SUSTAINABLE WATER STORAGE INFRASTRUCTURE FOR IRRIGATED AGRICULTURE: A CASE OF GATUNDU SUB-COUNTIES, KIAMBU COUNTY

BY:

NZAU PAUL MUTISO

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree in any other university.

PAUL NZAU

DECLARATION BY THE SUPERVISORS

This thesis has been done under my supervision and has been submitted for examination with my approval as University Supervisor:

DR. SILAS MUKETHA   MR. MURIMI

DEDICATION

This research project is dedicated to my dear wife and two sons.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Water stands as the ultimate limiting factor to Kenyans. Besides, it stands as the primary force that exacerbates soils degradations and significant land degradation. Drought and prolonged periods of dryness are the most dangerous natural risks that cause moisture levels to go below average. Irrigated agriculture is vital for producing food for dry areas classified as arid and semi-arid areas, as it bridges agricultural productions discrepancies emanating from rainfall deficiencies. Approximately one-sixth of land available for agriculture globally is under irrigation and acts as a food reservoir for more than a third of food produced globally. However, the ever-burgeoning population's demand for food, which gives more necessity for agricultural productions, is obtained from agricultural production. As the challenge of water scarcity for irrigation continues to elevate, the cost necessity for developing essential water resources consequentially increases; this becomes a limiting factor for enhancing this fundamental option for irrigated agriculture.

The rationale of this study is to explore the sustainability of water storage facilities for irrigated agriculture in the research area. The study utilized both secondary and primary data collection methods. It also entailed GIS analysis of existing data from satellite and aerial imagery. The fieldwork progressed from ward to ward in both sub-counties. The tools used in the field included cameras, household questionnaires, interview schedules, and observation checklists. The data collection methods entailed desktop review, questionnaire administration, field observations, and a face-to-face interview.

The study discovered that the primary water source for residents is piping. There are inadequate water storage facilities in Gatundu North and south Sub counties, and irrigated agriculture is rarely practiced due to over-reliance on rain-fed agriculture, land fragmentation, water shortage. Through remote sensing and GIS mapping, the study identifies suitable locations for dams and water pans. The primary strategy towards appropriate water storage structures was constructing dams and water pans at strategic locations. The study concludes that there is a need to establish sustainable water storage solutions in the study area to enhance irrigated agriculture.

The study recommends both short and long-term strategies towards achieving sustainable water storage structures for irrigated agriculture. The short-term strategies include preparation of land use zones, feasibility studies for identification of suitable locations, creation of awareness on the need for sustainable water storage structures for irrigated agriculture. The long-term strategies are

developing sustainable water storage structures, expanding irrigated agriculture to rain fed agricultural areas, and introducing irrigation scheduling in the area. These strategies will enhance the sustainability of the water storage structures, thus enabling irrigated agriculture.

INTRODUCTION

1.1 Background to the study

Developing countries aim to achieve food security by reaching and maintaining sustainable target levels in the production of staple food, for instance, a level of 70% of the national food need; besides, they also seek to ensure surplus production of cash crops for exportation. Currently, developing nations cannot stand the chance of neglecting agricultural food production, which acts as the backbone for holding the country's economy. Irrigation water supplies that are more stable will ensure farmers produce higher yields of high-value crops, boosting economic development. As a result, the population migration to already overcrowded cities should be slowed. Agriculture should yield more with a reduced part of the national water allocation, which is commonly understood.

Many countries' average production of water is now much under their potential. Technical, institutional, economic, financial, and social constraints exist in the sector. Free market economic solutions on institutional and regulatory changes brought some success, particularly in Turkey and Mexico, classified as middle-income developing countries by the World Bank. However, notwithstanding isolated accomplishments, significant progress remains to be made elsewhere. (Firoozabadi & Farahani, 2019). The questions stand: how can farmers use irrigated agriculture to enhance safe and sustainable production while utilizing the scarce water resource available in the country. Nations use research to solve problems, and it is a widely acknowledged approach in our economic and political lives. (Sanmuganathan, 1987)

In Kenya, water is the most significant constraint to land productivity. With the majority of rivers seasonal, water availability is often sporadic and limited. Scarcity leads to competitiveness and conflict between people. As a result, the task is to devise and implement effective techniques for managing and utilizing the available water. (Ngigi et al., 2007).

With East Africa's most diverse and largest economy, Kenya's economy relies heavily on agriculture with food and nutritional security as the first of the government's big four agendas. While agriculture remains the country's backbone, food production has been declining resulting to food imports. Most farmers are small scale cultivating less than 5 acres using essential farming technologies and methods and depend heavily on rain. The 2017 drought exposed that reliance on rein-fed agriculture exposes the farmers' livelihoods, national nutrition, and state resources to natural hazards. As grain production decreases, the production of horticultural crops has consistently remained a crucial source of foreign exchange earnings. It is because horticulture and floriculture employ irrigation techniques while food crops mainly remain rain-fed. It will be necessary to reduce dependency on rain-fed agriculture to achieve food security. To that end, the state encourages the continuation of irrigation projects started under previous administrations and also the adoption of initiatives like the Agricultural Sector Development Strategy (ASDS), which aims to boost smallholder yields by improving both access to water and the quality of inputs like hybrid seeds, fertilizers, and pesticides.

In 2018 the ministry of agriculture and technology announced plans to build 5,000 water pans for households in the country to collect surface run-off water. The programme is aimed at transforming Kenya from dependence on rain-fed agriculture production to irrigated agriculture. Research by FAO shows that only 2% of the total land under cultivation in sub-Saharan Africa is under modern irrigation systems. In Kenya, four percent of total productive land is under irrigation, and it accounts for 18% of entire agricultural production and 3% of the nation's GDP.

There is an urgent need for adaptive and innovative solutions that will elevate crop production levels, which should emanate from prudent research. Adoption of advanced irrigations strategies will prospectively increase the total yield of water consumed, land utilized, and unit of capital employed. Besides, coherent planning approaches will ensure coordination of development objectives of ever competing consumers of water resources. It is the basis for the World Water Councils Vision that seeks to develop a blueprint for managing and using water resources prospectively to the year 2025. With only 20% of Kenya's land arable and 35% of Kenya's population lives in the ASAL zones, Kenya is classed as a water-scarce nation.

Kiambu County is known as Nairobi's food basket. Agriculture is the county's most important economic activity, accounting for 17.4 percent of the country's total income. It is the most critical sub-sector in terms of employment and comprehensive contribution to the people's socioeconomic well-being. The county's primary revenue crops are coffee and tea. Maize, Irish potatoes, beans, and pineapples are the principal food crops farmed in the county. Even though maize is the primary food, the county lacks sufficient maize and beans to support the population, necessitating importing cereals and grains from neighboring counties (Kiambu CIDP 2018-2022).

Irrigated agriculture cannot exist without access to natural resources such as water. (Christine Mutua & Mark Boitt, 2017). Rain-fed agriculture is the most common farming style in Gatundu, yet it is unreliable owing to climate volatility. During the rainy season, rapid runoff frequently results in a large percentage of the water being wasted or even becoming destructive. An increase in population and climate-induced hydrological extremes place a higher demand for water services. Over-exploitation of water catchment areas has also worsened the situation. Environmental degradation increases the surface water runoff during precipitation leading to less water retention. Reduced rainfall volumes coupled with an increase in global temperatures and higher evaporation rates make rain-fed agriculture unrealistic.

As a result of these considerations, better water storage will play a critical role in ensuring Kenya's water security in the future. Artificial water storage plays an essential role in both emerging and developed economies and will continue to do so. It’s, therefore, necessary for reservoirs to be constructed to allow an off-season supply of water for both domestic and agricultural use. Harvesting rainwater whenever it falls presents opportunities to address water scarcity through water storage in small dams, pans, and other water conservation structures. (Gok, 2015). Small dams, including other water storage facilities, are important water sources for residential, livestock, irrigation, and different commercial needs.

Table 1: Kiambu county food crop production trend

Food crop	2013		2014		2015		2016	
	HA	Production (tons)	HA	Production (tons)	HA	Production (Tons)	HA	Production (tons)
Irish Potatoes	19,057	57,015	18,162	181,620	18,504	166,536	9,198	101,178
Maize	32,330	58,956	34,453	62,015	38,128	68,630	45,982	82,768
Beans	22,233	43,947	26,401	29,041	26,793	29,472	17,428	19,171
Bananas	4,317	92,041	4,279	149,765	3,457	120,995	3,515	123,025

Source Kiambu county 2018-2022 CIDP

Table 2: Kiambu county horticulture crop production trend

Horticulture crop	2013		2014		2015		2016	
	HA	Production (Tons)	HA	Production (Tons)	HA	Production (Tons)	HA	Production (Tons)
Cabbages	2,285.70	42,203.00	2,287.88	53,874.00	1,682.00	17,154.10	1,097.20	23,735.70
Carrots	766.40	12,092.00	897.30	15,331.50	813.80	15,335.00	509.70	11,349.50
Kales	5,699.00	158,955.00	3,803.05	111,397.70	3,668.20	113,638.50	2,240.70	66,941.20
Spinach	1,634.50	34,599.00	1,208.30	26,078.65	856.90	22,419.70	1,481.00	14,167.50

Source Kiambu county 2018-2022 CIDP

Table 3: Kiambu county Industrial crop production trend

Industrial crops	2013		2014		2015		2016	
	Area (HA)	Quantity (Tons)	HA	Quantity (Tons)	HA	Quantity (Tons)	HA	Quantity (Tons)
Coffee	2,286	42,203	10,800	9,658	10,288	9,332	9,800	12,623
Tea	766	12,092	16,795	442,226	16,940	217,477	17,840	229,031
Pyrethrum	5,699	158,955	5	1	4	1	3	1
Macadamia	1,635	34,599	811	5,677	818	5,726	809	5,663

Source Kiambu county 2018-2022 CIDP

The tables show that crop production in Kiambu County has been declining over the years, thus needing intervention. Gatundu's favorable climate and proximity to Nairobi and Thika urban areas present a unique advantage of providing them with food crops. Gatundu's proximity to JKIA also affords it to sell horticulture products to the Kenyan export market.

Farmers in the area confront reduced annual average rainfall and uneven rainfall distribution. In policy documents, rainwater harvesting is not fully addressed. Experts will be needed to help the government adopt Rain Water Harvesting into its programs and projects. According to KNBS, the population growth rate in Kenya in 2010 was 2.7%, and there was an increase factor of 2.5% over the last three decades. It has led to a significant increase in the Kenyan population. Feeding this population has posed a severe challenge. It is mainly caused due to lack of water management structures that can help realize optimal water usage. During the rainy season, heavy downpour usually causes flooding and water scarcity to sustain agricultural activities in the dry season. It leads to losses during heavy rainfall, and water is also wasted in large quantities. By designing earth dams and water pans, excess water will be stored and used in the dry season to sustain agricultural activities.

This research study will be of importance to the National Irrigation Board as well as the central government and the county government of Kiambu in proving information that, if acted upon, will improve the livelihoods of the people of Gatundu and the economy of Kiambu county while providing food security to the urban populations of Thika and Nairobi and also foreign exchange to Kenya. To enhance water availability for irrigated agriculture, inhabitants of Gatundu have to construct and develop techniques for harvesting rainwater.

1.2 Statement of the problem

Of the underlying challenges facing arid and semiarid areas are rainfall deficiencies and unstable agricultural production. This challenge makes the need for irrigation inescapable. More than a third of food production is currently provided by the land under irrigation practiced on one-sixth of total land globally under agricultural production. Demand for food globally continues to increase steadily as the population burgeons, hence an increasing need for farming productions to meet food demand; a large proportion of these productions emanated from irrigated areas. Consequentially there is much pressure on water resources for irrigation, making the anticipated cost of developing water resources relatively high, hence enhancing irrigated agriculture becomes a challenge. Engineering programs have been launched globally to increase water available for irrigation and other essential urban land use. Currently, nearly 80% of fresh water available is consumed in agricultural land use and food production. Besides, the demand for good quality water is anticipated to increase tremendously in the future.

Though numerous researches have been carried on rainwater harvesting and irrigation, generally there is no specific study on the suitability of locations for water storage structures for irrigated agriculture in Gatundu Sub counties. Therefore, this study is necessary as it will help get suitable sites for water storage structures for irrigated agriculture.

1.3 Research questions

The principal research question is: are there sustainable water storage infrastructures for irrigated agriculture in the study area? The specific research questions for this study are:

1) Are there adequate water storage facilities to ensure sustainable irrigated agriculture in the research area?
2) What factors affect the development of water storage facilities for irrigated agriculture in the research area?
3) Are there suitable locations for the development of water storage facilities for irrigated agriculture in the research area?
4) What strategies can be put in place to ensure adequate water storage facilities for irrigated agriculture?

1.4 Purpose of the Study

The aim is to investigate the sustainability of water storage facilities for irrigated agriculture.

1.5 Research objectives

1) To assess the adequacy of existing water storage facilities to ensure sustainable irrigated agriculture in the research area
2) To examine factors that affect the development of water storage facilities for irrigated agriculture in the research area
3) To evaluate the suitability of locations for water storage facilities for irrigated agriculture in the research area
4) To propose strategies that can be put in place to ensure adequate water storage facilities for irrigated agriculture

1.6 Assumptions of the Study

1) There are no adequate water storage facilities to ensure sustainable irrigated agriculture in the study area
2) There are suitable locations for water storage facilities for irrigated agriculture in the study area

1.7 Justification of the Study

Though numerous researches have been carried on rainwater harvesting and irrigation, there is no specific study on the suitability of locations for water storage structures for irrigated agriculture in Gatundu Sub-counties. The sudy is significant as it provides sustainable approaches to locating suitable locations for water structures. The study will contribute to policy formulation and professional practice by pkanners, surveyors and water engineers.

1.8 Scope of the study

The geographical scope of the study entails both Gatundu North and Gatundu South sub-counties, Kiambu County. The theoretical scope entails spatial, social, economic and environmental assessment of various locations to establish their suitability for water storage facilities for irrigated agricultural purposes only.

1.9 Operational Definition of Terms

1. **A pan –** A water-retaining structure created by excavation or a natural depression. Water is held at a lower level than the normal ground level.
2. **Dam** – This is a structure that is built across a waterway to contain and control the flow of water. Dams come in a variety of sizes, from modest earthen embankments used for farming to large concrete constructions used for water supply, hydropower, and irrigation." (International commission on large dams, 2000)
3. **Large dam** - These range in height from 5 to 15 meters
4. **Small dam** – These range in height of 2 to 5m (Mati, 2017).
5. **Roof Catchment** – It is a rainwater collected from a roof then focused runoff into a storage container.
6. **Rock Catchment** – It is a rainwater collected on a rock outcrop then focused into a container for storage.
7. **Agriculture** – Cultivation of land and use of land (whether or not covered by water) for food production, including crops and horticultural practising with the interpretation of the Crops Act, reproduction of plants and aquatic animals, sea ranching as well as fish keeping in the waters according to the Fisheries Act (GoK, 2013).

8 **Irrigated Agriculture** – The administration of regulated quantities of water to plants at necessary intervals. The irrigated agriculture sector is dominated by the cultivation of fruits and vegetables. To be profitable, the irrigated agriculture business needs water on demand. This water is usually provided as groundwater or surface water with a permit.

9 **Overhead Irrigation** – Irrigation in which water is distributed to the area above and around the plants in the hopes that it will reach the plants." While some water will evaporate during the process, causing some cooling, much will reach the root zone.

10 **Furrow –** Irrigation technique in which water passes across the field in narrow channels between each group of rows moistening the soil. The water is absorbed by the bottom and sides of the furrow, which is then absorbed by the crop roots.

11 **Drip Irrigation** – This method introduces wets the soil at very reduced quantities using emitters on plastic pipes. Only the soil next to the roots is soaked when water is introduced.

12 **Sustainable water storage**: These are water storage structures that meet current irrigation needs while without jeopardizing future irrigation needs. The suitability of such will be assessed in terms of potential, location vs. intended irrigation area, allocation, number, impact on people impacted by the projects, value of land, current land use, physiographic characteristics, soils and geology, and water volume.

1.10 Organization of the Report

Chapter 1: Introduction- It gives the background information, problem statement and purpose of the study. In addition, it offers the objectives of the research, the research questions and the assumptions of the study. This chapter also includes justifying the study, scope of work, and operational definition of terms.

Chapter 2: Literature Review- Elaborates on the adequacy of water storage structures to ensure sustainable irrigated agriculture, factors affecting the development of water storage structures for irrigated agriculture, and the criteria for selecting their suitable locations. In addition, it gives advanced strategies for ensuring adequate water storage facilities for irrigated agriculture. The chapter elaborates on best practices that have proven effective from the international context to the Kenyan scenario. Finally, the chapter reviews relevant policy and legal documents and the relevant institutions tasked with the implementation.

Chapter 3: Methodology- This chapter explains the techniques used by the researcher to achieve the study's goals. These factors include the research design, data collection methodologies, research instrument reliability and validity, data gathering procedures, and data analysis techniques.

Chapter 4: Study Area -The chapter outlines the location of the study area. It further discusses the physiographic characteristics, population, demography, human settlements, and housing. Finally, it looks at the physical and social infrastructure in the research area.

Chapter 5: Findings- Provides the implications of the study by bringing out the significant findings identified.

Chapter 6: Conclusion and Recommendations- Provides conclusion to the study and recommendations on how to enhance sustainable water storage infrastructure for irrigated agriculture. The chapter also presents propositions for further research.

CHAPTER 2. LITERATURE REVIEW

2.1 Overview

This chapter elaborates on the adequacy of water storage structures to ensure sustainable irrigated agriculture, factors affecting the development of water storage structures for irrigated agriculture, criteria for selecting suitable locations, and the strategies to provide adequate water storage facilities for irrigated agriculture. It will strive to follow best practices that have proven effective from the international context to the Kenyan scenario. The chapter will also look at the regional context to compare the suitability of water storage structures for irrigated agriculture in the Gatundu sub-counties with other successful interventions. Finally, the chapter will review relevant policy and legal documents and the relevant institutions tasked with implementing them.

2.2 Adequacy of water storage structures to ensure sustainable irrigated agriculture

Water harvesting envisions the process for collecting runoff water for future use. This technique has been adopted by farmers globally from time immemorial; they have used it to increase crop yields and mitigate soil erosion. FAO (2017) envisaged that comprehensive water harvesting techniques are available and applicable in various geographical conditions. Water usage is equal to or surpasses available renewable water supplies in many river basins worldwide, resulting in their protection. Certain countries are considering long-distance water transfers as a solution to ease local water shortages for a variety of reasons while simultaneously attempting to enhance water-use efficiencies and minimize consumption.

Many emerging African nations and Asia, on the other hand, are installing water storage at an unsatisfactory rate to face future challenges of climate change and rising water demand from different industries. A lack of water storage systems could result in huge economic losses due to flooding and drought, as well as considerable healthcare costs resulting from contaminated water. According to Rose et al. (2008), irrigated zones depending on potable water are expected to occupy over 40% of the global irrigation area. This increased demand for potable water has aided in intensifying agricultural production in areas where surface irrigation is already in place and on land where there would otherwise be no supply. In both cases, the strain on aquifers has increased to the point that many significant groundwater systems have been depleted, and the concomitant loss of water quality is worsening.

