo West National Park is mostly bush land with scattered trees in the north. In the south, the vegetation changes to open grassland plains. Around Lake Jipe and close to the Tanzanian border are large permanent swamps (Pellikka et al., 2004).The woody vegetation is dominated by *Acacia nilotica* and *Cambretum SSp* on the foothills of Mt Kilimanjaro. In the lowlands, common species include *Acacia Tortilis, A.Xanthophloea,Azima Tetracntha* and *Suaenda Monoica* especially under salin sodic conditions in the lowlands (Githaiga et al., 2003)

3.1.3: Land Use and Land Resources

The project area extends to the Tsavo West National Park to the East and to the south Western slopes of the Chyulu Hills, which are within the protected areas and the major economic activity is Tourism. It is also important to note that Mzima springs and its surrounding ecosystem is located in Tsavo West National Park while a number of other major springs like Nolturesh, Njoro Kubwa and Kimana as well as River Lumi emanate from the slopes of Mount Kilimanjaro .Tourism is of great importance in the area's economic development especially in the National Park, Lake Jipe as well as Lake Chala area. This is evidenced by the flourishing hospitality industry as well as creation of employment opportunities for both locals and non-locals. This by extension is connected to the country's economic development. The total contribution of Travel & Tourism to gross domestic product (GDP) was Kenya shillings 588.6 billion (bn) accounting for 9.9percent of GDP in 2015 and is forecasted to increase to Ksh. 1,078.9bn (10.1% of GDP) by 2026 (Nyakang'i ,2016).

Kenya is ranked second highest among African countries in bird and mammal species richness with an estimate of 394 mammals, 1100 birds, 201 reptiles (100 lizards, 100 snakes, and 1 crocodile), 100 amphibians, and 950 species of fish ,250 of which are freshwater. The decline in wildlife numbers globally, regionally, and locally has more been attributed to land use changes, human encroachment into wildlife habitats, recurrent droughts, poaching, and other anthropogenic activities (Nyamasyo et al, 2014). The dorminant species of wildlife include elephants, lions, buffaloes, zebras, gazelles, leopards, hippos among others.There are game lodges that are an important part of tourism and hospitality industry. There are also thousands of birds, insects and small mammals as well as exotic fruit trees such as guavas, mangos and avocados that adorn the landscape (Sheldrick,N., 2013) .The fruit trees are an indication that at one point, land encroachment for agriculture was rife.The forested as well as the riverline areas act as dry period grazing areas for wildlife and the Maasai community that live to the north of the project area although the latter's activities are limited to the fringes of the park (Washitemi et al., 2007). In most cases, grazing is largely unmanaged, causing overutilization and insufficient rest to promote regeneration (Sheldrick,N., 2013). However, illegal and unplanned human settlement in sections of the Chyulu Hills continues to exert pressure on the ecosystem; examples include rising cases of human wildlife conflict, damage to crops, destruction of property, poisoning and spearing of wildlife (Kanui et al., 2016) . Pastoralism is dominant in the lowlands, with large swaths of land set aside for group ranches and wildlife conservation. Rainfed agriculture dominates the highlands in the upper areas around Loitokitok Town while a thriving irrigation agriculture for horticulture as well as domestic purposes is supported by the swamps and rivers in the mid altitudes and the lowlands especially in Kimana and Rhombo regions (Githaiga, 2003). There are six major land use types in the study area; maize beans system that produces food for consumption, coffee bushes which are sometimes intercropped with beans or with maize, nippier, shrub land, fallow and horticulture.

3.1.4: Physiography and Drainage

The area varies in altitude from about 715 MASL at Lake Jipe in the South, 800 MASL at Mzima Springs in the East, to the highest areas of about 2100 MASL in the Chyulu Hills mainly composed of hilly cones.

The eastern side is characterized by the Chyulu Hills that rise to a height of 2100 MASL and are comprised of hundreds of small cones and flows (Sheldrick, N., 2013) . The drainage network in the watershed is mostly concentrated on the North-Western and South-Eastern in the case of the Tsavo River system and also North –South in the case of Lumi River system. The former is more hydrologically active in water provision than the Western zone which is on the rain shadow of Mt Kilimanjaro (Kiringe et al., 2016). Mzima Springs and their associated springs and pools are located at the eastern side of the project area. These include Mzima Springs, Mzima pools and Mzima River, which constitute an important part of the Tsavo River catchment. The western side is characterized by low lying ridges that slope in a south easterly direction. The Chyulu Hills and Kilimanjaro slopes act as important features as they are the end points on the north eastern side and Western side respectively. River Lumi whose head waters originate from the south Eastern Slopes of Mt. Kilimanjaro drains into Lake Jipe, which in turn is the source of River Ruvu that flows into Tanzania. Most of the tributaries feeding River Lumi remain dry most of the year, but the perennial flow is maintained by a series of high yielding springs (Grossmann, 2008) the biggest of which is Njoro Kubwa . These major features; lakes, rivers, Chyulu Hills, major springs are clearly visible in Figure 1.1.

3.1.5: Geology

The rocks of the area fall into three groups: the Archean rocks of the Basement System, the Tertiary volcanics and intrusives, and superficial deposits of Pleistocene and Recent age. The basements are composed of metamorphic and granites and are unconformably overlain by younger volcanics (Scoon, R., 2015).These rocks of the Basement System are poorly exposed and outcrops are confined to the inselbergs and the few dry river valleys and gullies. They include types derived from the metamorphism and granitization of originally calcareous, pelitic, psammitic, and carbonaceous sediments (Saggerson, P., 1959). Broadly speaking the area is characterized by a high grade of metamorphism characterized by K/Ar-ages of 400-600 million years (m.y). The volcanic pyroclastics and volcanic alluvium deposits at the base of Mt Kilimanjaro extend across the Kenyan-Tanzanian border and form basins which expand outwards from the mountain and are limited by the surrounding pre Cambrian basement rocks (Grossmann, 2008). The north-western half of the area is covered by lava flows, some of which have been erupted from Mt. Kilimanjaro, others from subsidiary vents on the plains. Successive flows in some cases, were thin and of varying composition. The volcanics are divided into the Rombo series, and the rocks of the subsidiary cones.

The lavas extruded from volcanoes on the plains, such as Warombo and Lemrika, consist essentially of vesicular olivine basalt. Thin superficial deposits which have accumulated since the vulcanicity ceased include boulder beds, grits, secondary limestones, clays, soils, and alluvium. Immediately outside the north-eastern corner of the area are the highly vesicular lavas of Mzima Springs. These are completely unweathered and free of vegetation, and must be of unusually recent age (Kiringe et al., 2016). The Chyulu-Oloitokitok belt consists of highly permeable and porous basaltic lavas and pyroclastics leading to low runoff creating an ideal environment for infiltration (Darlin, G., 1999) .

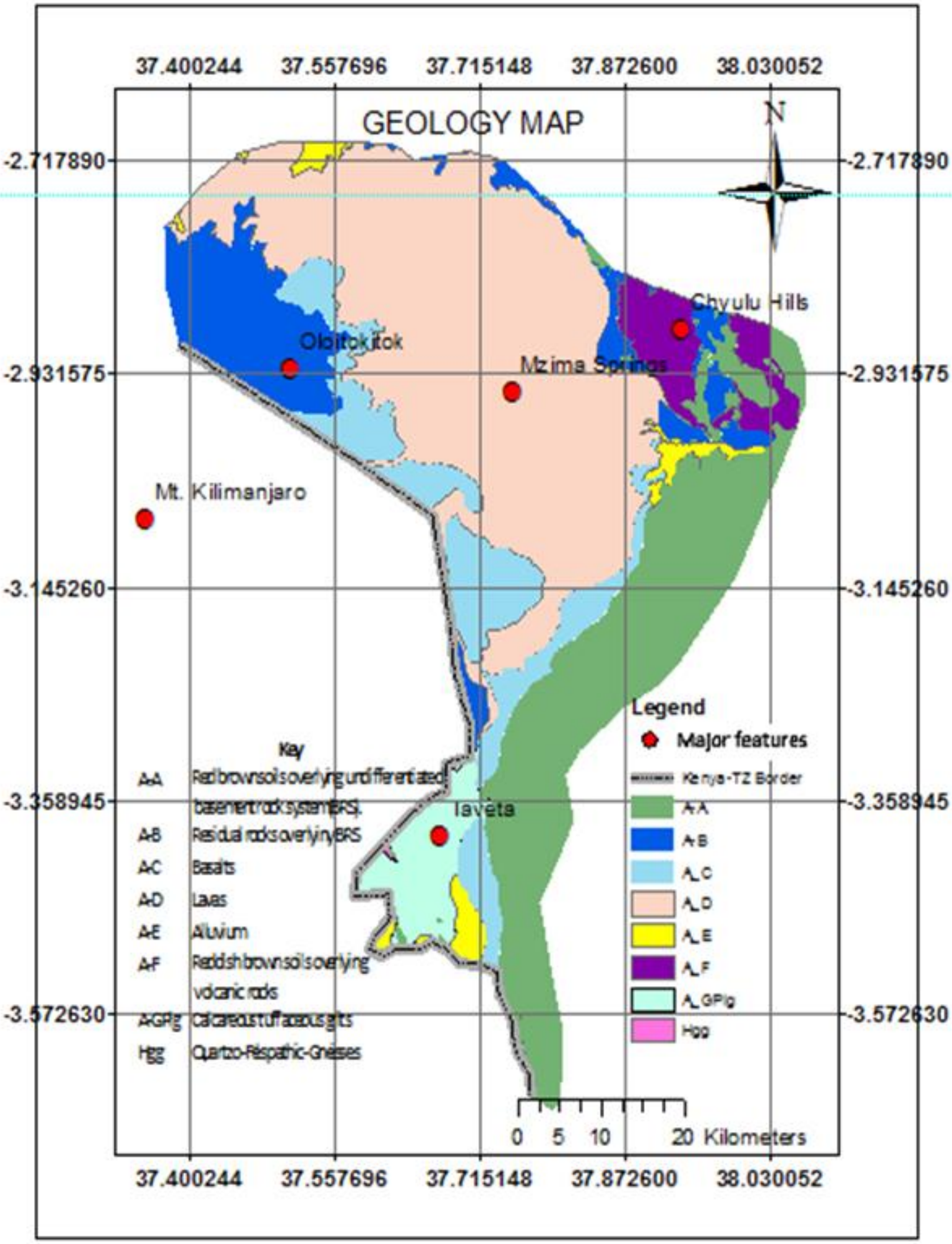


Figure 3.2: Geology map of the Project Area. (Source: Author)

The Chyulu hills themselves form a volcanic mountain range with a mixture of volcanic cones and barren lava flows (Tolvanen,R., 2004). Figure 3.2 above illustrates the geology of the project area.

3.1.6: Hydrogeology

Groundwater is an important water source on the plains and is available from these springs as well as shallow wells and boreholes. Most of the wells are in dry river beds. The depth of shallow wells varies between 3–30 metres (m). The average depth of the boreholes is 80 m, but water has sometimes been found at depths of up to 250 m (Grossmann, 2008). Land use and land cover plays an important role in the occurrence and development of groundwater as it influences groundwater infiltration and alters the rate of percolation of precipitation or surface runoff (Mwega et al., 2013). The Kilimanjaro aquifer includes the volcanic pyroclastic and volcanic alluvium deposits found at the base of Mount Kilimanjaro and extending across the Tanzanian - Kenyan border (CWSB, 2018). These deposits form basins which extend outward from the mountain and are limited by the surrounding Precambrian Basement rocks. Occurrence of groundwater in the surrounding basement plains is limited to faults, fractures and small parts of weathered zones and also to the bottom layers of wide alluvial valleys which are recharged by natural flood spreading (Grossmann, 2008). The surrounding Precambrian Basement rocks, which are impermeable zones, enhance groundwater storage and transmission within the aquifer by preventing transmission out of the aquifer. The porous, volcanic hills suck up precipitation like a giant sponge, with water percolating into a reservoir from which water works its way out along the interface between the volcanics and the underlying basement, emerging as springs at the tips of lava tongues that filled river valleys in the old land surface. (Sheldrick, N., 2013) . There is no groundwater available on the Chyullu Hills and therefore it forms an important water catchment area Water from regional groundwater flow systems within the region reaches the aquifers and high yielding springs at the base of the mountain in two ways: by diffuse flow and by concentrated flow (Grossmann, 2008). Most of the recharge is believed to come from the Chyulu Hills, recharging several springs at their foot. These Springs feed into the Tsavo and Athi Rivers. Mzima Springs is one of the major springs discharging 3.066 of the 5.866 cubic metres of water per second (m^3/s) in Tsavo River (Nyingi et al., 2013).

