UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

Department of Geospatial and Space Technology

USE OF GEOSPATIAL TECHNOLOGY IN RAINWATER HARVESTING:

Case Study of Karapul Sub-Location, Siaya County, Kenya

BY

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A Project report submitted in Partial fulfillment of the requirements for the Degree of Master of Science in Geographic Information Systems, in the Department of Geospatial and Space Technology of the University of Nairobi

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DECLARATION

I, Mary A. O. Gwena, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other university.

Mary A. Obat Gwena

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Name of student Signature Date

This project has been submitted for examination with my approval as University Supervisor.

Prof. G. C. Mulaku

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Name of supervisor Signature Date

DEDICATION

This project is dedicated to my son, Powell and my daughter, Grace for their patience and understanding throughout the period of my studies, and to all the widows who are struggling to fulfill their dreams in life.

ACKNOWLEDGMENTS

First and foremost, I give all glory and honor to the Almighty God for enabling me reach this far in my academics.

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ABSTRACT

Kenya is currently experiencing growing pressure on water resources caused by increasing water demand for agricultural, domestic and industrial consumption. This has been brought about due the effects of climate change and has necessitated the need to maximize and augment the use of existing or unexploited sources of fresh water. Rain Water Harvesting (RWH) has been considered as the most promising among others with efforts currently being made world over to provide water to meet the growing need. The focus of this study was to use geo-information technology in assessing the potential of rooftop rainwater harvesting (RRWH). Rooftop rainwater harvesting is the technique through which rain water is captured from the roof catchments and stored in reservoirs for future use.

The study was executed in Karapul sub-location in Siaya County, Kenya. The sub-location has had to contend with a water scarcity problem for decades owing to frequent droughts, changing climate pattern, fast growing population and the increasing demand for clean and safe drinking water. A total of 8,024 rooftops were digitized in the ArcGIS environment from ortho-rectified aerial photography of 40cm spatial resolution. Three different classes of rooftop types were captured in the digitization process, these were, iron sheets, tiles and grass thatched rooftop types. Run-off coefficients of 0.85, 0.6 and 0.2 were respectively assigned to the three rooftop classes. Estimated rainfall surfaces from the year 2000 - 2012 were used to extract mean monthly and mean annual rainfall. A local model combining, mean annual rainfall (Rt), rooftop run-off co-efficient (Rc) and average roof area (A) was used to estimate the rainwater harvesting potential.

Results from this work showed that 89% (389,528 km^2) of the area of study has a high potential for rainwater harvesting. The total estimated potential for the area of study was 588,301 m^3 of rain water, with iron sheet rooftops accounting for 95.6% (562,869 m^3) while grass-thatched rooftops accounted for 2.3% (13,276 m^3) and tiled rooftop accounted for 2% (12,157 m^3) of the potential. The outcome of this study highlighted the relevance of geospatial methods and tools in assessing rainwater harvesting potential. The results from this work are intended to aide in planning water provision and to help address the water scarcity problem in Karapul Sub-location. In addition, the methodology outlined in this study can be replicated in other areas in Kenya to determine the potential of rainwater harvesting and thus integrate rainwater as an alternative water source to ensure sustainable development.

The use of existing wells to act as storage for rainwater and geological studies to investigate the reason for drying wells and the fluctuating water struck levels are some of the recommendations.

Key words: *Rainwater Harvesting Potential, Rooftop Rainwater Harvesting, Geospatial Technology, Runoff Coefficient*

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LIST OF ACRONYMS AND ABBREVIATIONS

CBO	-	Community Based Organization
CSE	-	Centre for Science and Environment
DEM	-	Digital Elevation Model
DRWH	-	Domestic Rainwater Harvesting
GCMs	-	Global Climate Models
GIS	-	Geographic Information System
GNSS	-	Global Navigation Satellite System
IGAD	-	Intergovernmental Authority on Development
ILRI	-	International Livestock Research Institute
ICPAC	-	IGAD Climate Prediction and Application Centre
IPCC	-	Intergovernmental Panel on Climate Change
ICRAF	-	International Centre for Research in Agro-forestry
KNBS	-	Kenya National Bureau of Statistics
KRA	-	Kenya Rainwater Association
MDGs	-	Millennium Development Goals
NGOs	-	Non-Governmental Organizations
RELMA	-	Regional Land Management Unit
RWH	-	Rainwater Harvesting
RRWH	-	Rooftop Rainwater Harvesting
SearNET	-	Southern and Eastern Rainwater Network
SIDA	-	Swedish International Development Agency
SRTM	-	Shuttle Radar Topographic Mission
UN	-	United Nations
UNEP	-	United Nations Environmental Program

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is considered a scarce natural resource, even though 71% of land is covered by water. Out of the total water on the earth about 2.5% is fresh and being utilized for various purposes, the common ones being domestic, irrigation and industrial (Pawar-Patil and Mali, 2013). Water scarcity has become a serious global threat due to the ever increasing population growth, frequent droughts and changing climate pattern.

The term Rainwater Harvesting (RWH) refers to direct collection of precipitation falling on the roof or on the ground without passing through the stage of surface run-off on land (Athavale, 2003) .

RWH has also been defined by Fayez and Al-Shareef (2009) as a technology used for collecting and storing rainwater from rooftops, land surfaces or rock catchments using simple techniques such as pots, tanks or cisterns as well as more complex systems such as underground check dams; and the subsequent use of the harvested water.

Rainwater harvesting is an alternative water supply method that has become popular in recent years in most parts of the world to address the water scarcity problem. Rainwater harvesting requires at least an annual rainfall of 100-200 mm.

In most developing countries, lack of safe, clean drinking water has led to dire consequences in the form of dreaded water borne diseases. These include cholera, typhoid, amoeba and bacillary dysentery, among other diarrhoeal diseases and Kenya is no exception and has had to contend with some of these issues.

Kenya is currently experiencing growing pressure on water resources caused by increasing water demand for agricultural, domestic and industrial consumption that has brought about the need to maximize and augment the use of existing or unexploited sources of freshwater.

According to the National Water policy (2012), the country has only five water towers which are faced with severe degradation due to anthropogenic activities. Without their protection and conservation the ecosystem services and water security in the country would worsen having a negative effect on the economic development of Kenya and the living conditions of its population.

To this end, efforts have been made in the area of RWH and many projects have emerged in different parts of the country since the late 1970's. However these have been undertaken in a haphazard manner using local artisans without common designs and implementation strategies. There are however, many success stories that can be cited particularly in the arid and semi-arid areas of Kenya where rainwater harvesting has been replicated, e.g. Aroka (2010), Nthuni *et al* (2014) and Munyao (2010) all of which gave promising results and revealed the potential of RWH in different areas of Kenya.

However, Rainwater harvesting has not been fully utilized in many parts of Kenya such as Karapul Sub- Location, in Siaya County where rainfall is scanty and erratic.

In this era of climate change, Karapul Sub- Location has not been spared as this has impacted very significantly on both the availability and requirements for water in the Sub- Location. RWH is considered as one way of adapting to climate change.

The key contributing factor outlined by ICRAF and UNEP in 2005 is lack of tangible scientifically verified information that can be used to identify areas where RWH can be applied (Munyao, 2010).

In Kenya, just over 50 percent of Kenyans have improved sources of water (KNBS, 2013). The highest access is in urban areas where 72 percent of the population has access to improved sources of water meaning that individuals in urban areas have one and half times more access to improved water sources than their rural counterparts. Twenty five percent of water in Kenya is piped (6 percent of which is in dwellings). Only 0.7 percent of the population in Kenya collects rain water (KNBS, 2013). According to the KNBS statistics, rural access to water by type from unimproved sources indicates that a larger percentage of the rural population (29.6%) collects water from streams or river, 0.4% from ponds and 1.5% from lakes.

This is illustrated in Figure 1.1.

Despite bordering the largest fresh water lake in the region, Siaya County often experiences water scarcity. The main water supplier is the Siaya and Bondo (SIBO) Water and Sanitation Company which can no longer meet the ever increasing water demand and this is evident from the dry taps in the area which remain so most parts of the year. Other sources of water include boreholes, water holes, rivers and wells. A large number of water points cannot be used during the dry season because they are seasonal.

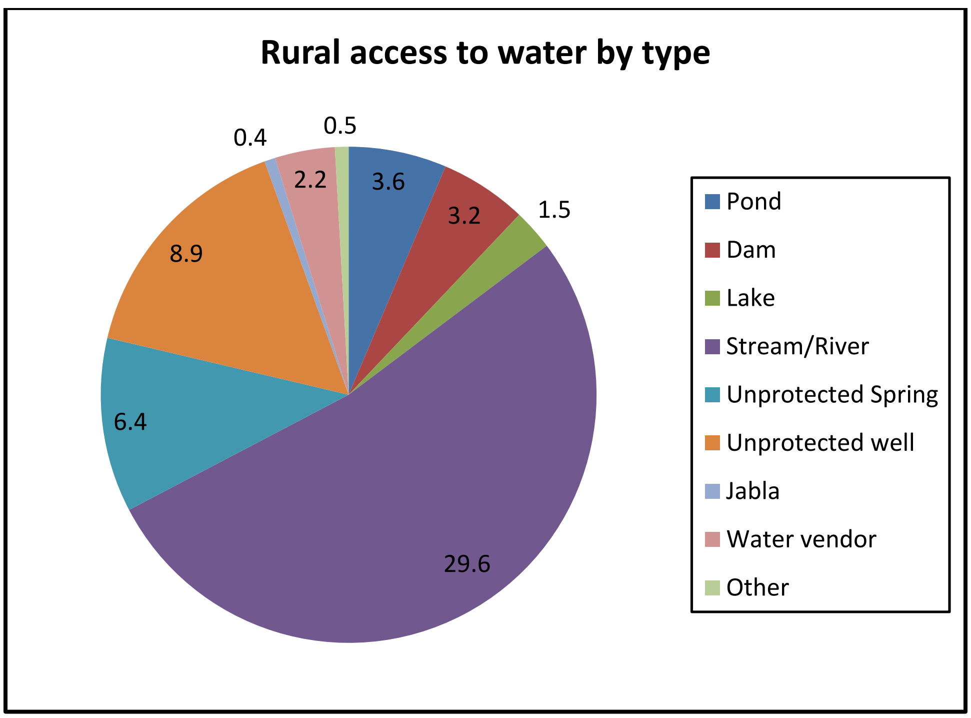

Figure 1.1: Rural access to water by type -Unimproved sources (Source: Data from KNBS and SID, 2013)

In alleviating poverty in Karapul sub-location and Kenya at large, water as a basic need is of priority. There is therefore need for an alternative water source to ensure the sub-county's sustainable development. Rooftop rainwater harvesting is not widespread in this area and most inhabitants have resorted to haphazard digging of wells while those who cannot afford to do so purchase the scarce commodity from the well directly or from vendors at a higher cost.

Plate 1.1 shows some of the means of transporting water from a borehole to homesteads in the region neighbouring Siaya Town. These include bicycles, motor bikes, pick-ups and private cars respectively. Areas far away from the town use water from the dams, streams and river. There is only one permanent river in the sub-location; *Wadh Bar* which is located to the extreme eastern side of the study area that has high rural influence.

Plate1.1: Some of the means of transporting water from one of the vending water points in Karapul sub-location

Inhabitants of Karapul Sub- Location can benefit from rainwater harvesting projects to assist in the control of environmental disasters such as the negative impacts of flooding, landslides and soil erosion while at the same time harnessing the rainwater for use in households, agriculture, and industries as well as for livestock and environmental improvement.

This project addressed this by developing a local model that can be used by utilizing Geospatial technologies such as Remote Sensing (RS), Geographic Information Systems (GIS) and Global Navigation Satellite Systems (GNSS) such as GPS.

1.2 Problem Statement

The increasing demand for safe drinking water arising from the increasing population has over stretched the existing water supply systems of Siaya County. Despite the fact that the County is just 35 kilometers from the largest fresh water lake in Africa, *Lake Victoria*, and the residents especially in Karapul Sub-location have over the years gone without this valuable commodity.

The water is transported using human labour by mainly women and school going children, hand carts on donkeys, wheelbarrows, bicycles, motorbikes, hired pick-ups and personal cars depending on individuals' social status.

The women and school going children are forced to walk long distances on foot in search of water. Access to any stream is also difficult and there is only one permanent river in the study area, *Wadh Bar*.

Having been classified as a social amenity by the Millennium Development Goals (MDGs), the county government is obliged to ensure that the inhabitants have access to clean safe drinking water. There is therefore need for an alternative water source to ensure the sub-county's sustainable development.

In retrospect, there is need for the county government to identify alternative sources of water supply as it seems that the existing sources have been constrained. Rainwater Harvesting can be harnessed as the alternative water source to address the water scarcity problem.

Geospatial Technology provides tools that can be used to better determine the potential of Rainwater Harvesting to ensure sustainable development.

1.3 Research Objectives

The **general objective** of this project was to demonstrate the use of geo-information technology in Rainwater Harvesting in Karapul Sub-Location in Siaya County.

Specific objectives were as follows:

- To identify available water points in the study area
- To assess and map the spatial distribution of the rooftop catchments for rainwater harvesting
- To develop a model for use in estimating rooftop rainwater potential
- To prepare rainwater harvesting potential maps for the study area

1.4 Justification

Water is an essential commodity that is required by every living thing. The UN Millennium Development Goal (MDG) 7 target 3 emphasizes the need to halve, the proportion of the population without sustainable access to safe drinking water and basic sanitation by 2015.

In the Siaya County Development Profile 2013, the water sub-sector has been cited as one of the main development challenges in County.

Siaya County is ranked among the bottom 10 in the country experiencing acute shortage of clean and safe water. The main water supplier in Siaya County is the Siaya and Bondo (SIBO) Water and Sanitation Company. This has become very unreliable as the taps are often dry and the residents have to opt for other alternative water sources. Furthermore, a large number of water points cannot be used during the dry season because they are seasonal. The water is sold to the residents at Kshs. 5 from the source and also vended at between Kshs. 10 and Kshs. 20, depending on the distance from water source and means of transportation.

During the long dry spells, the shallow wells and the streams dry up and the main water source becomes the deep wells who then exploit the residents. This translates to high costs of living by the inhabitants as the time and some of the money used on water could have been channeled to other economic ventures. Much of this water is not safe for human consumption and this issue has never been addressed for decades. In alleviating poverty in Karapul sub-location and Kenya at large, water as a basic need is of priority. There is therefore need for an alternative water source to ensure the sub-county's sustainable development. Rooftop rainwater harvesting is not widespread in this area. Furthermore, RWH has been proposed in the Siaya County Development Profile (2013) as one of the strategies to avert the water scarcity problem to enhance sustainable development. It is on the above basis that this project explores the use of Geospatial technology in determining the potential of rain water harvesting as part of the solution to the water problem in Karapul Sub-location.

1.5 Scope of the study

The study focused on the use of Geospatial Technology in estimating the potential of rooftop rainwater harvesting. The scope of the study was limited to Karapul Sub-location in Siaya County, Kenya.

1.6 Organization of the report

This project report is organized into five (5) chapters as follows:

Chapter one contains the background of the study and provides a brief overview of the area of study. It also provides information on the study and gives a highlight on the significance of the study as well as the goals and scope of the study.

Chapter two gives a detailed description of Rainwater Harvesting and explores the different methods of Rainwater Harvesting. It also highlights previous approaches which have been used in RWH modelling and also describe the model used in the study.

Chapter three explains the datasets available as well as the actual implementation of the models.

Chapter four provides information on the results and discussions on the results of the models.

Chapter five gives conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Rainwater Harvesting

The concept of rainwater harvesting can be dated back over 4000 years. (Liaw and Chiang, 2014). Commonly used systems consist of three principal components; namely, the catchment area, the collection device, and the conveyance system. This is illustrated in Figure 2.2.

2.2 Methods of Rainwater Harvesting

RWH can be classified into two broad classes, namely: Surface runoff harvesting and Rooftop harvesting. This is illustrated in Figure 2.1.

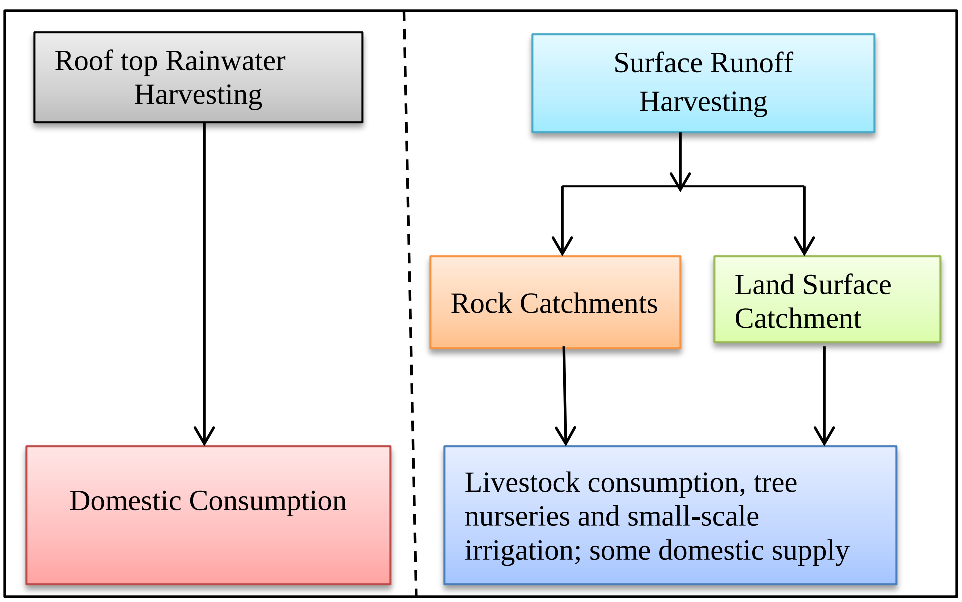

Figure 2.1: Rainwater harvesting systems and uses (After Wafler, 2010)

a) Surface runoff harvesting: Here, runoff refers to rainwater that flows off a surface other than roof (Awulachew and Lemperiere, 2009). The surface may be a rock, pavements, fields or roads. Some surfaces are permeable (e.g. field) while others are impermeable.
Rain that falls on the surface can be collected and used either for irrigation or domestic purposes. In some cases, depending on the quality, it has been used for flushing toilets and cleaning activities in household. It could even be used to recharge aquifers. This method is also very common in urban areas in many parts of the world, where the surfaces are less permeable and therefore the seepage is minimal (Nthuni *et al*, 2014). The amount of water collected by this method depends on the amount of the rainfall, the permeability of the surface, the area of the surface and the slope of the surface among other factors.

b) Rooftop rainwater harvesting: In this method, rainwater is collected from the roof catchments and stored in reservoirs. Rain does not reach the surface of the earth and therefore, the water collected by this method is less contaminated as compared to the rainwater collected from the surface runoff (Thomas and Martinson, 2007). This project will focus more on this type of RWH.