Furthermore, potable water extraction with motorized pumps consumes a lot of costly energy for farmers and contributes to climate change if fossil fuels are used. However, developing more storage capacities can be adopted as strategies for mitigating ground water overexploitation that results in the degradation of this resource and the burden of underneath aquifers. “Small and big dams, as well as their related reservoirs, can store water, generate hydropower, and give some protection from extreme precipitation events. Dams that are well-designed make water available when it would otherwise be scarce. Dams and huge reservoirs can negatively affect human populations, requiring relocation and causing a social disturbance. Dams and reservoirs may have severe ecological repercussions such as changes in river networks and flow regulation; water kept in reservoirs may evaporate faster than free-flowing water. Dam and reservoir design features should be carefully considered in order to avoid negative impacts and enhance benefits” (Richter et al., 2007).

Using a systematic planning approach that will ensure integration of storage structures, water harvesting and landscapes will be instrumental in mitigating drought, reducing vulnerability, and rainfall variation. Artificial water storages facilities have an impact on the ecology and the environment. Retrogressive planning practices and inadequate assessment of social and ecological impacts results outweighing the possible benefits obtained from these water schemes. Their negative repercussions may offset water storage projects' development benefits and services.

2.3 Factors affecting the development of water storage structures for irrigated agriculture

2.3.1 Low Water Use Efficiency

Water efficiency is low in agricultural production. According to Cooper & Gregory (1987), 40 to 60% of the water is utilized successfully by the plant; the rest is lost through runoff, percolation, or evaporation. Some of it may be recoverable, although this will require additional costs. The main reason for this s poor irrigation water management. Farmers confront recurring water shortages due to insufficient and unpredictable water delivery in the primary system, resulting in lower harvests and profits and considerably lesser irrigated fields than initially intended. Poor field planning and management results in increased water losses and lower yields. Ineffective water use is linked to various environmental issues, including waterlogging, agrochemical leaching and subsequent pollution of groundwater, including salinization caused by incorrect applications.

2.3.2 Unreliable Rainfall

Irrigation storage allows farmers to save water when it is plentiful and release it in short supply (FAO, 2017). The potential benefits of irrigation storage are contingent on several interconnected components" (Granit, 2012). The following are a few of the many considerations that should be considered:

- Land characteristics (fertility, Soil infiltration rate, depth of soil and water holding capacity)
- Rainfall amounts and intensities plus the rate of evapotranspiration
- Population density, labor, material costs, and water resource laws are all socioeconomic issues to consider.
- Hydrogeology of the site

i. Evaporation Losses

It's also important to calculate the amount of water that will be lost due to evaporation at the water's surface. It is possible to calculate the maximum daily evaporation loss using Equation.

$$Evol = Amax \times Eo \times 10$$

Where:

Evol = Maximum evaporative losses [m3/day]

Amax = Maximum surface area [ha]

Eo = Open water evaporation [mm/day]

ii. Seepage Losses

Seepage losses occur in the reservoir area's floor and along the embankment. A reasonable estimation of seepage losses is required during the planning stage (Guerra, 1990). Hydraulic conductivity values for various soil conditions are listed in Table 3-12. Equation 2-1, can be used to estimate maximum daily seepage losses (Kinzli et al., 2010).

Table 4: Hydraulic Conductivity

Water Depth (m)	Hydraulic Conductivity (m/s)	
	Lower Limit	Upper Limit
Permeable	2×10^{-7}	2×10^{-1}
Semi-permeable	1×10^{-11}	1×10^{-5}
Impermeable	1×10^{-11}	5×10^{-7}

Equation 2-1: $Svol = K \times Amax \times 86400$

Where:

Svol = Maximum losses [m3/day]

K = Conductivity [m/s]

Amax = Maximum surface area [ha].

2.3.3 Land Characteristics

When planning for an irrigation project establishing the land capability for crop productions that gives investment return in the irrigations works is vital. The land ought to be irrigable and arable by displaying the attributes listed below: -

1) Free of black alkali and salts that aren't easily removed through leaching
2) To avoid excessive loss through percolation below the root zone, the infiltration rate should be kept to a minimum.
3) High water holding capacity
4) Readily penetrable by water
5) Adequate in plant Nutrients

2.4 Criteria for selecting suitable locations for water storage structures for irrigated agriculture

For the best location for irrigated agriculture water storage structures, the valley allows for building a straight embankment dam. These kinds of places are typically a deep gorge at valley cross-sections. The foundation should be watertight from seepage and one where construction will be simple and a stable structure can be guaranteed. As a result, these storage structures should be placed in places that meet the following criteria: Surface runoff from precipitation on the catchment region and other runoff flows should be able to fill the structure minimum once a year.

The storage structure must fill with runoff or store enough water to fill the structure between runoff occurrences. The reservoir must have enough depth and volume to last through prolonged droughts. A topographical survey is typically conducted to evaluate gradient, storage structure breadth and height, calculate reservoir volume, estimate quantities, produce relevant licensing documents, and offer construction specifics.

The site should be located in a valley with a high depth to surface area ratio to minimize evaporation losses. Where steep slopes border, the valley is a straightforward approach to identify such a site. For example, to increase capacity, a dam can be built directly below the confluence of two streams. To eliminate cracks, loose soil, or other flaws that could cause seepage or failure, thorough site studies are required, particularly for the structure's foundation. The foundation must be solid impermeable rock with no soil pockets or fracture lines, and rock surfaces should not be broken or split to reduce leakage losses.

There should be no anthills, pits, sewage outflows, or salty or calcareous soils in the catchment region. It is necessary to examine the downstream hazard potential, and activities in the watershed that may impact the quality or quantity of flow are also evaluated.

The location must be convenient for the target users. The location of water storage buildings considers cultural and socioeconomic factors to serve a large population while respecting recipient communities' laws, customs, and social systems. Local communities should be supportive of the water storage construction whenever possible" (Jamali et. al., 2014).

Other factors to consider include:

Rainfall Data

To design a water storage structure, data for rainfall is v ital, preferably a minimum of 10 years. Reliable data gives an accurate design. Hydrological research and agricultural centers, meteorological departments, and airports can be good sources for data for defined areas. A simple technique for determining the required volume for storage and size for the water storage facility is elaborated below;

With a daily water usage of *20 l/c*d*, which is the industry standard,

the *demand for water becomes = 20 x n x 365 l/year*, Where *n=number of individuals*.

The amount of rainwater that may be collected is determined by the yearly rainfall, runoff coefficient and roof surface.

= *rainfall (mm/year) x area (m2) x runoff coefficient.*

The surface runoff process

This process is initiated by the first water drop that comes down as a rain fall. The first interceptions occur when the droplet interacts with vegetation like stems and leaves; this is termed as interception storage. This is followed by infiltration as the water touches the ground, this continues until a saturations level is reached where all air spaces in the soil has been filled by water after which more water results to consequential runoff as other ditches in the surface have been filled. The infiltration capacity of a particular soil type depends on the soil structure, soil texture, and the antecedent moisture content of the soil. Initially, dry soil has a higher infiltration capacity which drops as the rainfall increases. Runoff is therefore generated consequentially as rainfall intensity increases and when saturation capacity has been exceeded. This depends on the following factors:

i. ***Soil type*** – Porosity determines the water storage ability and impacts its resistance to water movement. This factor influences water's infiltration capacity. The porosity of different soil types varies. Loose, sandy soils have the largest infiltration capacity, whereas clay and loamy soils have significantly lower infiltration capabilities.

ii. ***Vegetation*** – Rain water intercepted and stored on foliage is determined by the plant type and the level of development. The impact of vegetation on the soil's infiltration capability is even more important. The soil is protected from the impact of raindrops by a high vegetation cover, which decreases the crusting effect. Furthermore, the root structure and organic compounds add soil porosity, permitting further percolation. Vegetation slows down surface runoff, especially on mild slopes, allowing water to penetrate and evaporate more slowly. Finally, an area extensively covered in vegetation permits lesser surface flow than bare soil.

iii. ***Slope and catchment size*** - According to (Sharma et al., 1986) there is a greater runoff in steep slopes than on the moderate ones. According to studies on experimental runoff plots. Furthermore, it was discovered that as the slope length increased, the amount of runoff reduced. This is due to reduced flow velocities leading to a longer concentration-time and exposure to infiltration and evaporation. Runoff effectiveness rises as the catchment size decreases, implying that the larger the catchment, the longer the duration of concentration and the lower the runoff effectiveness.

The amount of runoff in a specific catchment must be known when designing water collecting schemes. The volume of runoff is typically considered to be a ratio of the rainfall depth.

$$Runoff\ [mm] = K \times Rainfall\ depth\ [mm]$$

Where

K describes the percentage of runoff

2.5 Strategies to ensure adequate water storage facilities for irrigated agriculture

Rain is the primary water source in the hydrological cycle, while rivers, ground water, and lakes are all secondary sources. There has been a high reliance on supplementary water sources (CSE, India 2003). Rainwater harvesting (Worm & Hattum., 2006) is an ancient approach that has been used in regions of the world for over 4000 years, according to Worm & Hattum. Banana leaves have long been utilized as gutters, with the ability to collect up to 200 liters of water. Urban RWH has been on the increase in several parts of the world since the 1990s. Singapore, for example, which has limited land and water resources, has substantially invested in rainwater gathering. Water catchment areas cover about 48% of the land area (Appan, 1997).

2.5.1 Geographic Water Management Strategy

This is a GIS technique based on that contains three parts: data input, processing, and outputs, according to Unio., 2011. The first part of the system inputs the required. The processing part applies prescribed functions to grid cells and determines whether rainwater collection and storage methods are appropriate. The output component identifies places that are ideal for various rainwater gathering and storage systems.

At all levels, GIS techniques are being employed for natural resource planning and development. They've been used to examine a variety of water-related environmental issues, including soil erosion and land deterioration (Dhiman et al., 2002). Sharada, Kumar, and others (1993) investigated the use of GIS in complete catchments for location prioritizing in terms of soil conservation. The Soil Conservation Services-Curve Number (SCS-CN) approach has been accepeted and used (Das et al., 1996). Ross (1993) discovered that incorporating GIS into hydrologic modeling minimizes modeler subjectivity in parameter selection. It is critical in geographic water management to include the entire catchment as a geographical scope for water resource planning, development, and management. It is also proposed to use GIS tools to locate and analyze water harvesting and storage potentials. Rainwater harvesting systems have been in use for millennia, according to Mati (2007), and new ones are being created all the time. A simplified rooftop RWH system including transportation and storage structure is shown in Figure 1.

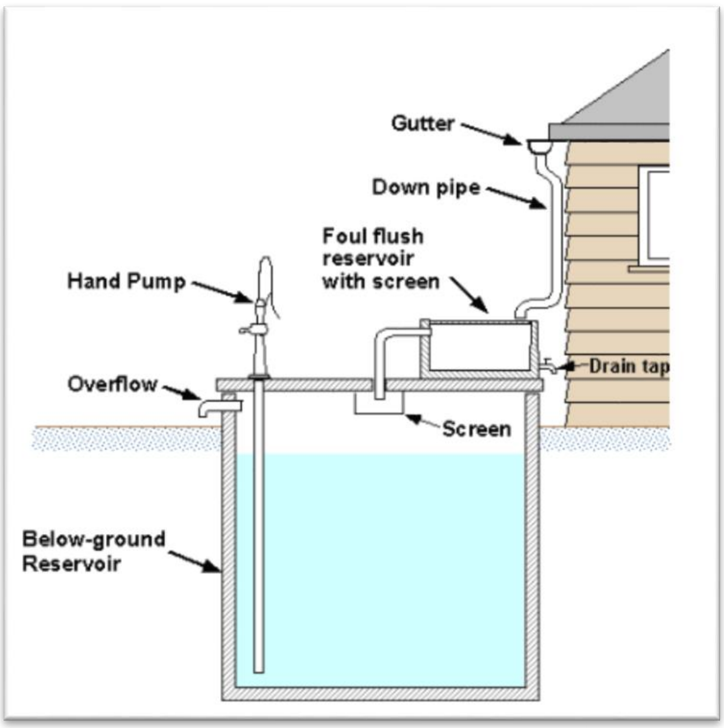


Figure 1: Rooftop rainwater harvesting system

2.5.2 Water storage Strategy

i. Storage tanks and cisterns

For a domestic RWH system water storage tank stands to be the greatest capital investment element. Water water tanks provide the best storage capacity while also being the most cost-effective. Cleaned areas of ground or rooftop act as a catchment area as depicted in China's courtyard collection system besides guttering can be locally manufactured or obtained at a lower price. Moreover cistern or a tank will be vital in areas where large water quantities are required.

Figure 2: Rainwater storage tank

Source: Mvua newsletter Dec 2015

ii. Creating Ponds & Water Pans

Pans are entirely reliant on surface runoff and do not get any groundwater. As a result, they are prone to water loss and are sometimes seasonal. The shape of a pan might be square, rectangular, or hemi-spherical. Water pans have a number of drawbacks, including small capacities, high siltation rates, water loss by seepage, and significant evaporation losses. On the other hand, Pans can be dug practically anywhere and lined with a variety of materials. Excavated ponds and pans are small reservoirs that are dug off-stream and have raised and compacted banks on all sides. The distinction is that pans depend surface runoff, whereas ponds are built on grounds with high water table. They are typically constructed near settlements and on grazing fields rather than farmlands. (Training Notes by Prof. Bancy Mati (JKUAT).

Figure 3: Water pan and pond

Source: Adopted from Prof. Bancy Mati Training Notes (JKUAT)

Figure 4: Water pan

Source: Training Notes by Prof. Bancy Mati (JKUAT

Because ponds recharge spontaneously, they have fewer seepage issues and are therefore favored over pans. The key constraint is the lack of a high-water-table site in dry areas where water is scarce." (Training Notes by Prof. Bancy Mati (JKUAT).

iii. Creation of small earth dams

Dams are classified according to their purpose, construction material, size, and shape. Earth dams, also known as earth-fill dams, use dirt with good ability to compact for constructing the embankment. Small earth dams are typically built to retain flow during the rainy season on a seasonal channel. An outlet features a stone apron and spillway to remove excess runoff, while the dam wall has a clay core. Small earth dams can offer enough water for irrigation and livestock watering operations. Small dams are used to channel irrigation water, hydropower creation, and also domestic use. They are at times used to channel water to a larger reservoir to boost its capacity (Nilsson & Berggren., 2000).

Figure 5: Illustration of a Small Dam

2.6 Previous Researches on Water Resources

(ECOTEC, 1991) A European Commission project on water research focused on 17 themes divided into four issues: water, exploitation, wastewater, and demand.

(GR, 1987) Over 70 people from various backgrounds attended a workshop on research requirements in third-world irrigation. There were more than 100 issues identified in water management, agriculture, design and planning, the environment, rehabilitation, institutions, socioeconomics, and performance evaluation. A total of 43 subjects were submitted for consideration. The requirement for authoritative information on system performance was prioritized.

(De Costa JR, 1992) River basin administration, environmental preservation, and improved irrigation technologies for small farmers; decision support systems; strategies for alleviating poverty and social inequity; alternative institutional arrangements for water management; effect of irrigation project on competing users; optimizing water allocations; M&E were among the 52 topics listed in nine categories.

(Feyen J, (1992)) A variety of topics were discussed, including irrigation performance evaluation, returns to irrigated/rainfed agriculture, yield response to water, farmers' organizations and participation, project management and organization, management structure and performance, and irrigation within a watershed.

(Commission of the European Communities, Review of Programmes, DGX11, Science, Research and Development, 1994) Focused on four areas: water and environment, particularly climate change; methods for conserving and enhancing water quality; waste: enhanced treatment methods, operating facilities and networks; and water analytical quality control.

Merrey et al., 1997 IWMI's present research agenda includes: performance evaluation of irrigation and water resource management; design and running of irrigation facilities, including salinity control; institutions, policies, environment, management; and health.

(1995, ICID) Identified the broad research areas of some of the world's leading irrigation institutes, as well as areas of research where IPTRID may complement them. Technology advancements were noted in particular in the work to improve food security and water management. Lessons learned from IPTRID's past experiences were outlined.

Merrey et al., 1997 The report summarizes the organization's efforts from 1984 to 1995 and identifies future irrigation research priorities. There were identified issues on performance evaluation, operation and design, policy, management, institutions, and environment and health. Institutional strengthening programs were expected to be implemented.

Leeds-Harrison (Leeds-Harrison, 1998) Focused on drainage and soil salinity research needs, identifying six key areas as follows: drainage and Irrigation integration to increase unit production; drainage advantages and investment plans; performance measures; soil reclamations; drain water disposal and recycling; planning and design tools

(H. Franzen, 1997). Compile a list of German organizations' R&D operations in the tropics and subtropics. There is a need for further study on surface water administration, including turnover programs and restoration.

(Commission, Freshwater: A Research and Innovation Challenge, 1998) combined water management, pollution, controlling shortfalls, preventing and managing crisis situations were among the 41 essential study clusters proposed during the consultation.

(According to Perry, 1999) It was suggested that the size of the irrigation system affected research priorities: Reliability at the small scale looking at the cost-benefit ratio on the service the farmer expects and their productive use. Institutional challenges on a medium scale. On a macro scale, greater data and analytical tools are needed to make sense of it.

2.7 Research Gaps

Among the previous studies on water storage structures, no specific study concentrates on the locational suitability of these structures towards irrigated agriculture.

2.8 Legal, Policy and Institutional Framework

This section focuses on the policies, legislative and institutional frameworks that relate to the supply of water and sanitation as a fundamental right in Kenya.

2.8.1 Relevant Regional Policies and Legislation

i. Achieving Food Security

The East African Community Agriculture and Rural Development Policy seek to ensure the community's food security. The policy argues that rational agricultural production should be promoted by developing interrelations and specialization under responsible use and management of land, water, fisheries, and forests to maintain the environment. The Comprehensive Africa Agriculture Development Programme (CAADP) seeks to improve agricultural development rates by expanding the area under sustainable cultivation and water supply systems and strengthening research and extension. These policies favor this research effort, which aims to improve food security by boosting irrigated agriculture's water storage capacity.

2.8.2 Relevant National Policies and Legislations

i. Access to Safe and Sufficient Water

Article 43 (1) subsections b and d of Kenya's 2010 Constitution acknowledges the delivery of water and sanitation services as a sacred right. It expressly specifies that everyone has the right to sufficiently clean and safe water quantities and is recognized as a core human right under the Constitution. It also delegated to the counties the duty for water supply and sanitation. Part IV of the Environmental Management and Coordination (Water Quality) Regulations of 2006 establishes irrigation water quality criteria. By 2030, Kenya Vision 2030 aims to improve and expand access to safe water and sanitation services beyond current levels by promoting agricultural productivity, increasing the territory under irrigation and drainage from 140,000 to 300,000 hectares, and implementing specific strategies to improve Kenya's water resource administration.