3.1.7: Soils

The type of soil is primarily determined by the bedrock and other land forms in an area. The soils of the project area are of volcanic origin (Kanui et al., 2016). Moderately deep firm clay soils have developed in the uplands of Loitokitok with basement system rocks rich in ferro-magnesium minerals. On the plains, undifferentiated basement system rocks have very deep, friable to firm sandy soils (Gichimbi,L., 2002). Volcanic red soils are found on the foothills of Mt. Kilimanjaro while volcanic pyroclastics are found in the Chyulu Hills. Areas around swamps have alluvial quartenary sediments , which are relatively deep (Githaiga et al., 2003).Figure 3.3 below shows the soils of the project area.

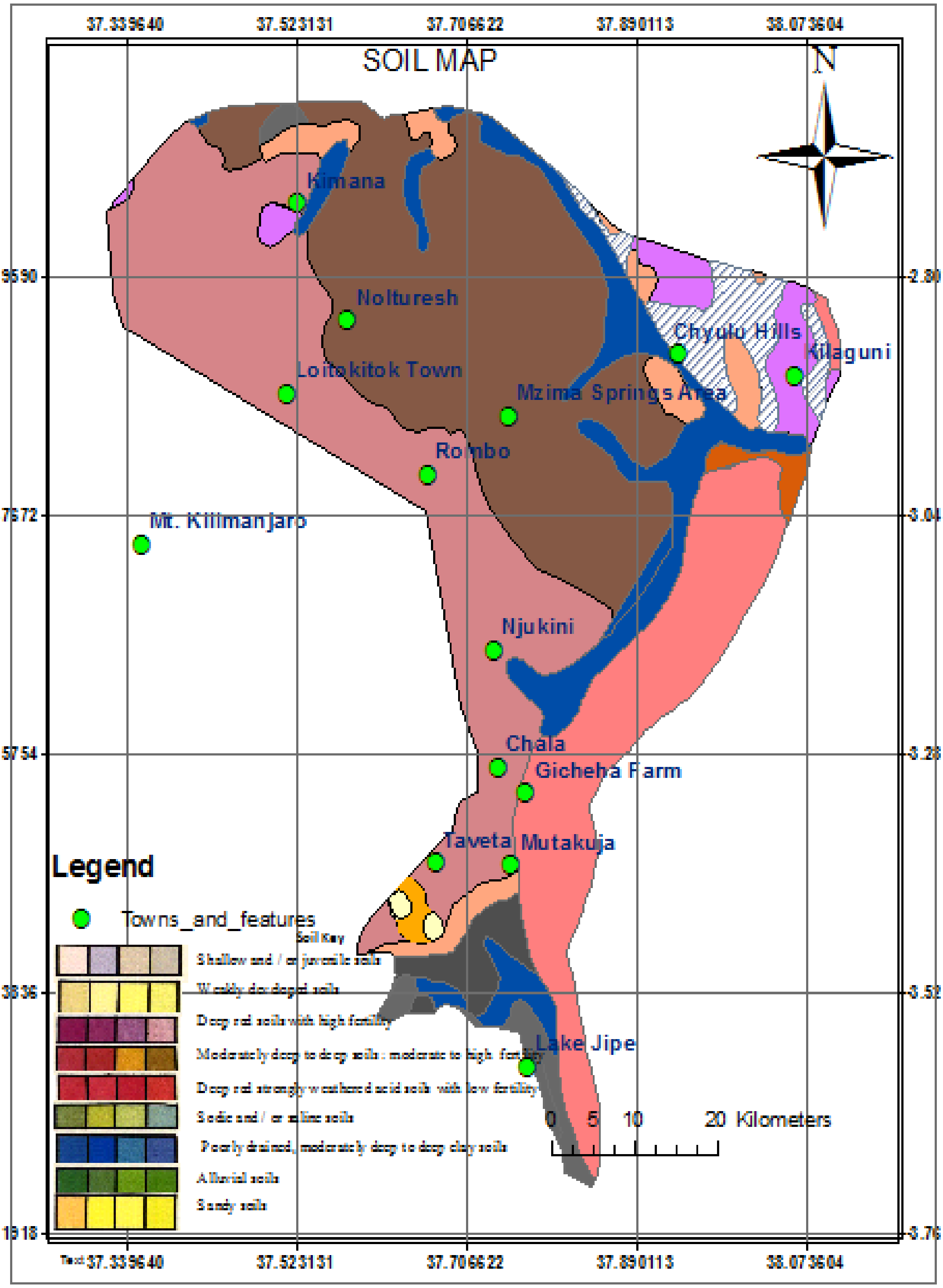


Figure 3.3: Soil Map of project area

3.1.8: Surface and Groundwater Resources

3.1.8.1: Surface Water Resources

Spatial distribution of surface water resources is uneven as they are associated with the main rivers including Tsavo and Lumi, Nolturesh, Mzima as well as Lakes Jipe and Chala on the western side of the project area. Lake Chala is a fresh water crater lake without a visible inlet or outlet but believed to be connected with the surrounding springs (Appendix 5). The central part of the project area is semi-arid with little of these resources. Surface runoff from Mt. Kilimanjaro contributes to small tributaries that drain into the Lumi River (Grossmann, 2008). However, the perennial flow of Lumi River is maintained by springs in the south of the project area, among them Njoro Kubwa that discharges 4m^3 per second. Most of the upper section of the river is dry for most of the year. The hydrology of the middle Athi Basin permits formation of numerous springs, water pools and shallow lakes. Rain and mist water seeps on Chyulu Hills and appears at Mzima Springs in Tsavo West National Park .These water systems are extremely important because they support the water needs of the people, agriculture, livestock and wildlife (Nyingi et al., 2013). Although Athi River as the main tributary to the Sabaki River tends to dry up in times of drought, Sabaki River in Malindi Sub County has never dried up due to permanent flow of the Mzima Springs. The hydrology of the western region of the project area is majorly influenced by Mt. Kilimanjaro, both with respect to the amount of rainfall it receives and to the sources of ground water produced by the Kilimanjaro Aquifer system (Ekisa,T., 2015). The surface water resources are fresh with the exception of Lake Jipe, that is saline.

3.1.8.2: Groundwater Resources

Rainfall infiltration on Mount Kilimanjaro has permitted the formation of permanent swamps and a lake in Amboseli (Nyingi et al., 2013). It is believed that most recharge to Kilimanjaro aquifer system is from the mountain although the recharging mechanisms are not well known . The role of springs and their contribution to river flows is considered to be of central importance . Previous studies have shown that groundwater recharge on the western side of the study area is maximun at 2100MASL where 1000mm of rain infiltrates and recharges the regional groundwater (Grossmann, 2008). Among the major springs on this side are Norturesh (Appendix 4), Kimana, Rhombo and Njoro Kubwa. Grossman concluded that most groundwater recharge takes place between 1500-3000MASL on the Western Side. However, the Chyulu Hills are comprised of hundreds of small cones and flows, some of which rise to over 2000 metres, forming a crucial water catchment for the Tsavo ecosystem. Precipitation is sucked into these cones and water percolates into a reservoir from which it flows out along the interface between the volcanics and the underlying basement rocks, emerging as springs, the main one being Mzima springs (Sheldrick,N., 2013). Although difficult to estimate the time it takes for rain to work its way into and out of the Chyulu, in part because of sparse rainfall Figures from atop the Chyulu, the data that does exist seems to indicate a three-year lag between heavy rainfall and increased discharge at Mzima. Previously, water recharge for this ecosystem has been estimated using soil moisture balance, hydro chemical data and isotope content where results showed that estimated recharge accounts for 13 percent of precipitation in the region (Kiringe et al., 2016)

3.2: Research Methodology

The research methodology approach involved the integration of the conventional methods backed by isotope hydrology. This involved conducting activities related to geology, hydrogeology, hydrology, water chemistry and isotope hydrology investigations. The steps involved were:

- Desk top studies of the project area and previous works undertaken
- Field work in the study area for sample and data collection
- Laboratory Chemical and Stable Isotope analysis
- Data analysis

These steps are described in detail below.

3.2.1: Desk top studies

Desk top studies were carried out in terms of geology, hydrogeology, isotope hydrology, hydrochemistry and hydrology as well as geochemistry of the study area. Existing hydro geological survey and well data was used to determine hydraulic properties of the aquifer and determine the groundwater flow direction. Previous isotope hydrology works were studied so at to shed some light in as far as the hydrology of the project area is concerned.

This involved carrying out desk studies of boreholes in the study area in terms of water struck levels, water rest levels as well as total drilled depth. Borehole data was obtained from borehole completion records from the Ministry of Water and Sanitation, in Maji House. Hydrology studies involved taking an inventory of existing rivers and springs in the project area as well as the major lakes and their physical setting. This data and information was obtained from the maps section in the ministry. The geology of the study area was also studied at length as well as hydrogeology and groundwater flow regimes. Previous works using isotope hydrology were also studied so as to appreciate the works and identify any existing gaps. Isotope hydrology provides knowledge about water resources that no other techniques can provide. Environmental isotopes can therefore be used to;

- Identify areas and altitude of groundwater recharge
- Define aquifer vulnerability to pollution and over exploitation
- Identify mixing between rivers, streams, lakes, springs and boreholes
- Identify sources of salinity in water quality analysis and studies.

Finally, geochemical studies were carried out to acquaint the researcher well with the chemical nature of the rocks and other resources of the area.

3.2.2: Field work

(i) Hydro geological, hydrology and hydro chemical analysis.

This involved sampling water from springs, rivers, lakes, boreholes and shallow wells in the project area. The location of sampling was recorded first using a hand held global positioning system (GPS) gadget. Sampling date was also recorded. All this was be done on the GPS and also in a field notebook as a back-up. This was followed by static water level measurement in the case of boreholes and shallow wells by use of a dipper, an equipment with a long-calibrated cord with a sensor at the end and beeps and lights on when the sensor is in contact with water. This is shown in Figure 3.4 below. The depth to the static water level was measured from the top of the casing to the water level, less the depth from top of casing to the ground level.

(ii) Insitu measurement of physical parameters was also carried out using a Multi Parameter kit (Appendix 1). The insitu physical parameters measured included potential of hydrogen ions (pH), electrical conductivity (EC), total dissolved solids (TDS), and temperature in degrees

Celsius (^{0}C), pH and dissolved oxygen (DO). The multi parameter kit was calibrated first depending on the parameter measured. For EC, the calibration was at 1413 Microsiemens per Centimeter (µS/cm) at 25^{0}Celcius (^{0}C) while for the pH, a standard buffer solution was used to calibrate before it was measured.

Figure 3.4: Taking borehole water rest level measurements using a dipper.

A clean container was rinsed and used to draw water sample and the measurements done by inserting the probes into the water sample until the readings stabilized. This was done for EC, stability of temperature, dissolved oxygen and pH. Dissolved oxygen did not require calibration and was recorded in milligrams per litre (mg/L) and percent of oxygen saturation (%O_2). The readings were recorded in a field notebook, where the location and elevation of the sampling points had been recorded.

Water rest levels of the various boreholes and shallow wells were measured first using a dipper and the boreholes purged or water fetched in the case of shallow wells in preparation for sampling.

(iii)Water sampling was done at two levels;

(a) sampling for laboratory analysis of cations and anions

(b) Sampling for analysis of stable isotopes

For laboratory measurement of cations and anions, the sample was filtered first using a 0.45-micron membrane filter and then poured into a 250 ml high density polyethylene (HDPE) sampling bottle and tightly capped and labelled, indicating the name of sampling location, sample number and sampling date. The samples were stored in storage boxes.

For the measurement of stable isotopes (^{2}H and ^{18}O), water sample from borehole or shallow well was poured into a large HDPE container ensuring that the pipe conveying the water from the borehole is immersed into this container and water let to flow continuously.

A rinsed 50ml HDPE container was then immersed into the larger container until full and tightly capped to avoid evaporation of the sample, taking care not to trap any air bubbles. For the case of lakes, springs and rivers, rinsed 50ml HDPE containers were immersed and tightly capped while still in the water. The springs were sampled at the source to ensure best results as shown in Figure 3.5 below. The samples were clearly labelled as earlier indicated. Samples for isotope analysis were stored in a cooler box and then preserved in a refrigerator before being shipped for laboratory analysis.