2.3 Rooftop Rainwater Harvesting (RRWH) for Domestic use

Technical Description

Rainwater may be collected from any kind of roof. Tiled or metal roofs are easiest to use, and asbestos sheet roofs, especially when damaged, should not be used as poisonous asbestos fibres may be released into the harvested water. This technology has been used where a more traditional reliable drinking water source has not been identified. In many developing countries, rainwater harvesting is accomplished primarily through household rain catchment structures which are best suited for use in the villages in hilly areas, where people live in scattered huts or in small settlements. The technology also has been adopted in other areas, where polythene sheet covering is used as a rooftop catchment on thatched roofs. Storage of rainwater collected from rooftop catchments is typically informal. Buckets, basins, oil drums, etc. are commonly placed under the eaves in order to store water to supplement normal water supplies. Such water is rarely used for drinking purposes (UNEP and OAS, 1995).

Household rooftop rainwater collection systems consist of the following elements:

Guttering: Guttering collects the rainwater runoff from the roof and conveys the water to the downpipe. Gutters may be constructed of plain galvanized iron sheets or of local materials such as wood, bamboo, etc. All gutters should have a mild slope to avoid the formation of stagnant pools of water. Gutters with a semicircular cross-section of 60 mm radius are sufficiently large to carry away most of the intense monsoonal rainfall.

Down pipe: A vertical down pipe of 100 mm to 150 mm diameter is required to convey the harvested rainwater to the storage tank. An inlet screen (#20 wire mesh) to prevent entry of dry leaves and other debris into the down pipe should be fitted.

Foul Flush Diversion: The first flush of water from the roof is likely to contain dust, dropping and debris which has collected on the roof. This contaminated water should be diverted from the storage tank to avoid polluting the stored rainwater. Such a diversion can be achieved manually by including a ninety degree elbow on the down pipe so that the pipe can be turned away from the storage tank to divert the flow for the first 5 to 10 minutes of a storm. Alternatively, separate storage for the initial flow of rainwater may be provided in the form of a pipe with sufficient volume to contain the foul flush. Once this volume is exceeded, additional rainfall will flow into the storage tank.

Filter: A filtering system may be placed between the down pipe, after the foul flush system, and the storage tank. Filters can be constructed using locally available materials such as sand, gravel, or charcoal, etc. placed within a container to a depth of 1.2 m. The media and the cross-sectional area of the filter should be chosen to provide a rate of filtration adequate to pass 5 to 7 m^3 of water per hour.

Storage Tank: The size of the storage tank in a particular area should be matched to the volume of water expected to be harvested based upon the area of the roof. The volume of the tank should also be related to the quantity of water required by its users, and be appropriate in terms of cost, resources required and construction methods.

Some elements which should be considered in designing a storage tank include the following:

- An access way with an area of about 0.25 m² (0.5 m x 0.5 m) to allow periodic cleaning of the tank.
- A double pot chlorinator of 5 litre capacity to provide continuous disinfection.
- A vent pipe and overflow pipe (fitted with screens) of 100 to 150 mm diameter to minimize the buildup of gases and to allow excess water to exit the storage tank.
- An outlet pipe of 100 to 150 mm diameter located at the bottom of the tank to allow the tank to be drained for cleaning (separate from the service tap which should be located above the bottom of the tank).
- A water level indicator, in the form of graduated transparent plastic pipe for above ground tanks or floats system for underground tanks, to assist the owner to gauge water use from the system.

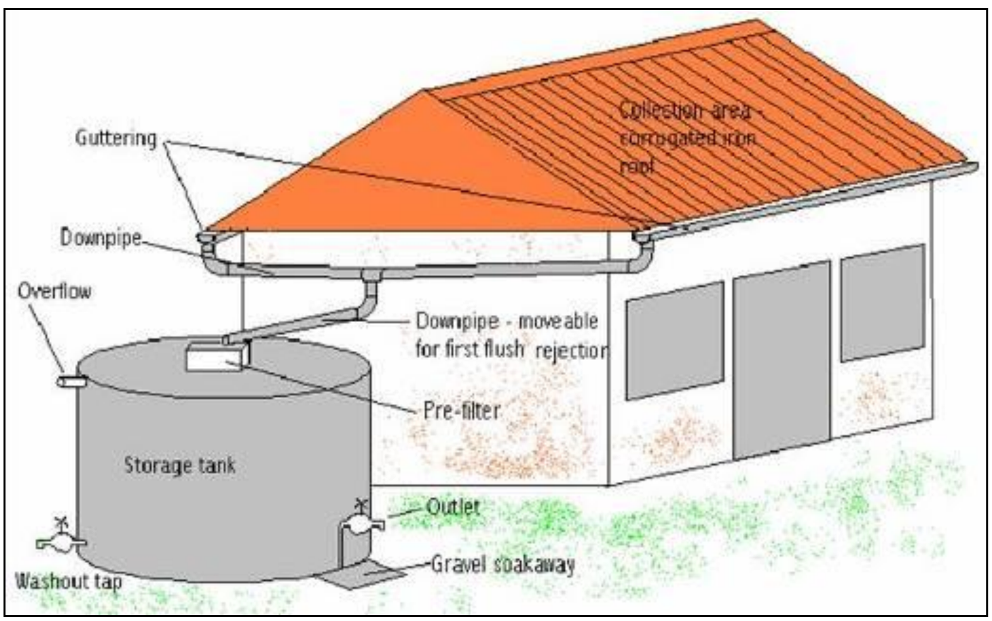

Figure 2.2: Conceptual sketch of rooftop rainwater harvesting system- (After Wafler, 2010)

Storage tanks may be constructed above ground and fitted with a self-closing tap provided near the base of the tank, or underground and fitted with a hand pump, depending on the height of the house and other site specific conditions. Underground tanks should be constructed with the top 30 cm of the tank above ground level to minimize debris from the surrounding land surface being washed into the tank (UNEP and OAS, 1995).

2.4 Rainwater Harvesting and Climate Change

Climate change is an additional threat that puts increased pressure on already stressed hydrological systems and water resources. The impacts of climate change are already visible given that temperature and rainfall variabilities have increased and intensified over the last two decades (Kahinda et al, 2010).

The increasing severity and frequency of meteorological disasters such as typhoon, heat waves and floods among others are currently being felt in many parts of the world. In many researches on climate change, Global Climate Models (GCMs) using satellite and other geospatial data is able to simulate the earth's climate and project the future climate in terms of parameters as precipitation, temperature and solar radiation (Anam, n.d).

The Intergovernmental Panel on Climate Change (IPCC) has also indicated that the climate of the world is changing and that nowhere is the challenge of developing effective strategies for adaptation to climate change more pressing than in rain-fed agriculture, where livelihoods of millions of the world's poorest people will become more precarious as rainfall patterns become more (ICPAC, 2011). Consequently, the effect of climate change has greatly been felt in other areas including the water sector. Other than the impacts on water for irrigation, the effect is also felt in water for domestic use, where economies and livelihoods of the majority of the inhabitants have been affected as taps remain dry while wells, boreholes and streams also dry up.

Kenya, like any other country in the Greater Horn of Africa, is facing challenges due to highly sensitive weather and climate variability and extremes such as droughts, floods, and changes in the patterns of cold, hot, wet and dry spells, among others. The intensities and frequencies of such extremes are expected to increase amidst the enhanced variability in climate due to the prevailing climate change (Ogallo L., 2011).

Climate change in Kenya is a supplementary hazard imposed on long-term water stressed conditions, socio-economic pressure and management challenges. These water stressed conditions are characterized by low, erratic and poorly distributed rainfall, high evaporation and excessive run-off and soil losses.

Climate change has the potential to impact very significantly on both the availability of and requirements for water in Kenya.

Rainwater harvesting (RWH) is listed among the specific adaptation measures that the water sector in Kenya and Africa at large needs to undertake, to cope with future climate change. At present, there is limited application of RWH, despite its high potential for alleviating the impacts of climate change on water security in many areas of Africa.

As mentioned elsewhere in this study, only 0.7 percent of the population in Kenya collects rain water.

2.5 Importance of rainwater harvesting to residents of Karapul Sub-location

The *Siaya County Development Profile Report 2013* has cited inadequate water supply as one of the major challenges to county development. It has also emphasized the need for promotion of rainwater harvesting within the region by construction of roof catchment facilities (first for schools), citing increased population, dropping groundwater levels in certain areas, low water quality and limited accessibility as well as high cases of water borne diseases as reasons for the urgency (Ministry of Devolution and Planning, 2013) .

Many areas within the sub-location are currently experiencing low water struck levels (80m), failing deep wells (e.g. Karapul primary School) and drying shallow wells particularly during the dry spells. Existing literature has revealed that the region is characterized by rock and soil conditions that possess limited ability to store surface and groundwater (Ministry of Devolution and Planning, 2013) , which explains the current situation. While the climate in Karapul Sub-location follows an annual cycle of two rainy seasons, harvesting and storing the rain that falls during the long rains (April to June) and short rains (September to December), can greatly reduce the volume of groundwater drawn from aquifers during dry the season. Maintaining higher groundwater levels can help to sustain a critical base flow in streams, and therefore protect fish and aquatic health. Reduced groundwater extraction also helps to prevent saltwater intrusion in wells located in coastal areas (Regional District of Nanaimo, 2013).

In regions serviced by community water systems, RWH systems can complement existing infrastructure. Widespread adoption of RWH systems can potentially delay, and even reduce, investment in expanding existing or adding additional infrastructure.

Capturing, storing, and using rainwater where it falls has been known to:

- conserve groundwater supplies;
- delay the need for costly water utility expansions by reducing dry spell water demand;
- slow down and even eliminate storm water runoff; and,
- reduce energy consumption compared to wells (Regional District of Nanaimo, 2013).

Some advantages of rain harvesting include easy accessibility, low set-up and maintenance costs, higher sustainability and its easy adaptability to different types of communities.

2.6 Stakeholders in Rainwater Harvesting in Kenya

In Kenya, water management is not a reserve of one organization. Concerted efforts are being made by several institutions to ensure that this precious but scarce commodity is well managed for sustainable national development. The key players in RWH management in Kenya include: - The Ministry of Water which is tasked with policy formulation. The National Water Policy (2012) is under their docket. The ministry is responsible for water affairs in collaboration with its stakeholders and development partners and local communities to ensure that the policy objectives and the guiding principles outlined in the policy and subsequent specific and detailed strategies based on it are fully implemented, monitored and evaluated for optimal impact.

The Water Resource Management Authority (WRMA) is the lead agency on matters relating to water including; water monitoring, catchment management, weather data collection and its effects on water, catchment strategies among other functions. Water Services providers charged with the supply of clean piped water to the residents In Karapul sub-location, SIBO Water Company is supposed to play this role. Water Appeal Board is charged with resolving of water disputes.

Others are: Water Services Trust Fund, Catchment Area Advisory Committees (CAACs),

The Ministry of Environment and Natural Resources, and Ministry of Agriculture, Kenya Forest Service and the Department of Surveys who perform their respective mandates as inscribed in the constitution of Kenya. The National Government (Law Courts) to handle legal issues concerning water. Several Non-Governmental Organizations (NGOs) and Community-Based Organizations (CBOs) have also played a major role in promoting rainwater harvesting in a number of communities in Kenya. The Swedish Government, for example, through the Swedish International Development Agency (SIDA) undertook RWH pilot projects in Talek, in Maasai community, Lare in Laikipia District and Kusa in Nyando District, which ended in 2000, 2004 and 2005 respectively (Nthuni, et al, 2014). There is also World Water Fund (WWF) and USAID.

The Southern and Eastern Africa Rainwater Network (SearNet), which was established in 1999 with the assistance of the Regional Land Management Unit (RELMA) of UNEP (United Nations Environmental Programme), has enabled Kenya to exchange information on RWH with other countries within the eastern and southern Africa regions through Kenya.

At the local level, church organizations and women groups have been very active in this field (Mati *et al.*, 2006). Also at the national level, Kenya Rainwater Association (KRA) is bringing together individuals, institutions and organizations actively involved in enhancing rainwater harvesting and utilization for sustainable development. The Water Resource Users Association (WRUA), brings together water users, riparian land owners, or other stakeholders who have formally and voluntarily associated for the purposes of cooperatively sharing, managing and conserving a common water resource (Wate Resource Management Authority, 2007)

The private sector has been instrumental in the manufacture of components needed to implement RWH projects such as gutters, roofing material, pipes and water tanks (Nthuni, et al, 2014) . This has greatly contributed to the advancement of RWH technology.

Lately, are the architectures, who are designing ‘green buildings’ that have systems for harnessing the natural resources such as rain water and solar power among others to ensure sustainable development.

2.7 Relevance of RWH to Millennium Development Goals

The Millennium Development Goals (MDGs) contain a set of measurable and time bound Goals and targets for eradicating extreme poverty, hunger, illiteracy, discrimination against women, child mortality, disease and environmental degradation. Target 10 of Goal 7 of the MDGs aims at halving, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation (UN Habitat, 2005). In Africa, a lot of effort is still required to revamp the water sector in order to meet the MDGs. RWH is currently the most promising alternative water source for domestic as well as irrigation purposes. The implementation of this technology can potentially help achieve the Millennium Development Goals (MDGs), especially, Goals 1, 2, 3, 4, 5 and 7 as explained in the following paragraphs.

Goal 1 (Eradication of extreme poverty and hunger):-

Economies and livelihoods of the majority of Kenyans are dependent on rain-fed agriculture that is highly sensitive to weather and Climate variability, and to climate extremes such as droughts, floods, and changes in the patterns of cold, hot, wet, dry spells, among others. Availability of RWH will help in restoration of the ecosystem, improve crop yields, reduce crop failure and provide water for domestic, livestock and irrigation purposes. This will greatly promote the economies and livelihoods and hence contribute towards eradication of extreme hunger and poverty.

Goal 2 (Achieving Universal Primary education):-

The Government of Kenya through the Ministry of education is currently funding the primary school feeding program aimed at motivating children from less privileged families to attend school and hence achieve goal 2. This calls for a continuous supply of clean, safe water for cooking and drinking and consequently an alternative water source. Many school going children are sometimes required to carry water to school while many are engaged in fetching water for domestic use. This drains their energy and time that could have been used for studies. RWH offers a vital alternative water source that could help these problems in addition to providing water for sanitation, construction works in schools.

Goal 3 (Promoting gender equality and empowering women):-

The majorities of Kenyan rural women are housewives and depend on their male counterparts as bread winners. Such women are left out when it comes to decision making. The burden of looking for water also limits women’s ability to dedicate their time and ability to income generating activities and as such they lack the bargaining power within the household and the community as a whole. RWH can provide the solution to help convert the time utilized in fetching water by the women, in income generating activities.

Goal 4 (Reducing child mortality):-

Access to safe drinking water leads to improved health and sanitation, especially in children under the age of five years. Such children are always at a risk of water-borne diseases like diarrhoea, typhoid and amoebeosis. Child mortality can be reduced by using clean water and improved sanitation. RWH offers an opportunity to access clean and safe drinking water and hence prevent the water-borne diseases and consequently reduce high child mortality rate.

Goal 5 (Improving maternal health):-

The quantity and quality of water from rivers, streams, ponds, boreholes and wells may not be sufficient to meet the special needs of women during pre- and post-natal periods. This is because most of these water sources may be far away and/or dry up during dry spells. By walking for long distances to the nearest water points, the expectant mother may put their life and that of the unborn child at risk. RWH provides safe and clean water at homesteads and therefore improving the maternal health.

Goal 7 (Ensuring Environmental Sustainability):-

Harvesting and storing the rain that falls during wet seasons (when up to 80 per cent of rainwater runs off to the ocean) helps in the reduction of the volume of groundwater drawn from aquifers during dry months. By maintaining higher groundwater levels, a critical base flow in streams is sustained, and therefore fish and aquatic health are protected. Reduced groundwater extraction also helps to prevent saltwater intrusion in wells located in coastal areas (Regional District of Nanaimo, 2013) . Capturing, storing, and using rainwater where it falls can conserve groundwater supplies; delay the need for costly water utility expansions by reducing drought water demand; slow down and even eliminate storm water runoff; and, reduce energy consumption compared to wells. All these ensure environmental sustainability and hence help achieve goal 7. Goals 6 and 8 were considered secondary hence their relevance was not discussed in this study.

2.8 Use of Geospatial Technology in Rainwater Harvesting

Geospatial Technology refers to the technology of measurements, analysis and graphic representation of earth phenomena using technologies such as GIS, Remote sensing and GNSS (eg, GPS)

The global and geographic nature of climate systems has propelled geospatial technologies to the forefront particularly in the area of RWH. The value of geospatial technologies in water resources and Climate Change research cannot be overemphasized.

Geospatial technology has been used to assess the impact of climate change to water resources by down scaling large-scale Global Climate Change Model (GCM) resolution to regional scale. Projected hydrological data can then be used together with geospatial data such as Digital Elevation Model (DEM), river network and landuse map which are then entered into a hydrologic model to simulate future flood flow magnitude (Anam, n.d). A 2D hydraulic model, together with satellite imagery and population data can simulate the flood extent and subsequently map out the population affected and the economic loses of the projected floods. The outcome of such studies can be used to reduce water related disasters, enhance the resilience of water-related infrastructure and improve the resilience of communities in the context of climate change adaptation. RWH has been recommended as one such way to adapt to climate change.

2.9 Case Studies

Growing water scarcity, population growth and global climate change call for more efficient alternatives for water conservation (UN Habitat, 2005). RWH has been considered as the most promising among others with efforts currently being made world over to provide water to meet the growing need. In India for example , an attempt has been made to estimate the potential of roof rain water harvesting in a Pirwadi village of Kolhapur district (MS), India, with geospatial techniques (Pawar-Patil and Mali, 2013) . Google image of study area, Global Mapper and Arc GIS 9.3 software were used to identify and calculate the various types of roof areas of houses and buildings located in the village. Rande’s coefficient of runoff index for various types of roof and Gould and Nissen formula (1999) were utilized for calculation of potential of roof rain water harvesting. Analysis revealed that, the total potential of roof rain water harvesting estimate was 11,457,490.78 litres, which was considered to be more than enough to satisfy the total annual drinking and cooking requirement of the people in the village. Thus rain water harvesting techniques were found to be proficiently useful to tackle the water scarcity problem in rural areas.

In South Africa a lot of efforts have been made to harness the potential of RWH to mitigate the effects of dry spells due to spatial and temporal variability of rainfall. Kahinda M., J.et al (2008) employed the use of Geospatial technology to enable the identification of areas suitable for RWH to facilitate planning and implementation purposes. In the study, in-field RWH and ex-field RWH suitability maps were developed based on a combination of physical, ecological and socio-economic factors. Model Builder, an extension of ArcView 3.3 that enables a weighted overlay of datasets, was used to create the suitability model, comprising the physical, ecological and vulnerability sub-models from which the physical, the ecological and the vulnerability maps were derived respectively. Results indicated that about 30% was highly suitable for in-field RWH and 25% as highly suitable for ex-field RWH. The implementation of this method was envisaged to support any policy shifts towards wide spread adoption of RWH.