Furthermore, the National Policy on Water Resources Management and Development directs sufficient water for commercial, domestic, and industrial purposes. Its goal is to ensure the water sector's long-term development and management. The Urban Areas and Cities Act argues for an assessment of the city's or urban area's current degree of development and the identification of areas that lack basic services such as clean, safe drinking water and a clean and healthy environment.

ii. Revitalization of Agriculture

The Agricultural Sector Development Strategy succeeds the Strategy for Agriculture Revitalization and aims to put Kenya Vision 2030 into action in the agricultural sector. It identifies boosting agricultural commodity and enterprise productivity, commercialization, and competitiveness and establishing and managing key production elements. The National Food and Nutritional Security Policy strive to ensure adequate provision of safe food in both quantity and quality to all Kenyans to ensure their optimal health. It also strives to provide accessible and affordable food to poor communities while protecting them with ingenious and cost-effective safety nets tied to long-term development. It targets chronic, poverty-related food insecurity and malnutrition and the persistence of acute food insecurity and malnutrition linked to frequent and repeated emergencies.

iii. Management of Water Resources

The Water Resources Management Authority was established by the Water Act of 2002 to manage the country's water resources. The Act maintains the notion of water resource management based on catchments. The Authority will identify catchments and form Catchment Advisory Committees to guide catchment management. The 2006 Water Quality Regulations (Legal Notice No. 121 of 2006) primarily to safeguard human health and the environment by establishing standards for each category or class of water use, such as household, agricultural, industrial, and recreational uses, wildlife and fisheries, and water utilized for other purposes. It gives detailed instructions on water quality criteria for residential use and irrigation water quality restrictions in (Part II) (Part IV). Cultivation, for example, is forbidden within 50 meters.

2.9 Institutional Framework

2.9.1 Regulating water storage structures and water allocations

The Water Resources Management Act (WRMA) regulates water resources and is responsible for assuring public safety. As a result, dam designs and building activities must be reviewed to make certain that they achieve acceptable criteria in compliance with rules. NEMA is also in charge of making sure that the project complies with all applicable laws. NCA also oversees the construction sector, coordinates its growth, supervises its activities, and the accreditation and licensing of suitably qualified and experienced workers and construction site supervisors (National Construction Authority Regulations, 2014).

The Ministry of Water and Sanitation is tasked with policy, coordination, and performance monitoring in the sector and defining standards. Certified Water Resource Professionals and Qualified Contractors are also registered with the Ministry. The County Government is in charge of ensuring that all proposals are consistent with the county's development strategy. Any water storage project should be implemented with close collaboration between the development partner and all of the institutions mentioned above.

2.9.2 The Development Partner

Is an organization that provides technical and/or financial assistance to the design and/or planning and implementation. Once the structure is completed, the development partner is no longer involved in the project. However, the development partner may impose limitations on the project pertaining to legislative requirements, environmental considerations, fiduciary controls, and benefit sharing agreed upon with government entities and the project proponent.

2.9.3 Role of the Community & other stakeholders

To ensure adequate planning, coordination, implementation, and long-term benefits, stakeholders must actively participate in developing successful water conservation infrastructure. The value of actively creating and maintaining connections with impacted communities and other stakeholders over the entire project life has proven to be effective and improved project results. The community must engage fully in the project execution process for an overall benefit. Other stakeholders could act as a watchdog in the public interest, monitoring any matters that may impact the public or the environment.

2.9.4 Technical Team

This will depend on the magnitude of the proposed project.

a) Design Engineer
b) Hydrologist
c) Land Surveyor
d) Geotechnical Engineer
e) Electro-mechanical Engineer
f) Environmentalist/Sociologist
g) Qualified Contractor - The Qualified Contractor's job is to deliver construction services to their customer. These responsibilities include constructing water storage facilities that meet the authorized design and specifications. All contractors must be properly registered and accredited with the National Construction Authority. National Construction Authority Regulations, 2014). The project proponent/owner can hire only a contractor who is registered with the NCA.

2.10 Case Studies and Best Practices

Some of the established water storage facilities that have proven effective for irrigated agriculture are:

2.10.1 Large Dams

i. Sao-Francisco catchment

The entire watershed of Sao-Francisco in Brazil is evacuated by the Sao-Francisco River and its tributaries and encompasses 629,885km2 (Maneta et al., 2009). The river travels from south to north for 2860 kilometers, passing through several regions (Braga and Lotufo, 2008). The southern landscape consists of steep rocky hills. High mountains can be found in the Northwestern and Southern regions. Grasslands are prevalent at middle altitudes, especially towards the catchment's western margin. Crop and livestock farming occupy the majority of agricultural lands. Cereals are typically farmed as a stand-alone crop or in combination with legumes. A variety of fruits are also grown across the watershed.. Cattle, goats, and sheep are currently used in animal farming (Maneta et al., 2009).

ii. Nile catchment

As the world's longest river it extends 6850 kilometers north from East Africa to North Africa.
The majority of the downstream area is arid or semi-arid, with minimal water flow but significant evaporation (Karyabwite, 2000). Egypt's economy is based mostly on agriculture. The Nile rises every year in August and September, fertilizing the farms along the river's banks. The agriculture sector continues to be the most important determinant of the Nile's water balance. During the dry season, farmers use ground water to irrigate. Several lakes and man-made reservoirs can be found in the Nile Basin. The Jebel Aulia Dam, with a capacity of 3 km3, was created to improve the White Nile's natural storage capacity.

The Roseries Dam was built in Northern Sudan to boost irrigated agriculture and electricity generation. Lake Tana, Ethiopia's largest lake, has a surface size of 3673 km^2. The Khashm el Girba Dam was built to give another income source for the 70,000 residents displaced by the High Aswan Dam's rising water level. The 169-square-kilometer Lake Nasser reservoir impounds the Nile around 320 kilometers upstream in Egypt and nearly 160 kilometers upstream in Sudan.

2.10.2 Small Dams

i. Sand Dams

Sand dams have been built in numerous sections of the country, including Magomano, Gachuriri, and Manzyundu in Kyuso, and Marimwe in Mbeere North. Water percolates in the sand during flooding, and later, the water is evacuated by excavating the sand or plumb and tap system at the concrete wall's lower portion of a sand dam. These dams have aided in the supply of water for domestic and livestock usage and the watering of tree nurseries by minimizing the need to travel vast distances to find water. By storing water, farmers are also able to attend to more and higher yield crops, while also reducing runoff, soil erosion, and land degradation.

ii. Earth Dams

Dams built in Kyuso, Masamba at Itivanzou, and Manzyundu have demonstrated their viability for irrigated agriculture in the following ways: they have supplied water for domestic use, livestock, and irrigation; they have recharged soil water in the immediate area, resulting in substantial vegetation growth; they have helped control floods and reduced soil erosion and land degradation, and they have improved health due to increased availability of water.

Figure 6: Earth dam in Ngomeni

iii. Water Pans

Water Pans were built in Narok's Ilaretok, Ngomeni's Mandongoi region, and Suswa's Ole Sharo Hills. Water pans are simple to make with local labour. They are a good water source for household use and irrigation as they reduce surface flow, flush floods, and the resulting land degradation due to erosion; and they boost soil moisture content and crop productivity. Lined with a material that doesn't allow seepage, pans may be dug virtually anywhere with run-off water. To reduce and control silting, the catchments must be adequately vegetated, and the silt must be removed on a regular basis.

Figure 7: Water pans in Ewaso Nyiro

Figure 8: Water pan in Suswa

As a result of the constructed water pans irrigated agriculture has been achieved in these areas

Figure 9: Green gram farm and Maize farm in Ewaso Ngiro

Figure 10: Pumpkin farm in Mulot

2.11 Conceptual Framework

Theories are meant to explain, anticipate, and understand facts, as well as to challenge and extend present knowledge, all while remaining within the bounds of fundamental restricting assumptions. The theoretical framework is the structure that holds or supports the theory of a research investigation. The conceptual framework is essential for guiding the entire research study technique.

Suitability of Water Storage Facilities

- No. existing facilities
- Precipitation
- Soil type
- Environment Population
- Purpose of Water storage facility
- Size/ Capacity of reservoir
- Land use
- Elevation vs intended irrigation area
- Vegetation cover
- Proximity to farms
- Topography of land

Moderating Variables

- Government policies and Institutions
- Technology
- Corruption

Irrigated

- Type of crop, livestock
- Area suitable for irrigation
- Water demand per type of agriculture
- Type of irrigation technology
- Access needs for irrigated agriculture

2.12 Conclusion

The chapter has reviewed relevant literature in relation to the suitability of water storage structures for irrigated agriculture. Most of the literature reviewed refers to these structures as Rain Water Harvesting facilities, and this is so as these storage structures depend on rain as the primary water source. For this study, the structures are referred to as water storage structures.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the methods used by the researcher to achieve the study's goals. These factors include the research design, data collection methodologies, instrument validity and reliability, data gathering procedures, and data analysis methods.

3.2 Research Design

A cross-sectional descriptive research design has been employed in the study. The goal of this design is to convey the current state of a variable or occurrence. Many independent variables influence the location of suitable water reservoir sites, and this method effectively determines their correlations and impacts on the dependent variables.

3.3 Target and Accessible Population

The study targeted specific locations in the two sub-counties deemed suitable for the development of water storage facilities. The analysis is based on the criteria provided in the handbook for small dams and pans. The other target population was the large and small farm holdings.

3.4 Sampling Design

3.4.1 Sampling Frame

The sampling frame for specific farm holding was based on their proximity to potential water storage infrastructure locations.

3.4.2 Sample Size

According to Kothari, in the case of a finite population, the following formula applies:

$$n = \frac{z^2 . p.q.N}{e^2 (N-1) + z^2 . p.q}$$

Where: p=sample proportion

q= 1-p

Z= value of the standard deviation at a given confidence level

n=size of sample

$$e = z.\sqrt{\frac{pq}{n}}$$

The study therefore made use of the available finite population

Table 5: Sample Size

Sub-County	Wards	Population	Sample	Proportion (%)
Gatundu South	Kiamwangi Kiganjo Ndarugo Ngenda	87,290	84	7.0
Gatundu North	Gituamba Githobokoni Chania Mangu	76,916	74	6.2

Due to the study's homogeneity nature, the researcher opted to administer 20 questionnaires in each ward, presenting a total of 160 household questionnaires.

3.4.3 Sampling Technique

Probability and non-probability are the two types of sampling procedures. This study has made use of non- probability sampling as it is deemed time effective and cheap.

3.5 Data collection methods

Data was gathered from a variety of sources, both qualitative and quantitative. This aided in data triangulation and reaching the best level of validity for the findings. Primary and secondary data sources were used. Interviews, questionnaire administration, desktop reviews, observation, and photography were the primary data collection methods used in this study.

3.5.1 Secondary data

This involved a review of the existing documents on the computer. To offer a robust foundation for the study issue, existing satellite imagery and topographical survey data from the Shuttle Radar Topographic Mission (STRM) or the Aster Digital Elevation Model were analyzed. Rainfall data, soil types, and other physiographic data were also examined. Finally, the researcher looked at case studies and best practices in locations where irrigated agriculture water storage facilities have been erected and are working correctly.

3.5.2 Primary data

The data from the field study were collected using a variety of approaches. These techniques were be used. However, they were not be limited to:

i. The questionnaire

Questionnaires were employed since they are the only data collecting tool that can capture a large amount of data in the least amount of time. The questionnaires were administered to the end users of the water storage facilities and to landowners where probable locations were identified. These factors are translated into evaluations of the physical, social, and technological settings.

ii. Key informant Interviews

Using a key informant interview schedule, the National Irrigation Board and the County Agriculture, Livestock & Irrigation officials were conducted to get their perspective.

iii. GIS & Remote Sensing

A geographic information system (GIS) is a tool for gathering, storing, and analyzing geographical and non-spatial data (Mati et al., 2006). Using GIS tools and geographical analysis, many theme layers may be created. These layers can then be combined to determine the best locations for water storage buildings. GIS programs with Remote Sensing capabilities were utilized to find potential locations for water storage buildings. To obtain precise information with high geographical and temporal precision, remote sensing was utilized. In GIS settings, for example, land-cover information and curve numbers (CNs), which were required for runoff calculation, were easily retrieved.

iv. Observation Method

This involved observation and photography aided in gathering information on irrigation methods adopted, type of crops grown, available water storage structures, vegetation cover, and animal breed kept.

3.6 Data Analysis methods

3.6.1 Quantitative Data

Statistical Packages for Social Scientists (SPSS) and Excel were used to examine the data from household questionaires.

3.6.2 Qualitative Data

Using descriptive techniques, data from key informants was qualitatively examined.

3.6.3 Spatial Data

The use of ArcGIS and Global Mapper software tools to modify satellite data, cadastral maps, and physiological data resulted in a study of possible sites for water pans in Gatundu.

3.7 Validity and Reliability of research instruments

The most important criterion is validity, which demonstrates how well an instrument measures what it's meant to assess (Kothari, 1990). The study's findings should accurately reflect reality. Multiple data generating techniques, including key informants and household surveys, were used to guarantee validity in this study. The degree to which an instrument produces consistent findings over time is referred to as reliability (Mugenda & Mugenda, 2003). Before the questionnaire was delivered, a pilot study comprised of households was randomly picked from the available population and utilized to conduct a questionnaire pilot study.

3.8 Data presentation

Maps, tables, bar graphs, photos, and pie charts were used to present the final analyzed data.

3.9 Data Needs Matrix

Research Objectives	Data needs	Data Source	Data collection	Data Analysis	Data presentation
To assess the adequacy of water storage facilities to ensure sustainable irrigated agriculture in the study area	Domestic rainwater harvesting techniques Existing water pans, ponds, earth dams for irrigation use	Primary	Questionnaires Observations	SPSS	Tables Graphs Descriptive texts
To examine factors that affect the development of water storage facilities for irrigated agriculture in the study area	Physiological data; Climatic conditions Temperature and sunshine Rainfall Geology Soil type Topographic data Forest and Vegetation cover	Secondary & Primary	Literature review, Observations, Interviews	SPSS	Photographs Descriptive texts Tables Graphs

To evaluate suitability of locations for water storage facilities for irrigated agriculture in the study area	Satellite imagery Cadastral maps (RIM) Topographic data Watersheds	Secondary &Primary	Literature review, Observations, Interviews	Spatial analysis with GIS Global mapper Remote Sensing	Photographs Descriptive texts Maps
To propose strategies that can be put in place to ensure adequate water storage facilities for irrigated agriculture	Storage techniques Suitable locations Willingness of the people	Primary Secondary	Literature review Interviews Questionnaires'	SPSS	Descriptive Texts Maps

Table 6: Data Needs Matrix

3.10 Flow chart of Methodology for determining suitable locations for water storage structures

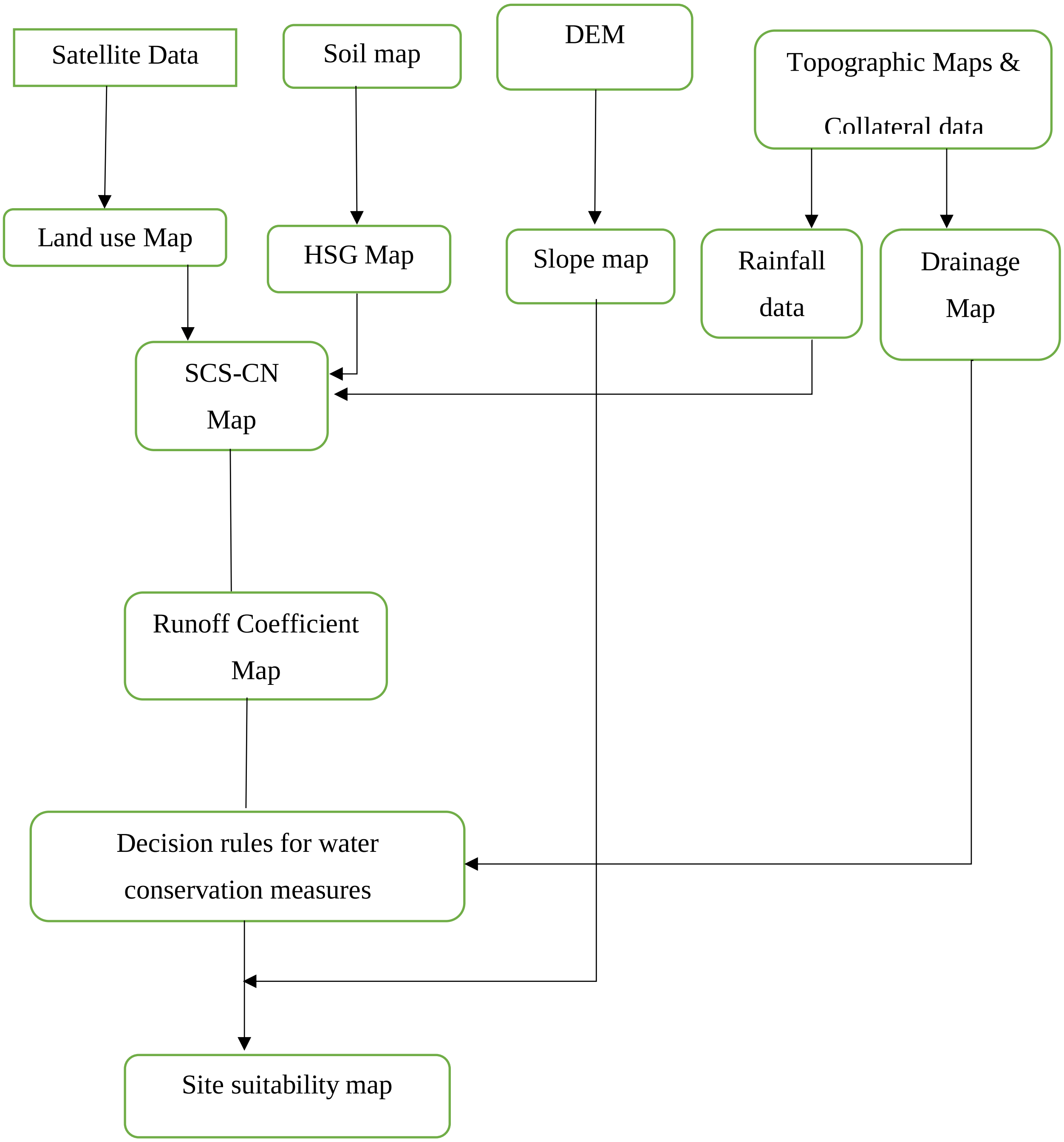


Figure 11 : Summary of Methodology

CHAPTER 4. STUDY AREA

4.1 Overview

The chapter outlines the location of the study area; it goes further to discussing the physiographic characteristics, population and demography, human settlements and housing. Finally, it looks at the physical and social infrastructure in the study area.