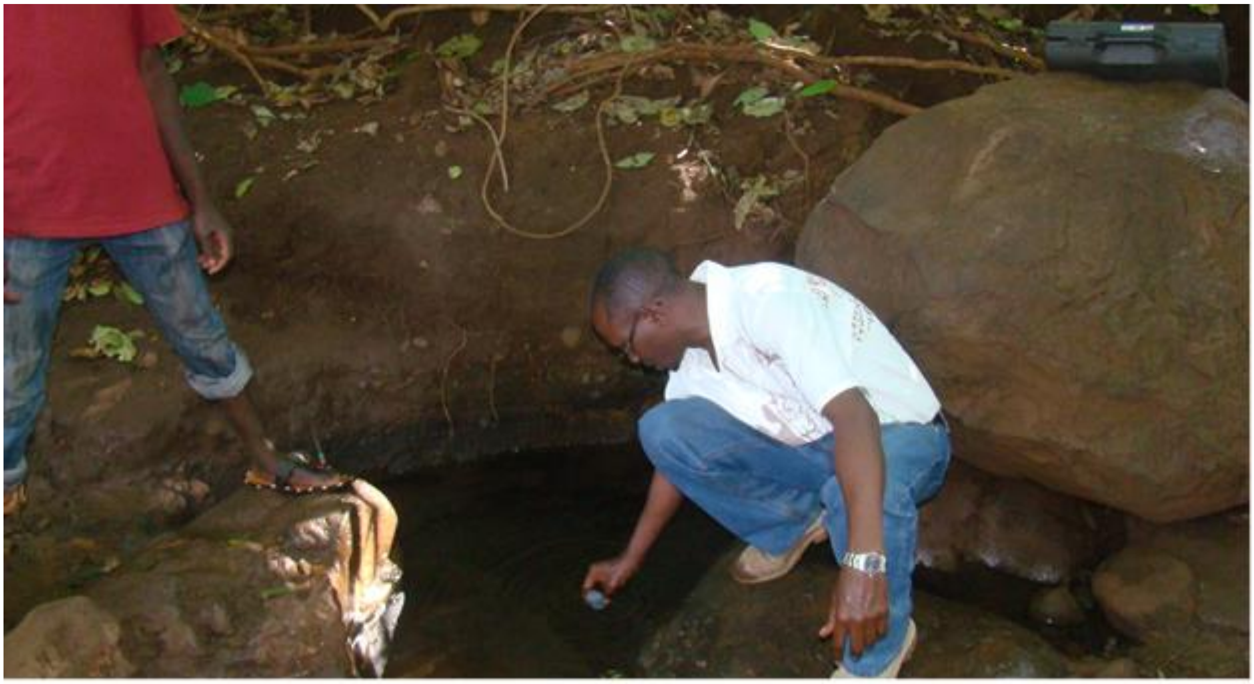


Figure 3.5: Taking stable isotope samples at the source of Njoro Kubwa Springs

3.2.3 Laboratory Chemical and Stable Isotope analysis

This involved laboratory chemical and stable isotope analysis of the samples including anions and cations, bi carbonates, sulphates and nitrates among others.
The Laboratory analysis for all the samples was done at the Structural and Isotopic Analysis Laboratory in the National Center for Nuclear Energy Science and Technology, Rabat, Morocco.

The analysis was done at the end of every sampling campaign. This included both chemical analysis and stable isotopes analysis for all the samples. The Analytical techniques used involved the use of Laser Spectroscopy using Picarro L2130i for stable isotope analysis (appendix 2) and Ion Chromatography System (ICS) 5000^+ for Anions and Cations (appendix 3).
In the case of the stable isotope analysis, the wavelength of a diode laser in the laser machine is tuned over selected H_2O, $^1H^2HO$ and $H_2{}^{18}O$ absorption lines near 1390 nm. The integrated areas of the high-resolution absorption lines are combined with measured gas temperature to yield the molecular concentrations, from which the atomic ratios $^2H/^1H$ and $^{18}O/^{16}O$ are determined directly.

Delta values are calculated using the atomic ratios of VSMOW-calibrated standards in a linear regression procedure.

The ICS 5000^+ is a high resolution, fast analysis high-pressure, ion chromatography that has increased mass sensitivity and is perfect for sample analysis as it is one of the modern fast and efficient equipment.
The ICS works on the basis of the fact that all ions carry an electric charge, are soluble in water and exhibit conductivity in solution. The existence of these ions in solution is usually in various forms and dependent on the pH of the eluent (fluid used in extraction of the cation/anion). Therefore, all ions must be in solution form before analysis by use of ICS. A high capacity cation exchange membrane in the acid form is then used to extract cations from the eluent and replaces them with H^+.

Conductivity was done through conducimetry, which refers to the conductivity of ionic solutions caused by mobility of ions towards respective electrodes in presence of an electric field and is measured by using conductometer. The pH was measured using pH meter. The bicarbonates were analyzed using titrimetry method.

Expression of the results for the stable isotope analysis was in delta values δ (‰) with respect to the Vienna Standard Mean Ocean Water (VSMOW).

3.2.4 Data Analysis

Chemical data analysis was done using diagramme software as well as binary diagram in addition to theoretical analysis. Isotope data analysis was also be done by use of theoretical interpretation, isotope hydrology interpretation, diagramme, surfer 10 and ArcMap10.3.

Result presentation was in the form of piper diagrams, plots and binary diagrams for both chemical and isotope analysis.

CHAPTER 4: RESULTS AND DISCUSSION

A total of 31 samples were collected in the sampling campaign in the recommended area. The samples collected included spring samples, borehole samples, shallow wells, lakes and rivers. There was a challenge in accessing some of the springs and rivers as the vegetation was too thick. Though there were many boreholes in the area and especially Taveta Town and its environs, the researcher only took a few water rest levels due to flaws in borehole completion design. Some boreholes had no airlines while others were poorly fitted, making it difficult to use a dipper. For the rest of the area, he relied on shallow wells.

The Laboratory analysis for all the samples was done at the Structural and Isotopic Analysis Laboratory in the National Center for Nuclear Energy Science and Technology, Rabat, Morocco.

The analysis was done in November 2016 for samples collected in that year and December 2017 for the samples collected in 2017.This included both chemical analysis and stable isotopes analysis for all the samples. The Analytical techniques used involved the use of Laser Spectroscopy using Picarro L2130i for stable isotope analysis and Ion Chromatography IC5000+ for Anions and Cations. Conductivity was done through conducimetry while pH was measured using pH meter. The bicarbonates were analyzed using titrimetry method.

For the determination of groundwater flow direction, the researcher used the boreholes and shallow wells whose water rest levels could be measured during the field campaign. The rest of the boreholes data was acquired from the borehole completion records from the Ministry of Water and Sanitation. However, the researcher noted that the project area has a relatively low borehole density. Figure 4.1 below shows the location of sampling sites while table 4.1 shows the results of sample analysis.