In Kenya, Nthuni et al (2014) carried out a research to model the potential of rainwater harvesting in Kakamega area in western Kenya using remote sensing and GIS techniques. The main aim of the study was to determine the potential of RWH as an alternative or preferred source of safe water for domestic use. Spatial modeling techniques using amount of rainfall, census data and classification results from very high resolution QuickBird satellite imagery were applied to implement various approaches. Four conceptual models were developed at different levels of detail, namely, Kakamega-Nandi forest area (3900 km^2), the area covered by the satellite imagery (473 km^2 of farmland) and Buyangu village (1.9 km^2). The four models were implemented in ArcGIS environment using the ModelBuilder. The results revealed the potential of spatially explicit simulation to guide planners and to demonstrate the benefits of RWH to the local people. The study also revealed that the rainfall in the Kakamega-Nandi area is enough to meet the demand of the entire area.

CHAPTER THREE

METHODOLOGY

3.1 The Study Area

The research was based in Karapul Sub-location, located in Alego/Usonga constituency, Karemo Division in Siaya County, Kenya. It lies between approximately Latitude 34°00‘00" East and 34°30‘00" East and longitude 00°30 ‘00 “South and 00°20‘00 " North. It is located in the western part of Kenya approximately 35kilometres from the shores of Lake Victoria.

The neighbouring constituencies to Alego/Usonga where Karapul is located are: Ugenya to the North- West, Ugunja to the North- East, Gem to the East, Bondo to the South and Budalangi (Busia County) to the West. Figure 3-1 illustrates the location of the study area within Siaya County and Kenya respectively.

Karapul Sub-location is one of the three sub-locations in Siaya Township location, others being Mulaha and Nyandiwa. Of the three Sub-Locations, Karapul is the fastest growing in population due to its proximity to Siaya Town. The current population is estimated as 16,000 persons (KNBS, 2009 Census), which is almost equivalent to the population of the other two sub-locations combined. It covers a spatial extent of about 14 square kilometers and the elevation ranges between 1,356.12- 1.392 metres at the highest points and 1,235 – 1.270 .83 metres above mean sea level.

Karapul sub-location has 14 villages namely; Agage, Ndere, Ngoya, kanyawangwe, Mufwayo, Kalwande, and Urogi in the rural part of the sub-location; and Usere “A’, Usere “B’, Rabango, Pandi, Banana, Ramba-Pundo and Ramba- Got Ojur in the Township side. The area is a mixture of urban (towards Siaya town), and rural (away from the town) with different infrastructure. The main economic activities are mixed farming and trade.

The majority of residents of Karapul Sub- Location collect their water for daily use from shallow wells, deep wells (boreholes) and streams. Most of the shallow wells are dug by individuals in their homes and the boreholes are dug after formal application and consequent approval by the

Water Resource Management Authority (WRMA). Temperatures range from between 21° C in the North East to about 22.5 ° C towards Lake Victoria.

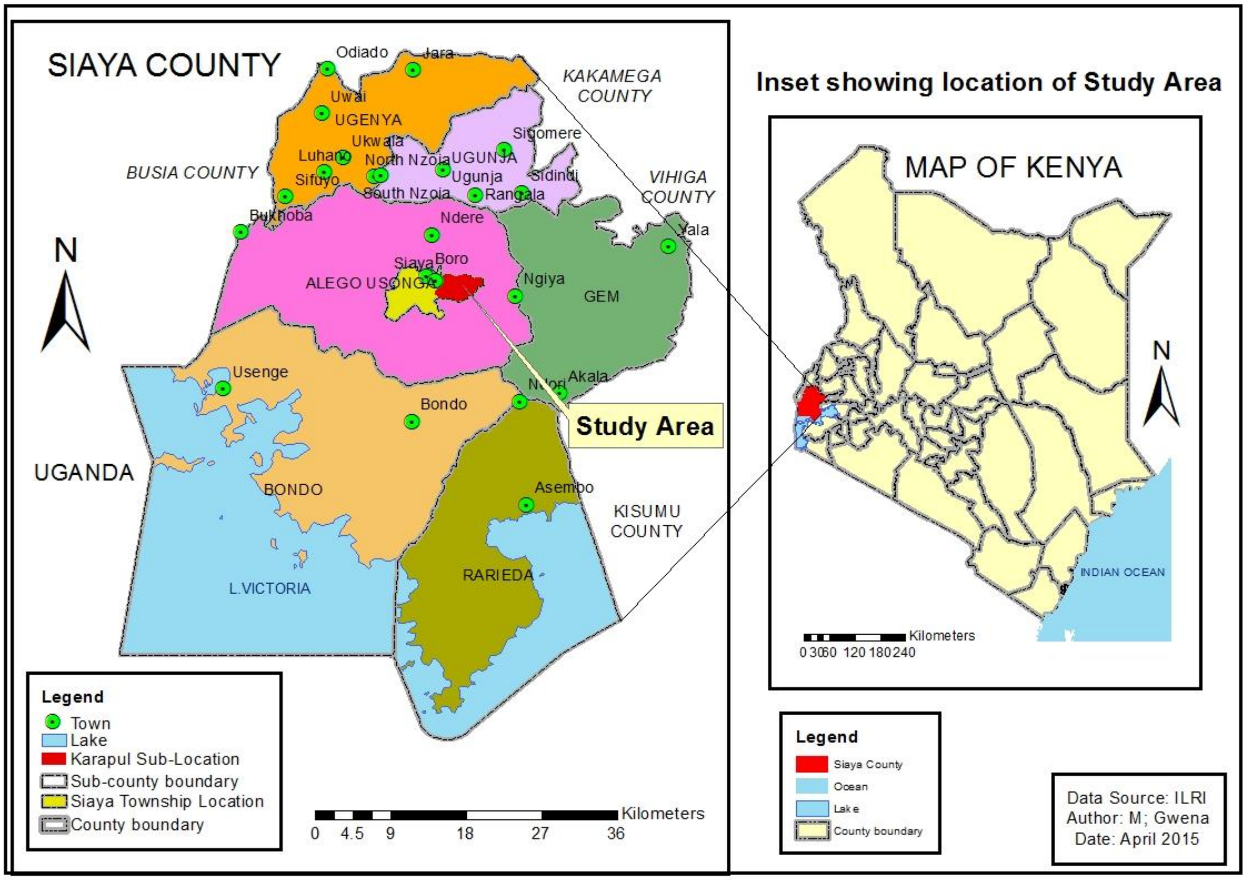

Figure 3. 1: Insets showing location of Study Area

Karapul Sub-location experiences rainfall range of between 800mm – 1,600mm. The rainfall pattern is influenced by Lake Victoria to the southern part (Convectional rainfall) and Mount Elgon to the North western part (Relief rainfall) of the study area. The Study area is illustrated in Figures 3.1 and 3.2.

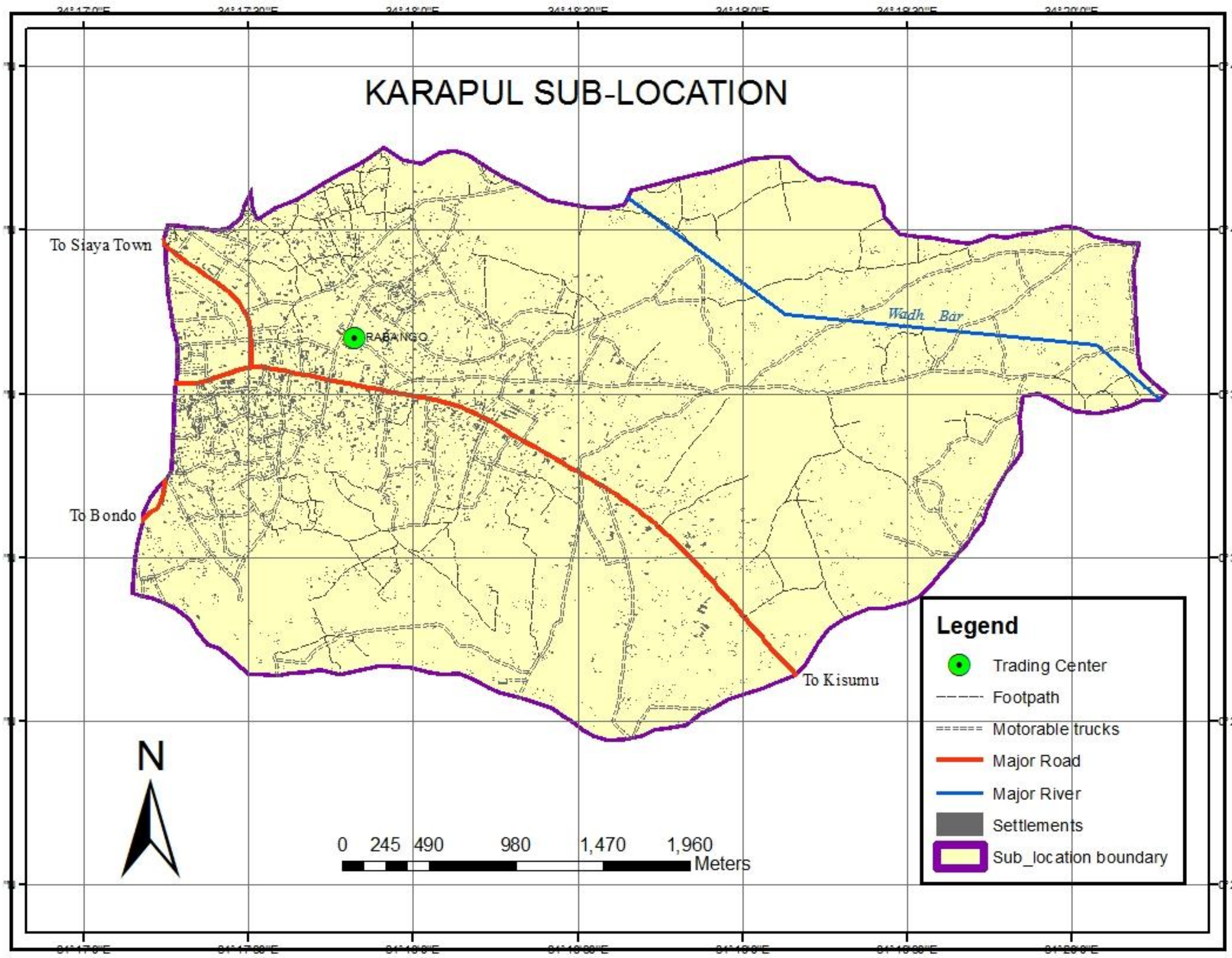

Figure 3. 2: Map of the Study Area

3.2 Data Sources and Tools

The following were considered to be able to fulfil the objectives of the exercise:

3.2.1 Data Sources

Table 3.1: Data and Data Sources

No.	Data Type	Characteristics	Source
1	Topographic Map	1:50, 000	Survey of Kenya
2	Orthophoto Imagery	40cm resolution (2013)	Milestone Geo-Systems
3	Shapefiles	Rivers, Major roads,	ILRI
4	Water Points	In excel format	WARMA
5	Spot heights	Shapefiles	Milestone Geo-Systems
6	Precipitation	Various years	FEWS NET website
7	Demographic	Population, households, poverty	KNBS and field verification
8	Other attribute Data	Semi/structured	Questionnaires, interviews, discussions, direct observation.

3.2.2 Tools

To be able to achieve the objectives of this study, the following hardware and software requirements were utilized:

a) Hardware:

- Laptop with a monitor display of 1024x768 pixels, Memory, 3.0 GB RAM and 2.1 GHz processor speed.
- Memory stick: 16 GB storage size
- Handheld GPS receiver: Garmin, with 10 m positional accuracy.
- Digital Camera: Resolution, 14.1 Mega pixel

b) Software

ArcGIS 10.1 environment provided the modules for re-projecting data, georeferencing, digitizing, editing, attribute entry, DEM processing and data analysis (Spatial Join) which culminated into the development of the required models and preparation of thematic maps.

Microsoft Office Suite (2010) provided the necessary environment for MS Excel, MS Word, and MS Power point.

MS Excel was used as an interface to download the GPS points and existing water points. It was also useful in the processing of rainfall data.

MS Word was used for report compilation whereas MS Power Point was used to carry out progress reports and final presentation.

3.2.3 Method

The following techniques were employed in carrying out this project and to ensure its successful completion. The stages involved included Project Planning; Identification of relevant data sets; Data Collection; Data Preparation/Organization, Image Interpretation; Digitization; Data Editing; Field verification, Data Validation, Data Integration, Attribute Table Design and entry; Calculation of Rooftop Area; Development of the model, Calculation of Potential of RRWH and Evaluation of the outputs. Overview of the methodology is illustrated in Figure 3.3.

a) Project Planning

This involved tasks such as study area evaluation, preparation of a work schedule, identifying project goals and deliverables, identification of appropriate hardware and software support and finally identification of relevant data types necessary for accomplishing the project.

b) Identification of Relevant Data sets

The data sets relevant to the study were identified, and the necessary arrangements made to collect them.

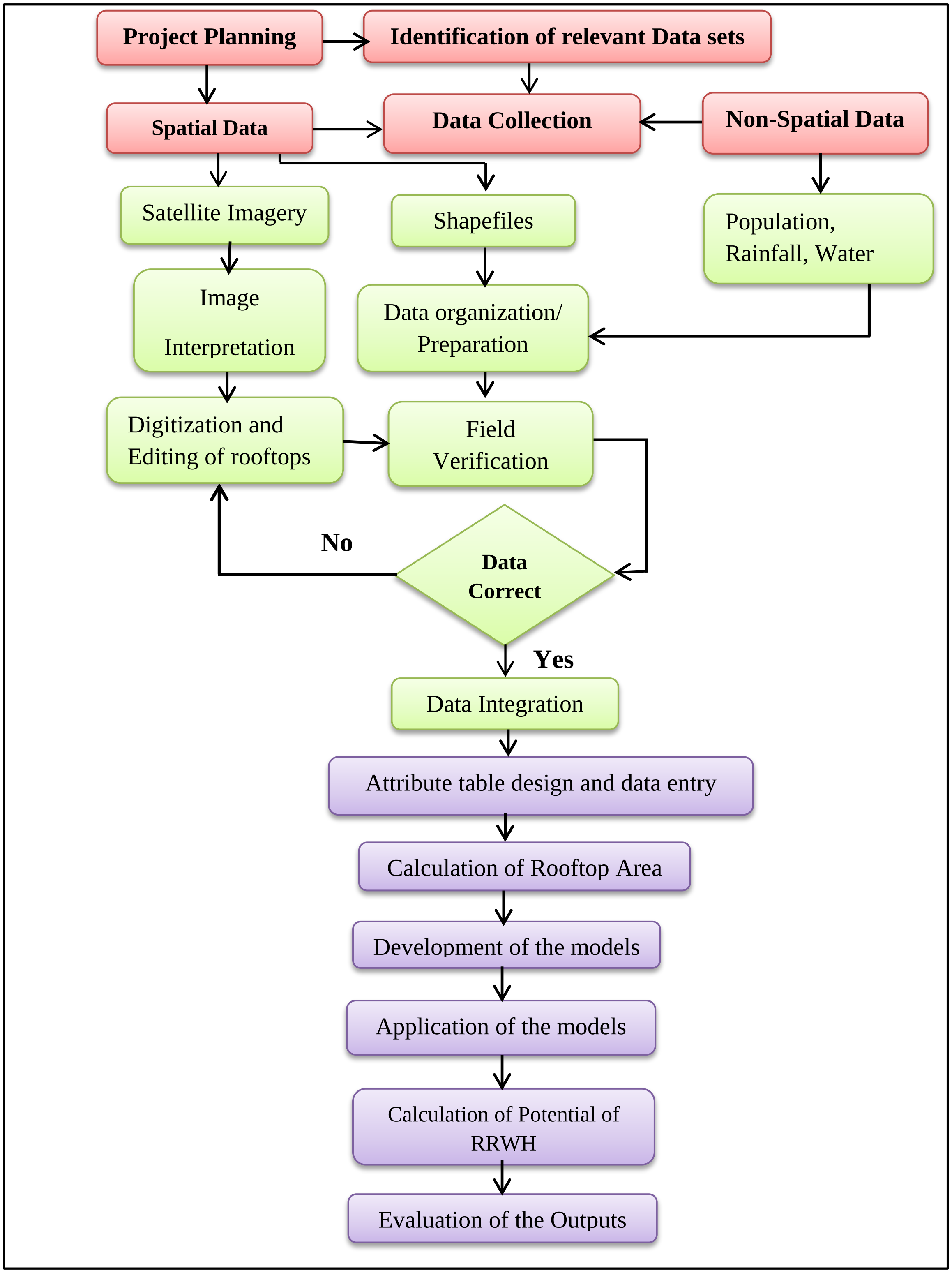

Figure 3.3: Overview of Methodology

3.3 Data Collection

a) Spatial Data Collection

i) Topographic Map

This was obtained at the scale of 1: 50 000 from the Department of Surveys. The topo map was used for the purposes of confirming georeferencing and also for general reference and orientation.

ii) Orthophoto Image (40 cm Resolution)

The Orthophoto (Orthorectified) Imagery was obtained from Milestone Geo-Systems already georeferenced to Arc 1960 Datum and UTM Zone 36 S. The Imagery was clipped to the area of Study as illustrated in Plate 3-1.This provided the base map for extracting the rooftop catchment area, some water points and roads. Human visual interpretation technique was adopted since the image was of very high resolution (40 cm) and features could easily be identified and digitized. The acquired image portrayed a high concentration of settlements to the western part of the study area and sparse settlements to the eastern side of the study area. This is illustrated in Plate 3-2 (Western side, towards Siaya Town) and Plate 3-3 for the eastern part (Rural) respectively.