4.2 Location

Gatundu North and South sub counties are among 10 other sub counties in the Kiambu County, Kenya. Gatundu town located 17km off Thika road in Gatundu south sub county and Kamwangi located 23km off Thika road in Gatundu North are the main towns within the two sub counties. Gatundu south covers a total area of 192 square kilometers with a population of 114,183 whereas Gatundu north covers 289 square kilometers with a population of 100, 613 making a total of 481 square kilometers. Gatundu North and south are situated in Central, Kenya; its geographical coordinates are 0° 59' 0" South to 0° 50' 0", 36° 58' 0" East to 36° 44' 0".

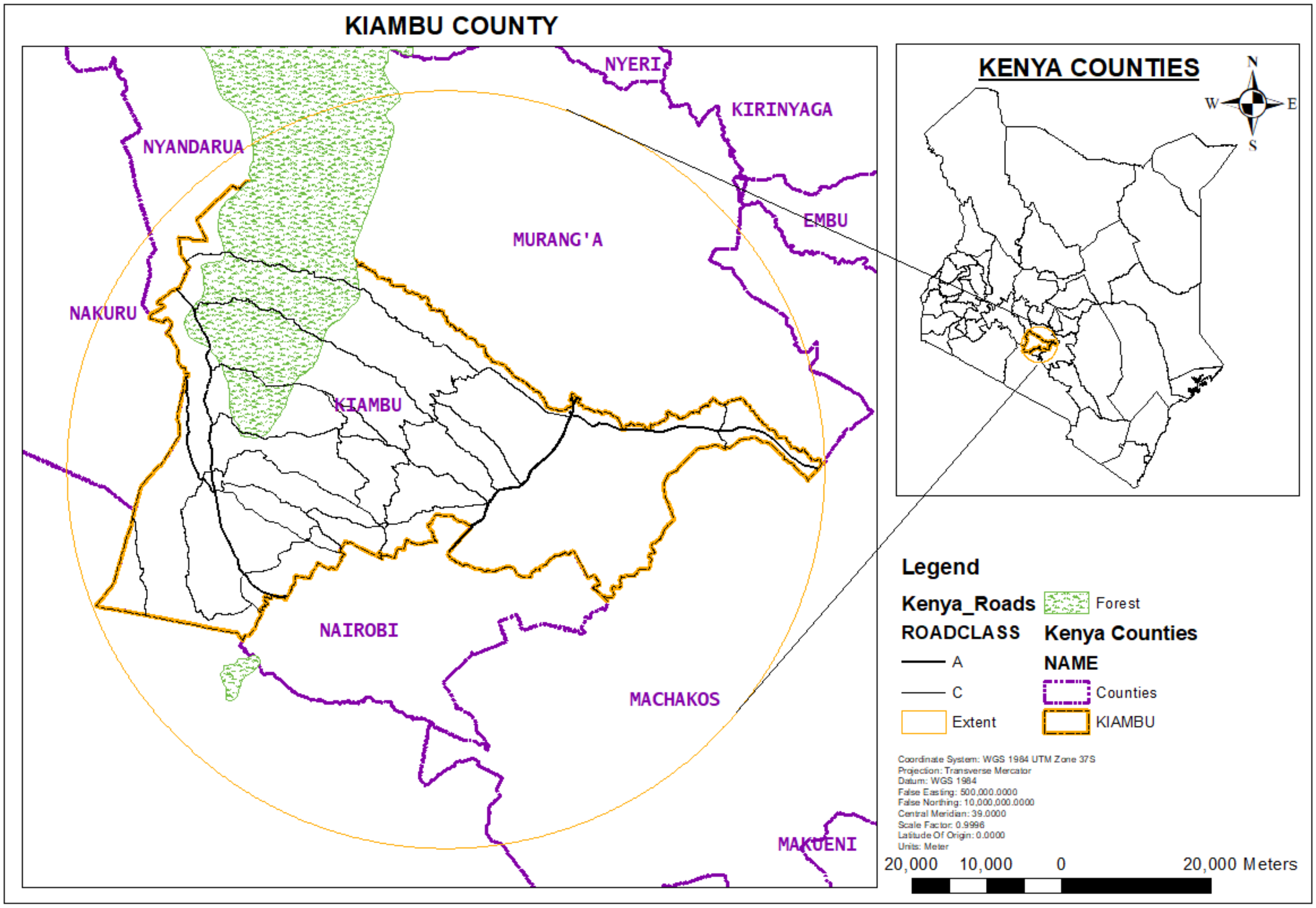


Figure 12: Location of Kiambu County in Kenya

Source, Author 2019

Kiambu County is centrally located within Kenya *(figure 13)* and is abutted by several counties which include Nakuru, Nyandarua, Murang'a, Machakos, Kajiado and the capital city Nairobi (*see figure 13)*.

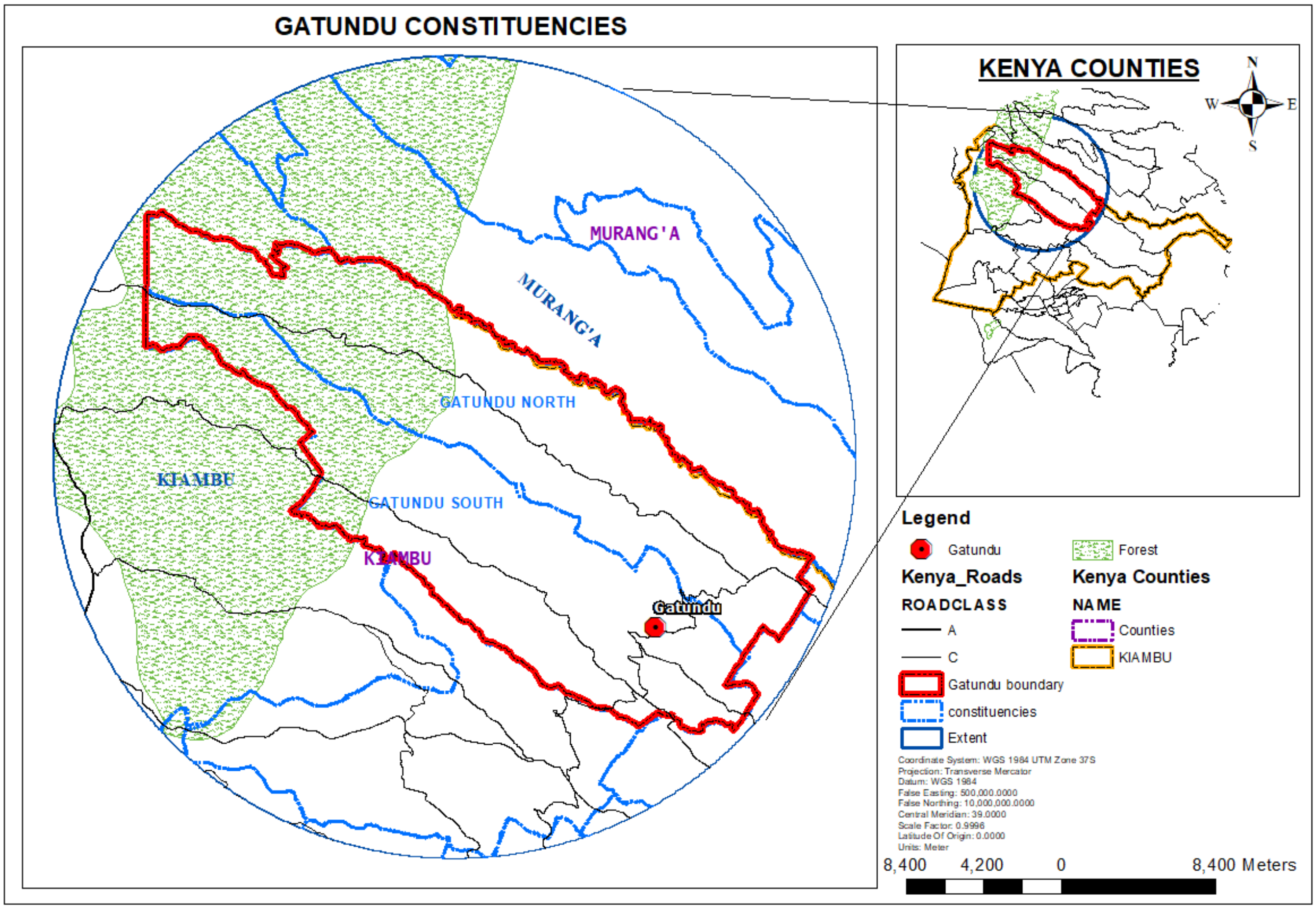


Figure 13: Location of Gatundu North and South in Kiambu County

Source, Author 2019

Kiambu County is constituted by 12 sub-counties. Gatundu North and south constituencies also referred to as sub-counties in this case the planning area are located in the northern segment of Kiambu County *(figure 14)*. The planning area abuts Lari, Githunguri, Juja, Thika sub-counties and Murang'a County to the North.

4.3 Physiographic Characteristics

4.3.1 Relief and Topography

Plateaus, hills, and high-elevation plains define the region in general. The height varies between 1400 and 2500 meters above sea level, as indicated in fig 4-1. The terrain has an undulating pattern with short ridge spans and deep canyon valleys. Although other industries like as horticulture crops, maize, and sheep husbandry are also performed, the region is mostly a dairy and tea zone.

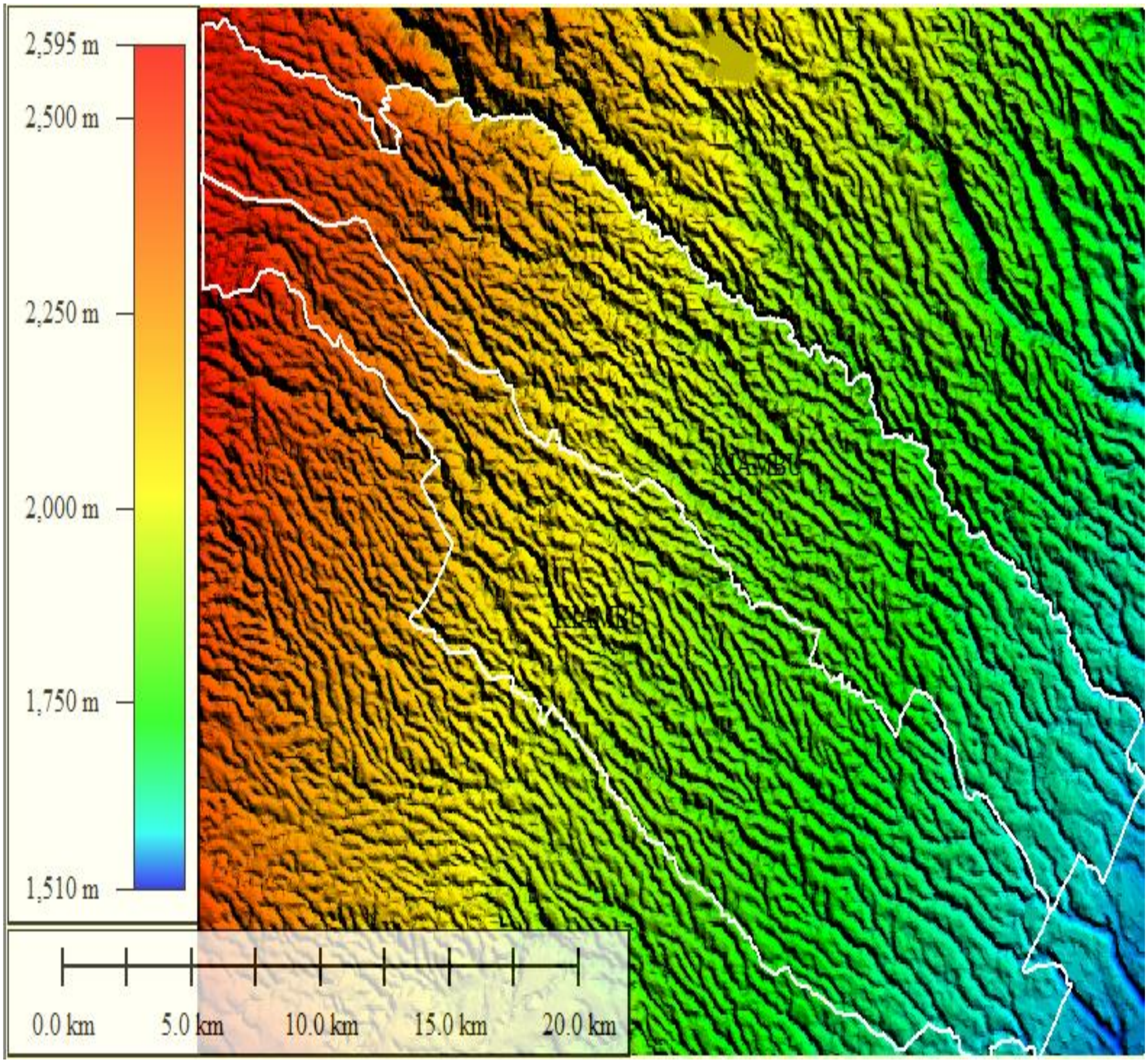


Figure 14: Digital Elevation Model of Gatundu

Source: Author, 2019

Figure 15: ***Steep topography in Gachege area, Gatundu North***

4.3.2 Climate

The Aberdares Forest Ecosystem has a strong impact on the climate of Gatundu Sub County; the environment is characterized by mist and rain throughout the year, with rainfall ranging from 1000mm on the Northern Western slopes of the Aberdares to 3000mm in the South Eastern. Throughout the year, there is a lot of rain. The humid zone is found inside the Kikuyu Escarpment Forest's upper sub-catchment, which is the source of the Rwabura and Thiririka Rivers, as well as other tributaries that flow into the Ndarugu River and other nearby rivers. The sub-humid and semi-humid zones of the middle sub-catchment provide agricultural area for small-scale agricultural operations such as tea cultivation, dairy farming, and woodlots. (Madindou, 2018).

4.3.3 Rainfall

Rainfall patterns in Gatundu are bimodal with the long rains occur beginning in March to end in May and the short rains from October to November. The amount of rain that falls each year varies according to elevation. Higher elevations receive up to 2,000mm of rain each year, while lower elevations receive as little as 600mm. The annual rainfall averages 1,200mm.

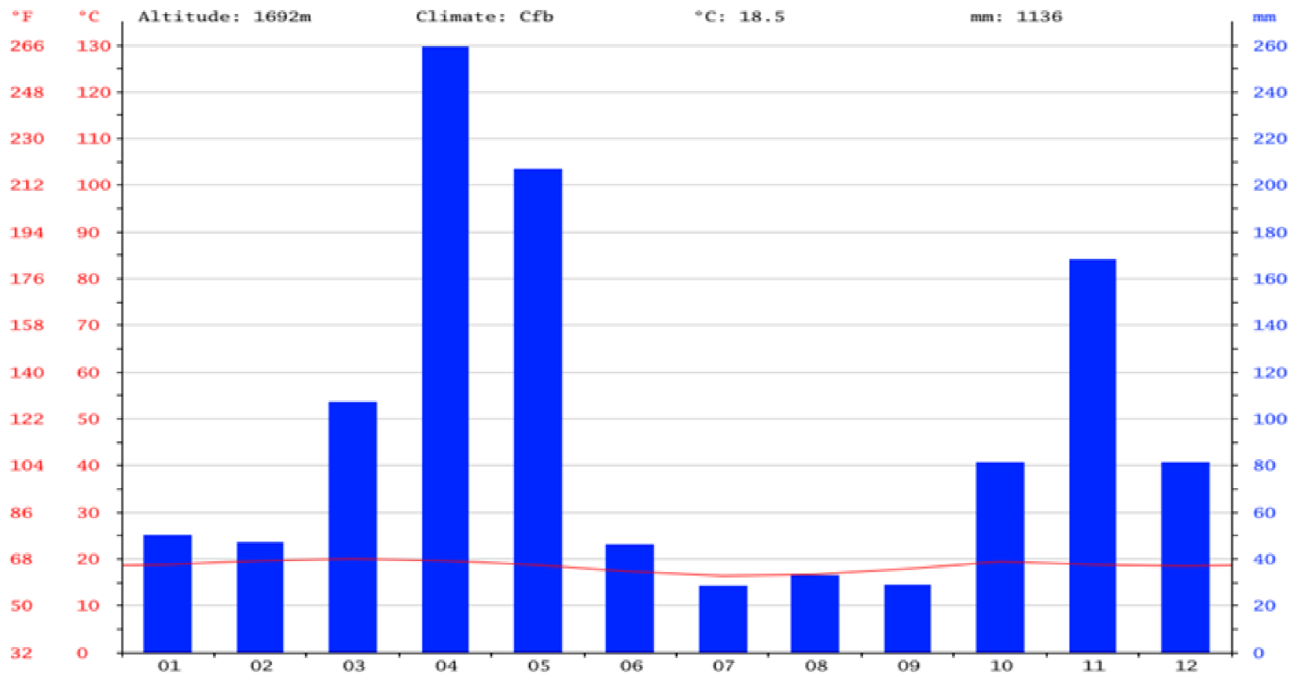


Figure 16***: Average Rainfall distribution in Gatundu area***

Source, CIDP, 2018-2022

4.3.4 Temperature and Sunshine

The coldest months are July and August, with an average temperature of 20°C, while the warmest months are January to March, with an average temperature of 26.40°C. The average relative humidity in the area varies between 54 percent during the dry months and 300 percent during the rainy months of March to August..

4.3.5 Geology and soil type

Pyroclastic rocks with modest basalt intercalations make up the geology of the Gatundu Sub County, which straddles the Pliocene to Lower Pleistocene periods. Riverbeds in severely cut valleys have rock exposures. High level upland soils, plateau soils, and volcanic footbridges soils are the three major types of soils that encompass Gatundu South. The productivity of these soils varies, with high-level uplands derived from volcanic rocks being particularly fruitful. (Ashun, 2014).