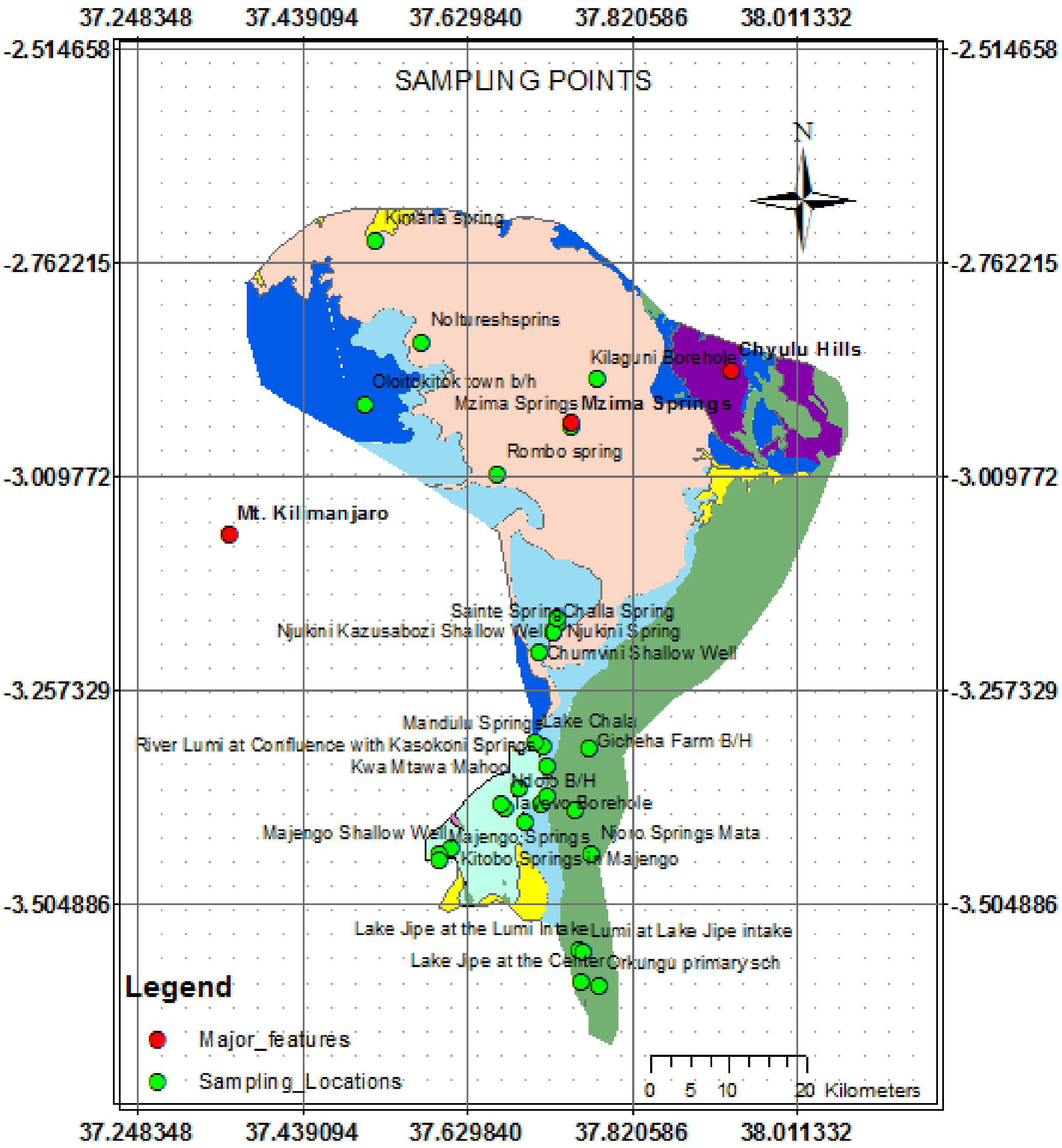


Figure 4.1: Sampling Locations

Table 4.1: Results of Analysis

			Coordinates			Field data			Laboratory Analysis												
			Latitude	Longitude	Altitude	Cond	Temp.	D.O	δ^2H	$\delta^{18}o$	CE (µS/cm)	pH	HCO_3^-	Cl^-(mg/l)	NO_3^-(mg/l)	SO_4^{2-}(mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Mg^{2+} (mg/l)	Ca^{2+} (mg/l)	ionic Balance
Sampling date	Type Code	NAME	N/S DDMMSS .DD	W/E DDDMM SS.DD	(m)	□S/cm	degC	mg/l	‰	‰	Réf 25°C	Unité pH	(mg/l)	LQ (0.08)	LQ (0.17)	LQ (0.13)	LQ (0.21)	LQ (0.01)	LQ (0.05)	LQ (0.14)	
18-05-16	GWS	Kimana spring	-2.73583	37.5225	1315	357	21.8	5	-23.8	-5.05	319	5	213.5	8.73	2.62	2.61	36.76	6.86	15.12	19.58	0.02
18-05-16	GWS	Nolturesh sprins	-2.85333	37.57676	1534	211	16.7	6.3	-28.3	-5.17	191.8	6.3	132.98	3.61	1.61	4.62	30.73	8.81	5.83	5.64	-0.03
18-05-16	GWS	Rombo spring	-3.00629	37.66334	1227	352	22	6.4	-22.3	-4.24	321	6.4	180.56	19.56	10	4.7	23.13	6.38	18.14	29.1	0.04
19-05-16	GWB	Orkungu primary sch	-3.59911	37.78135	749	4300	29.6	5.9	-18.2	-3.26	3890	5.9	348.92	950.94	54.09	764.83	546.84	37.52	159.49	247.57	0.01
18/09/2017	GWB	Oloitokitok town b/h	-2.92549	37.5108	1752	254	21.5		-21,8	-4,45	271	7,37	179,34	5,80	2,11	1,39	28,97	7,94	8,60	14,61	-0.04
18/09/2017	GWS	Njukini Spring	-3.18171	37.73457	1029	272	21.6	7	-20,7	-4,29	289	7,19	189,10	10,38	4,55	1,73	20,10	7,50	14,30	23,95	-0.01
18/09/2017	GWS	Sainte Spring	-3.19029	37.7297	997	201	20.1	6.79	-20,4	-4,41	225	6,95	N.A	6,80	6,31	3,48	8,96	3,65	6,57	11,07	--
18/09/2017	GWS	Challa Spring	-3.19032	37.72972	995	189.3	20.4	7.8	-19,2	-4,37	190,9	6,95	140,30	4,02	0,47	1,64	12,29	4,10	9,25	15,71	-0.06
18/09/2017	GWB	Gicheha Farm B/H	-3.32349	37.76985	909	318	24.8	8.26	-18,5	-4,26	329	7,09	195,20	15,41	2,33	2,89	30,67	5,43	14,50	24,63	0.02
19/09/2017	SWL	Lake Jipe at the Lumi Intake	-3.55924	37.76002	719	402	24.3	1.5	-14,1	-3,45	405	7,39	267,18	11,31	<LQ	0,39	55,32	5,76	15,52	21,47	0.02
19/09/2017	SWL	Lake Jipe at the Center	-3.5963	37.76144	715	1164	24.9	7.98	20,8	3,59	1173	8,59	610,00	85,30	<LQ	0,25	190,00	19,60	20,19	14,24	-0.05
19/09/2017	SWR	Lumi at Lake Jipe intake	-3.56055	37.76294	721	495	25.2	1.83	-10,3	-3	496	7,47	312,32	21,77	<LQ	0,97	82,96	7,07	17,12	21,49	0.04
19/09/2017	GWS	Njoro Springs Mata	-3.44735	37.77326	806	2720	27.6	5.32	-18,4	-4,29	2670	7,79	555,10	474,79	<LQ	212,85	419,21	38,64	65,79	76,61	0.03
18-05-16	SWL	Lake Chala	-3.31824	37.70818	864	345	27.4	6.2	17.4	3.24	328	6.2	228.1	11.17	0.64	2.38	23.88	7.41	25.28	22.72	0.04
19/09/2017	GWS/W	Mutakuja Village S/W Mata	-3.39617	37.75438	822	2590	29.3	4.41	-18,5	-4,08	2530	8,09	633,18	431,52	3,20	200,66	371,39	9,54	62,76	83,41	-0.02
19/09/2017	GWB	Salim Swaheh B/H	-3.38807	37.71468	762	733	26.5	4.92	-12,4	-2,89	723	7,45	305,00	84,57	2,75	7,28	63,65	6,43	28,60	58,43	0.04
19/09/2017	GWB	Tavevo Borehole	-3.39314	37.67289	778	271	21.1	7.15	-16,2	-4,05	271	7,8	189,10	6,14	3,88	2,16	14,45	5,33	17,38	18,66	-4%
19/09/2017	GWB	Vitalis Kongelo B/H	-3.38084	37.72225	767	1168	28.1	5.62	-16,8	-3,66	1147	7,77	437,98	153,07	17,42	27,30	94,94	10,07	58,06	88,33	5%
20/09/2017	GWS	Njoro Kubwa Spring	-3.41086	37.69596	731	178.4	19.8	7.79	-18,1	-4,21	179,9	7,26	129,32	5,62	1,20	1,91	13,07	4,65	9,74	13,82	-4%
20/09/2017	GWS	Kitobo Springs in Majengo	-3.44125	37.61143	692	216	20.5	7.56	-22,4	-4,77	213	7,21	152,50	4,61	0,35	1,63	13,82	4,21	11,50	15,63	-5%
20/09/2017	GWS/W	Majengo Shallow Well	-3.44812	37.59792	718	1068	23.4	4.82	-23,8	-4,96	1054	7,46	358,68	151,67	1,09	36,22	167,74	5,00	34,79	38,86	6%
20/09/2017	GWS	Majengo Springs	-3.45382	37.5969	717	389	22.9	6.2	-23	-4,57	381	7,49	268,40	7,09	<LQ	2,10	33,15	6,56	20,16	31,99	2%
20/09/2017	GWB	Ndolo B/H	-3.38817	37.66933	792	245	22	7.72	-18	-4,31	242	7,38	170,80	5,68	1,54	2,35	15,54	4,88	14,91	16,40	-3%
20/09/2017	GWB	Kwa Mtawa Mahoo	-3.37162	37.69012	807	175.2	24.1	7.79	-17,7	-4,19	172,6	120,37	130,54	6,32	2,96	1,28	12,22	3,52	9,07	15,19	-6%
20/09/2017	GWB	Confluence of R.Lumi with Kasokoni Sp	-3.34484	37.72123	811	1384	25.7	1.81	-24,1	-4,69	1412	7,63	427,00	270,01	<LQ	28,30	166,97	4,85	54608	83,32	3%
20/09/2017	GWS	Mandulu Springs	-3.32188	37.71723	840	385	24.3	5.4	-19,2	-4,08	380	7,28	234,24	16,67	4,93	6,12	29,84	5,14	18,20	34,29	1%
20/09/2017	GWS	Challa Dispensary Springs	-3.29794	97.73955	892	1428	26.9	6.02	-19,3	-4,26	1402	7,67	456,28	233,46	7,11	16,10	153,27	8,84	48,04	80,00	1%
20/09/2017	GWS/W	Chumvini Shallow Well	-3.21227	37.7118	990	271	24.7	5.57	-21,4	-4,41	268	7,29	165,92	16,77	3,54	4,23	17,40	3,69	15,15	19,98	-4%
20/09/2017	GWS/W	Njukini Kazusabozi Shallow Well	-3.17486	37.73383	1002	338	22.9	7.11	-22,1	-4,46	334	7,25	203,74	17,20	5,95	28,25	44,62	2,94	18,14	29,69	5%
20/09/2017	GWB	Kilaguni Borehole	-2.90789	38.06049	840	1160	26	6	14.28	5.32	1143	7.1	322	43.31	1.87	3.04	34.7	23.22	9.95	57.6	3
20/09/2017	GWS	Mzima Springs	-2.95056	37.75003	655	550	24.1	6.7	-13.94	-3.55	544	7.8	120.37	9	1.5	20.6	62.6	2.6	18.48	20.8	4

Expression of the results and the uncertainty is in value δ (‰) with respect to the V-SMOW with ± 0.3 ‰ for $\delta^{18}O$ and with ± 1 ‰ for $\delta^{2}H$.

From the analysis of results of isotope, hydro-geology, geochemical and hydrology data from samples that were collected in the field, the researcher noted the following:

4.1: Interaction between surface water and groundwater

4.1.1: Area and Altitude of recharge

Using stable Isotopes, the altitude of recharge of the various water bodies in the project area were calculated using ^{18}O and altitude plot. The following results were obtained:

- Lake Chala, Lake Jipe, Rombo springs, and Njoro Kubwa springs all have the same recharge area. Using the isotopic data, the researcher was able to calculate the altitude of the recharge using the altitude effect on the isotopic composition of tropical precipitation (Gonfiantini and Gat, 1981). Nolturesh and Mzima springs have no relationship and are recharged at different areas although Mzima spring is the most important because it taps to a bigger reservoir. Also, Mzima springs has no relationship with the other springs of the Kilimanjaro side since the rains of the latter are more depleted (-4.08 **‰/**- -5.17 **‰/**) compared to Mzima springs which is more enriched (-3.55 **‰).**
- Using the altitude effect on the isotopic composition of tropical precipitation (Gonfiantini and Gat, 1981) the Altitudes of recharge are dictated by the isotopic gradient for volcanic aquifers, which in our case is 0.27 **‰/100** metres. Using this ratio and the $\delta^{18}O$ values, the altitude of recharge was identified as follows:
  a. Altitude of recharge for lake Chala is 1550m – 1650m
  b. Altitude of recharge for Nolturesh springs is 1900m – 2000 MASL.
  c. The Altitude of recharge for Mzima springs is 1350m – 1450m

From the plot, it is evident that Mzima Springs is recharged at a lower altitude as compared to the others.

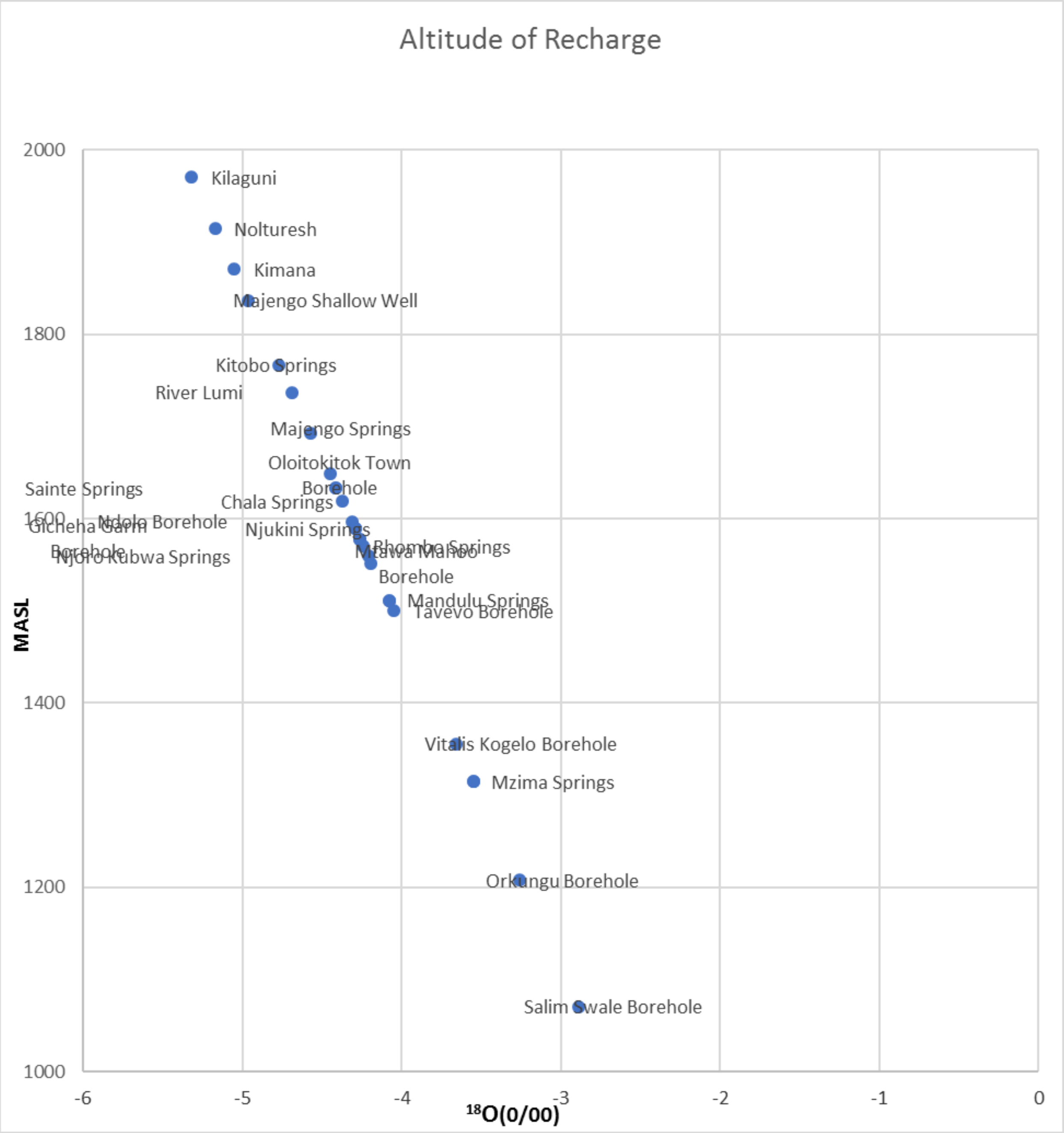


Figure 4.2: Altitude of recharge for boreholes, springs and shallow wells

4.1.2: Relationship of Lake Chala and the surrounding springs.

A Plot of ^{18}O versus ^{2}H was done on the water resources from the Kilimanjaro. It was quite evident that Lake Chala does not recharge the springs but the two sets of waters share the same source of recharge. This is shown in Figure 4.3 below.