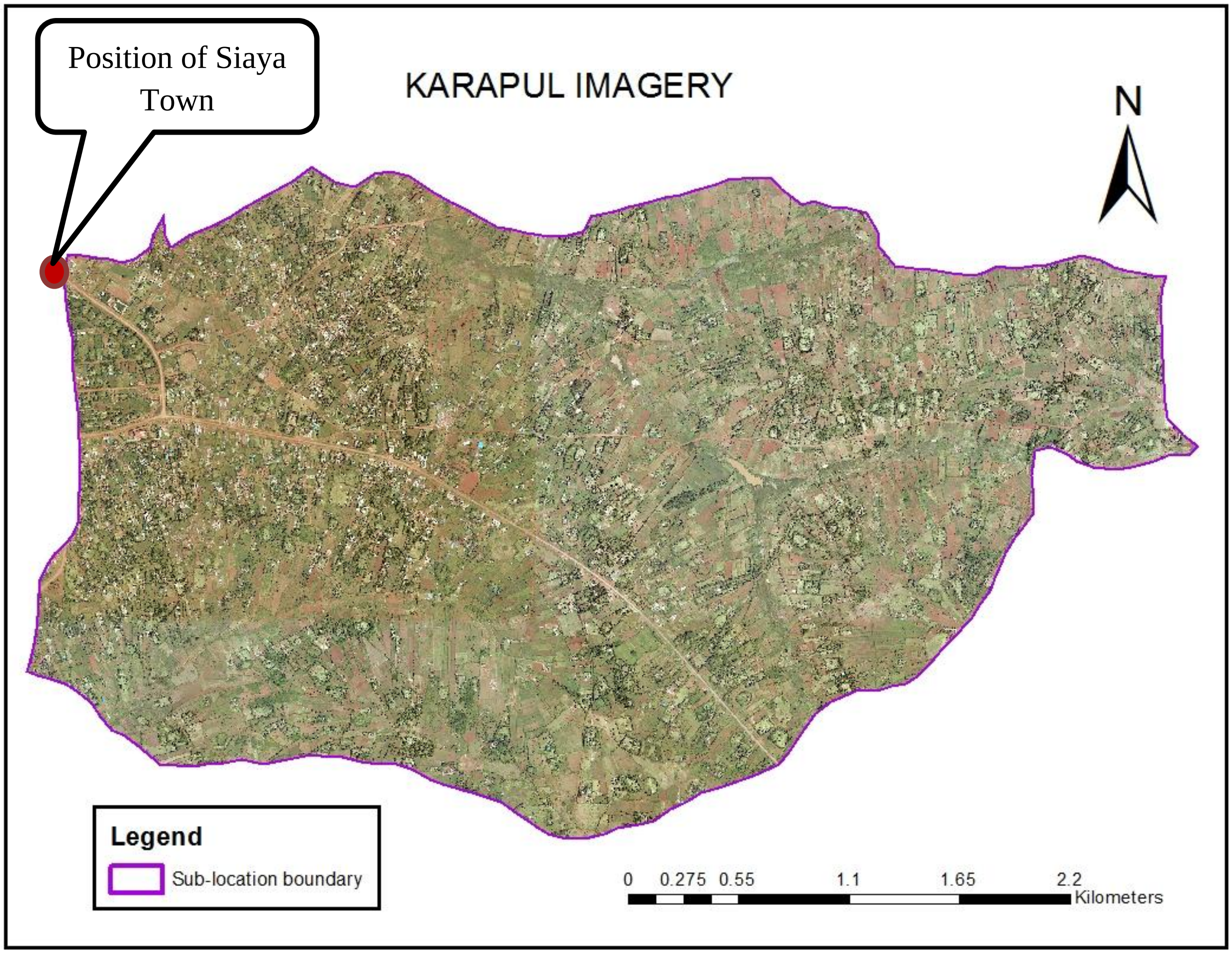

Plate 3.1: Orthophoto Imagery clipped along the Study Area

The clipping of the imagery was done in ArcGIS environment using the Geoprocessing tool. The clipping was based on the sub-location boundary. This was necessary to enable working with a smaller image to enhance computer processing efficiency.

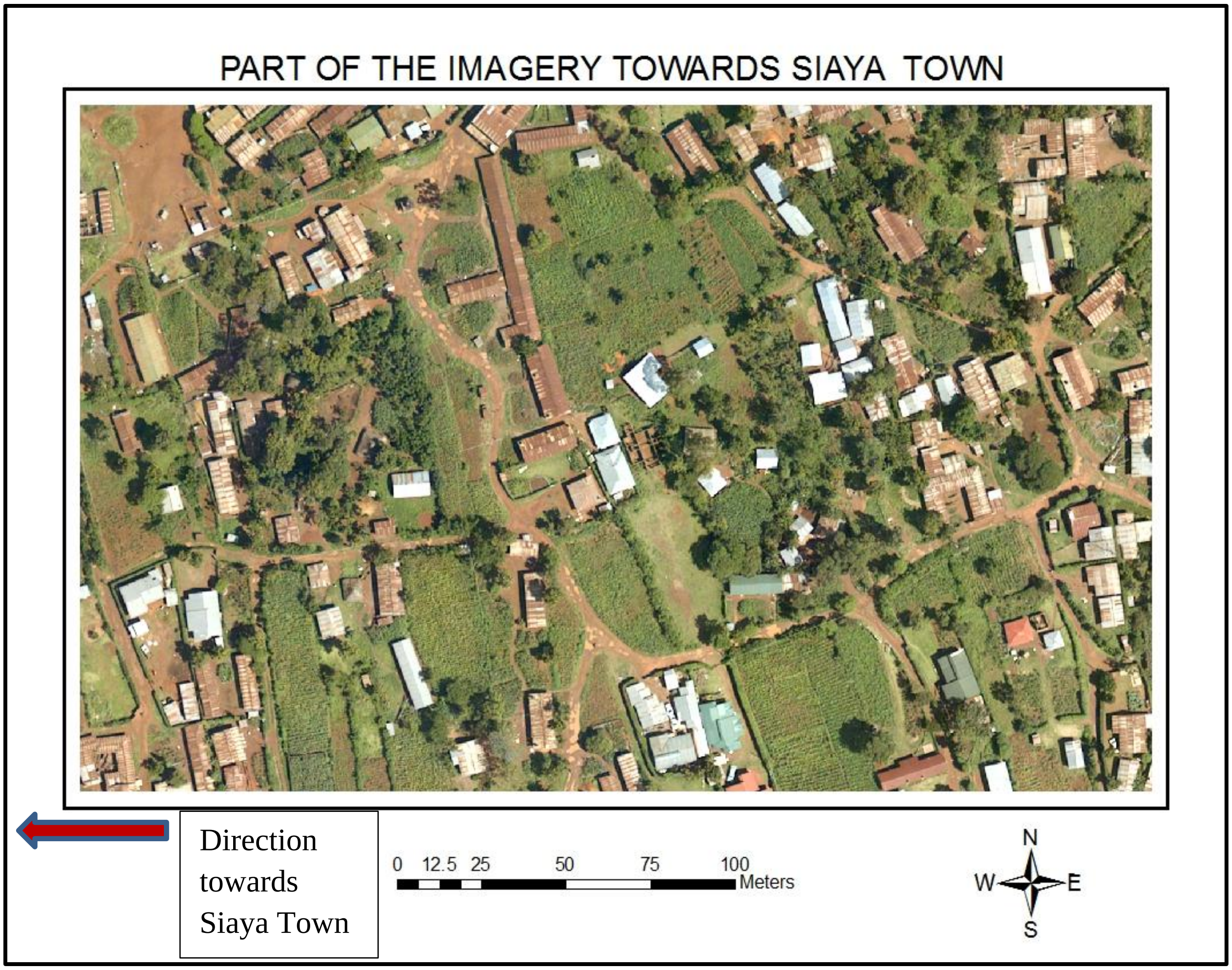

Plate 3.2: Part of Imagery showing the area towards Siaya Town

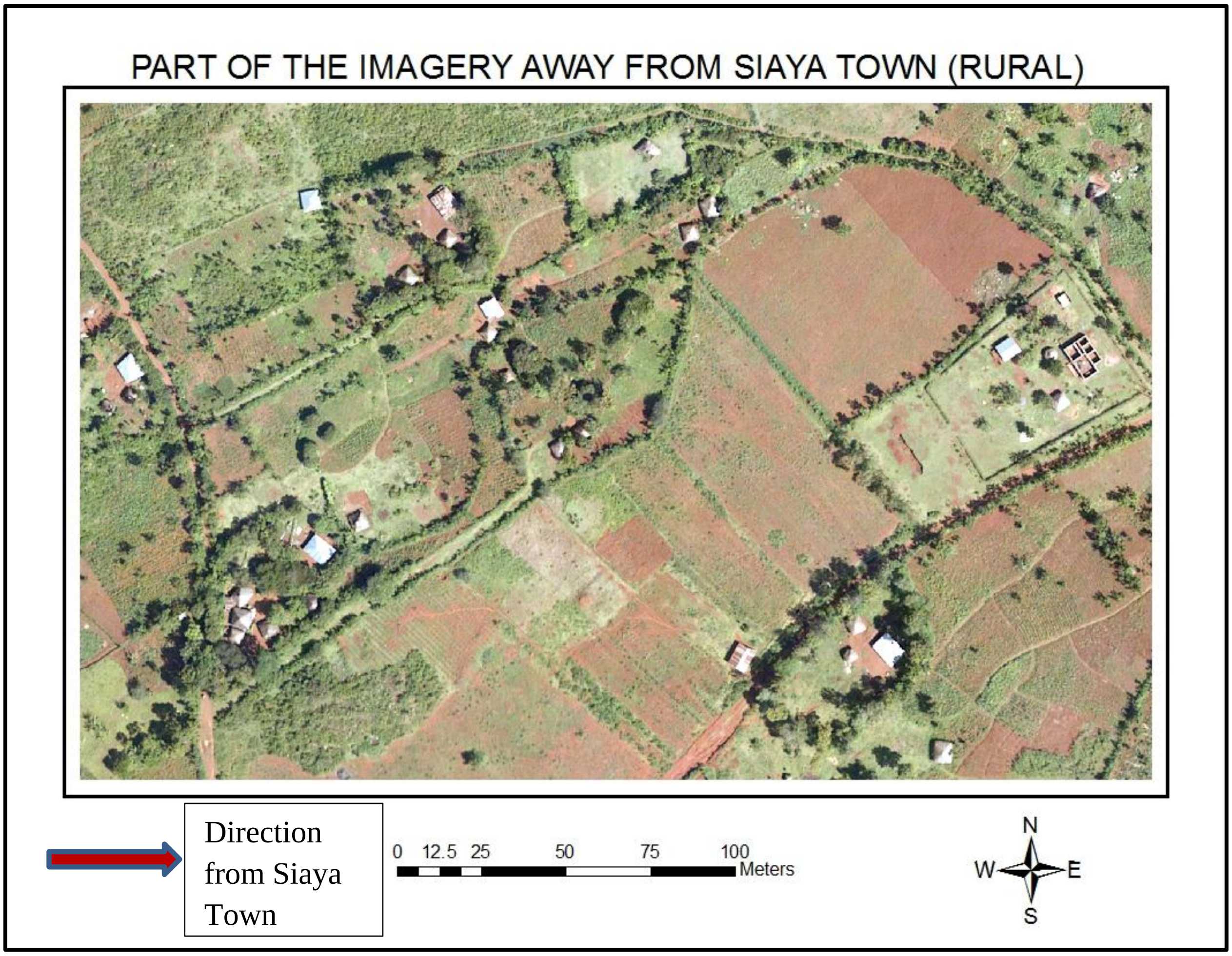

Plate 3.3: Part of Imagery showing the area away from Siaya Town- (Rural)

i) SRTM Data

This was necessary to enable the understanding of the topography (elevation) and to see if it had any influence /correlation with the other variables used in the study. The DEM for the study area was developed from spot heights derived from SRTM.

ii) Shapefiles

These were used mainly as base data and included existing water points, administrative units, town centers and rivers. Other shape files such as roads and footpaths were digitized from the imagery.

b) Non-Spatial Data Collection

These included, Population; Rainfall; Water requirements, number of houses per household and household average occupancy data.

i) Rainfall Data

Rainfall data was found to be very critical in the determination of RRWH. The existing rain stations are located in Kisumu and Kakamega towns which are far away from the area of study and could not offer useful reliable data for this study. The resolution, quantity and temporal aspects of the rainfall data were found to be critical for the study.

FEWS NET website (http://earlywarning.usgs.gov/fews/downloads/index.php) provided rainfall estimates data for every 10 days (decadal) for the months of January to December. The data was for 13 years ranging from the year 2000 to 2012. The resolution of the rainfall data was 1000m pixel size which was scalable and hence was found appropriate for the study.

ii) Information extraction from questionnaires

Data obtained during field visit was used to extract main water sources for the inhabitants of Karapul Sub-location, water uses, average household occupancy data, water requirements data and the number of houses per sampled households data. Data from the field was necessary for the purpose of computing water demand per household and per capita water requirements in order to give a uniform standard per individual. However, in this study only the latter was computed. The sampling was randomly done and sampled point picked using a handheld GPS receiver. The required data items were identified and their respective fields created and populated using data from the questionnaires and the imagery.

c) Data Preparation/organization and Conversion

The **SRTM** was processed and spot-heights derived to obtain the DEM for the area.

The **non-spatial** data was cleaned and re-projected from WGS 84 to GCS and UTM zone 36S.

The resolution for **rainfall data** was improved from 1000 pixels to 100 pixels through resampling in ArcGIS environment. The data was then clipped to the study area through automation using an edited code in python which was customized to suit the task at hand.

The **imagery** was first enhanced to improve interpretability and then clipped to the study area using the sub-location boundary shapefiles obtained from ILRI website. Image enhancement and clipping were carried out using tools in ArcGIS environment.

The image was then explored for understanding and georeferencing confirmation before carrying out image interpretation.

d) Image Interpretation

The approach used was human visual interpretation since the image was of high resolution (40 cm) and features could easily be distinguished. Human visual interpretation was facilitated by the common interpretation elements namely, shape, pattern, orientation, size and association among others.

e) Rooftop Digitization and editing

This was necessary in order to extract roof tops from the imagery (Raster) and create vector data. Different roof types were identified on the imagery based on the material used, namely, iron sheets, tiles and grass thatched. Data editing was necessary to ensure data integrity and quality assurance and quality control. It was achieved interactively during digitization process and by using appropriate zoom levels.

f) Field verification

Field visit was done in the month of February for 3 days to be able to carry out ground truthing. It was facilitated with the assistance of the administration in order to supply the questionnaires, verify the water points, confirm georeferencing, to collect a few rooftop measurements and to assess the situation on the ground through direct observation.

g) Quality Control

Quality assurance during digitization was achieved through use of snap tolerance which ensured that no gaps existing within the line and polygon features, by using a polygon drawing tool that ensured perpendicularity of the rooftops as well as appropriate zoom levels to enhance digitizing accuracy. Available editing tools in ArcGIS environment ensured that perpendicularity of the roof tops was maintained.

h) Data validation

Accuracy assessment for rooftops was achieved through use of ground truth data in which actual ground measurements from selected household owners were compared with the values computed by ArcGIS software.

i) Data Integration

Data integration was made possible after cleaning up the data, harmonizing the projection parameters and datum and consequently being able to overlay the various data sets to be able to carry out the required analyses.

3.4 Development of the RRWH conceptual model

The conceptual models were derived from the already existing RWH approaches described in chapter 2. The RRWH conceptual models provided a framework for estimating RWH potential in the study area. This is illustrated in Figure 3.7.

3.4.1 Creation of Fishnet

Techniques for estimating areal daily rainfall require the availability of a gridded altitude and gridded monthly rainfall at a certain scale (Lynch and Schulze, 1995).

For the purpose of this project, a gridded surface was generated using the *Create Fishnet* tool under Data Management Tools in Arc Toolbox in ArcGIS environment. A gridded surface of 100m x 100m grid cell was necessary to take care of the variations within the data sets and adapted as a basis for creating the models. The tool enabled the creation of a feature class containing a net of rectangular cells. Creating a fishnet requires three basic pieces of information: the spatial extent of the fishnet, the number of rows and columns, and the angle of rotation (ESRI, 2015). For the purpose of this study, the spatial extent was determined by the sub-location boundary of the study area. The cell sizes for rows and for heights were given as 100m by 100m respectively. The output feature class type was given as polygon. The angle of rotation was not necessary. Figure 3.5 illustrates part of the procedure of generating grid cells for the study area.

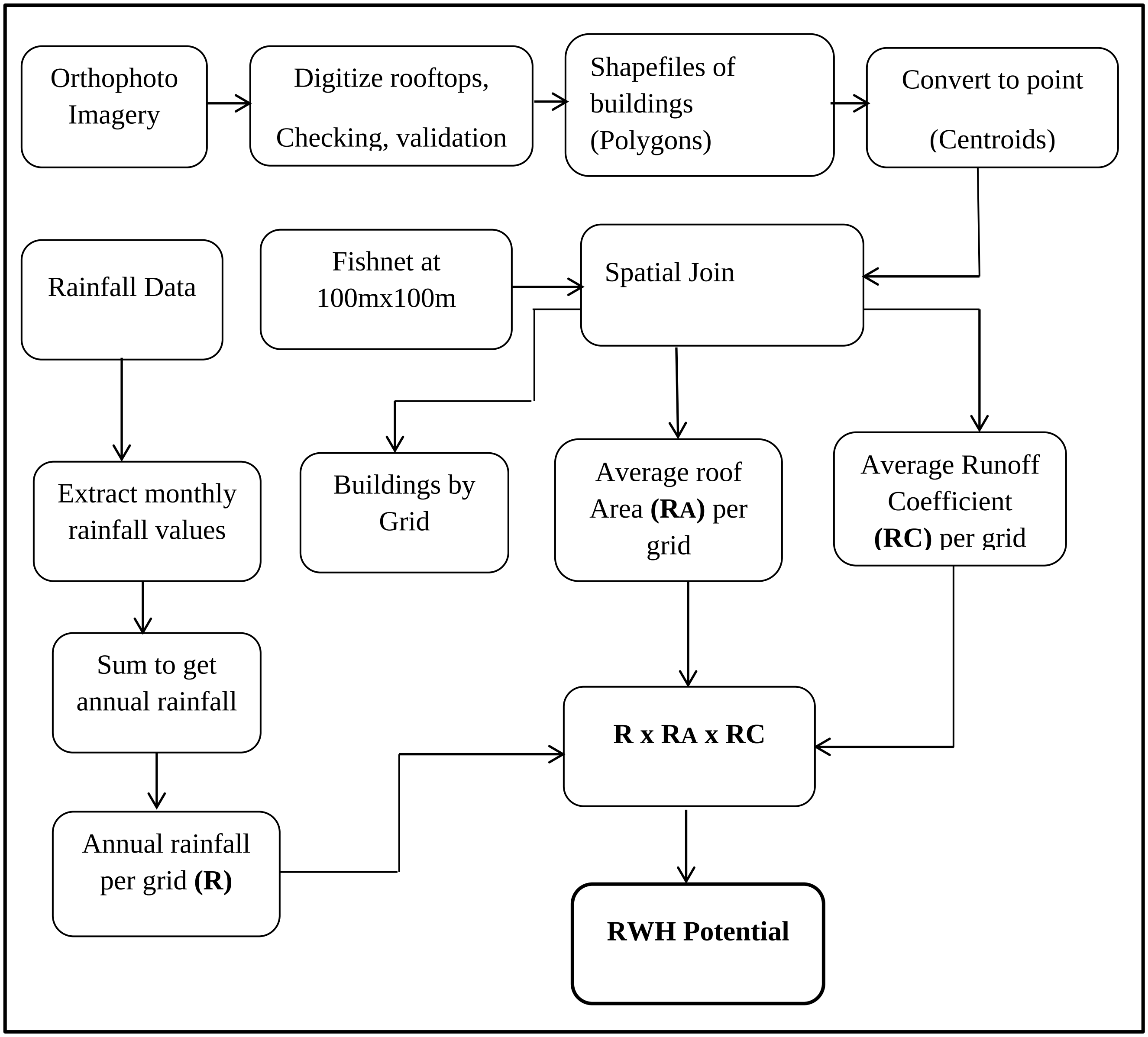

Figure 3. 4: Conceptual model for implementation of RWH potential

The Rooftop Rain Water Harvesting model

The amount of water that can be collected depends on the roof catchment area, the amount of rainfall and the runoff coefficient among other factors (Nthuni, 2010). This study relied heavily