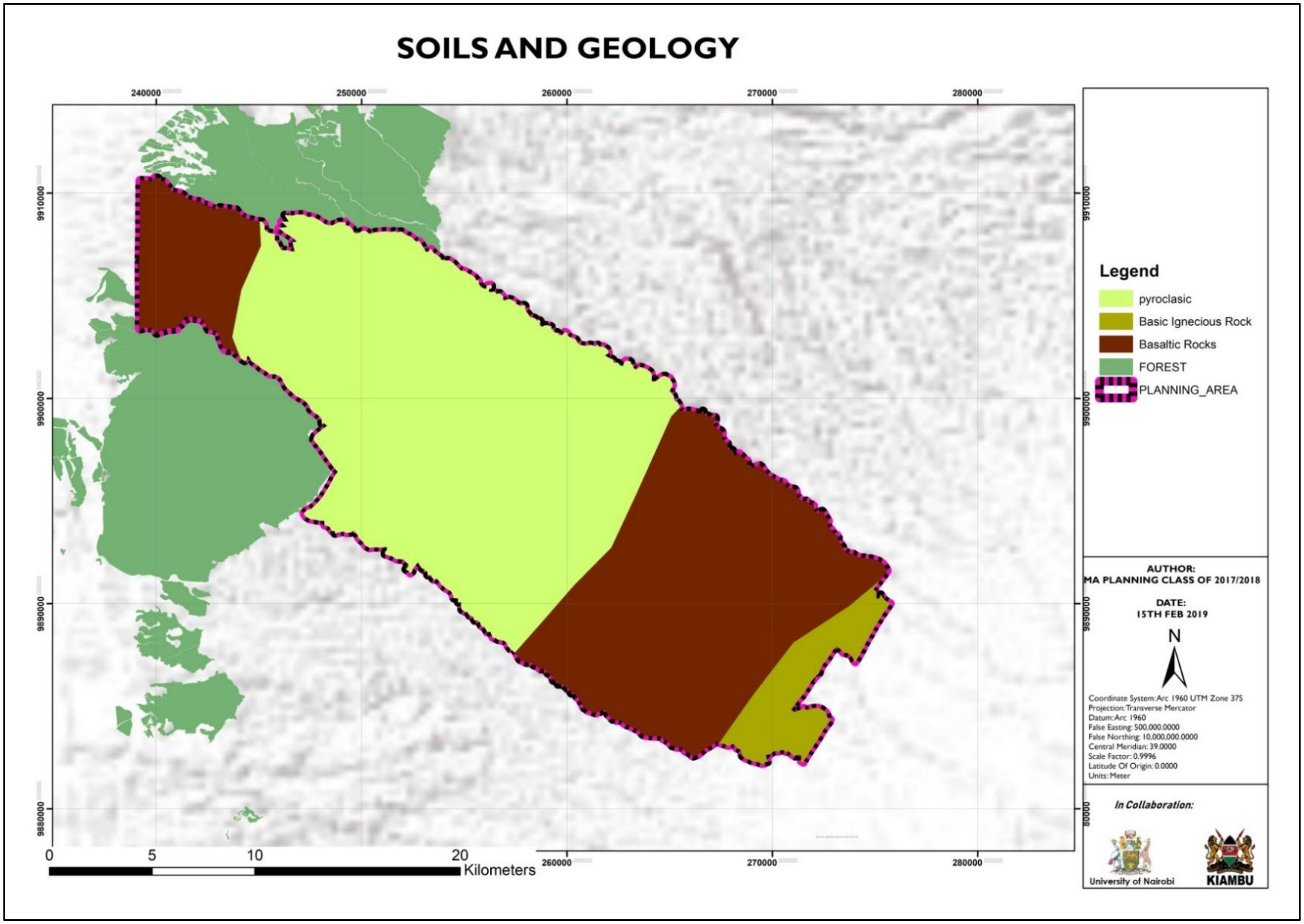


Figure 17: Soils and Geology

Source: Author

4.3.6 Forest and vegetation Cover

Natural, plantation, and private woods are the three primary types of forests in Kiambu county. Exotics are mostly grown on private farmlands. The county contains eight designated forests, the most notable of which are the Kieni and Kinale woods. Kiambu county's gazetted forest covers a total of 40,032.81 hectares. The Kieni forest in Gatundu covers 13,723.6 hectares. The Kieni forest and vegetation cover in Gatundu are depicted on Maps 4-6.

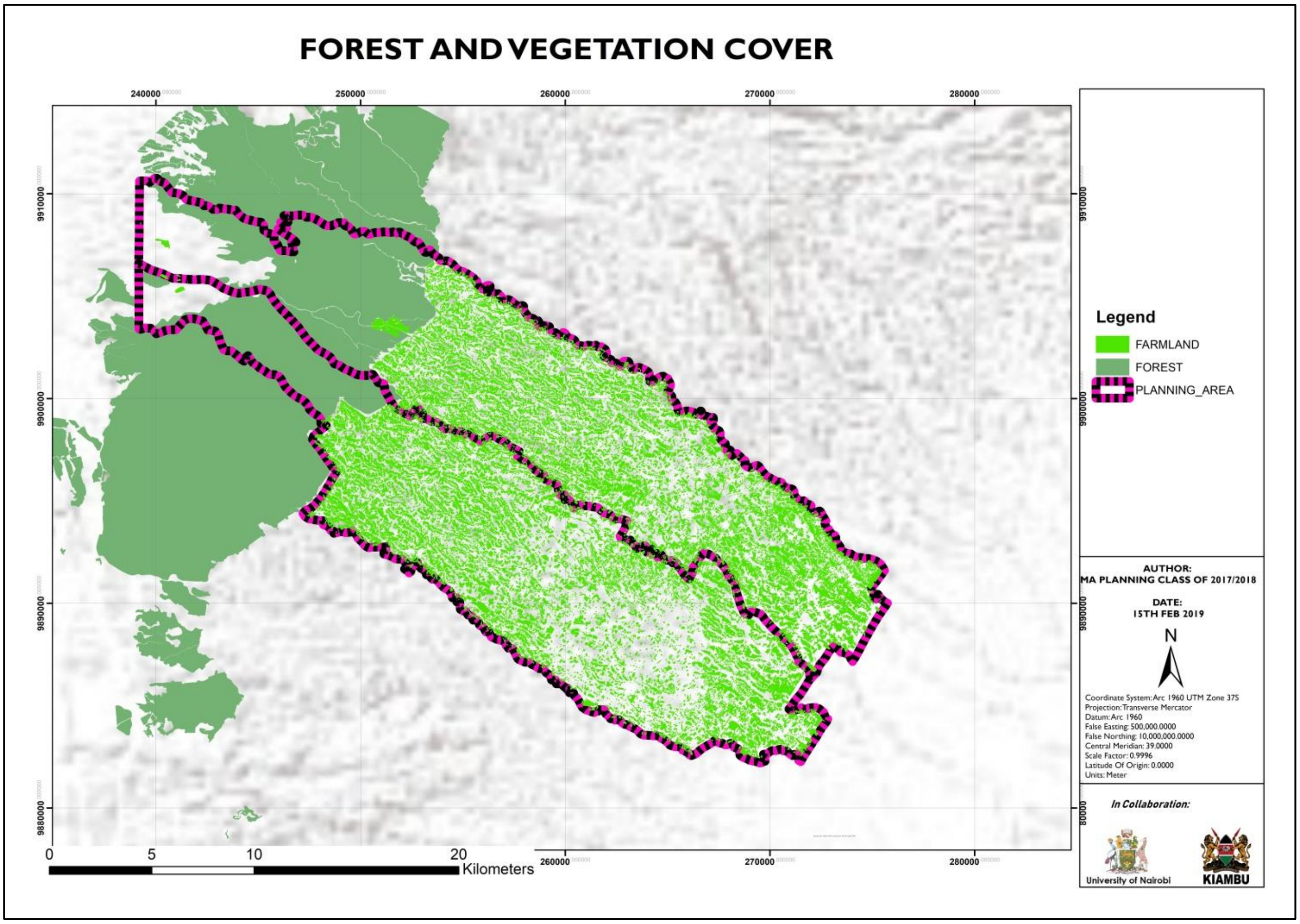


Figure 18: ***Forest and vegetation Cover***

Source: Author, 2019

4.4 Population and Demography

4.4.1 Demographic Dynamics

Demography is the study of population characteristics. It gives a mathematical representation of how certain traits evolve over time. Any statistical element that influences population rise or fall can be included in demographics, however some characteristics are particularly important: Size, age structure, density, mortality, fecundity rates, and sex ratio of the population (Dodge 2006).

4.4.2 Population size & density

The number of persons existing in a subjectively defined geographic region is referred to as population size. The number of persons per unit area or volume, on the other hand, is a dynamic feature that changes over time as inhabitants are added to or withdrawn from the population.. (Lebreton et al. 1992). Gatundu Region is composed of two constituencies i.e. Gatundu South and Gatundu North. The Population size and density in the two constituencies are as per the table below:

Table 7: ***Population size and density in Gatundu***

Constituency	**Pop. Size**	**Density (per km2)**
Gatundu South	113,864	593
Gatundu North	100,119	352
Total	213,983	945

Source: KNBS (2009 Census)

4.4.3 Population Distribution

The distribution of people is characterized at many levels (global, local, national, and regional) and with various sorts of borders (political, geographic, and economic) (SUDA, 2017). Population distribution in Gatundu is as below;

i. Gatundu South Constituency

Gatundu South Constituency has a Population of 113,864 within an area of 192.0 km^2

Table 8: ***Population distribution in Gatundu south***

Ward	**Population**	**Area in Km^2**	**Sub-Locations**
Kiamwangi	20,371	27.80	Kigongo, Kiamwangi, Nembu and Gathage
Kiganjo	27,040	55.20	Mundoro, Gachika, Ndundu, Kiganjo, Gatitu and Kiamworia
Ndarugo	20,229	50.40	Kirangi, Munyu-Ini, Gacharage, Karatu, Gitwe and Karinga
Ngenda	46,224	35.40	Ituru, Kahuguini, Wamwangi, Kirangari, Kimunyu, Handege, Ritho and Githunguchu

Source: KNBS

ii. Gatundu North Constituency

Gatundu North Constituency has a Population of 100, 119 and an area of 289.0 Km^2

Table 9: ***Population distribution in Gatundu North***

Ward Name	**Population**	**Area in Km^2**	**Sub-Locations comprised**
Gituamba	27,587	54.80	Mataara, Gituamba, Kiriko, Ndiko, Ngorongo, Maria-Ini and Kanyoni
Githobokoni	21,383	133.60	Kieni, Gakoe, Kamunyaka, Njahi, Mwimuto, Gachege, Gathaithe and Gatei
Chania	26,350	28.80	Kamwangi, Nguna, Kairi, Igegania, Makwa and Muirigo
Mang'u	24,799	29.70	Nyamangara, Mitero, Mukurwe, Mangu, Gatukuyu and Karuri

Source: KNBS

4.4.4 Population Composition/Structure

The population's composition may be characterized in terms of fundamental demographic characteristics such as gender, age, family and household status, as well as economic and social context characteristics such as language, occupation, education, religion, ethnicity, wealth, and income. (SUDA, 2017). Gatundu population is composed as in the table below;

Table 10: Population Composition/Structure in Gatundu

Constituency/ Wards	**Gender**			**Age group**						**Demographic Indicators**			
	Total Pop	*Male*	*Female*	*0-5 yrs.*	*0-14 yrs.*	*10-18 yrs.*	*15-34 Yrs.*	*15-64 Yrs.*	*65+ Yrs.*	*Sex Ratio*	*Total dependancy Ratio*	*Child dependancy Ratio*	*Aged dependency Ratio*
Gatundu South Constituency	**113,864**	**54,799**	**59,065**	**16,410**	**42,742**	**23,725**	**35,954**	**63,585**	**7,537**	**0.928**	**0.791**	**0.672**	**0.119**
Kiamwangi	20,371	9,740	10,631	2,952	7,635	4,240	5,791	11,077	1,659	0.916	0.839	0.689	0.150
Kiganjo	27,040	13,057	13,983	3,903	10,217	5,756	8,764	15,099	1,724	0.934	0.791	0.677	0.114
Ndarugu	20,229	9,604	10,625	2,925	7,727	4,427	6,503	11,339	1,163	0.904	0.784	0.681	0.103
Ngenda	46,224	22,398	23,826	6,630	17,163	9,302	14,896	26,070	2,991	0.940	0.773	0.658	0.115
Gatundu North Constituency	**100,119**	**48,414**	**51,705**	**14,743**	**38,004**	**20,888**	**31,744**	**55,617**	**6,498**	**0.936**	**0.800**	**0.683**	**0.117**
Gituamba	27,587	13,416	14,171	3,976	10,362	5,712	8,922	15,559	1,666	0.947	0.773	0.666	0.107
Githobokoni	21,383	10,313	11,070	3,378	8,583	4,544	6,734	11,635	1,165	0.932	0.838	0.738	0.100
Chania	26,350	12,651	13,699	3,781	9,833	5,445	8,266	14,579	1,938	0.923	0.807	0.674	0.133
Mangu	24,799	12,034	12,765	3,608	9,226	5,187	7,822	13,844	1,729	0.943	0.791	0.666	0.125

4.4.5 Population Projections

Population projections are computations that indicate how fertility, migration, and death will change in the future. They aren't forecasts, predictions, or estimations. Rather, they are somewhere in the middle of forecasts and predictions. (Divisha, 2018). According to the KNBS (2009), Gatundu population is projected as follows;

Table 11: ***Population distribution and density by sub-county***

	2009 Census		2018 projections		2020 projections		2022 projections	
Name of Sub County	Population	Density (Km^2)	Population	Density (Km^2)	Population	Density (Km^2)	Population	Density (Km^2)
Gatundu South	114,180	593	136,634	710	141,735	736	149,830	778
Gatundu North	100,611	352	120,396	421	124,890	437	132,024	462

Source Kiambu 2018-2022 CIDP

4.5 Human settlements and Housing

The settlement pattern in the study area has been influenced by rainfall, soil fertility, topography, road networks and urbanization.

4.5.1 Land Use Patterns

There exist various land uses in Gatundu. Majority of them entails farming, institutional, commercial and residential. Major industries include milk processing. The cost of land is high due to the soil fertility of the area.

4.5.2 Settlement Patterns

In general, the Gatundu region is highly inhabited. Infrastructure, food supply, and proximity to Nairobi City, among other variables, all have a role in population dispersal. Market centers and adjacent districts, on the other hand, show a high population density. A diverse range of high, middle, and low-income residents characterizes settlement patterns..

The rural settlements are generally dispersed, and the population densities are lower as compared to urban zones. The primary activities in these settlements are agriculture, livestock keeping, forestry and residence. Most people undertake farming activities in the parcels in which the live. Gatundu has different settlement patterns including:

i. Dispersed Settlements

Buildings in dispersed settlements are spaced out, such as a farmhouse in the middle of a field or a few dwellings in a hilly location. These are very few as compared to the Nucleated and Linear settlements. These can mainly be seen around Kenyatta road where people hold expansive swaths of land. The figure below shows some of the dispersed settlements in Gatundu.

Figure 19: Dispersed settlements in Gatundu

Source Google earth

ii. Nucleated Settlements

Buildings are grouped around a central point in nucleated settlements. A church, a crossroads, a market area, or a water source might serve as the settlement's focal point. This can be seen near the shopping centers e.g. Gatundu town, Kimunyu and Kamwangi centers. Figure 20 shows some of the nucleated settlements in Gatundu

Figure 20: Nucleated settlements in Gatundu

Source Google earth

iii. Linear Settlements

The form of linear settlements is long and narrow. They frequently follow roads, canals, riverbanks, or narrow valleys with little space for spread.

Figure 21: Linear settlements in Gatundu (Source Google earth)

4.6 Physical and Social Infrastructure

The following is the information on physical and social infrastructure in Kiambu County.

4.6.1 Physical Infrastructure

iv. Road network

i. Road network

Road infrastructure is considered to be a key prerequisite of social and economic development of any country. Kiambu County has a total of 2,033.8 kilometers of bitumen roads, 1,480.2 kilometers of gravel roads, and 430.1 kilometers of dirt roads. The roads especially the dirt ones require regular maintenance to ensure they are motorable during rainy seasons. The sub counties of Gatundu South and Gatundu North are accessed and served by roads of various classes, standards and conditions. The major roads are of bitumen standard, traverses major urban centres in the area and transcend the region.

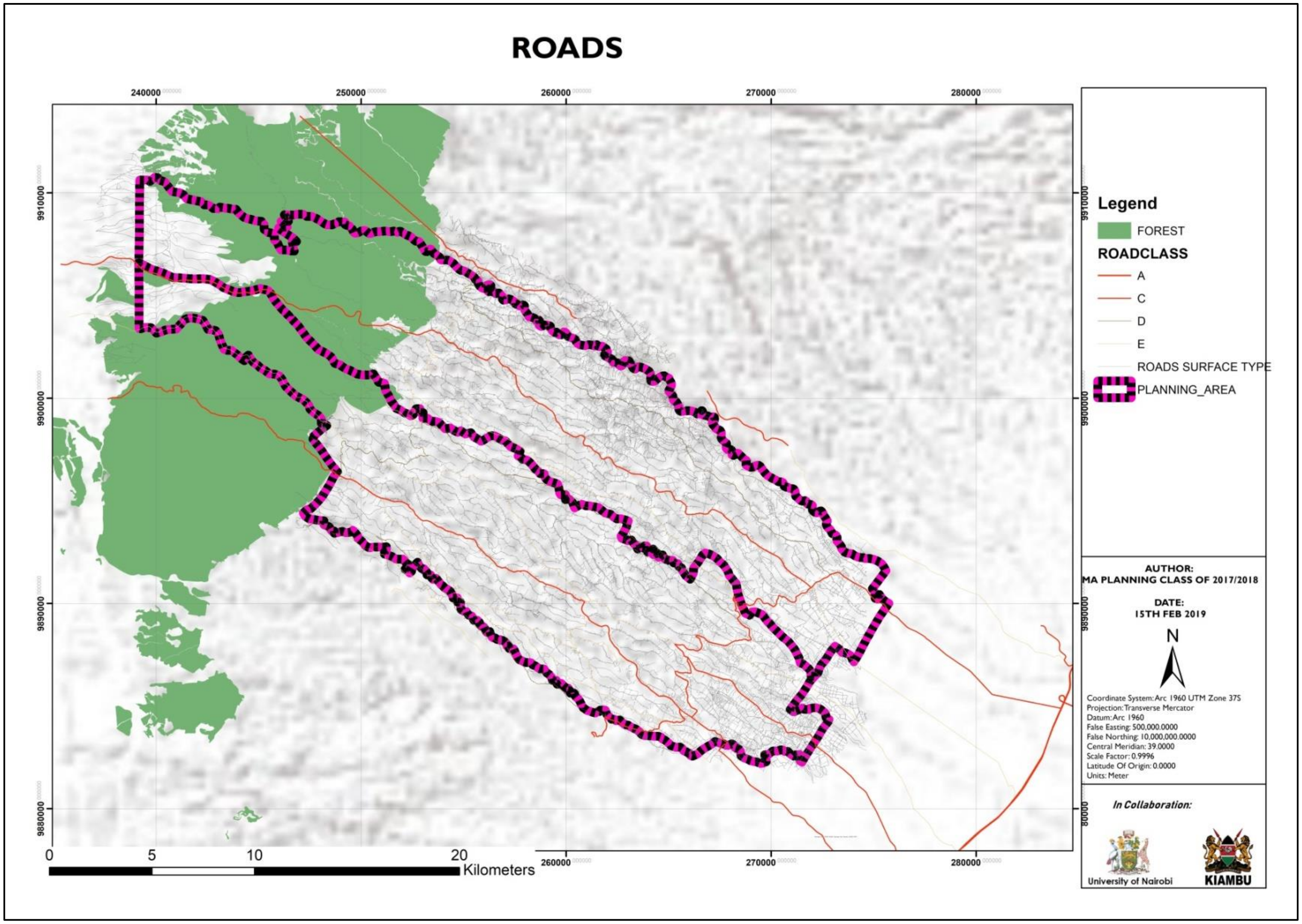


Figure 22: Roads in the Study area

Source: Author, 2019

v. Water Supply

In Kenya, water management has been a problem for decades. One of the most significant obstacles is the widespread belief that water should be a free commodity and utility supplied by the government. Water scarcity is more prevalent in Kenya's rural regions, with the majority of the population living in the ASAL, putting a pressure on women and children who are charged with finding water, particularly for household usage. The quality of water, the continuity of water supply, and wastewater treatment are the other major concerns with water in Kenya. The scarcity of water in rural regions has also been a major issue, with water shortages hurting agriculture and livestock use. (Notley *et al*, 2010). There are several water companies in Kiambu Counties with the study area being supplied by Gatundu water and Sanitation Company limited (GATWASCO).