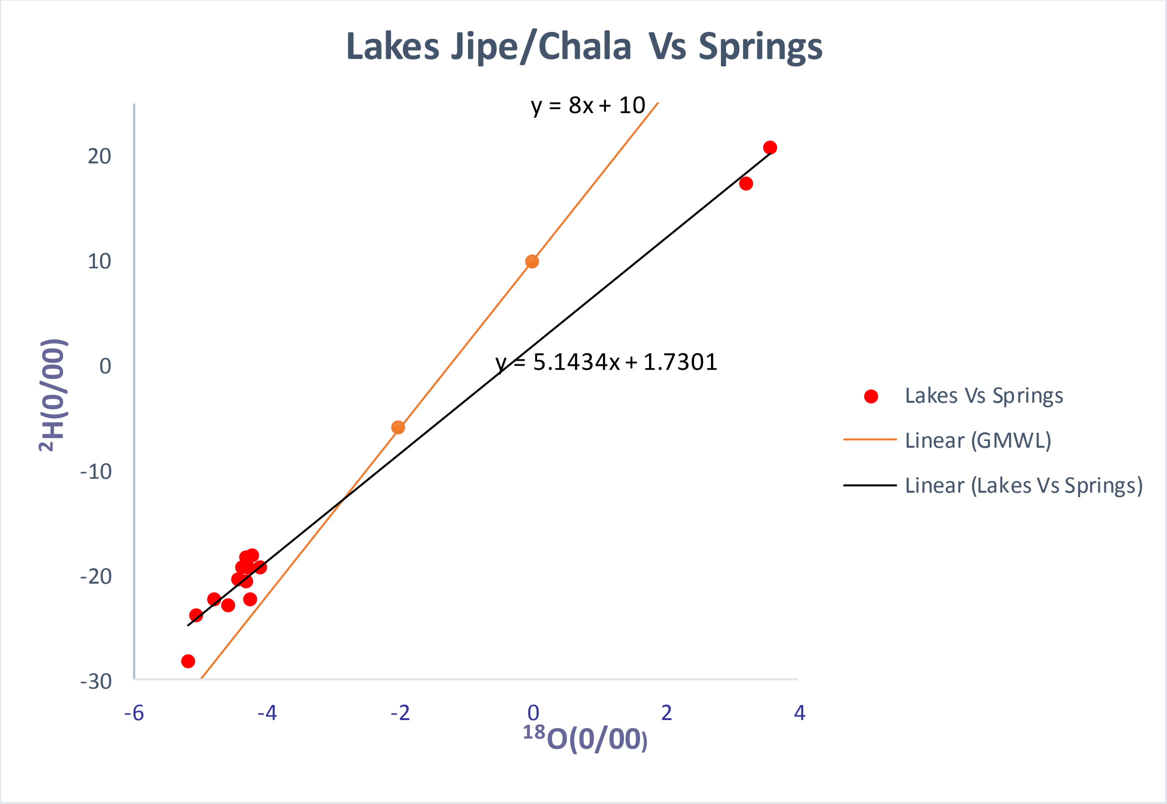


Figure 4.3: Relationship between Lake Chala/Jipe and surrounding springs

These sources have the same recharge area as dictated by the isotopic composition. The highly depleted nature of some of these waters is an indication of high-altitude recharge. However, a drop in the level of Lake Chala would lead to a drop-in water discharge from the springs. This is because they are recharged from the same area.

4.1.3: Mixing

Two types of mixing are evident from the results. The first type of mixing refers to mixing of the waters in relation to the water types based on the major cations and anions. This is best displayed using the piper diagrams. It is evident that a majority of the boreholes, springs and shallow wells share similar characteristics. Of importance to note are waters rich in calcium sulphate and magnesium chloride mixing with calcium chloride and sodium sulphate, as in the case of Orkungu Borehole and its surroundings, which is very close to Lake Jipe. This borehole was also noted to have the highest salinity levels in the study area. The waters from Mzima Springs are also a mixture of magnesium bicarbonate waters and sodium bicarbonate waters. Figure 4.4 below shows Mzima Springs waters fitting between the above mentioned two water types in terms of chemical composition. Lake Jipe at the mouth of River Lumi as well as Oloitokitok town Borehole also share the same type of mixing as Mzima Springs. Chala Dispensary Springs also depicts mixing between magnesium bicarbonate waters and waters rich in calcium sulphate and magnesium chloride. Figure 4.4 below illustrates the various water types based on the major ions while Figure 4.5 shows mixing of the various water types based on these major ions.

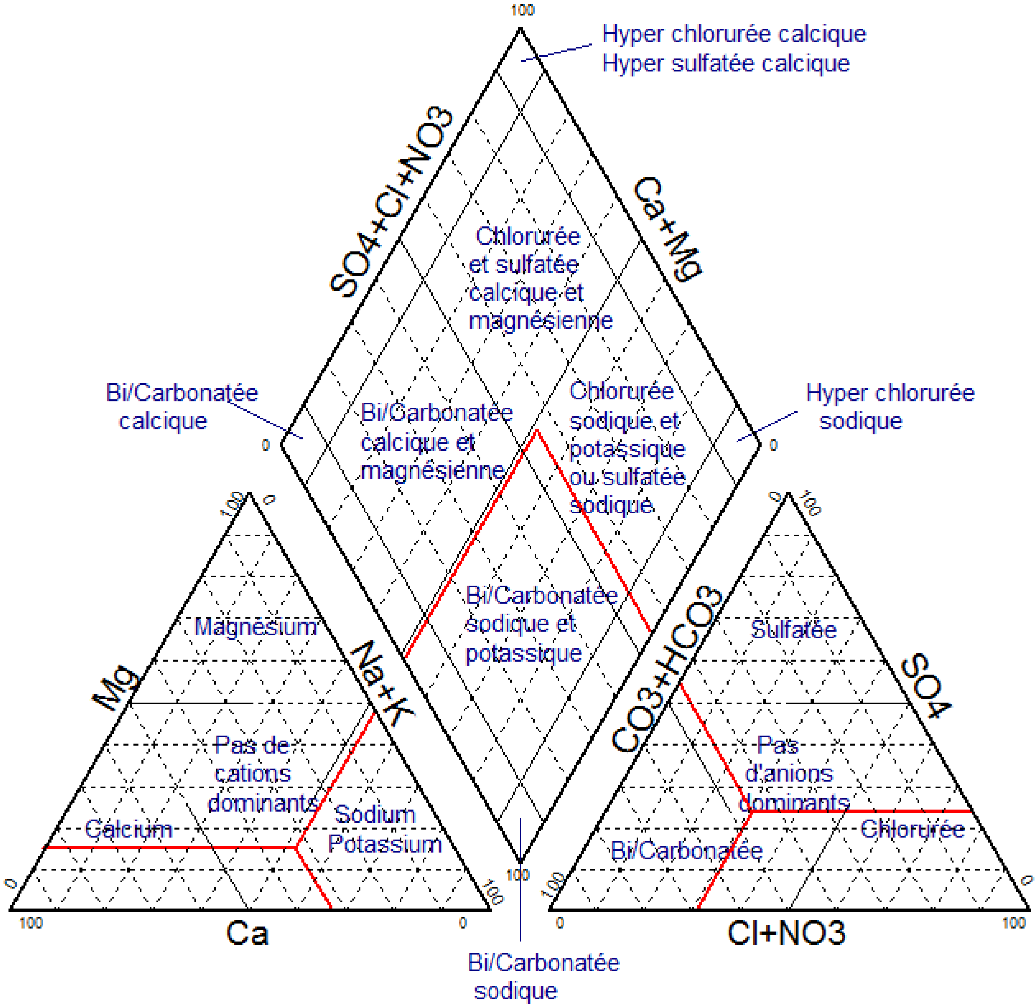


Figure 4.4: Types of water based on the major ions

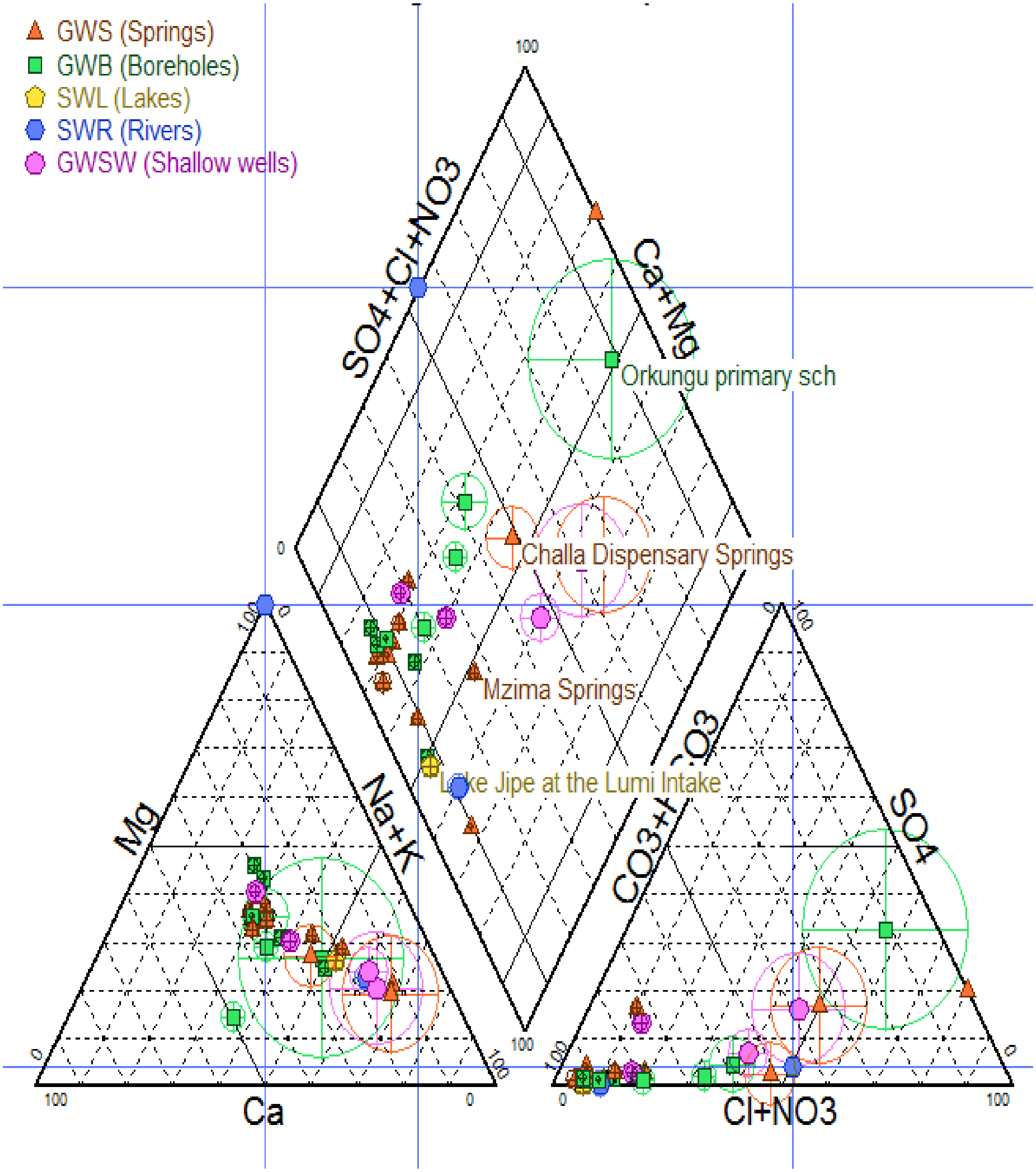


Figure 4.5: Areas of mixing of water types

There is also evidence of mixing of relatively fresh waters with mineralized waters as shown by fresh water infiltration zones in Figure 4.6 below.

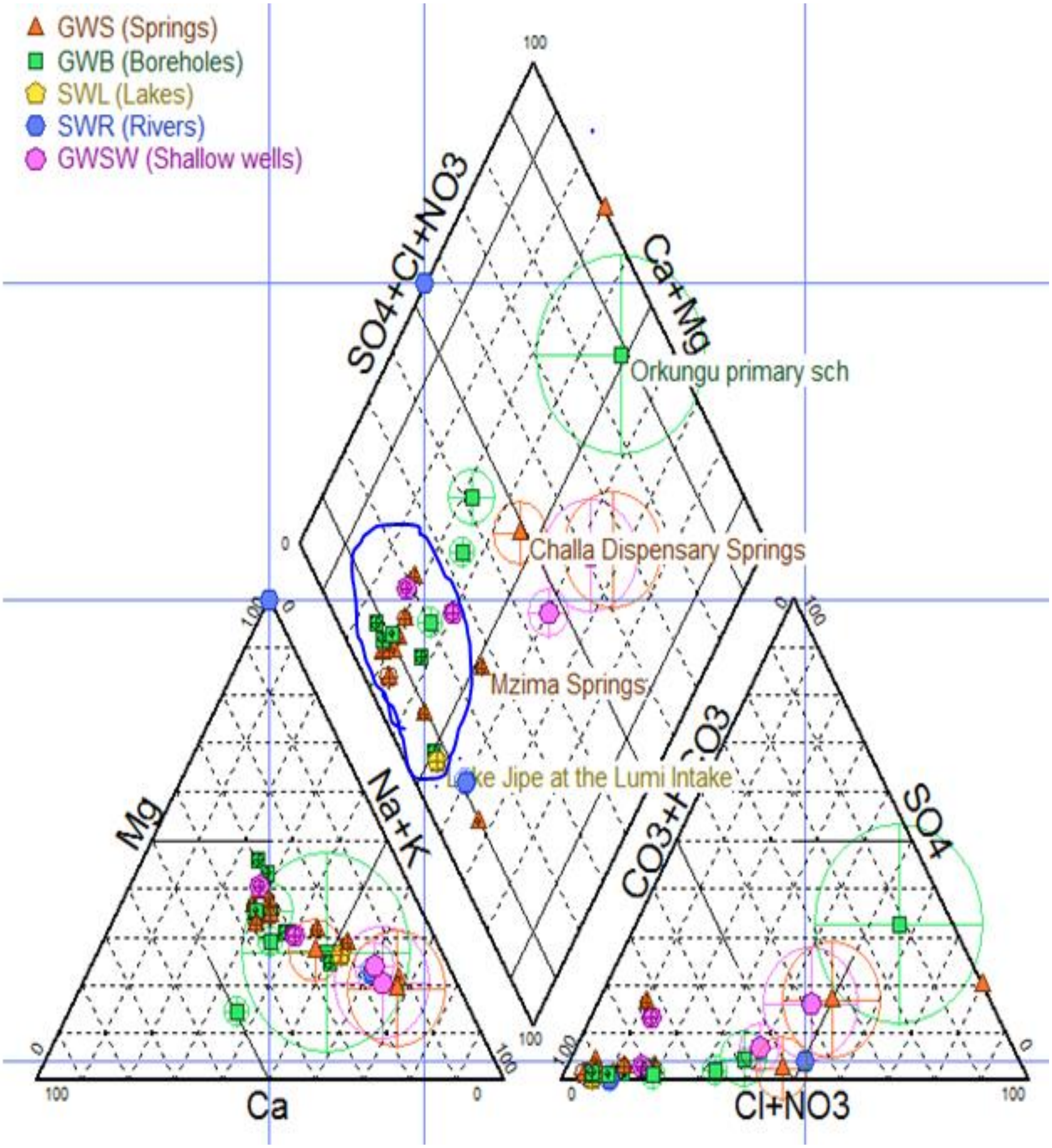


Figure 4.6: Areas of fresh water infiltration

The second type of mixing is that of the various water sources. Different waters from different sources have different isotopic signatures depending on various factors. There was noted some degree of mixing among these various water sources as evidenced by the tread line on the plot of ^{18}O vs ^{2}H. Waters from some shallow wells, springs and boreholes are mixed. Waters from Vitalis Kogelo borehole, Kwa Mtawa Mahoo Borehole, Mutakuja Shallow Well, Sainte Springs, Mandulu Springs as well as Chala Dispensary Springs are all mixed as shown in Figure 4.7 below.