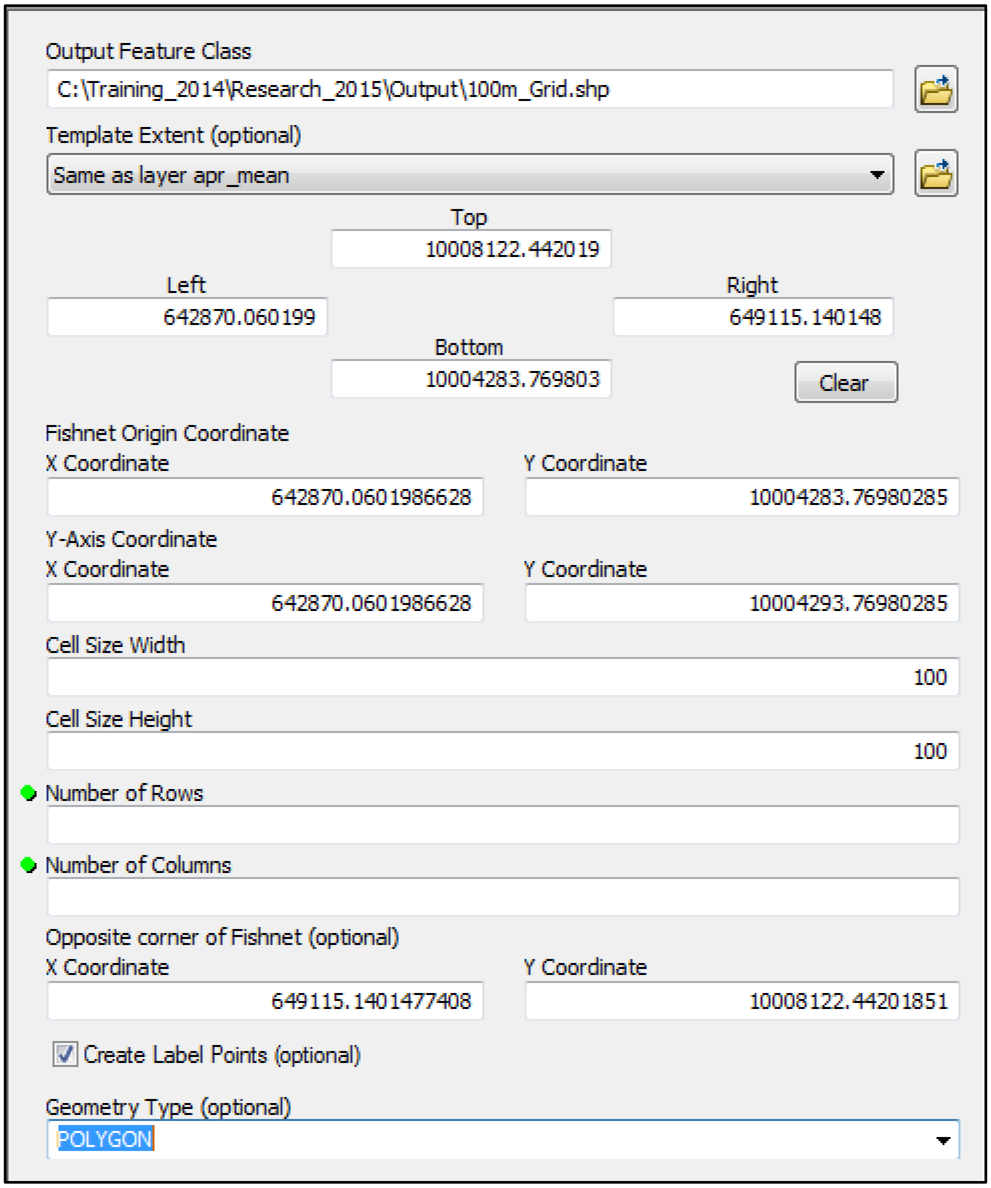

Figure 3. 5: Showing procedure of generating the 100m by 100m grid cell

The model was based on those used by previous researches, except that the approach was different owing to the fact that this study used spatial join as opposed to ModelBuilder used by Nthuni, (2010) in order to obtain the desired results. The study strived to find a simpler approach to estimate the RWH potential within the study area as recommended by previous researchers.

3.4.2 Roof Catchment Area (RA)

The rooftops covered in the study area were all digitized indiscriminately irrespective of size, use, and condition and roof material. The digitized roofs provided the roof catchment area was found to be very critical in determining the RWH potential.

(TWDB, 2005) has defined Roof catchment area as the "footprint" of the roof, i.e. the area covered by roof surface. It is calculated using equation 1.

$$A = L \times W \qquad [1]$$

Where:

A = Roof Catchment area in m^2,

L = Length of the roof and

W = Width of the roof.

The average catchment area (R_A) was the computed, based on the cell size. The buildings were converted to points for ease of analysis before being used in the final model for estimating the RWH potential.

3.4.3 Runoff Coefficient (RC)

Runoff Coefficient (*RC*) has been defined as the ratio of the volume of rainwater that runs off the catchment surface to the total volume of rain that falls on that particular catchment surface (Tripathi and Pandey, 2005). In order to calculate the runoff coefficient, data is collected for a specific period of time *t* i.e. for several months or years and can also include a number of storm events. The average value out of the calculated coefficients for each storm is determined and termed as the runoff coefficient of that particular roof.

$$RC = V_t/TR_t \qquad [2]$$

Where *Vt* is the runoff volume and *TRt* is the total volume of rain that falls on the roof catchment surface after time *t* respectively. *TRt* determined by multiplying the depth of rainfall after time t by the effective roof catchment area given by equation 1. Runoff coefficient plays an important role in assessing the runoff availability and it depends upon catchment characteristics. It is the factor that accounts for the fact that not all rainfall falling on a catchment can be collected. Some rainfall may be lost from the catchment through various means, including; overshoot from gutters during heavy rains or splash outs, retention on the surface itself or possibly leaks through the catchment surface and evaporation (TWDB, 2006).

For the purpose of this project, different Runoff Coefficient values were assigned to the various roof types according to their collection efficiency as follows: Iron sheet roofs - 0.85, tiled roofs - 0.6 and grass thatched roofs – 0.2. The areas without buildings adapted null (zero) values. The average Run-off Coefficient was then computed and used in the calculation of the Potential of rooftop rainwater harvesting. This is illustrated in table 3.2.

Table 3.2: Showing digitized rooftops and their Runoff coefficients as percentage

Roof Type	**No. digitized**	**Estimated Collection Efficiency (as % of precipitation)**
Iron sheets	6,429	85
Tiles	92	60
Grass thatched	1,503	20

3.4.4 Mean Annual Rainfall

Temporal fluctuations for the rainfall were considered at two different time scales, namely monthly and annual intervals. These were processed using MS Excel and the Raster Calculator in ArcGIS to obtain the sum total of the rainfall data for 13 years ranging from the year 2000 to 2012. The mean monthly rainfall was then computed per grid cell and the resulting value was then used to calculate the mean annual rainfall. The model adopted is illustrated in equation 3.

$$\sum_{k}^{n} R_i \qquad [3]$$

Where $k = 2000$

$n = 2012$

Ri = Estimated amount of Rainfall received in mm during the year i

3.4.5 Spatial Join (Analysis)

Spatial analysis using *Spatial Join* was performed to be able to combine values in MS excel table and the attribute table in ArcGIS environment for the purposes of analysis. This necessitated the creation of a common field to base the *join* on.

A *spatial join* joins attributes from one feature to another based on the spatial relationship. The target features and the joined attributes from the join features are written to the output feature class (ESRI Desktop help). By default, all attributes of the join features were appended to attributes of the target features and copied over to the output feature class.

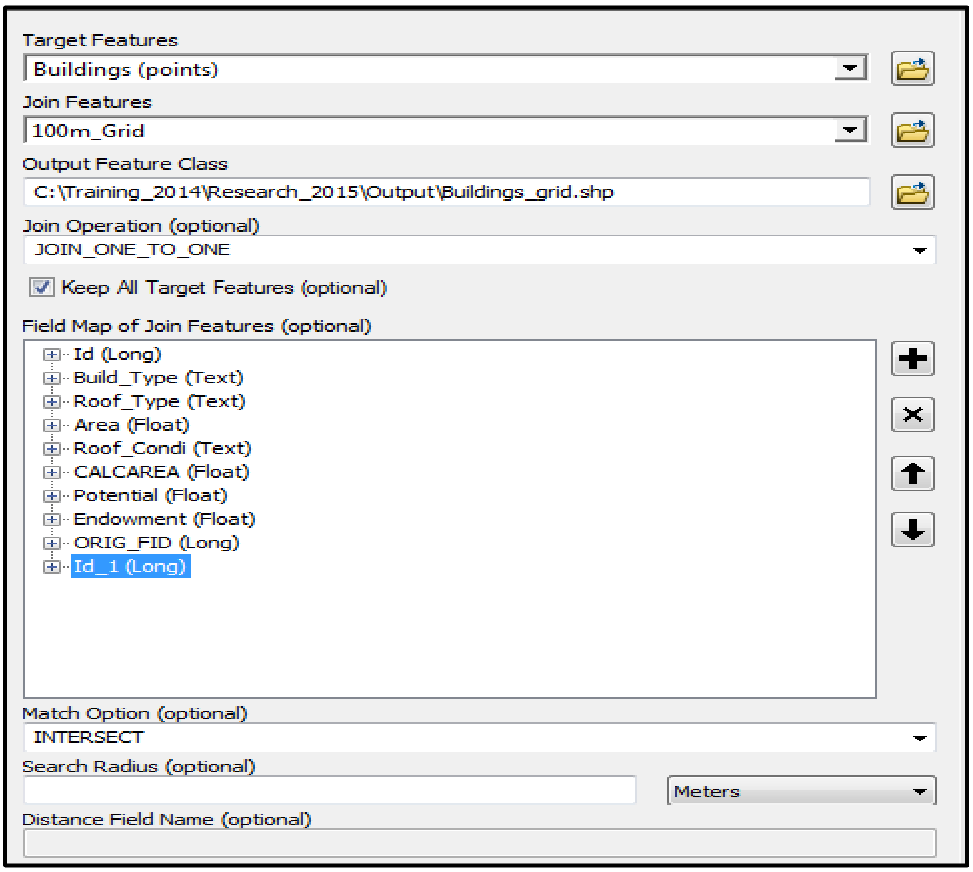

Figure 3.6: Spatial Join between 100mx100m parameters and rooftops

A one to one spatial join was necessary in order to obtain the number of houses per grid cell.

3.4.6 The Potential of rooftop rainwater harvesting (Pt)

Potential of roof rainwater harvesting refers to the capacity of an individual roof to harness the water that falls on that roof in a particular year covering all rainy days (Nthuni, 2010). The annual yield of water which is probably measured in unit of liters is the product of roof type and annual average rainfall of an area. Rain water yield varies with the size and texture of the catchment area. A smoother, cleaner and impervious roofing material contributes to better water quality and greater quantity. Potential of roof rainwater harvesting in a study area has been evaluated by using the formula adopted from Gould and Nissen, (1999) and Nthuni et al, (2014), as given in equation 4.

$$P_t = A * R_t * R_c \qquad [4]$$

Where,

Pt = Potential of roof rainwater harvesting in cubic meters for a specific period of time *t*

Rt = Average annual rainfall in mm;

A = Roof area in Square meters

Rc = Coefficient of Runoff and

* = Multiplication operator.

In determining the potential of rooftop rainwater harvesting (P_t), the above mentioned parameters; Average Rooftop area (R_A), Average Annual Rainfall (Rt) and Runoff Coefficient (R_C) were computed using the Raster calculator in ArcGIS environment.

CHAPTER FOUR

RESULTS AND ANALYSIS OF RESULTS

4.1 Results

The following results were obtained in line with the objectives of this study:

4.1.1 Existing water points

Details of the official water points in form of deep wells (boreholes) obtained from WRMA, Siaya County office are summarized in table 4.1.

Table 4.1: Existing water points- (boreholes) in the study area (Source: WRMA)

Applicant	Total Yield (m^3) per day	Alt_MSL	Total depth (m)	Water allocation
Mwisho Mwisho Investment LTD	-	1325	65	30.000
Sussy Grand Hotel	-	-	-	-
Bama Hospital	5	1322	80	22.500
Karapul Filling Station	3	1311	80	30.000
Town Gate Plot	-	-	-	-

The official numbers of water points obtained from WRMA, Siaya County office were only five in form of boreholes (deep wells) to serve the residents. The boreholes are located in the area towards Siaya town. They are mainly owned by business men and a health institution (Bama Hospital). One borehole for a local primary school in the area is said to have failed after approval by WRMA and subsequent drilling and hence was not included. Another borehole experienced varying water struck levels from 35m, 60m, and finally settled at 80m (Source: WRMA). Each borehole is allocated a certain amount of water per day as indicated in table 4.1.

The water points were mapped and the results are illustrated in Figure 4.1. They comprise of deep wells (boreholes), small natural wells (shown as dams on the map), and a river. As mentioned elsewhere in this report, there is only one permanent river called *Wadh Bar* in the study area located to the eastern side of the study area with rural setup. A few streams also exist but they dry up during long dry spell. The boreholes are concentrated on the central, western region of the study area.

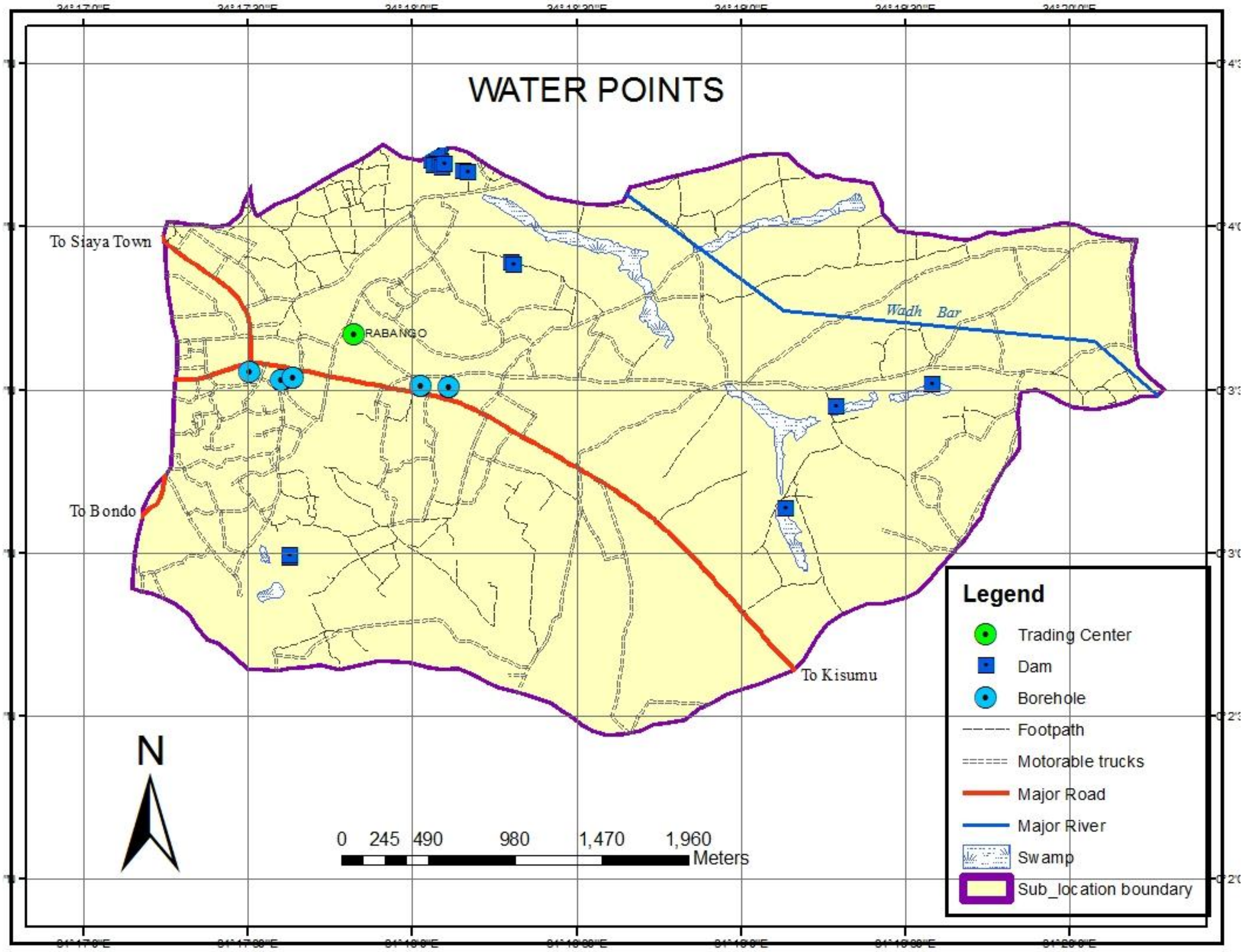

Figure 4.1: Map of existing water points

Most residents in the study area buy water from the existing boreholes at a fee of between 5 kshs per 20 litres jerrican (if bought directly) to between 10 kshs to 20 kshs if transported and sold to a household, depending on the means of transportation and the distance from the water point. The means of transporting the water are varied as mentioned elsewhere in this study. Plate 4-1 shows one of the areas where a borehole is located. The water from the borehole is pumped into elevated tanks before selling to the residents.