Water supply in Gatundu is irregular. GATWASCO is the major supplier of water in the area and it covers a small section of within the CBD. Residents have adapted various strategies to cope. These include reducing the amount of water used and sinking shallow wells and boreholes as well as harvesting rain water in tanks

Figure 23: Rainwater harvesting in Kirangi

4.6.1.1.1 Irrigation infrastructure

Kiambu County has a total irrigation capability of over 62,812 acres based on available surface, subsurface, and water collecting capacity. So yet, just 7,500 acres (12%) have been irrigated (Govenment, 2018-2022).

Kamwamba, Wamoro, Gatina, Kawira, Nyamuku, Kiruiru, Karia, and Waruhiu ATC are among the nine irrigation projects launched by Kiambu County. Water harvesting was pushed, and two water pans, Waruhiu and Kimuyu ATC, were created. Njuno, Githongo, and Chiboni are some of the irrigation projects that have been designed.

The need for water in Gatundu is growing as the population grows. Potable water is one of the alternatives for addressing the region's inconsistent water supply. Residents' perceptions of groundwater as contaminated, a lack of funds to install wells in and a lack of understanding about the value of potable water are among the challenges facing groundwater usage in Gatundu. (Government, 2013).

Figure 24: Shallow well in a home in Karangi for small scale irrigation

Source: Author, 2019

vi. Sewerage and Sanitation

Gatundu has no sewer system and no sanitation services are planned. Pit latrines, soak pits, and septic tanks service 94.3 percent of the properties in Gatundu North (KNBS, 2013). Soak pits and septic tanks frequently overflow, dumping raw sewage into drainage channels and eventually into the porous subsoil, creating a pollution risk to groundwater and soil contamination. Inadequate sanitation has a range of financial and economic consequences, including direct medical expenditures and lost productivity at the family level, necessitating more investment in its development. (Kamau & Sakwa, 2012).

vii. Energy access

Kenya's energy economy is dominated by petroleum and electricity, with wood fuel serving the basic energy needs of rural people, the slum dwellers, and the informal economy. According to a national energy analysis, wood fuel and other biofuels contribute for 68 percent of overall energy use. Despite the government's ambitious goal of increasing power connectivity from 15% to at least 65 percent by 2022, Kenyans have limited access to electricity (Bhattacharyya, 2013).

Kiambu County has a 98 percent power coverage rate, with efficient last-mile coverage. Due to the rural electrification initiative, the number of rural households with access to electricity has increased. The overall number of households with access to electricity is now 70%, with this number anticipated to increase to 100% by 2022. Solar energy is used by fewer than 5% of the population, but biogas is used by 25% of farmers in Githunguri, Kikuyu, Limuru, and other sub-counties where dairy farming is prevalent. Wind coverage is not currently active as a source of electricity, although it is being tested in a trial project at Nachu-Ndeiya. UN Habitat has backed this initiative to promote renewable energy. In terms of street lighting, the Kenya Power and Lighting Company has played a significant role. The utilities directorate has installed flood masts around the county. (Kiambu CIDP, 2018).

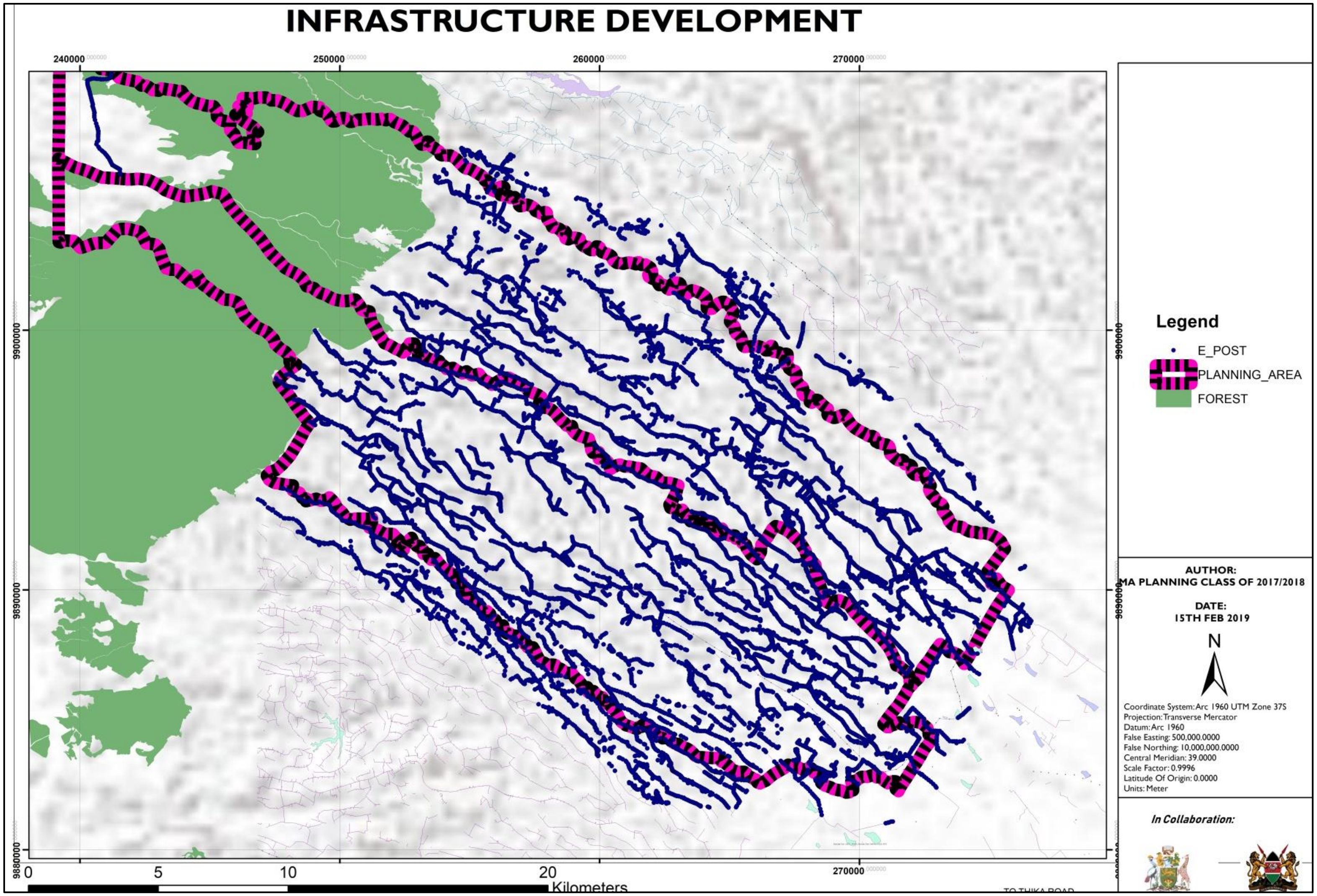


Figure 25: Infrastructure Map

4.6.2 Social Infrastructure

viii. Educational Facilities

4.6.2.1.1 Primary Schools

There are 180 primary schools in Gatundu, with 100 in the Gatundu North sub-county and 80 in the Gatundu South sub-county. The total number of students enrolled is 295,409, with 115,375 males and 113,910 females.

4.6.2.1.2 Secondary Schools

Gatundu North Constituency has 31 secondary schools while Gatundu South Constituency has 38 secondary schools. The region has a total 69 secondary schools.

4.6.2.1.3 Tertiary institutions

There are currently two tertiary institutions comprising of Gituamba Polytechnic and Mang’u Polytechnic, both located in Gatundu North Sub-county. These institutions play a major role in ensuring secondary school students in the locality acquire the necessary skills required in the job market. KMTC Gatundu campus was officially inaugurated by His Excellency President Uhuru Kenyatta on 13th April 2016. It is located approximately half a kilometer from Gatundu town, next to Gatundu level IV Hospital. Education is key in ensuring sustainable water storage for irrigated agriculture as it helps create awareness to the farmers.

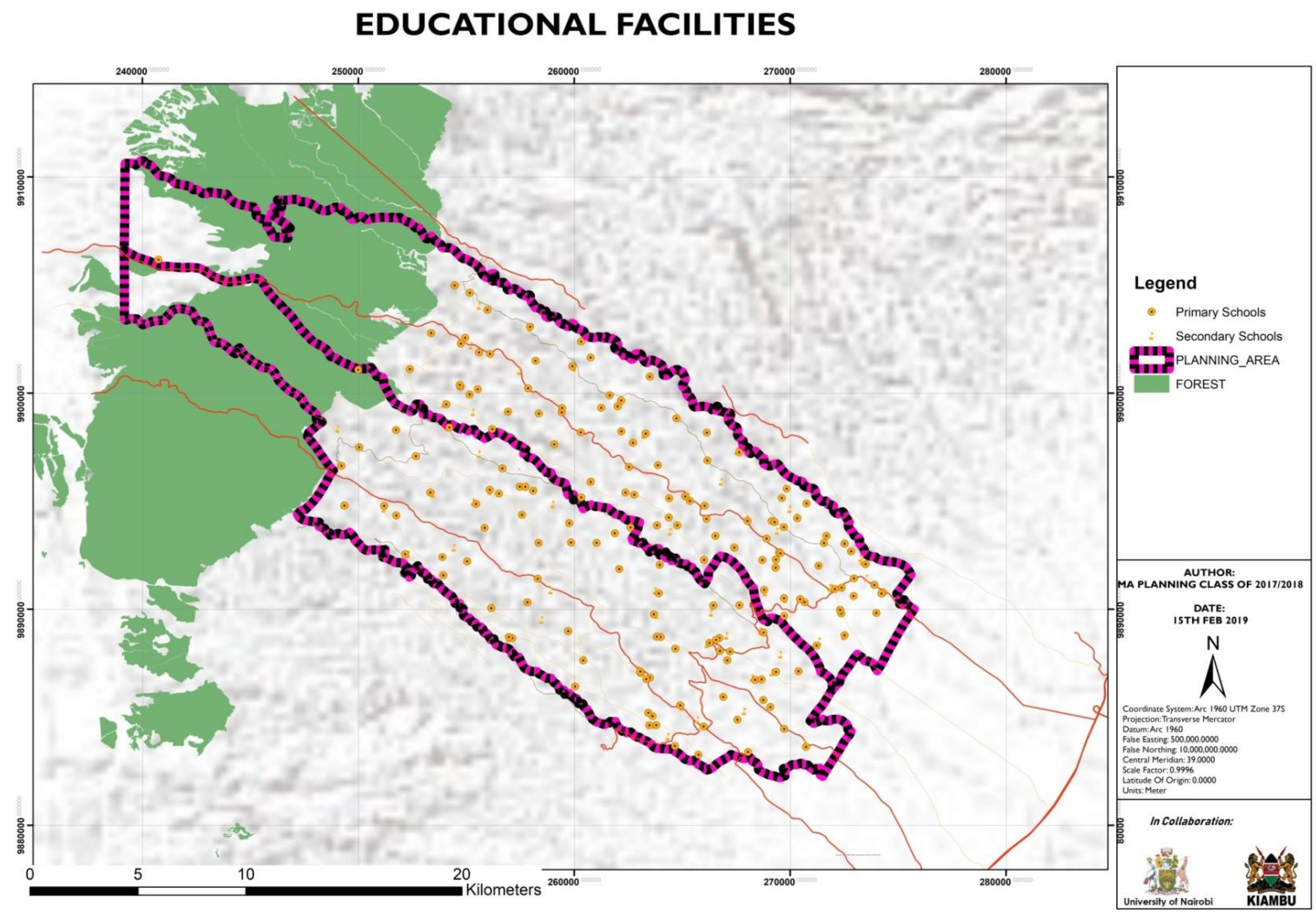


Figure 26: Schools in the study area

ix. Health Facilities

The Kiambu County administration has a goal for health care that includes providing accessible, affordable, and high-quality treatment to all Kiambu residents. Gatundu South and Gatundu North Constituencies are both part of Kiambu County, therefore they share a common vision (County Government of Kiambu, 2015). According to the Kiambu County CIDP 2013-2017, the county has a total of 364 health institutions. The county has one level-five hospital at Thika, three level-four hospitals and four level-three hospitals. Within the county, there are twenty level-2 health facilities and 54 level-1 health facility dispensaries that are widely spread. The other institutions are private with 17 Mission Hospitals, five nursing homes, 36 dispensaries, and 169 private clinics. The county's doctor-to-population ratio is 1:17,000, while the nurse-to-population ratio is 1:1,300. The average distance to the health center is 7 kilometers, and the amenities are easily accessible due to the excellent road network..

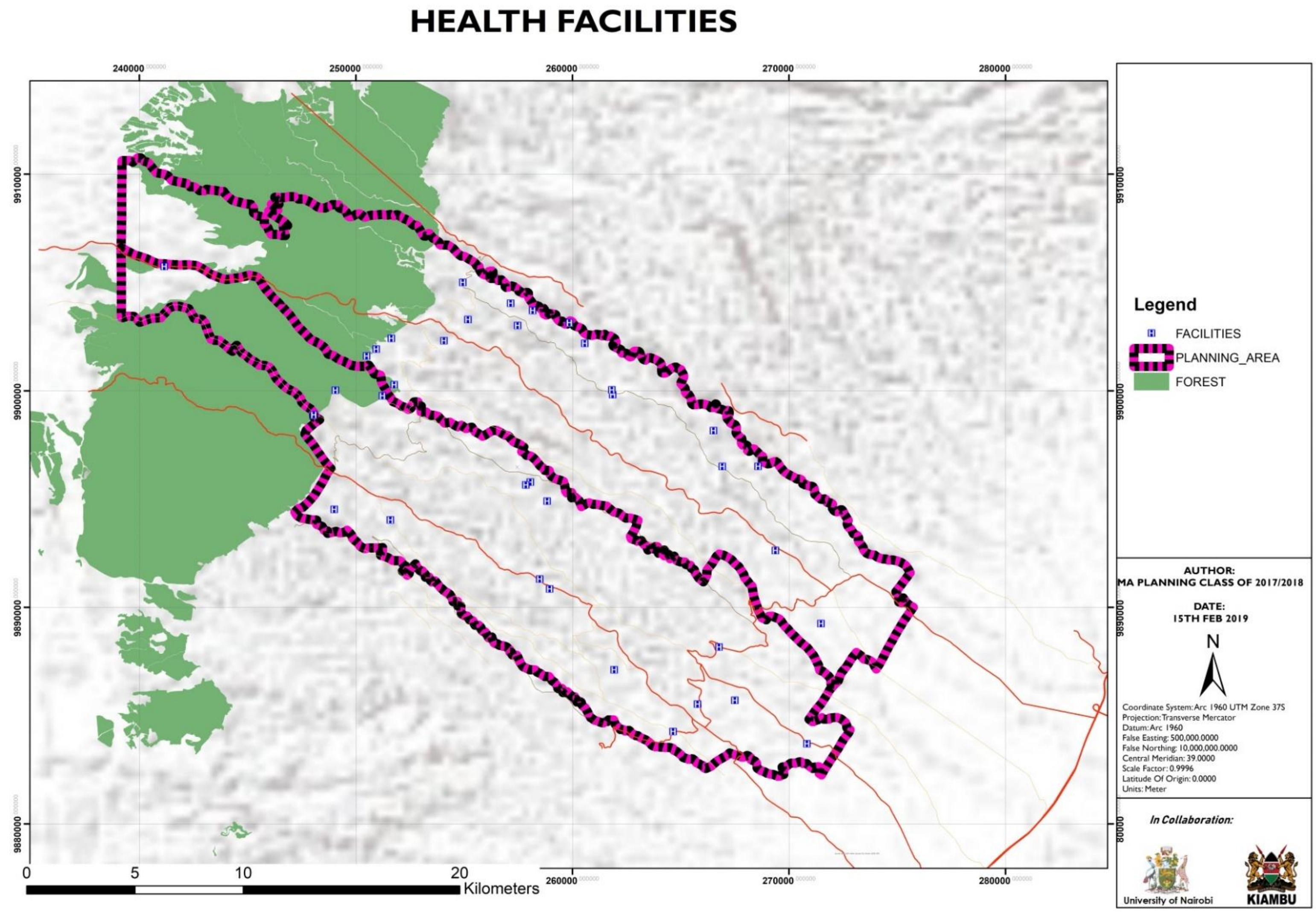


Figure 27: Health Facilities

x. Recreation Facilities

Other than tourist attraction sites such as Kinare Forest in Lari, Fourteen Falls in Juja, Chania Falls, Paradise Lost and Mugumo Gardens in Kiambaa, Gatamaiyu Fish Camp, Mau Mau Caves and other historical sites in Githunguri and Gatundu Constituencies, Kiambu county has no national parks or game reserves.

4.7 Conclusion

The chapter has reviewed the sectors that are likely to have direct impact on development of sustainable water storage structures for irrigated agriculture. The resource base of an area is directly proportional to the production rate and level of the area. Water the main commodity that promotes irrigation agriculture is scares in Gatundu North and South sub-counties. There is need to invest in sustainable water storage facilities for irrigated agriculture, in order to fully utilize the available potential.

CHAPTER 5. FINDINGS

5.1 Overview

This chapter presents an analysis of the data gathered during the period of the study. It presents the findings of the enquiry into the stated study objectives. The contents of the house hold questionnaires were analyzed quantitatively and that of key informants analyzed qualitatively to identify emerging issues relevant to the research questions. The analysis expresses findings on the adequacy of water storage structures in the study area, the factors affecting development of water storage structures in the study area. The criterion for choosing suitable locations for water storage structures has also been analyzed. Finally, the strategies and proposals suggested by the stakeholders have also been put into consideration. The findings and analysis here in lay a solid ground for the making of appropriate recommendations towards achieving sustainable water storage for irrigated agriculture.

5.2 Adequacy of water storage structures to ensure sustainable irrigated

5.2.1 Source of Water

Several sources of water were identified in the study area with piping taking the lead as the main source of water in the area with 40% and dams having the least with 1%. This is a clear depiction of water shortage in the area despite the existence of rivers whose potential can be tapped into to support irrigated agriculture.