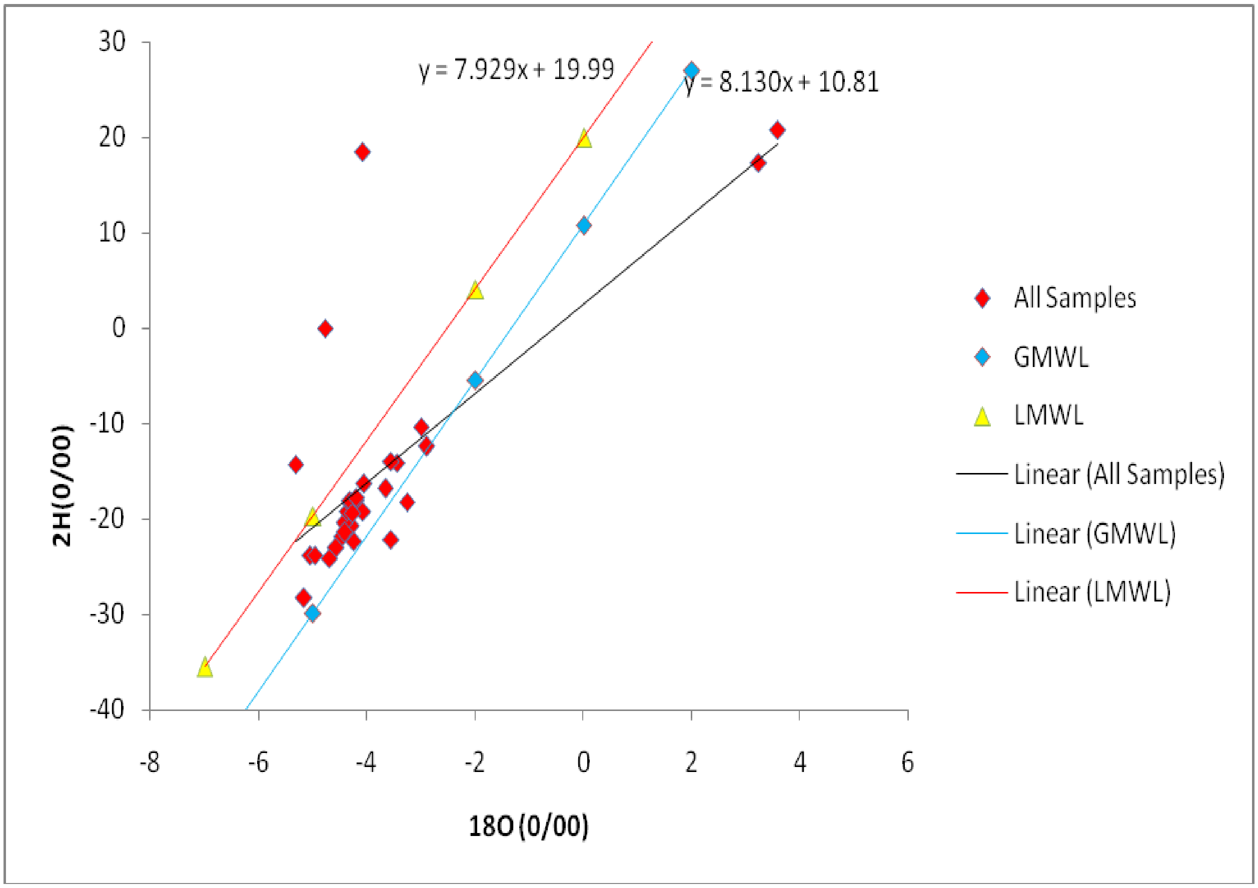


Figure 4.7: Mixing of water sources

There was noted some degree of mixing among the various water types. Of importance to note is that Mzima springs, Orkungu borehole, River Lumi at the confluence with Kasokoni springs as well as Lake Jipe at the mouth of River Lumi are highly mixed as compared to the others.

There is interaction between the aquifers from which Tavevo , Kwa Mtawa Mahoo and Ndolo boreholes are tapping their waters and also between Ndolo borehole and Mandulu Springs, as shown by the plot of ^{18}O versus ^{2}H in Figure 4.7 above..

This is a clear indication that over exploitation of waters from either of the above sources will directly affect the other. This means a drop in the level of water from these boreholes will lead to a drop-in volume of water discharged from the spring and vice versa.

4.2: Water Quality

4.2.1: Origin of salinity

A plot of Electrical Conductivity (EC) versus ^{18}O was done for all the samples whereby two groups were identified from the plot; the springs from the Kilimanjaro area are fresh and the second group was saline. It was identified that some water sources were deriving their salinity

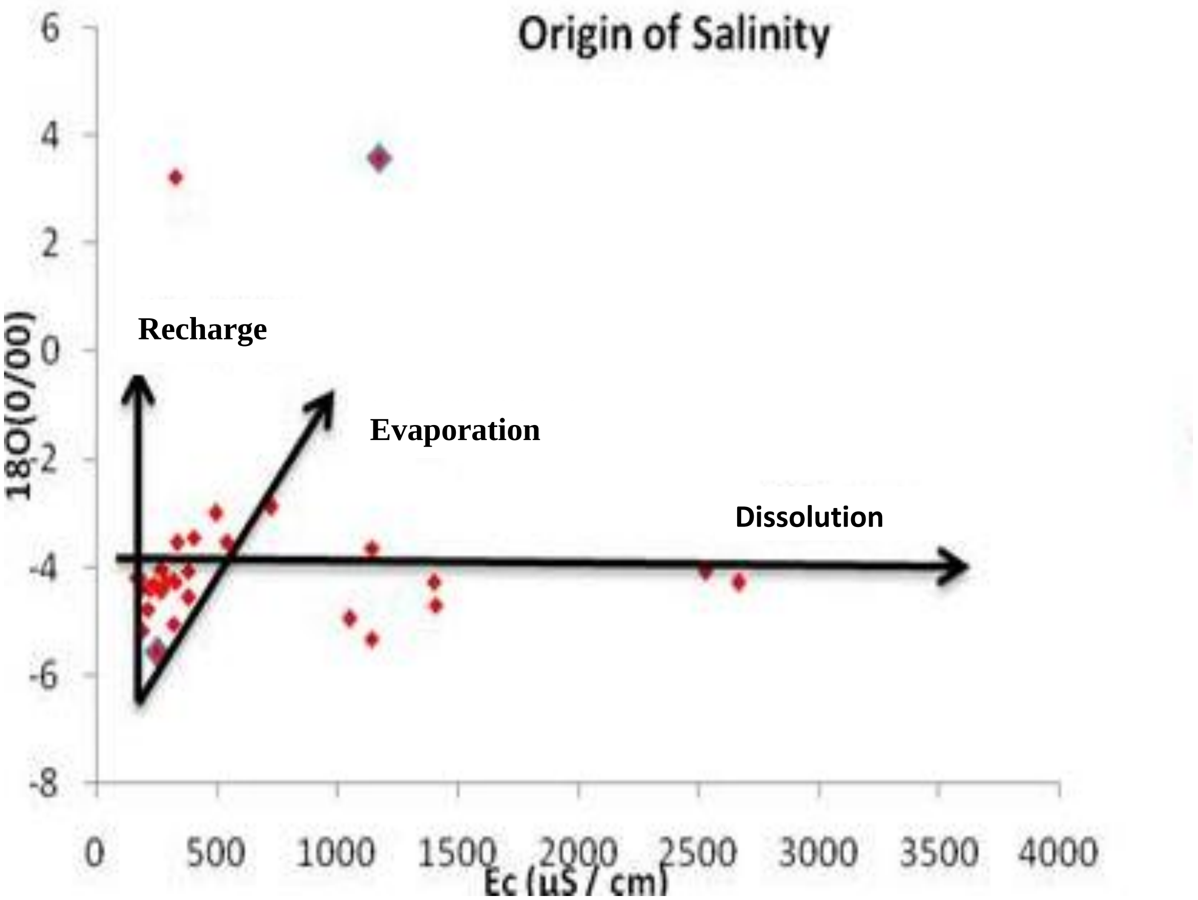


Figure 4.8: Origin of Salinity

from dissolution (formation of solution of calcium sulphate) and some from evaporation as shown in Figures 4.8 above and 4.9 below. Dissolution of gypsum is increasing the salinity of these waters especially those in the south of the project area.

These include Lake Jipe and Orkungu borehole.

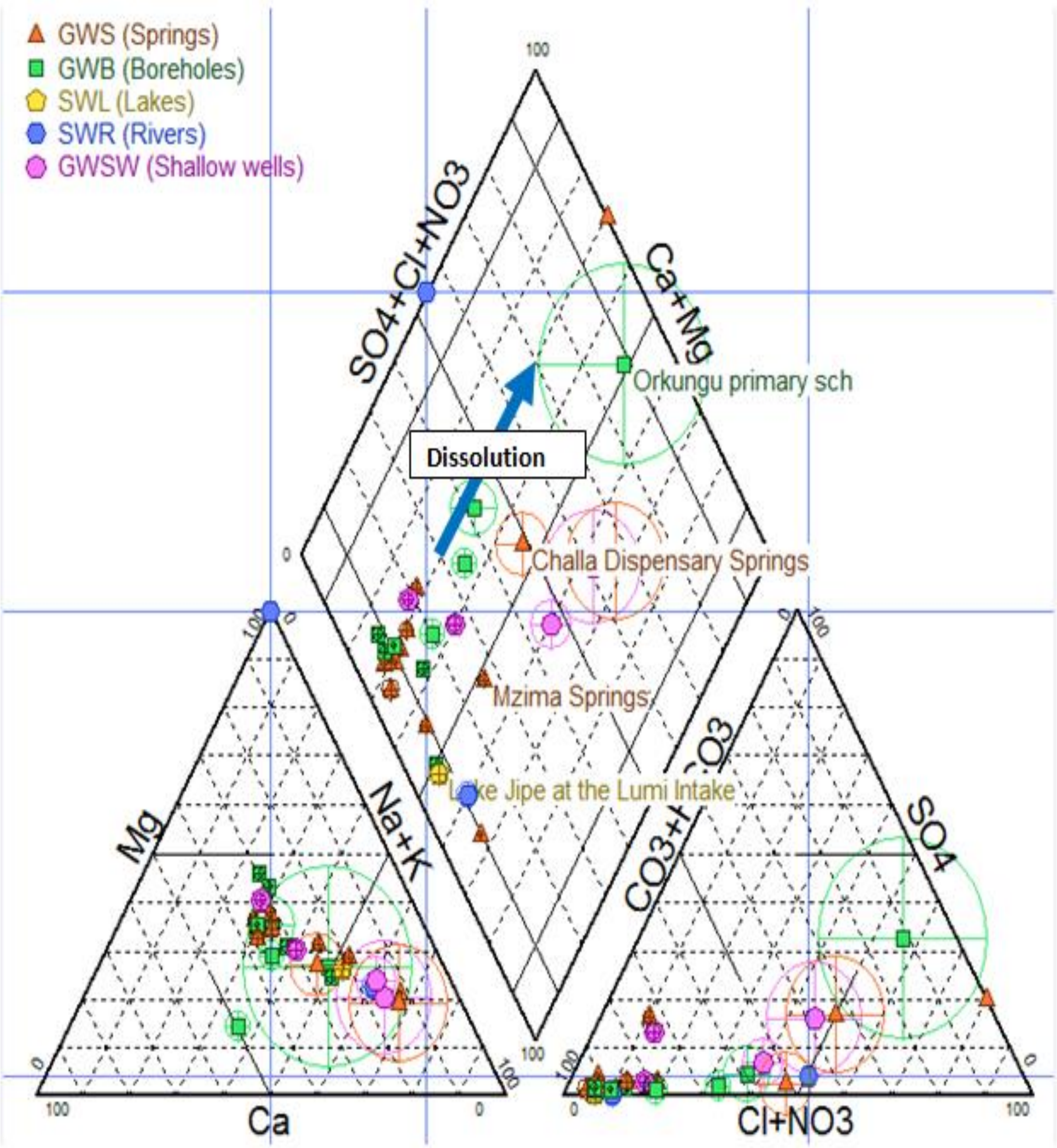


Figure 4.9: Sources of salinity

4.2.2: Lake Jipe

The lake was initially known to be fresh. However, it is getting saline and this is a key area of interest. The springs that discharge into the lake are fresh but samples from the lake centre and at the mouth of River Lumi which drains into the lake showed that it was saline, although it has both an inlet and an outlet. From the data, the researcher was able to conclude that salinity of Lake Jipe is due to evaporation though it was agreed more data was needed to be able to ascertain this information. The stable isotope analysis also confirms this as the lake is highly enriched as compared to boreholes and springs, which are depleted in both $\delta^{18}O$ and for $\delta^{2}H$ values.