Plate 4.1: Photo of one of the water points (borehole) at a Petrol station

4.1.2 Results from the questionnaires

A total of 100 questionnaires were administered and about 60% results were obtained. From the correspondences:

- The majority of residents of Karapul sub-location use water from dug wells.
- Many use water for domestic use (drinking, cooking and cleaning).
- Many do not have a rain water harvesting system but would wish to have, the majority if facilitated.
- Many do not know their rooftop areas (foot prints)
- The average number of persons per household is 5 persons.
- Water consumption per person per day is 20 litres (assuming there is no laundry)

4.1.3 Digitization of rooftops and conversion to point

A total of 8,024 rooftops were digitized comprising of 6429 iron sheets, 1503 grass thatched and 92 tiled roof tops respectively. The distribution of the rooftops is such that, the iron sheet types are concentrated more towards the town and less away from Siaya town. The opposite is true for the grass thatched rooftops. Tiled roof are the least and are concentered closer to the town. The distributions of the digitized rooftops are mapped in Figure 4.2.

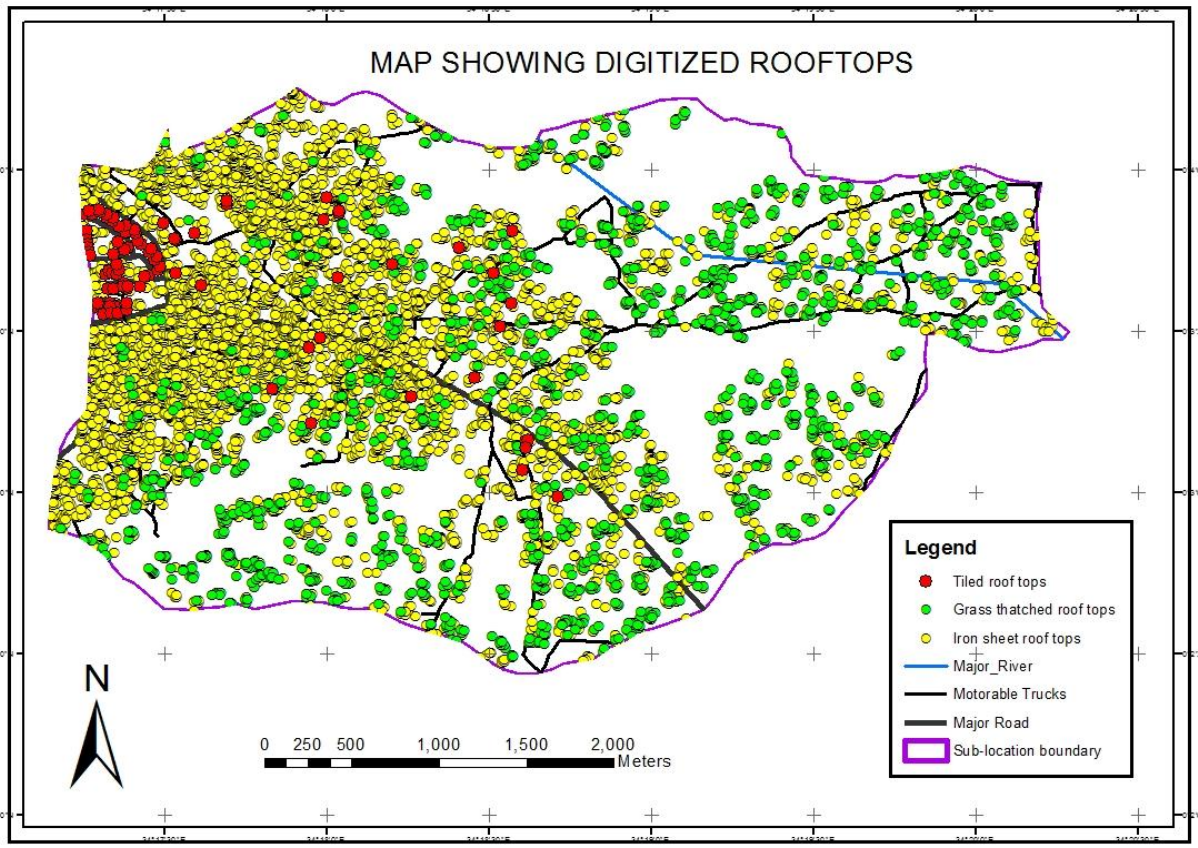

Figure 4.2: Distribution of digitized rooftops

An attribute table was designed and populated for the rooftops. Field for roof type for roofing material used as well as the field for roof area was created. Part of the same is shown in Table 4.3. Roof conditions were outside the scope of this study and hence were not considered and the same has been recommended for further investigation.

Table 4.2: Abstract from the attribute table for roof catchments

Table

Buildings_27032015

Area	FID	Shape *	Id	Build_Type	Roof_Type	Roof_Condi	CALCAREA	E
3.119	3	Polygon	0		Iron Sheets	Poor	31.1952	
4.642	4	Polygon	0		Iron Sheets	Fair	4.64218	
4.341	5	Polygon	0		Iron Sheets	Fair	43.4182	
9.275	6	Polygon	0		Iron Sheets	Good	9.27472	
1.223	7	Polygon	0		Iron Sheets	Good	12.23	
8.675	8	Polygon	0		Iron Sheets	Good	86.7599	
8.487	9	Polygon	0		Iron Sheets	Good	8.48666	
1.523	10	Polygon	0		Iron Sheets	Good	152.335	
1.351	11	Polygon	0		Iron Sheets	Good	135.197	
1.024	12	Polygon	0		Iron Sheets	Good	10.2445	
6.747	13	Polygon	0		Iron Sheets	Fair	67.4775	
8.051	14	Polygon	0		Iron Sheets	Good	80.5193	
5.13	15	Polygon	0		Iron Sheets	Good	51.3043	
3.733	16	Polygon	0		Iron Sheets	Good	3.733	
1.031	17	Polygon	0		Iron Sheets	Fair	103.138	
2.52	18	Polygon	0		Iron Sheets	Good	25.2017	
4.516	19	Polygon	0		Iron Sheets	Good	45.1614	
2.425	20	Polygon	0		Iron Sheets	Good	24.25	
1.817	21	Polygon	0		Iron Sheets	Good	18.1771	
3.179	22	Polygon	0		Iron Sheets	Fair	31.793	
1.191	23	Polygon	0		Iron Sheets	Good	119.119	
2.025	24	Polygon	0		Iron Sheets	Good	20.259	
1.029	25	Polygon	0		Iron Sheets	Good	10.2917	
3.211	26	Polygon	0		Iron Sheets	Good	32.1195	
1.276	27	Polygon	0		Iron Sheets	Good	127.64	
1.887	28	Polygon	0		Iron Sheets	Good	188.701	
6.42	29	Polygon	0		Iron Sheets	Good	64.2059	
3.165	30	Polygon	0		Iron Sheets	Good	3.16525	
2.632	31	Polygon	0		Iron Sheets	Good	26.3203	
3.933	32	Polygon	0		Iron Sheets	Good	39.3384	

0 (0 out of 8024 Selected)

Buildings_27032015

4.1.4 Map of Mean annual Rainfall

Rainfall is the main factor to implement RWH. The rainfall variation is highest on the north-west part of the study area (1710mm-1722mm) and least on the eastern part (1689mm-1692mm). Moderate variations (1698mm-1704mm) are found mainly in the middle part of the study area.

The rainfall variations within the study area were computed based on the 100m by 100m grid cell and are illustrated in Figure 4.3.

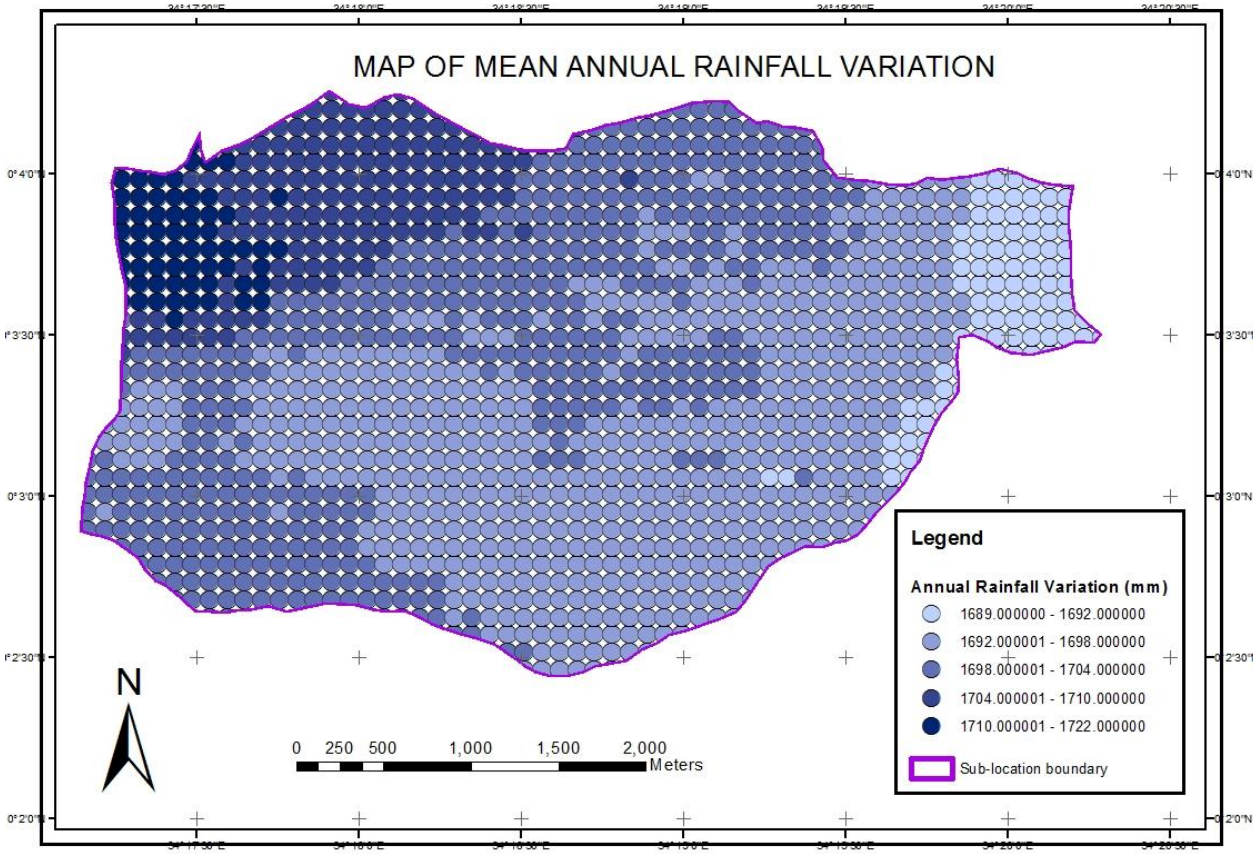

Figure 4.3: Mean Annual Rainfall variation per grid cell

4.1.5 Map of Coefficient of Runoff

The various rooftops (Iron sheets, tiles and grass thatched) were each assigned a runoff coefficient of 0.85, 0.6 and 0.2 respectively, depending on their catchment ability as earlier mentioned in this report. A map of Coefficient of run-off was generated using average runoff coefficients for the different rooftops. The results are displayed in Figure 4.5.

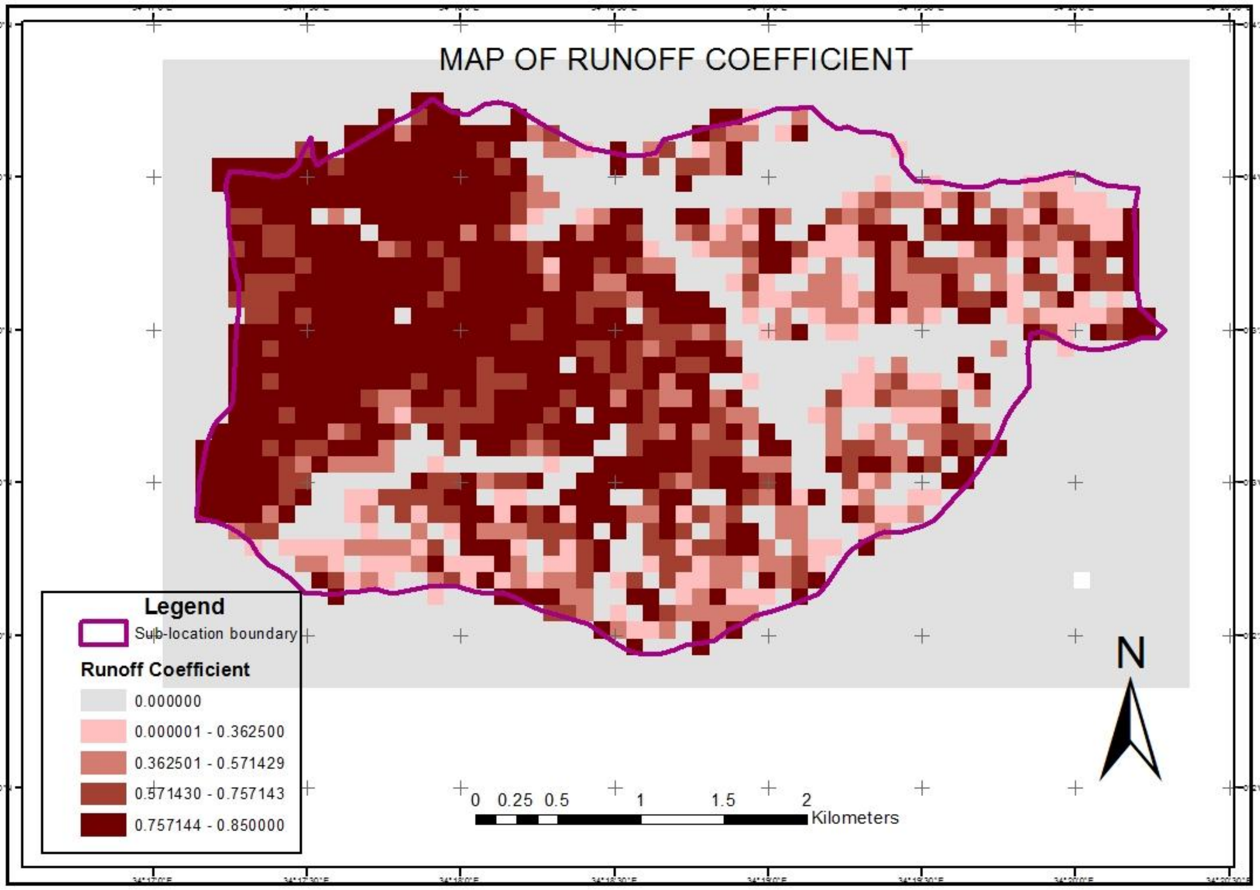

Figure 4.4: Average Runoff Coefficient per grid cell

The range of runoff coefficient is between 0-0.85. There are higher concentrations of runoff coefficient on the western side of the study area (0.75-0.85) than the eastern side except for a few patches to the extreme end on the eastern part. The regions with no (zero) runoff coefficient within the study area appear light grey on the map.

4.1.6 Map of Average rooftop Area

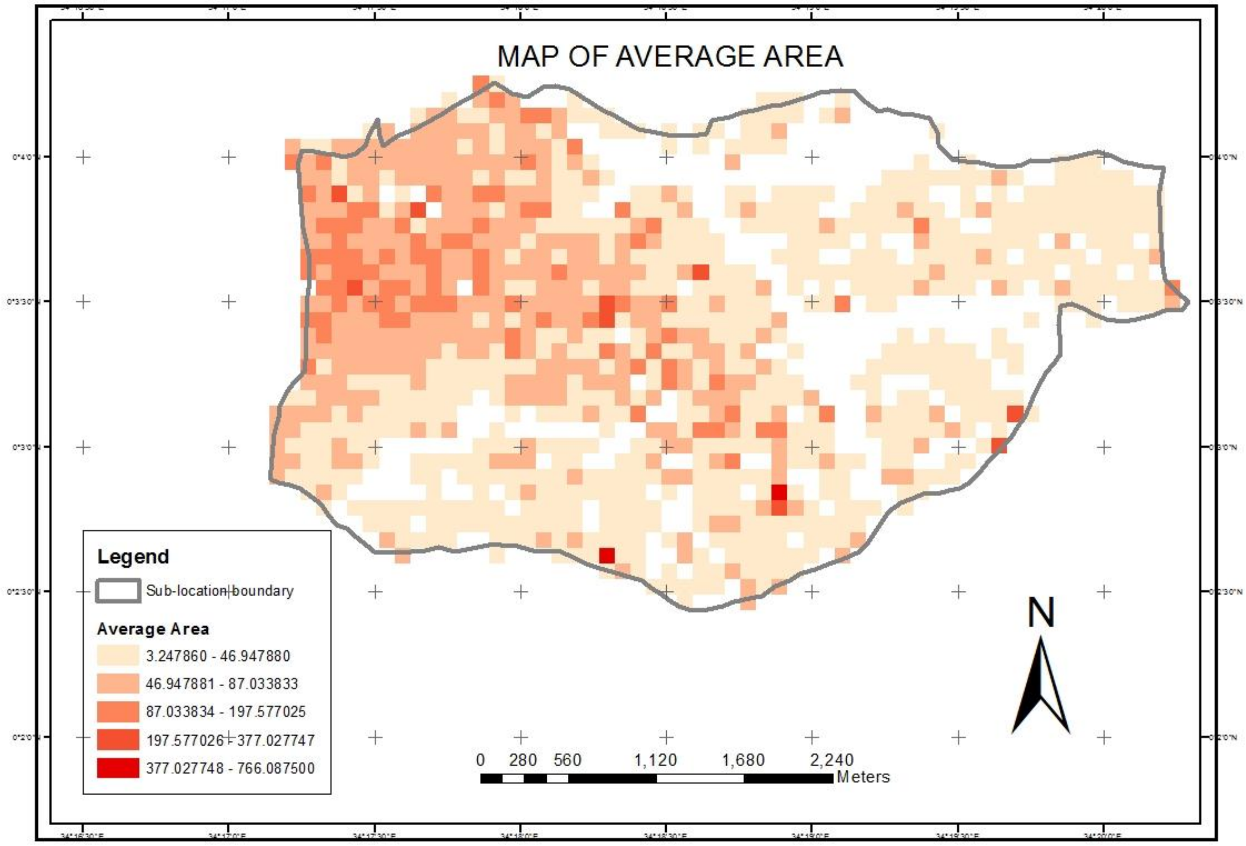

Figure 4.5: Map of average area per grid cell

The map reveals that the average area per grid cell of rooftops, ranging from 3.24786 square metres for the lowest, to 766.0875 square metres for the highest average area respectively. The highest average areas are found on the western part of the study area whereas the lowest average areas are found on the upper, lower and eastern parts of the study area. The areas with zero values appear white on the map.

4.1.7 Verification of roof area

This was necessary to ensure quality control in digitizing. Areas of some sampled roofs were collected from the field and compared with the areas computed after digitizing. Only iron sheet roofs were considered. Results are illustrated in table 4.3.