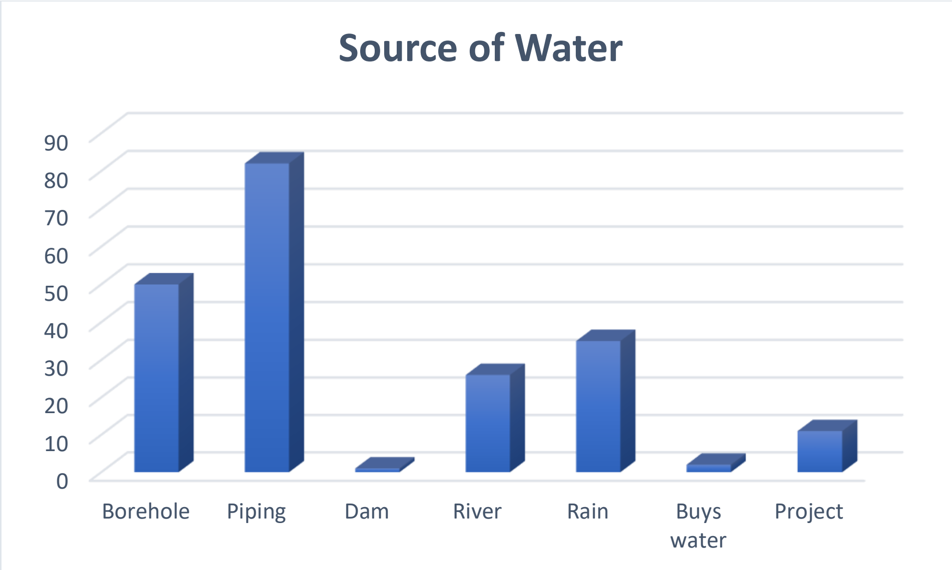


Figure 28: Source of Water in the area

5.2.2 Distance to water source

When asked about the distance to water source, with 99% of the population travelling less than a kilometer to get water. Only 1% of the population travel to about 3km to get water (*see table 12*). This is supported by the fact that piping is the major source of water in the area. The main water provider in the area is Gatundu water and Sanitation Company. Considering that piped water is rationed, it is not sustainable for irrigation agriculture.

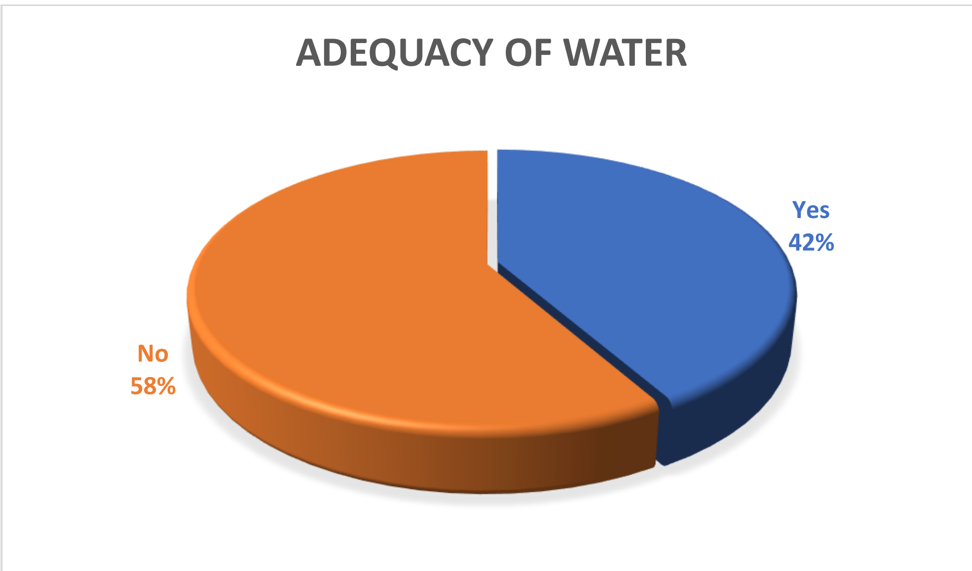
Table 12: Distance to water Source

Distance	Frequency
0-1	120
2-3	1

5.2.3 Adequacy of the available water

A question on whether the available water is adequate for irrigated agriculture was asked. Out of the sampled population 58% confirmed that the available water is not adequate for irrigated agriculture. This is further supporting the Kiambu county CIDP (2018-2022) which states water shortage in Kiambu as a major challenge despite the existence of several rivers. It further supports the key informant's response on the inadequacy of water storage facilities for irrigated agriculture in the area. The response also indicated that the available water pans in the area are not sustainable as they were pilot projects and were used to demonstrate the usefulness of water pans in irrigated agriculture.

The researcher found out that there were public water storage tanks in Gatundu north which could support irrigated agriculture, but they are underutilized. The only available dam in the area is Karimenu dam whose construction is underway.

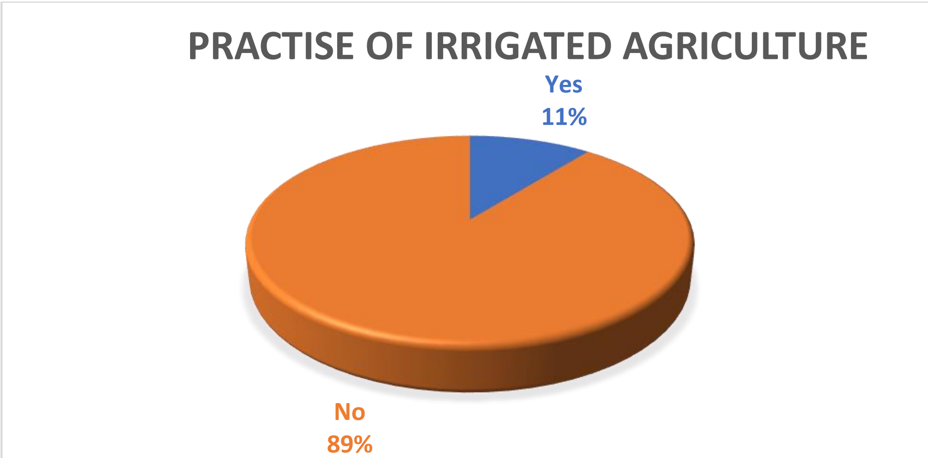


As much as the study area is endowed with several water sources whose potential could be tapped to support irrigated agriculture, Gatundu North and South lag behind in terms of irrigated agriculture as the available water is deemed inadequate.

5.3 Factors affecting the development of water storage structures for irrigated agriculture

5.3.1 Practice of Irrigated Agriculture

Only a small percentage of the sampled population practices irrigated agriculture. This contradicts the areas potential for irrigated agriculture. This finding is supported by the county integrated development plan states that Irrigation potential in Kiambu County is about 62,812 acres (254 km^2), however only 7,500 acres (12%) are irrigated (Govenment, 2018-2022). The small percentage which practice irrigated agriculture is mainly found along the main rivers in the study area. These rivers include Karimenu, Chania, Thiririka, Komu and Ndarugu.



5.3.2 Type of Crop Grown

The large percentage that did not practice irrigated agriculture appeared to be growing tea, coffee bananas and avocados. These crops survive in cold and wet areas and rarely need to be irrigated thus favorable for the area.

Figure 29: Banana Plantation in the study area

Source: Field survey, 2019

Figure 30: Coffee Plantation

Source: Field survey, 2019

Figure 31: Tea Plantation

Source: Field survey, 2019

Another portion of this population relied on rain fed agriculture to grow maize, beans, pineapples and potatoes.

Figure 32: Potatoes in the study area

Source: Field survey, 2019

Figure 33: Maize and Beans in the study area

Source: Field survey, 2019

Figure 34: Pineapple Plantation

Source: Field survey, 2019

5.3.3 Factors Affecting Irrigated Agriculture

The 69% of the population that does practice irrigated agriculture sited lack of enough water as the main reason. This has led to overreliance on rain fed agriculture. Others 25% cited lack of resources as the contributor to not practicing while 6% thought it was wastage of time (*see figure 33*). This is supported by the key informant's response on water shortage as the main hindrance to irrigated agriculture.

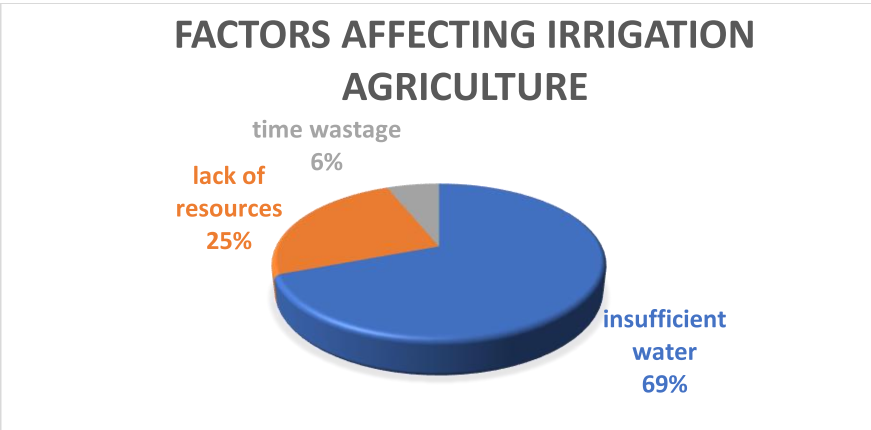


Figure 35: Factors affecting irrigated agriculture

The agricultural officer in Gatundu sub-county office also cited land fragmentation and land disputes as factors affecting irrigated agriculture. In other cases, lack of value addition for the farm products which has in turn affected the production levels of the area was highlighted as a challenge to irrigated agriculture

5.4 Criteria for choosing suitable locations for water storage structures for irrigated agriculture

The study adopted hydrological analysis in determination of suitable locations for water storage structures for irrigated agriculture. In the determination the following factors were considered:

a) Physiography of the study area
b) Soil and geology data
c) Settlements in the study area.
d) Agricultural projects in the area.
e) Roads and their pipe culverts.

With the aid of GIS and remote sensing, these factors aided in determination of the best locations for water pans and dams. Using the direction of flow several flood areas were identified as suitable for location of water pans. River valleys along the permanent rivers were also identified as suitable for location of large dams to support irrigated agriculture.

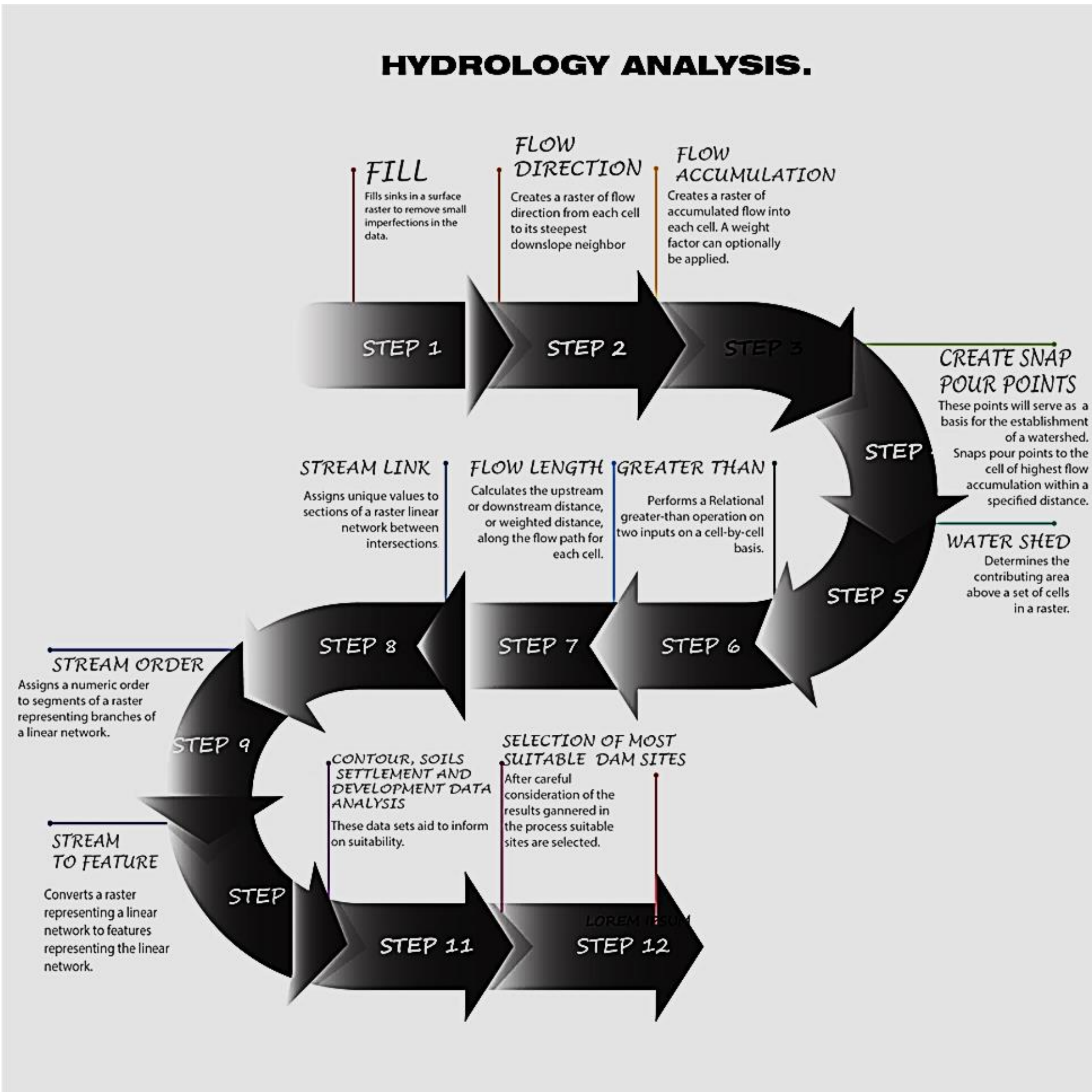


Figure 36: Hydrological Analysis

Source: Author, 2019

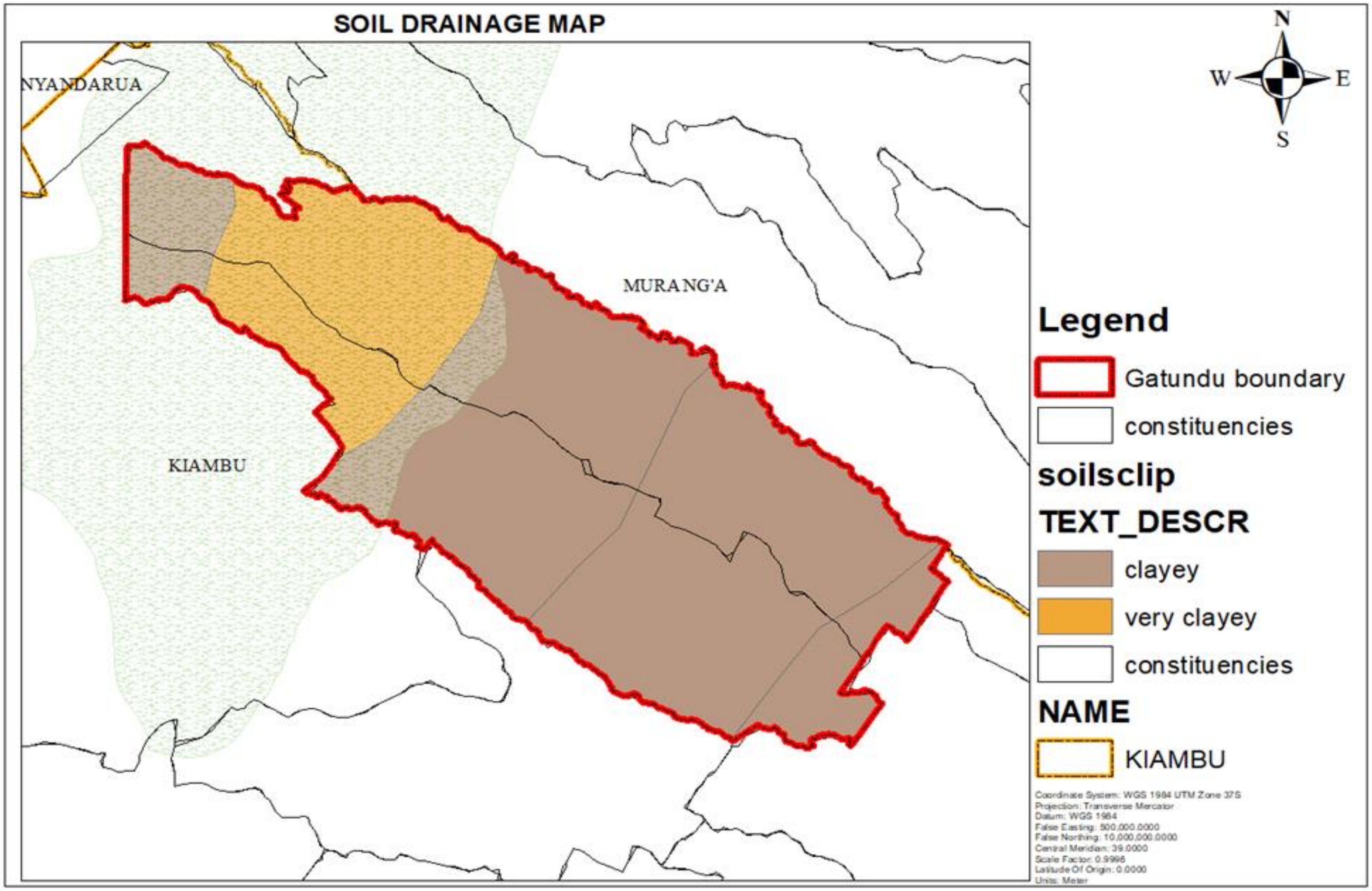


Figure 37: Soil Drainage

Source: Author, 2019

5.5 Strategies to ensure adequate water storage facilities for irrigated agriculture

5.5.1 Support for Construction of Water Storage Facilities

Majority of the interviewed population 94% gave a positive response to support of construction of water storage facilities for irrigated agriculture. The 6% percent who did not support claimed that the available water is enough, their land is not suitable for irrigated agriculture and that water storage structures kill people.