4.3: Groundwater flow direction

The data obtained during the fieldwork was not adequate to determine ground water flow direction using stable isotopes. At the time of the research, it was not possible to access the high elevation points on the Kilimanjaro side as well as the Chyulu Hills, which would have enabled high altitude sampling for either springs if any, glacial waters or ice for comparison with the other water samples in the project area. However, he was able to use borehole data both measured from the field and borehole completion records at the Ministry of Water and Sanitation to determine groundwater flow direction using Surfer 10.3. Figure 4.10 below shows the borehole distribution in the project area.

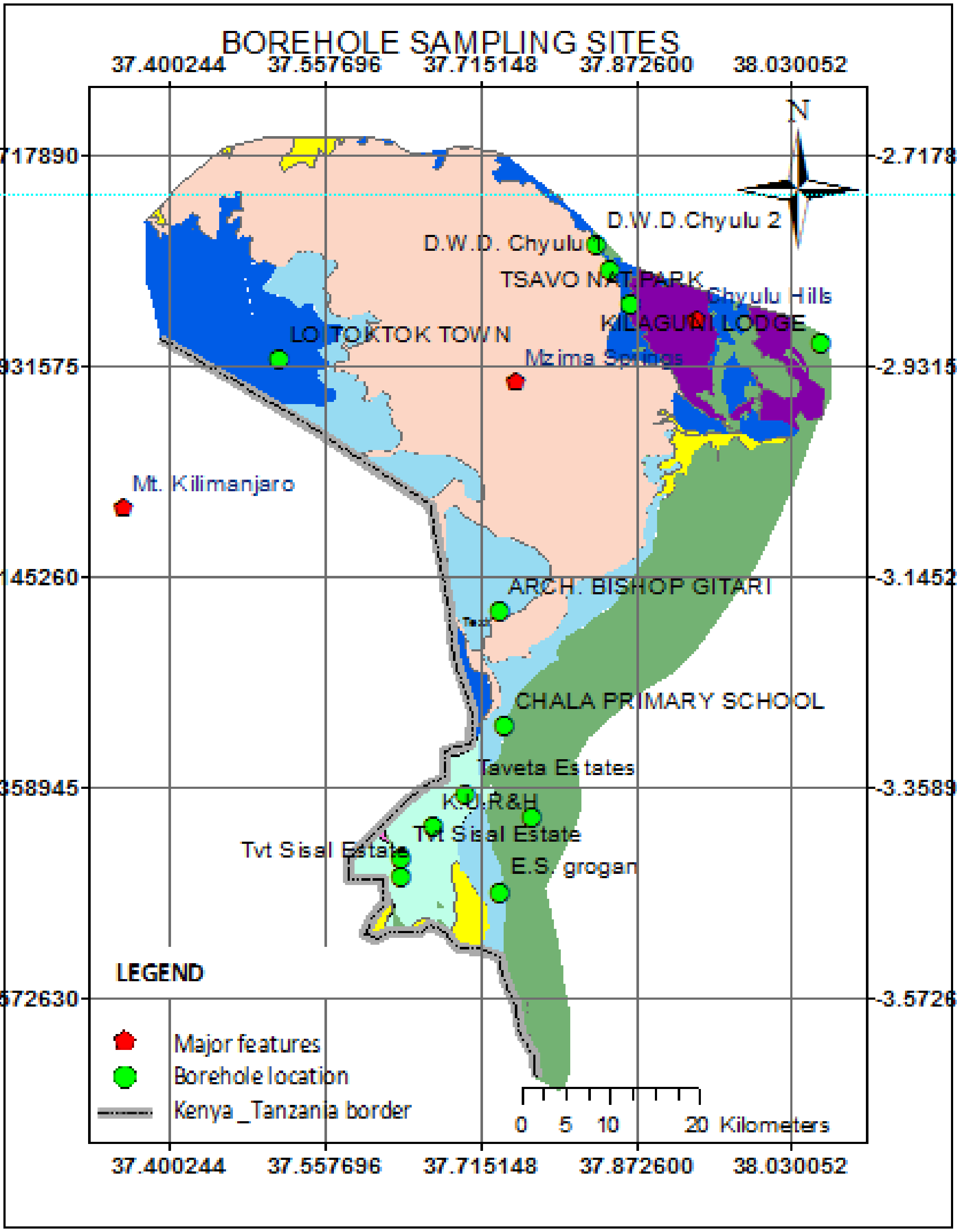


Figure 4.10: Borehole distribution

Based on the Piezzometric levels obtained from various boreholes in the project area, groundwater flow direction as dictated by gradient and presence of major discharge points was determined. Table 4.2 below shows the boreholes used in deriving the piezometric levels. The boreholes were randomly distributed across the project area and their locations ranged from the highest (1752 Masl) in Oloitokitok Town to the lowest (716Masl) in the south, adjacent to the wildlife conservancy in Jipe.

Table 4.2: List of boreholes for piezometric levels

OWNER	Longitude	Latitude	ALT	WRL	WRL Alt
Taveta Estates	37.59999	-3.36649	792	13	779
E.S. grogan	37.73328	-3.46648	716	13	703
Tvt Sisal Estate	37.63328	-3.44978	722	30	692
Tvt Sisal Estate	37.63329	-3.43308	762	35	727
K.U.R&H	37.66668	-3.39978	762	30	732
D.W.D. Chyulu 1	37.99999	-2.73313	1067	121	946
D.W.D.Chyulu 2	38.03329	-2.71653	1006	46	960
KILAGUNI LODGE	38.06049	-2.90789	840	53	787
KWAMUNA JOSEPH	37.32007	-2.49117	1310	28	1282
LOITOKTOK TOWN	37.5108	-2.92549	1752	92	1660
ARCH. BISHOP GITARI	37.73457	-3.18171	1020	70.6	949.4
CHALA HOLDINGS LTD.	37.67694	-3.39111	775	30	745
CHALA PRIMARY SCHOOL	37.73955	-3.29794	888	10	878
TSAVO NAT.PARK	38.06669	-2.79982	975	39	936

The other boreholes were distributed to the eastern and Western sides as well as the centre of the project area.

A plot of shaded relief of the project area indicating the general relief of the project area is shown in Figure 4.11 below.