Table 4. 3: Comparison of verified and digitized area

Sample	Verified area (sqm)	Digitized roof area(sqm)	Difference
1	169	100.535	68.465
2	120	103.865	16.135
3	63	50.7892	12.2108
4	198	176.219	21.781
5	198	176.219	21.781

4.1.8 Map of RWH Potential areas

Figure 4.7 shows the map generated for RWH Potential areas (as densities).

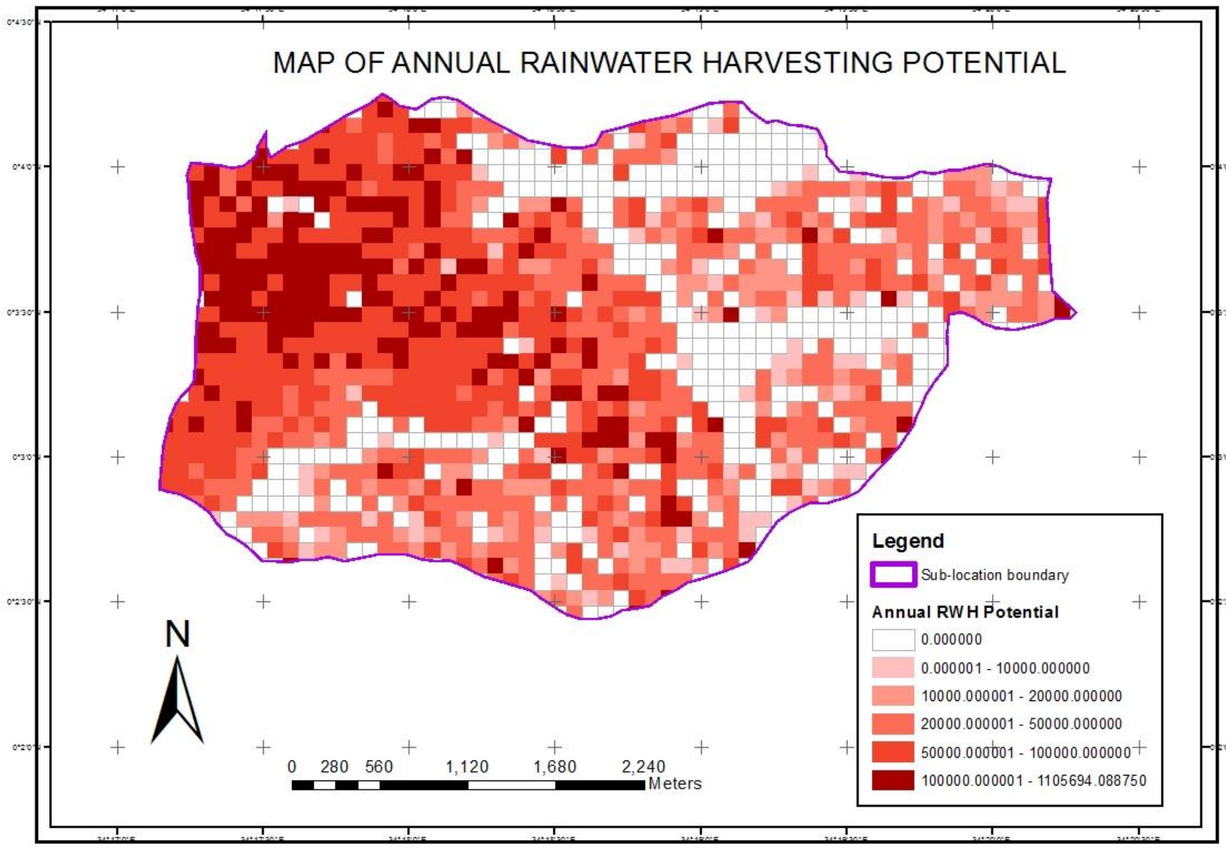

Figure 4.6: RWH Potential areas

There are dark red areas to the north- west part of the study area and less to the eastern part.
The highest range is 100,000 – 1105694 litres on the western side of the study area, while the lowest range (0.000001- 10 000 liters) is found towards the eastern side of the study area.
Areas without buildings adopted zero value. More of this is towards the eastern side of the study area.
Table 4.4 gives a summary of the results of the RWH potentials for different roof types in Karapul sub-location.

Table 4.4: Comparison between Run-off Coefficient, total area and RWH Potential

Roof Type	Runoff Coefficient	Total Area	Potential (litres)	Potential (m^3)
Tiles	0.6	13015.32813	13275634.69	13275.63
Grass Thatched	0.2	35755.1912	12156765.01	12156.77
Iron Sheets	0.85	389528.5321	562868728.9	562868.73

4.2 Analysis of Results

4.2.1 Existing water points

From the results in table 4.1, it is evident that there are a lot of data gaps in the data acquired, a clear indication that the data collection and verification is not updated by the authorities concerned. The questionnaires results revealed that many residents within the study area have dug shallow wells haphazardly, probably due to the desperate water situation in the area. The shallow wells are however not in the records in WRMA office. The fluctuating water struck levels revealed by table 4.1 is an indication of fluctuation in the water aquifer and this calls for further investigation.

According to the expected projection (Ministry of Water, 1988), Kenyans were not expected to walk for more than 500m to access water.

Proximity analysis approach was used to assess the adequacy of water to the residents of the study area. The analysis method is basPed on the distance derived from certain features (Chou, 2009). A buffer operation can be applied to any feature, type including points, lines and polygons

(Chou, 2009). Buffer operations in GIS at 500m were used to assess the adequacy of the existing water points. The river was however, not considered in the analysis.

Analysis results revealed a glaring evidence of water inaccessibility within the study area since most households fall outside the 500m buffer. Further more water from the existing dams is not suitable for drinking and can only be used for agriculture and for watering animals. The generated buffers at 500m from the existing water points is illustrated in Figure 4.7.

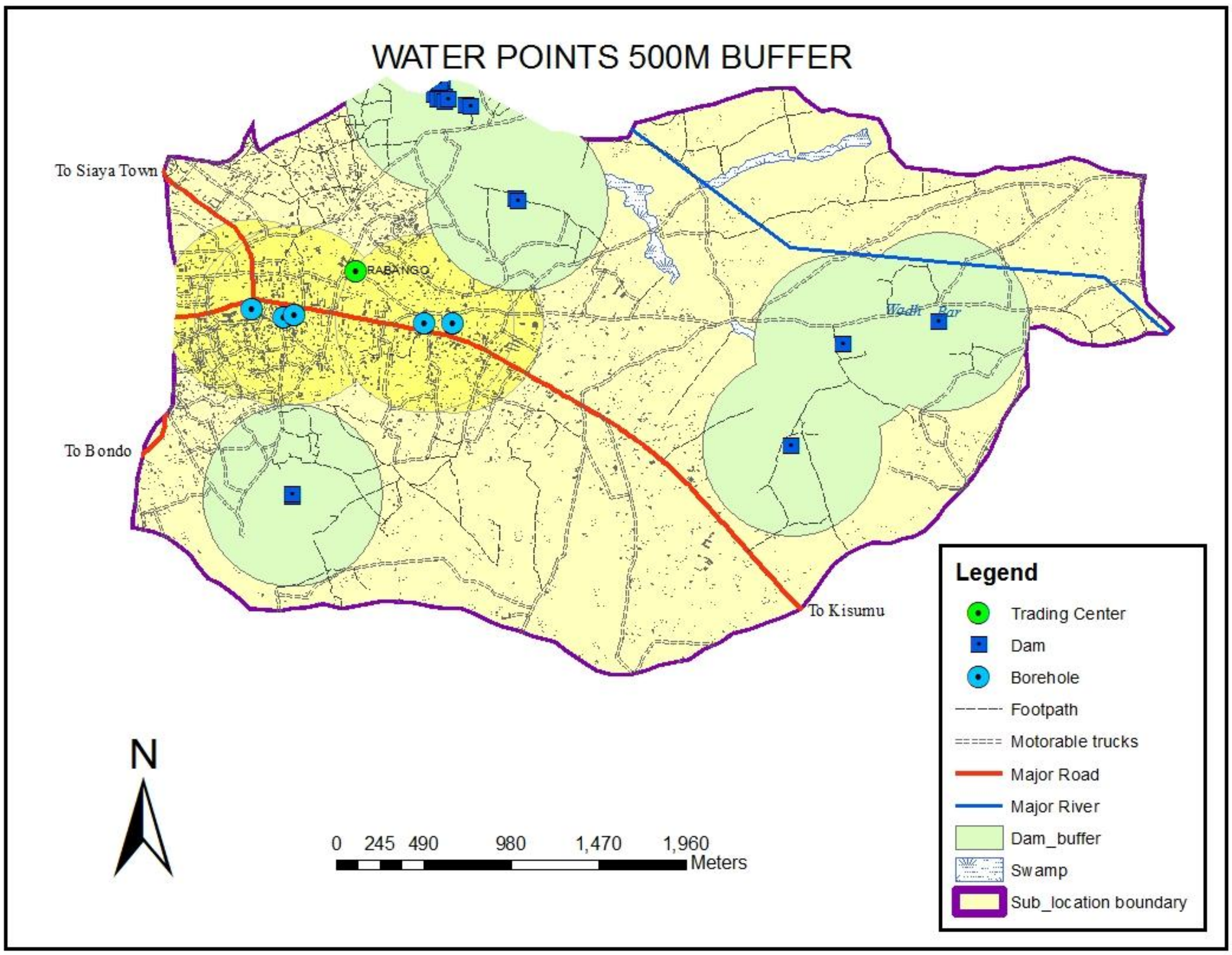

Figure 4.7: 500m buffer on existing water points

Results from the 500m buffer on boreholes indicate that out of the 8024 digitized buildings, only 2559 fall within the 500m borehole buffer. This means that the majority of Karapul residents are disadvantaged in terms of water accessibility around this area. The analysis results are illustrated in Figure 4.8.

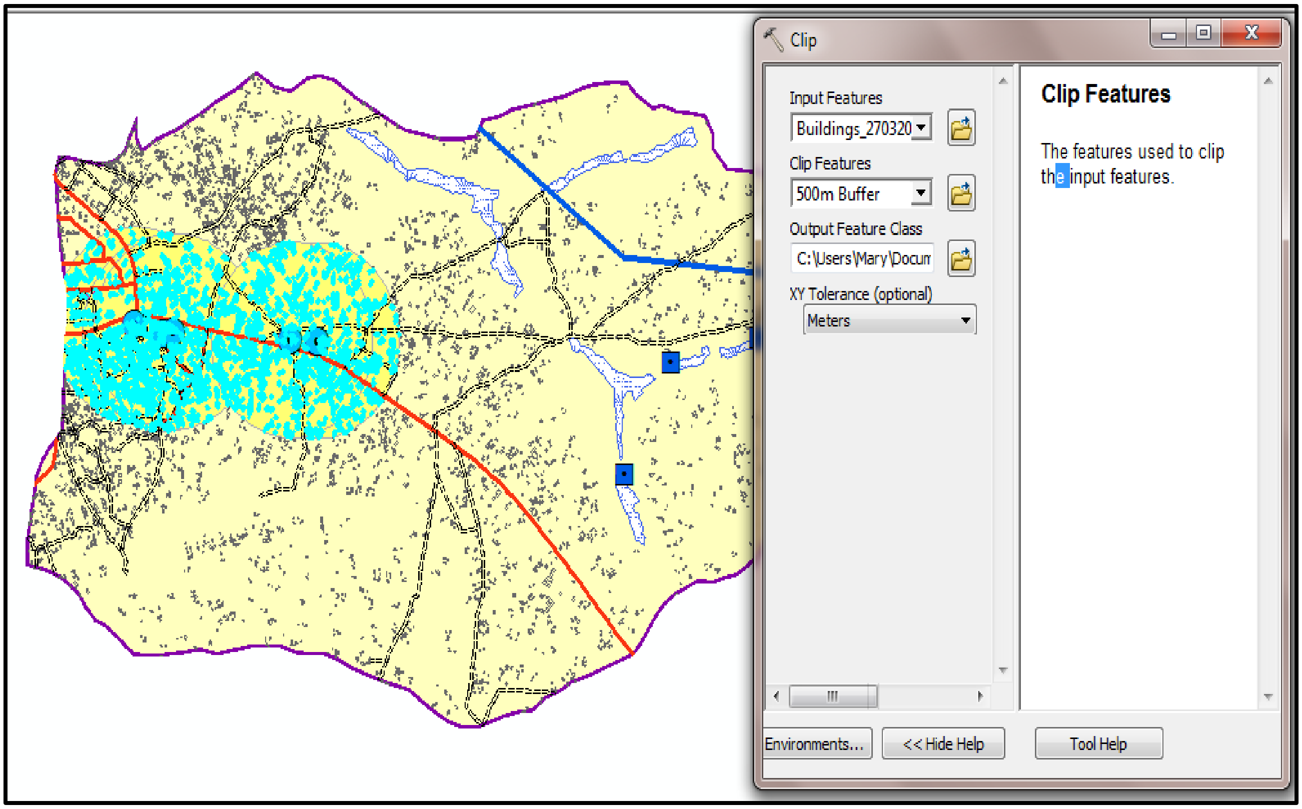

Figure 4.8: Results of the 500m buffer on boreholes

Results from analysis of existing dams revealed that only 1607 buildings out of the 8024 digitized are within the 500m buffer. This means that a total of 6, 417 buildings travel over 500m to the nearest water point. This is another indication of inadequacy in terms of accessibility. The results are illustrated in Figure 4.9.

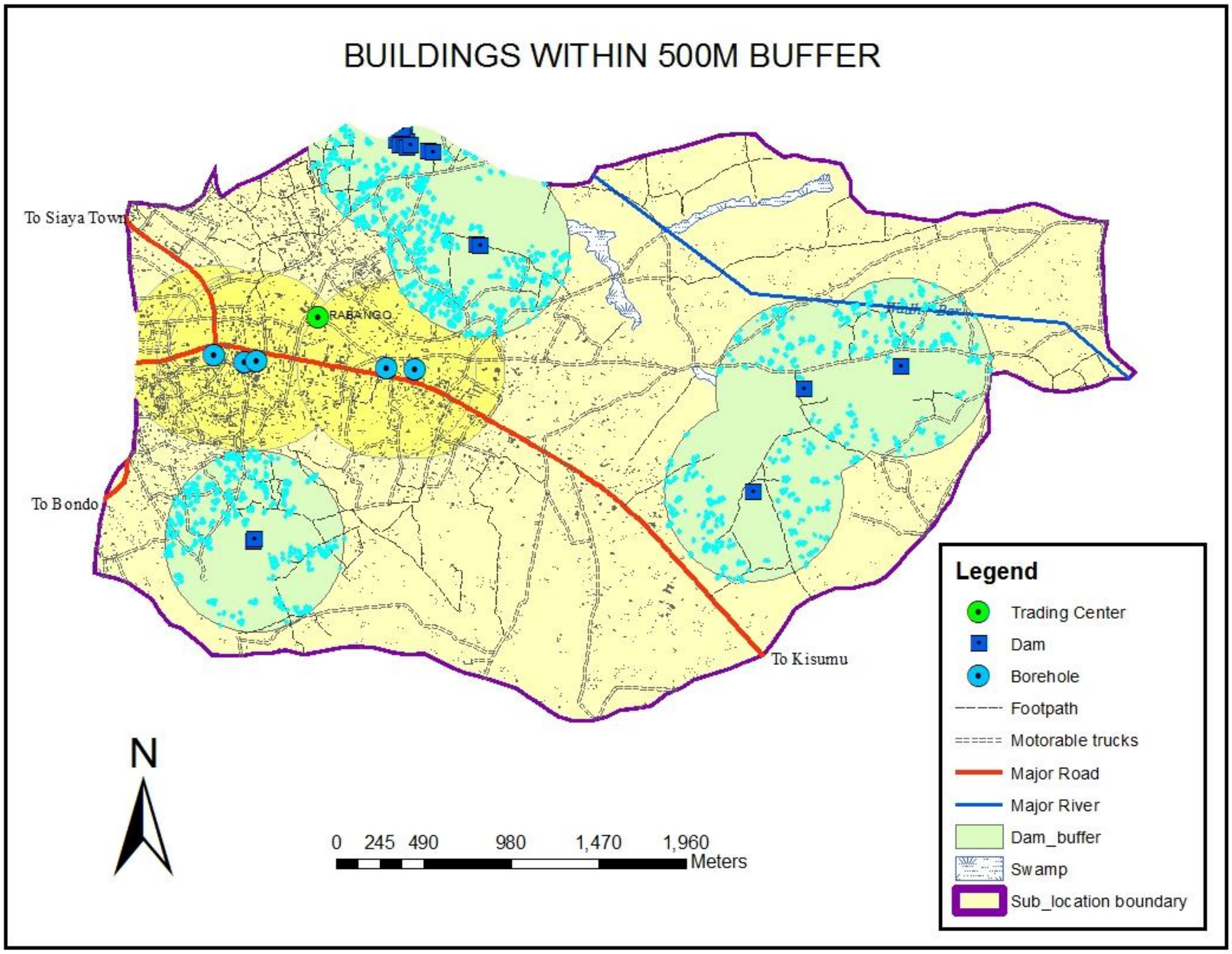

Figure 4.9: Results of the 500m buffer on dams

4.2.2 Mean monthly Rainfall

Karapul sub-location like many parts of Siaya County experiences dual rainfall seasons. The long rains are experienced in the months of March, April and May whereas the short rains are experienced between the months of August and November.

Form the bar graph (Figure 4.10), the mean monthly rainfall for the years 2000 to 2012, (from January to December), varies from 75mm in January to 200mm experienced in the month of April. Thus the longest dry spell of 90 days is experienced between the months of December to February. This coincides with the acute water shortage experienced in the study area during the said months. There is need to harvest the water during the wet seasons for use during the dry months. This will save the residents a lot of resources in terms of time and money wasted in search of this precious commodity.

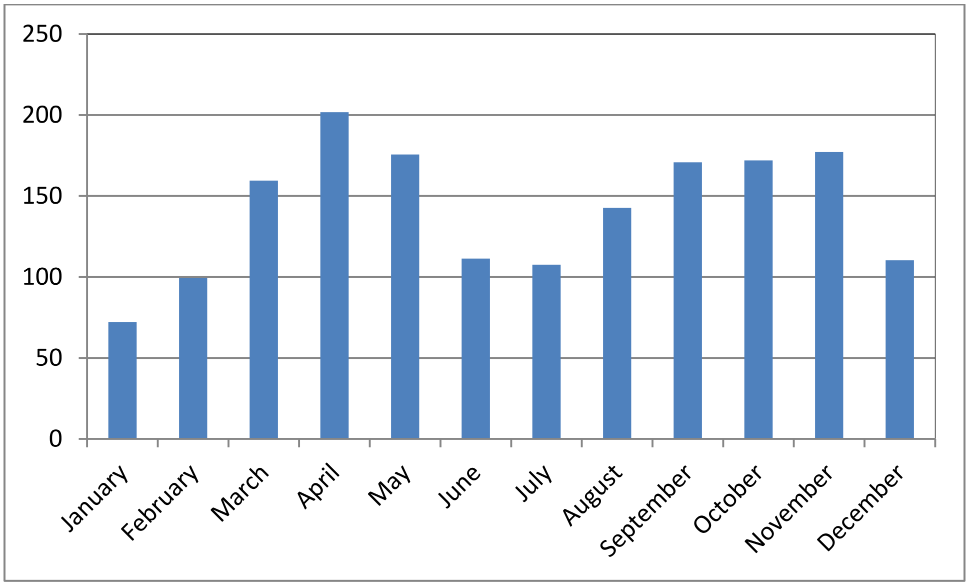

Figure 4.10: Graph of mean monthly rainfall for the years 2000-2012

Mean monthly Rainfall for 2000-2012 from January to December computed reveal very low Figures (75mm-200mm). The prospects of borehole drilling being very poor as earlier mentioned in this study call for an alternative source of water for Karapul sub-location inhabitants.

4.2.3 Runoff Coefficient

Analysis results for the runoff coefficient reveal that the roof tops with iron sheets ranked highest followed by, tiled roofs while the grass thatched roofs ranked least. The results are an indication that the estimated collection efficiency for the various roof types varies and this has a great influence on the outcome of the estimated RWH potential. This is illustrated in Figure 4.11.

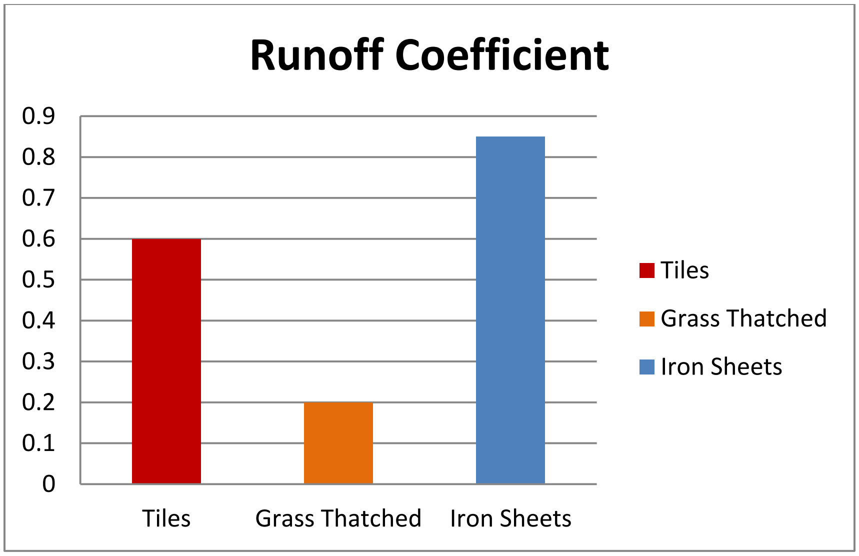

Figure 4.11: Graph of Runoff coefficient for the different rooftops

4.2.4 Total Roof area

A total of 8,024 roof tops were digitized. Analysis of the digitized rooftops revealed that iron sheet roofs took the majority catchment area (389,528.5321sqm.), taking 89%, followed by grass thatched roofs (35,755.1912sqm), taking 8%, while the tiled roofs were least with 13015.3281sqm occupying only 3% of the total digitized roof area.

This is illustrated in Figure 4.12.

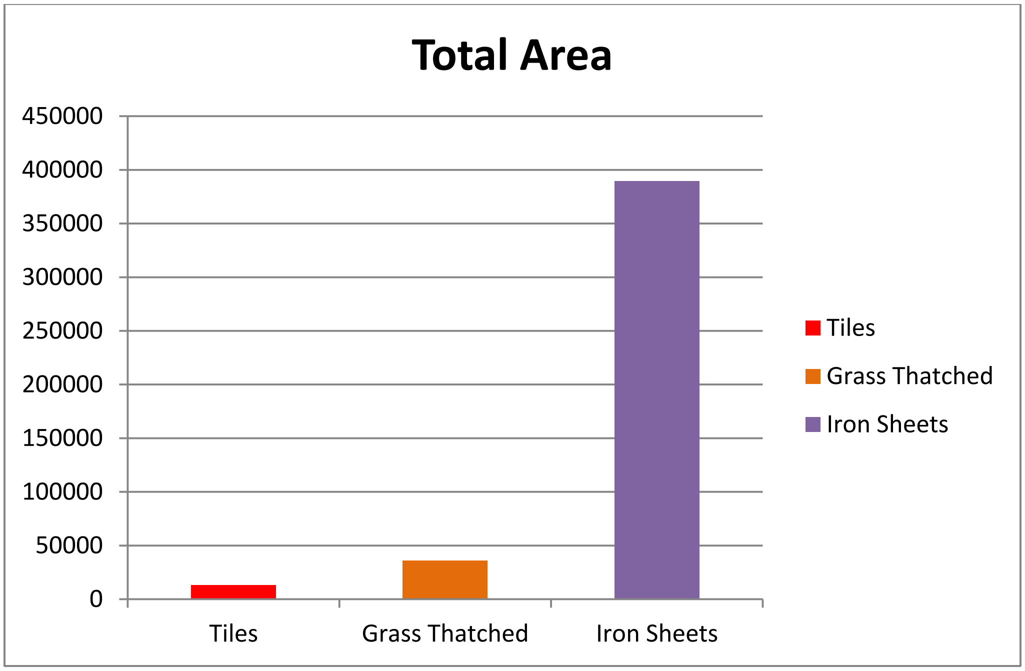

Figure 4.12: Total area for the different rooftops

From the results, it is evident that catchment area is a very critical factor in determining the RWH potential. This is because despite the fact that tiled roofs had a higher runoff coefficient (0.6) compared to grass thatched roof with only 0.2, the latter still ranked higher in area than the tiled roofs. This is mainly because the grass thatched roofs were more in number hence exhibiting a larger roof area (35,755sqm) than the tiled roofs (13,015sqm).

4.2.5 Verification of roof area

From the results in table 4.3, it is clear that there are discrepancies between the two roof areas i.e, the ground truth and the one computed in the software environment. This is subject to further research and should be investigated to unveil the underlying reason for the glaring differences,

4.2.6 Potentials for different roof types

Analysis results reveal that the RWH potential for iron sheet roofs is highest with 562,869 m^3 while those of the grass thatched is 13,273 m^3 and tiled roofs has a potential of 12,157 m^3 .This is mainly because as much as the tiles have a runoff coefficient of 0.6, they were few in numbers hence the performing dismally in the analysis compared to the grass thatched roofs.

Out of a total of the digitized 8, 024 rooftops, iron sheets took up 96% indicating high potential, while tiled and grass thatched roofs each had 2%, an indication of poor potentials respectively.

The above results are illustrated in Figure 4.13.

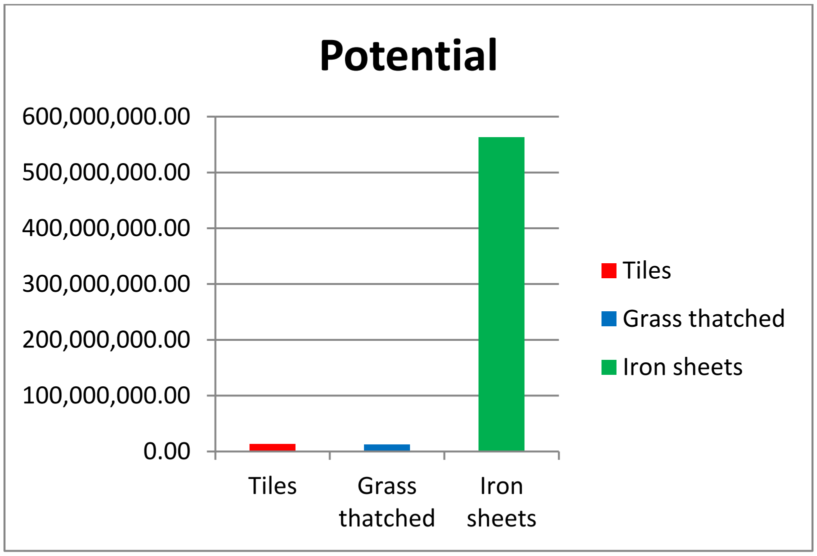

Figure 4.13: Potentials of different rooftops

Summary of the final potential yields are summarized in table 4.5.

Table 4.5: Summary of final results

	Runoff Coefficient	**Estimated Yield (m^3)**	**Percentage Yield**	**Coverage (sqm)**
Tiles	0.6	13,276	2%	13,015
Grass thatched	0.2	12,157	2%	35,755
Iron sheets	0.85	562,869	96%	389,529
Total Yield		**588,301**		

4.2.7 Correlation between catchment areas and RWH potential

By using Geostatistical analyst tool and Inverse Distance Weighting (IDW) method to generate a surface for the study area, the study revealed that areas with high densities (showing in red colour on the map) correspond to the areas with high RWH potentials. This is illustrated in Figure 4.14.

Thus, there is a high correlation between average areas of the roof tops and RWH potential. This also corresponds to the areas where runoff coefficient is high, giving an indication that iron sheet roofs with a runoff coefficient of 0.85 have high RWH potential compared to the tiled and grass thatched roofs with runoff coefficient of 0.6 and 0.2 respectively.

Rooftops with large catchment areas within the study area are mainly educational and health institutions. This is an indication that such institutions could be sensitized and/ or assisted to install RWH systems to save on water costs.

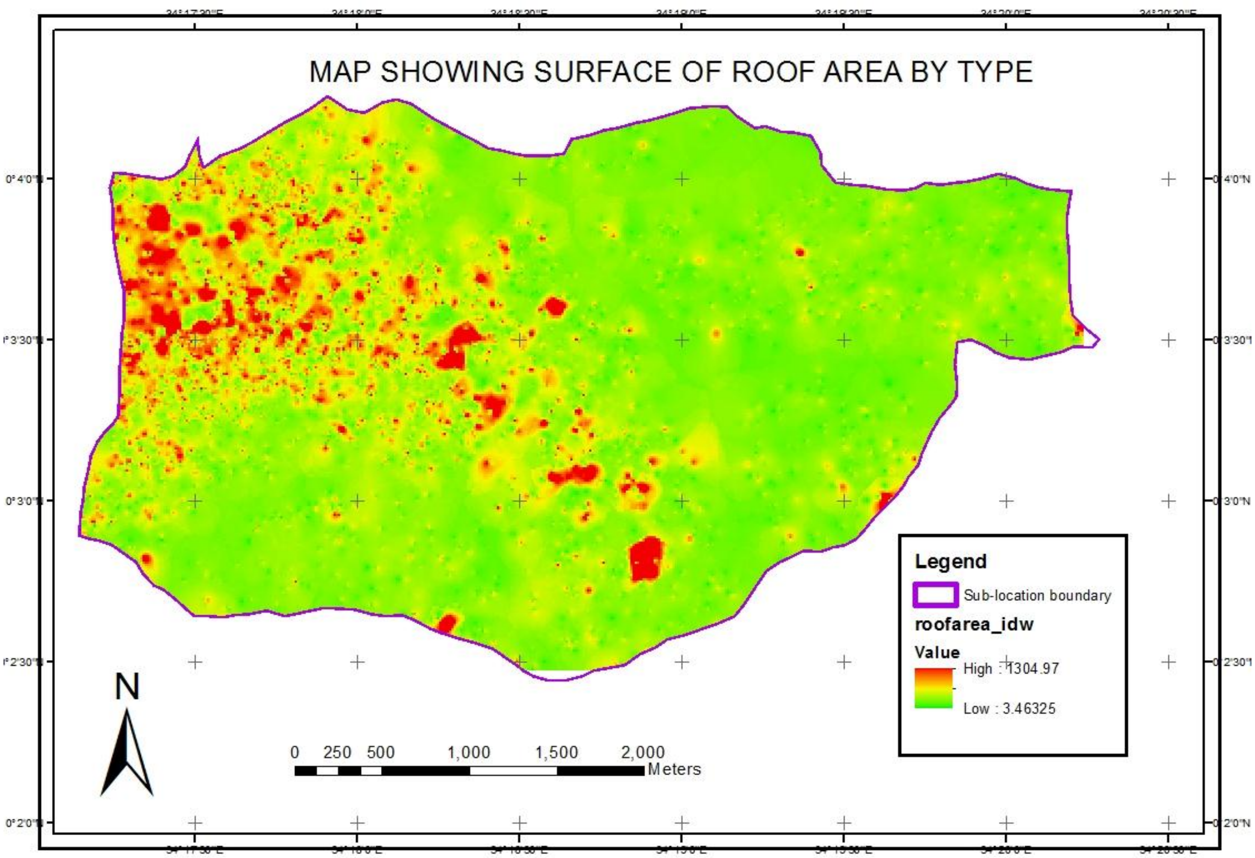

Figure 4.14: Geostatistical analysis of roof area by type

4.2.8 Potential Yield versus Demand

Per capita water demand and availability were computed using the information obtained from the field using the questionnaires and RWH yields. This was necessary in order to assess the adequacy of water in the study area. The computation was done based on the following assumptions:

Total population = 14,000 persons (2009 census)

Daily minimum water requirement per person (in rural areas) = 20 litres (WRMA)

Water requirement for the population per day (Wd) = (20 x 14 000) = 280,000 liters = 280 m^3.

Average water yields for each borehole per day = 4 m^3 = 4,000 litres

Number of water points (bore holes) = 5

Water availability (Wa) = 5 x 4,000 = 20,000 litres

Per capita water availability = (4 x 5 ÷ 14,000) = 1.4286 litres (0.0014286 m^3).

Potential of RWH for the study area = 588,301 m^3 per year (Pt) (Table 4.5)

Assuming that one year = 366 days (Dy), water demand per day is given by equation [5]

$$\frac{Pt}{Dy} = \frac{588{,}301{,}000}{366} = 1{,}607{,}379.781\ litres\ per\ day \qquad [5]$$

Water surplus (Ws) = RWH potential (Pt) + yield from boreholes (Wa) – daily water requirements (Wd)

$$Ws = Pt + Wa - Wd \qquad [6]$$

Ws = (1,607,380 – 280,000) = 1,327,380 litres per year

From the above computations, it is clear that the Per capita water availability is 1.4286 litres which is about 18.57 litres (20 – 1.4286) which is below the daily water requirement per person hence very much inadequate. The results from existing boreholes with water demand per capita indicate that there is serious need to explore other alternative water sources. From the study, the potential of RWH is 588,301 m^3 which gives a water surplus of 1,327,380 litres per year and this can comfortably satisfy the water demand as well as be put to other uses.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objectives of this study were:

- To identify available water points in the study area
- To assess and map the spatial distribution of the rooftop catchments for rainwater harvesting
- To develop a model for use in estimating rooftop rainwater potential
- To prepare rainwater harvesting potential maps for the study area

These have been carried out, and it is concluded that:

- Karapul sub-location in Siaya County has a vast and untapped potential for rainwater harvesting.
- Rainwater harvesting will improve water supply, food production, and ultimately food security.
- Water insecure households or individuals in Karapul Sub-location will benefit the most from rainwater harvesting systems.
- Places where per capita is high are likely to adopt the RWH to reduce the cost of water.
- Since rainwater harvesting leads to water supply which leads to food security. This will greatly contribute to income generation.
- Rainwater generally meets drinking water quality standards, if system is well-designed and maintained.

In this study Geospatial technology has successfully been used to determine rainwater potential for use in rural communities. It has also revealed the inadequacy in the existing water sources.

Geospatial technologies offer viable tools that can be used to integrate scientific information that could readily be used to identify areas that stand to benefit from specific rainwater harvesting technologies.

The outcomes of this study could assist water authorities and building designers to set broad policies for future rainwater development and to integrate DRWH systems with existing water supply systems to foster sustainable development.

5.2 Recommendations

From the study, it is recommended that:

- Knowledge of Python and MS Excel are necessary to facilitate the automation of data processes particularly where large statistical data are involved. Processes performed on rainfall data such as resampling, clipping, summation, monthly and annual averaging could not be sustained by the ordinary tools in the ArcGIS software environment.
- A special software or code to enable automating of rooftop digitization, especially where many rooftops are involved, should be explored.
- The residents for Karapul sub-location should be sensitized to embrace RWH as an alternative to fresh water for domestic use.
- Funding for such projects is highly recommended.

It is also recommended that for further study, the following should be considered:

- All the existing wells should be officially mapped by the responsible authority to avoid information gaps.
- The use of existing wells to act as storage for rainwater should be explored.
- Geological studies to investigate the reason for drying wells and the fluctuating water struck levels.
- A model for calculating tank sizes should be developed and used to assist the residents who will adopt the RWH as an alternative water source.
- The discrepancies in the footprint areas cited in Table 4.3 could be further investigated.
- Roofing materials and roof conditions should be taken into consideration and health expert advice sought to enhance water quality and also to improve on the results.

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APPENDICES

Appendix 1

Questionnaire for Rainwater Harvesting System

Homestead/Sample Number…………………………….

Contact Person (Respondent)…………………………….

1. Current source of water…………………………………………………………………….

2. Details of water demand:

   Average occupancy (persons) ☐

   Average consumption (Litres/day) ☐

3. Rainwater Harvesting

   Existing RWH system ☐

   Size of tank ☐

4. Why do you have a rainwater harvesting system?..

5. What do you use the water for?...

6. Do you think installing a system which could save water by collecting rainwater and re-using it to drink, cook, flush toilets, water gardens and water animals, would be a good thing?

   Yes ☐

   No ☐

7. What reasons would make you most likely to install a rainwater harvesting system?

   ………………………………………………………………………………………………..

Thank you for completing this survey. It will only be used for the purposes of research for this academic research. Your details are completely confidential and will not be used for any other purpose.

Appendix 2

Field Observation Sheet for rainwater harvesting system

(*Tick as appropriate)*

Homestead/Sample Number……………………………………….

Contact Person (Respondent)…………………………………..

Building Type

Single family home ☐ Multiple families home ☐

Residential apartment/ block ☐ Commercial block ☐

Hotel ☐ School/University ☐

Office Building ☐ Leisure facility ☐

Other…………………………………………………………………………………………….

Roof type/material

Flat concrete roof ☐ Pitched roof with tiles ☐

Pitched roof with profiled metal sheeting ☐ Grass thatched ☐

Others…………………………………………………………………………………………

Condition of the roof

Good ☐ Fair ☐ Poor ☐

Rainwater Harvesting

Area of roof to be collected from (M^2) ☐ Size of tank ☐

Tank Location:

Indoor ☐ Underground ☐ Above ground ☐ Outdoor ☐

Others…………………………………………………………………………………………