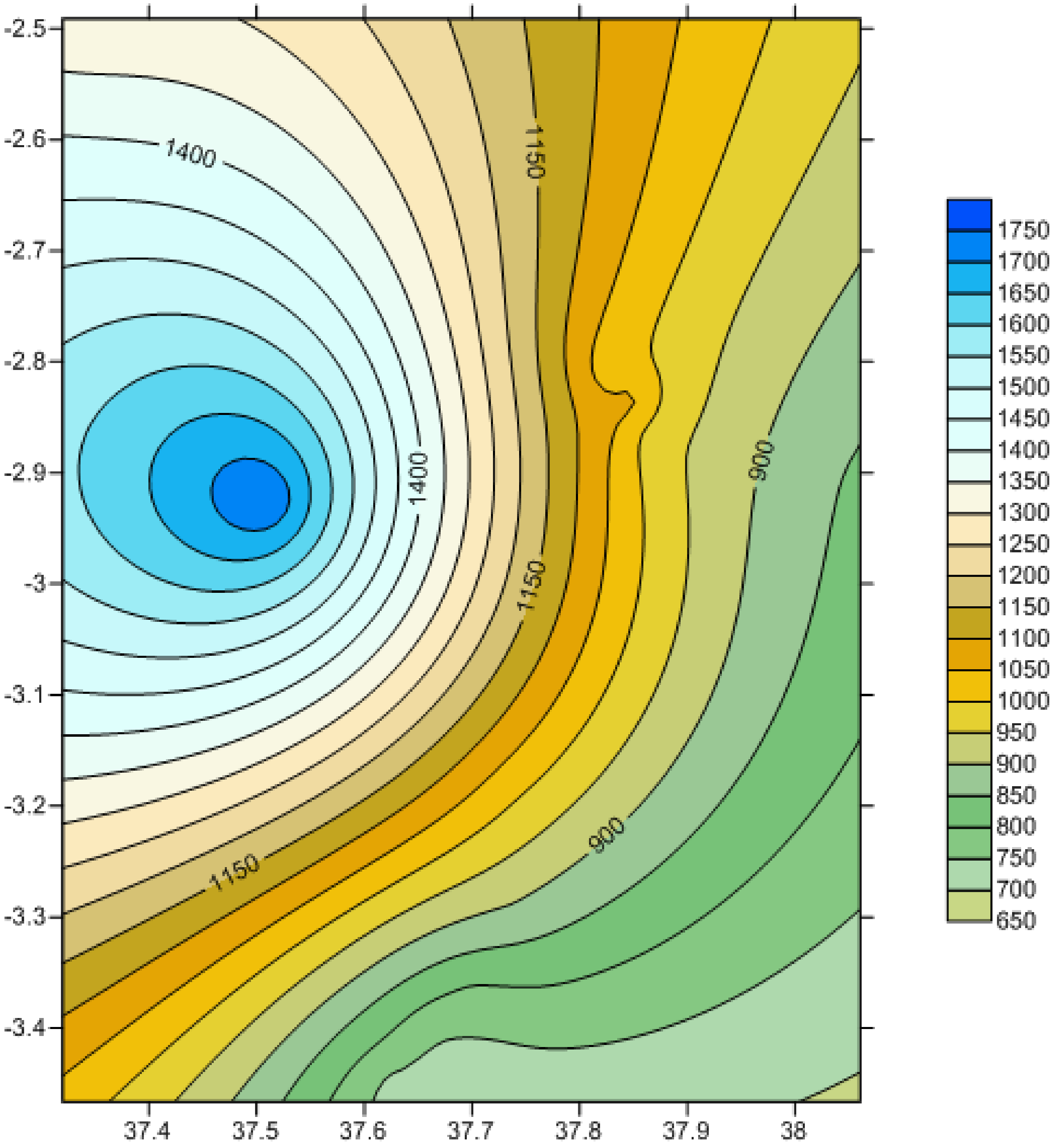


Figure 4.11: General elevation as depicted by general relief

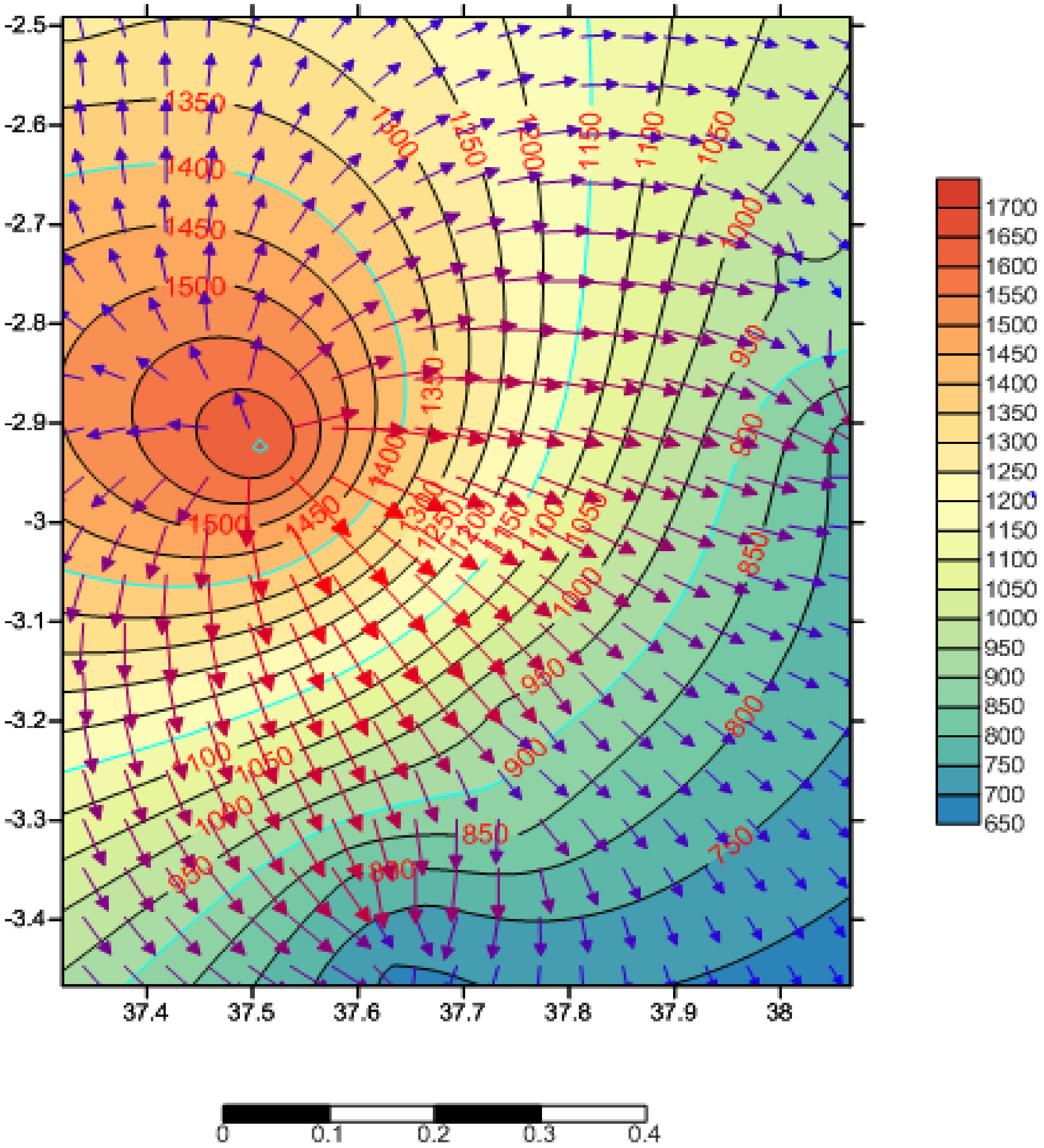


Figure 4.12: Groundwater flow direction by magnitude

According to Figure 4.12 above, the highest piezometric level is 1752 MASL, which is located at Oloitokitok Town. From this point, ground water flow is towards all the directions. However, this flow varies by magnitude. Higher groundwater flow magnitude is noted towards the Western and Northern directions. The magnitude is less towards the East and least South East between 1600 and 950 MASL in reference to the highest point.

It is worth to note that along the higher altitudes from the highest point towards the North, then East followed by southeast and finally south flow path, groundwater flow is relatively uniform in magnitude as depicted in Figure 4.12 above.

Around the Central region, groundwater flow is towards the Easterly, South Easterly and South directions while on the Western side, the flow is towards the Southern direction. There is an increase in magnitude in ground water flow in the lower groundwater levels from 950 MASL. This could be an indication of regional groundwater flow emanating at these lower levels and increasing the lower groundwater flow magnitude noted from 1600 to 950 MASL.

There are notable points of convergence in groundwater flow in the East and South as seen in the diagram. This could be an indication of major points of groundwater discharge probably major springs.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1: Conclusion

A summary of the research work undertaken in the project area is discussed below.

Groundwater resources in the Kilimanjaro Aquifer System are recharged at different altitudes and locations as observed from waters from the Kilimanjaro slopes and Chyulu side.

Mzima Springs and the springs from Mt. Kilimanjaro (Nolturesh, Kimana, Rhombo, Njoro Kubwa) have no relationship since they are recharged by different rainfalls with different isotopic signatures with Mzima rains being more enriched and the others more depleted.

The altitude of recharge for the waters from the Kilimanjaro side ranges between 1550-2000MASL while that of the Chyulu side is 1350-1450MASL.

Lake Chala does not recharge the surrounding springs. However, the lake and the springs share the same source of recharge.

There is mixing of both water types and water sources in the project area. Calcium Sulphate and Magnesium Chloride waters mix with Calcium Chloride and Sodium Sulphate waters especially in the south around Lake Jipe and Orkungu borehole region. Mzima Springs waters are a mixture of bicarbonates of magnesium and Sodium. Relatively fresh waters are also mixing with mineralized waters from the Kilimanjaro side.

There is groundwater interaction between aquifers especially from which Tavevo, Kwa Mtawa Mahoo and Ndolo boreholes are tapping their waters as well as Mandulu Springs. This interaction means that over exploitation of groundwater resources from any of the boreholes will directly negatively affect these other sources.

A section of water sources from the Kilimanjaro side are saline. This is as a result of evaporation from the water sources and dissolution of gypsum as controlled by the geology of the area.

Groundwater flow direction is from the highest point generally towards the easterly and south easterly directions as dictated by the Piezzometric levels. There are major discharge points towards the East and South. The flow magnitude is highest towards the North and North East from the highest point in the project area. There is also a high flow magnitude emerging at the lower altitudes and in particular between 750- 700 MASL towards the East and 950-850 MASL in the East and South East directions.

5.2: Recommendations

Based on the above conclusions, a number of recommendations can be drawn. These include the following;

More work of collecting precipitation in the high-altitude areas is required, for comparing with the isotopic signatures of stable isotopes from boreholes and springs. This may be done by collection of either rainfall samples at these altitudes or ice. Comparison of these isotopic signatures with those of boreholes, shallow wells, springs and lower stratified levels in the lake will shed more light on sources of recharge, altitude of recharge and also groundwater flow direction. This will bridge the gap on determination of groundwater flow using stable isotopes since it requires sampling at higher altitude.

The waters of some water sources in the project area are directly interacting in that exploitation of water from one source is directly affecting the others. This calls for more work in setting the exploitation thresholds for sustainable management for human activities and also biodiversity along some of these water courses.

Mzima springs is only affected by mixing in terms of water types and not water sources. Therefore, interbasin transfer from this source will not adversely affect the other water sources and biodiversity along the waterways associated with it as long as the exploitation is done sustainably.

The Southern part of the project area (Lake Jipe and Orkungu Borehole regions) are affected by high salinity levels, which are nature controlled. Since a majority of households depend on these sources for drinking, it is recommended that simple desalination plants be set up for water for households’ drinking and cooking.

5.3: Further Research

Ground water flow magnitude is increasing in the lower piezometric levels. Further research is recommended on stable isotopes so as to determine whether this could be regional flow from high altitude in the Kilimanjaro Mountain or what could be the cause of the increased ground water flow magnitude at these lower levels.

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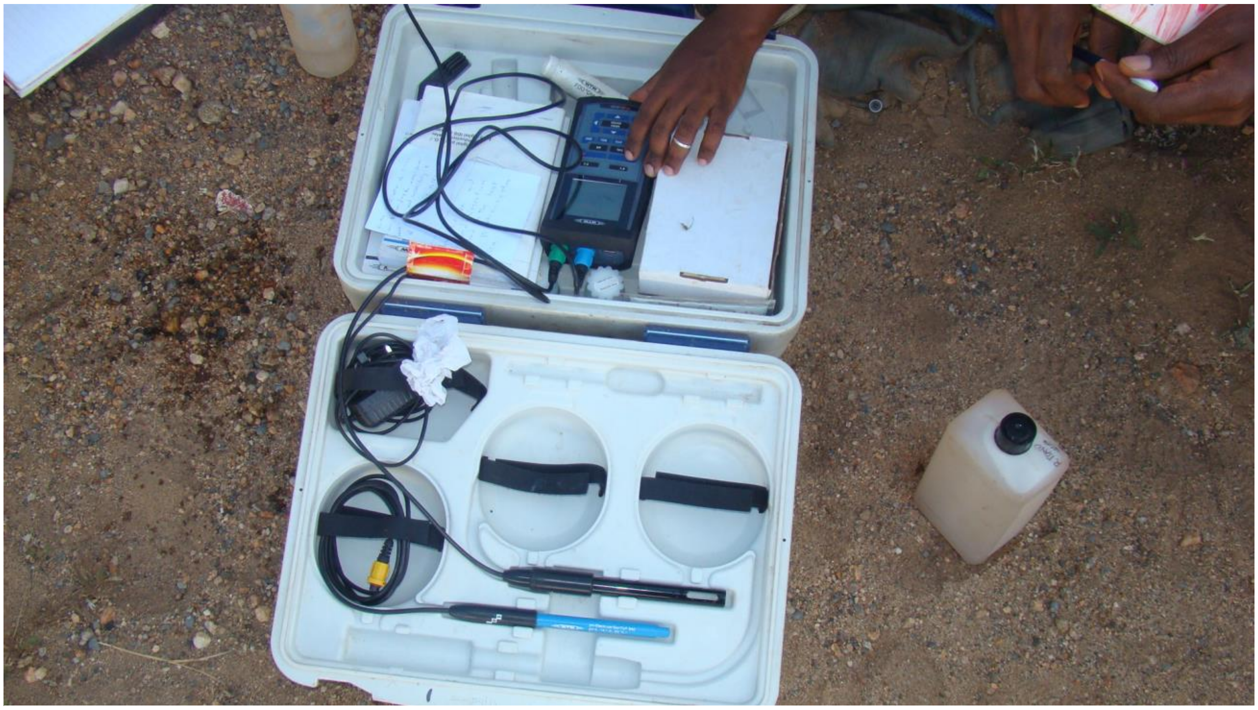
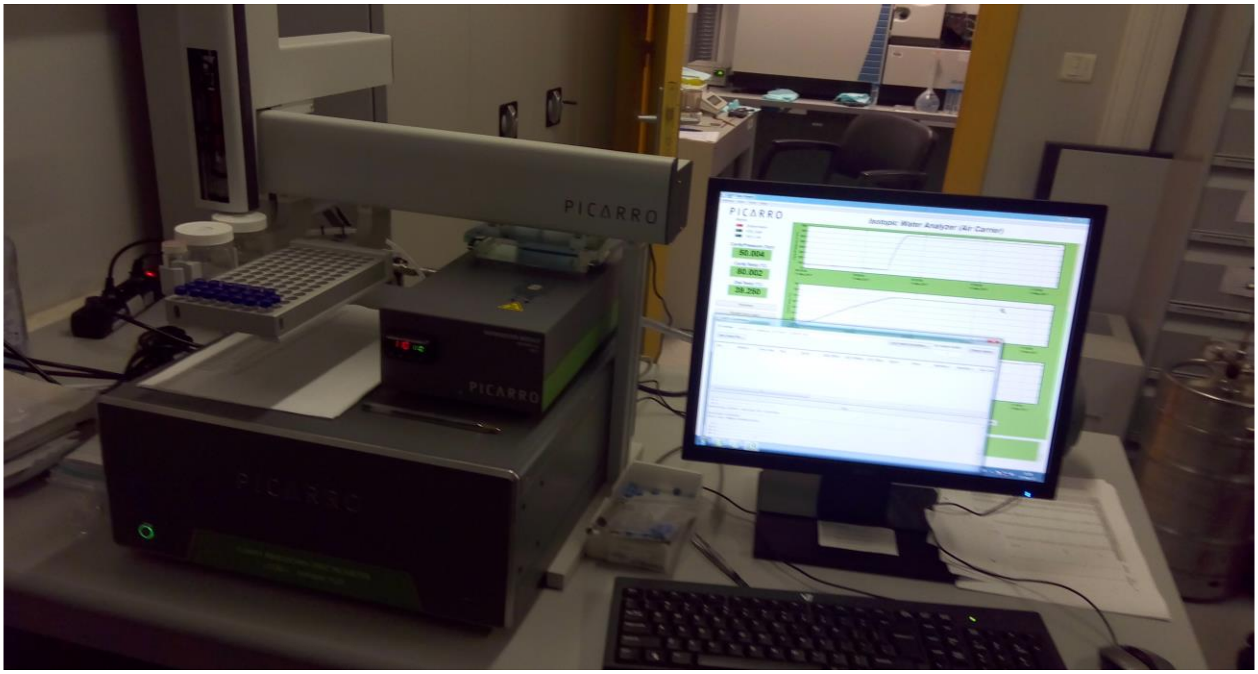
APPENDICES



1: Sodo multi parameter kit for *insitu* water sample measurements



2: Picarro L2130i at the CNESTEN Stable Isotope analysis Laboratory, Morocco

3: Thermo Scientific Dionex ICS-5000+ HPIC

4: Nolturesh springs; Protected at the source

5: Lake Chala; Fresh water crater Lake without a visible inlet or outlet.