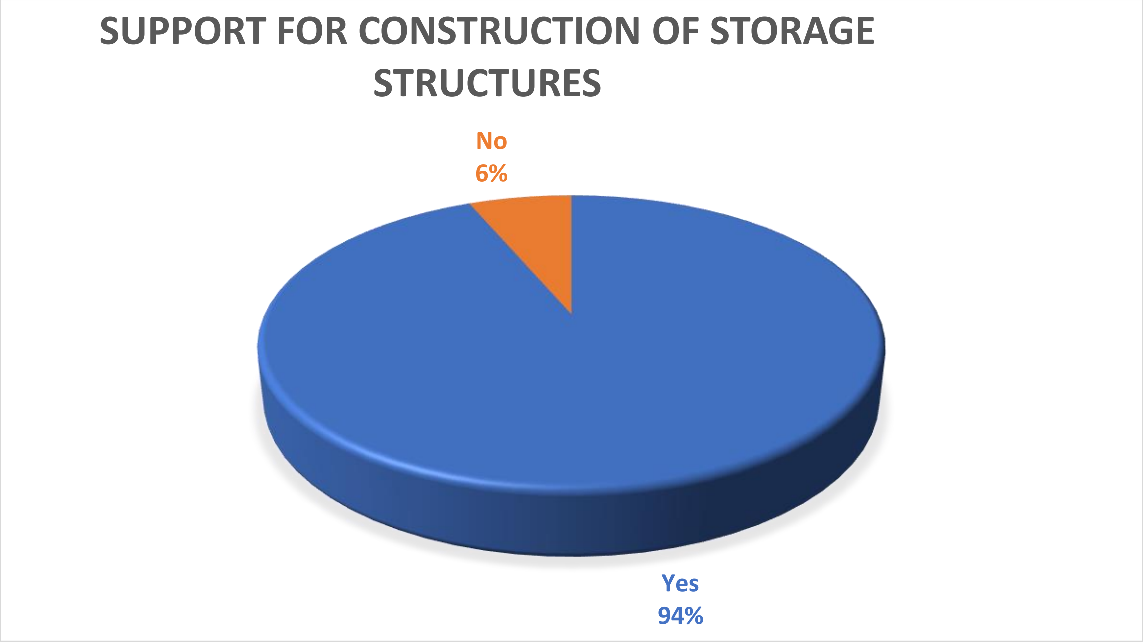


Figure 38: Support for Construction of Storage structures

5.5.2 Collaboration with the residents

The respondents, who supported construction of suitable water storage structures for irrigated agriculture, gave proposals for the support they would provide. With 58% promising to provide free labour, 27% to give financial support and 15% promising to donate land for construction of the same. This is an indication that the residents of Gatundu North and South are ready to accommodate suitable storage structures for irrigated agriculture. This is supported by the key informants' response of welcoming the idea of suitable water storage structures for irrigated agriculture in the area as they saw in as an added advantage not only to the sub counties but also to the farmers.

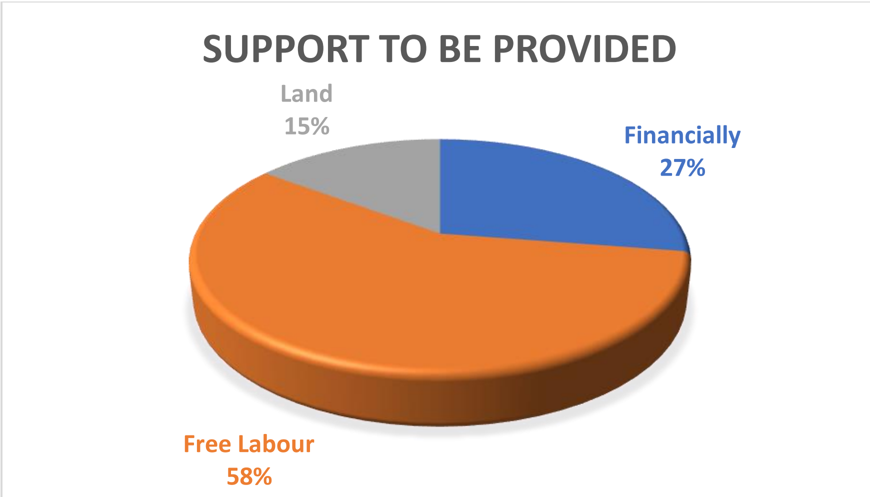
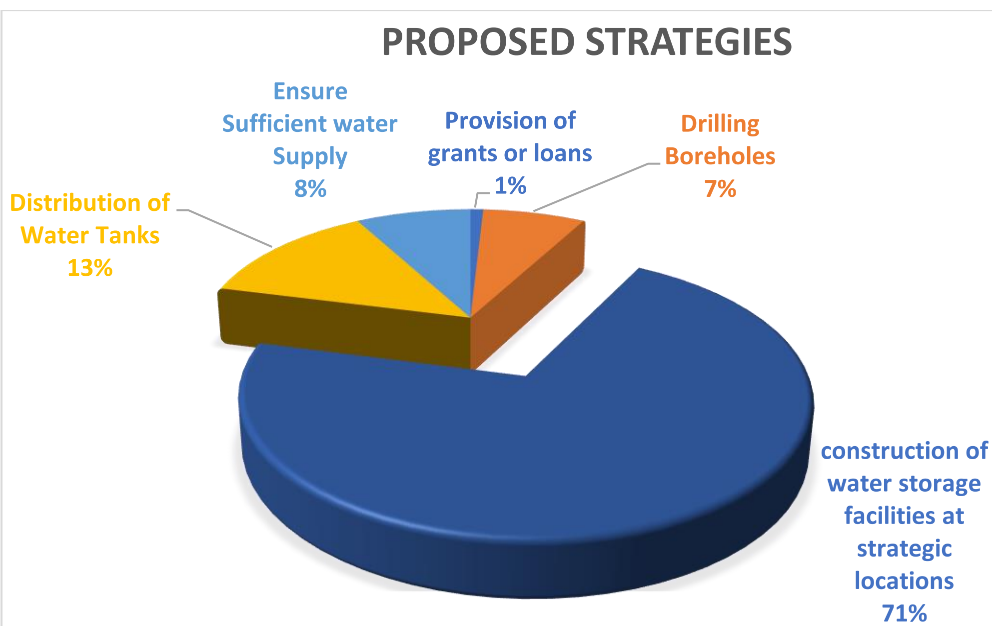


Figure 39: Support to be given

5.5.3 Proposed water storage strategies

In order to achieve sustainable irrigated agriculture, the residents proposed construction of water storage structures at strategic locations. This will not only serve the adjacent farmers but also those far from the structures. For storage structures located on high grounds, water can flow by gravity through canals to the farms; while for storage structures on low grounds water can be pumped to a storage tank on a high ground then it flows by gravity through canals to the farms.



CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Despite the study area being endowed with rivers whose potential can be tapped into to support irrigated agriculture, the area lags behind in terms of irrigated agriculture. There are no adequate water storage infrastructures to support irrigated agriculture thus the residents entirely depend on rain fed agriculture. Poor land tenure, land fragmentation and lack of value addition for arm products adversely affect irrigated agriculture in the study area.

6.2 Recommendations

Informed by the objectives and findings of the study, the following proposals were identified to achieve sustainable water storage structures for irrigated agriculture in Gatundu North and South Sub counties. The recommendations have been classified into short and long-term recommendations.

6.2.1 Short Term Recommendations

i. Land use zoning

In order to create more land for agricultural use, water harvesting, development of irrigation schemes, and factories for food processing there is need to prepare land use zoning for Gatundu North and South Sub counties.

ii. Feasibility studies

For identification of viable areas for construction of water pans and mega dams, a feasibility study to determine rivers with the highest potential for construction of mega dams to support irrigated agriculture and flood areas for construction of water pans is required. A detailed topographic analysis is also necessary to decide if the reservoir water can be supplied by gravity or by a pumping system.

iii. Creation of awareness

Community sensitization on the need to establish sustainable water storage structures for irrigated agriculture is required. Training programs on the appropriate and standardized irrigation schemes, proper terracing of the farms, the best irrigation methods, irrigation scheduling are therefore required.

6.2.2 Long Term Recommendations

These are recommendations that are expected to be implemented within ten years

iv. Development of water storage structures

After identification of suitable locations for water storage structures, it is advisable to develop them in order to benefit the community. The suitable locations for the water pans and dams are as shown in figures 41- 45. For proper implementation phasing is required.

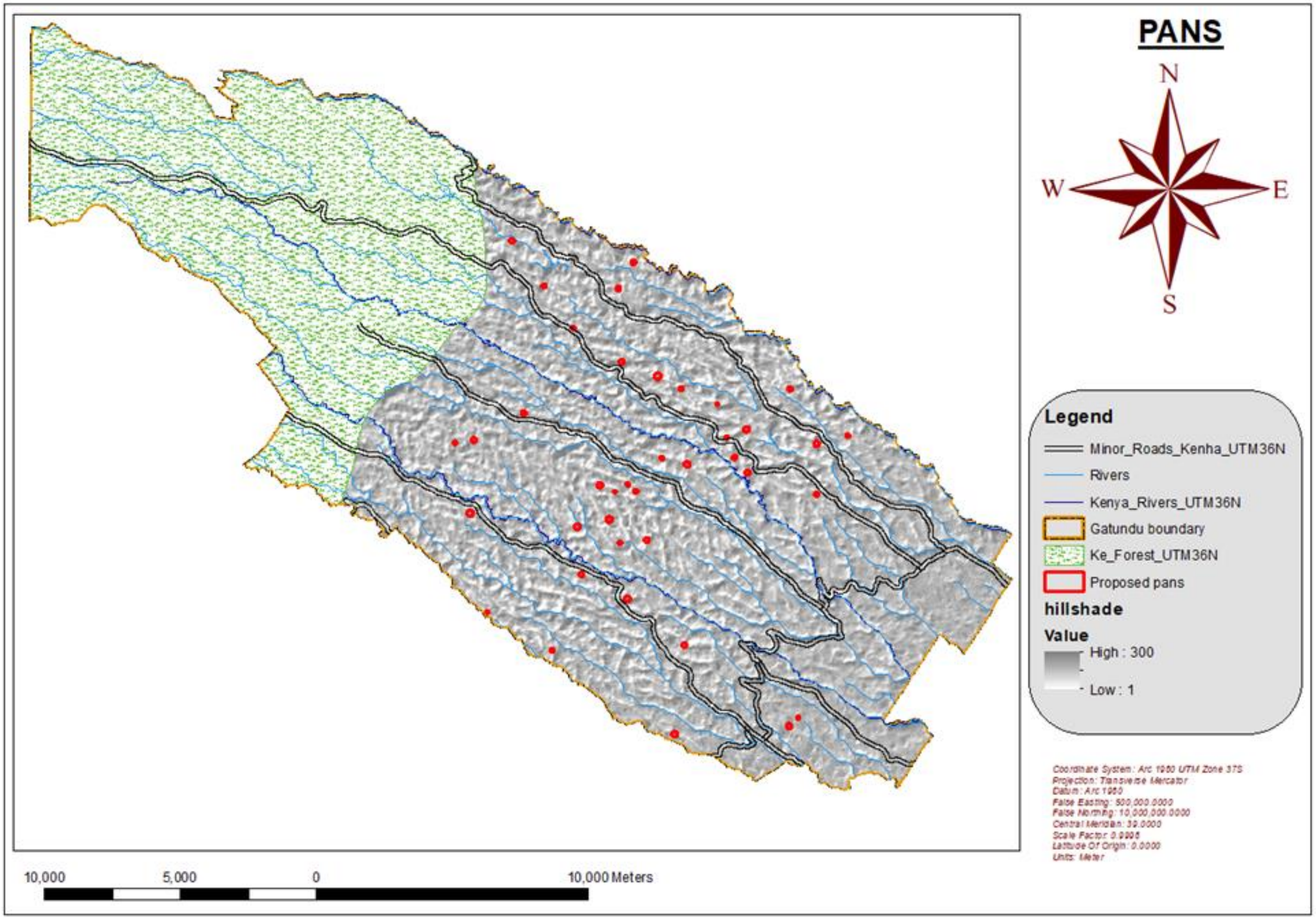


Figure 40: Selected Sites for Water Pans

Source: Author 2019

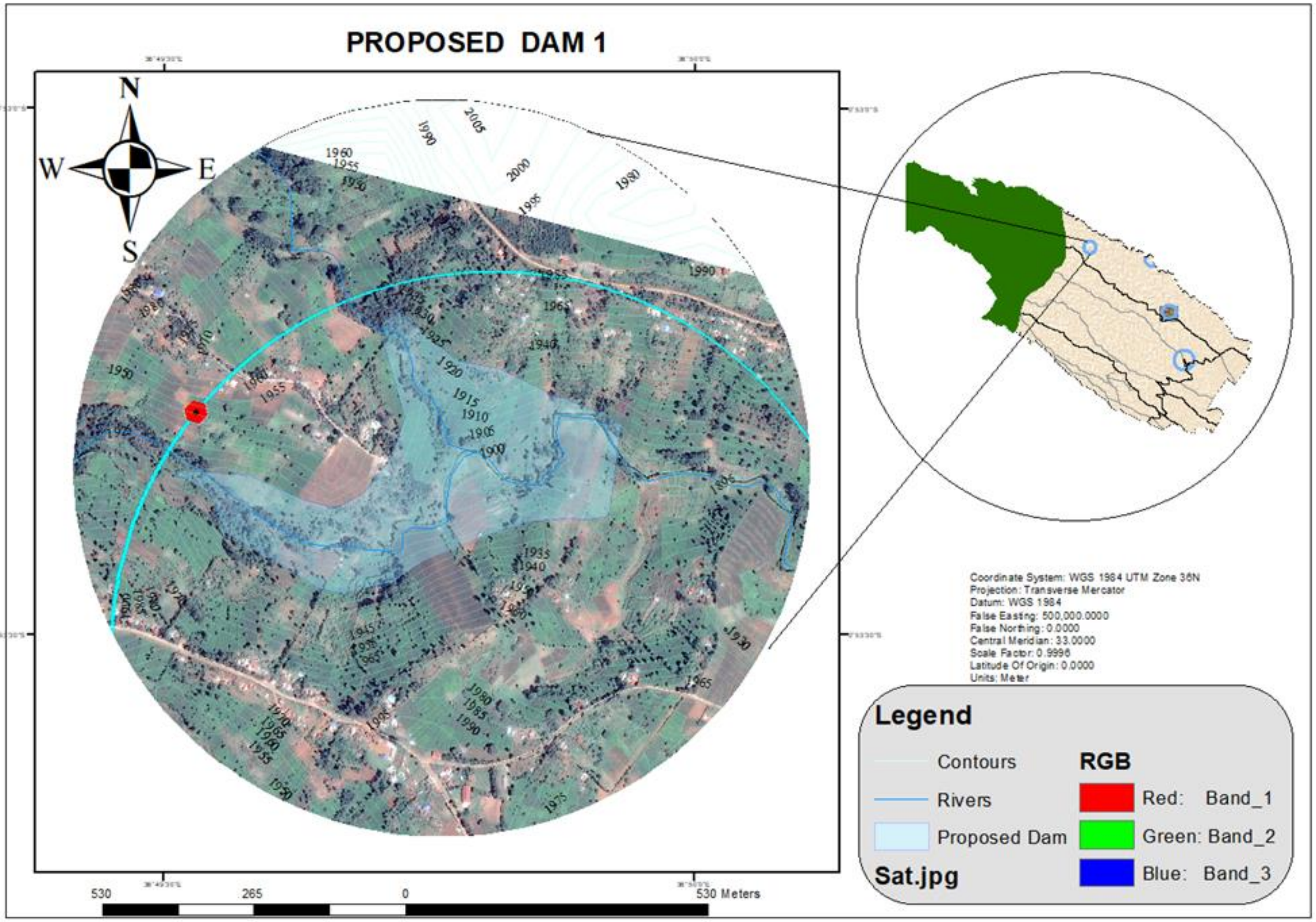


Figure 41: Proposed Site for Dam 1 along Karimenu River

Source: Author 2019

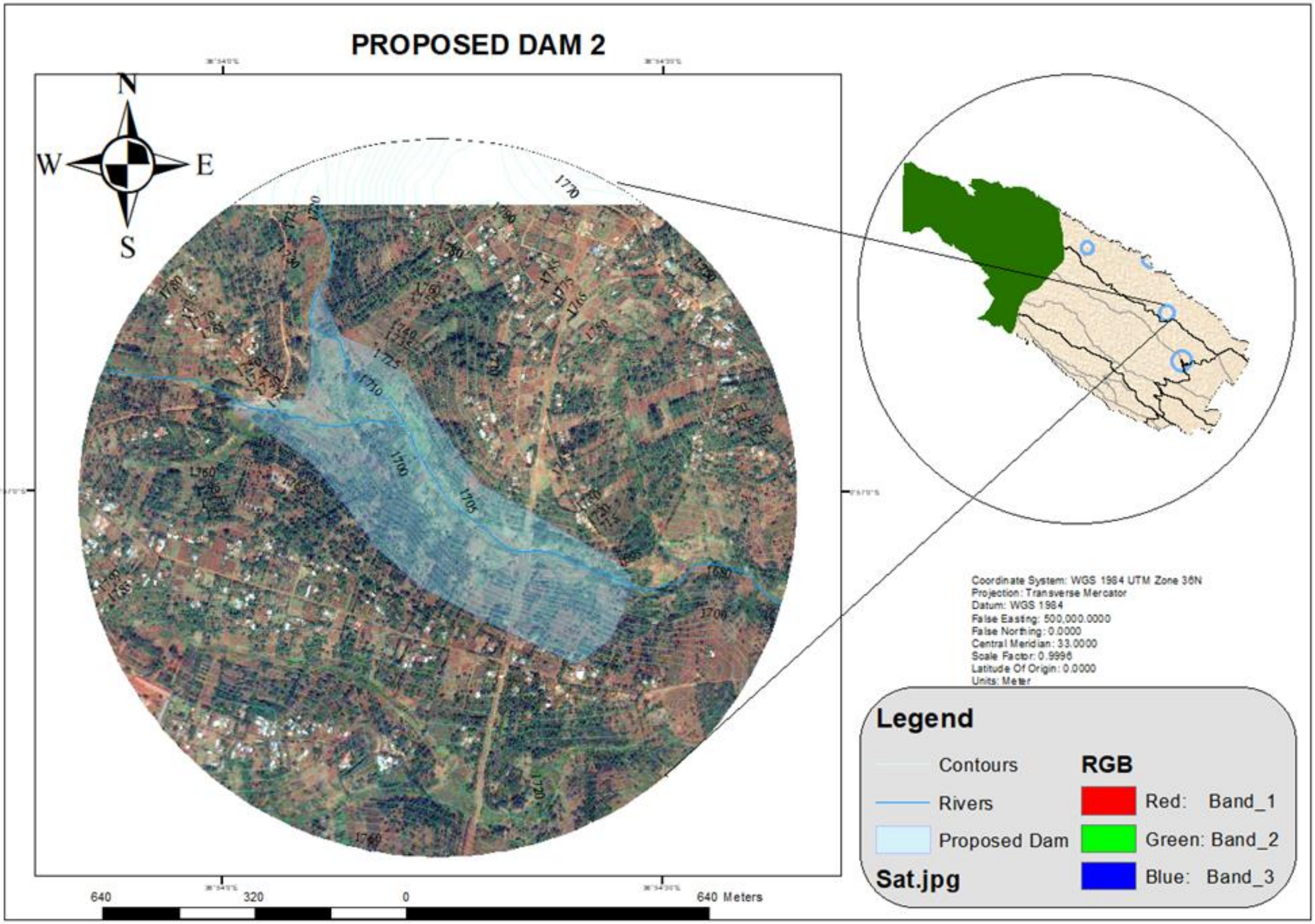


Figure 42: Proposed Site for Dam 2 along Karimenu River

Source: Author 2019

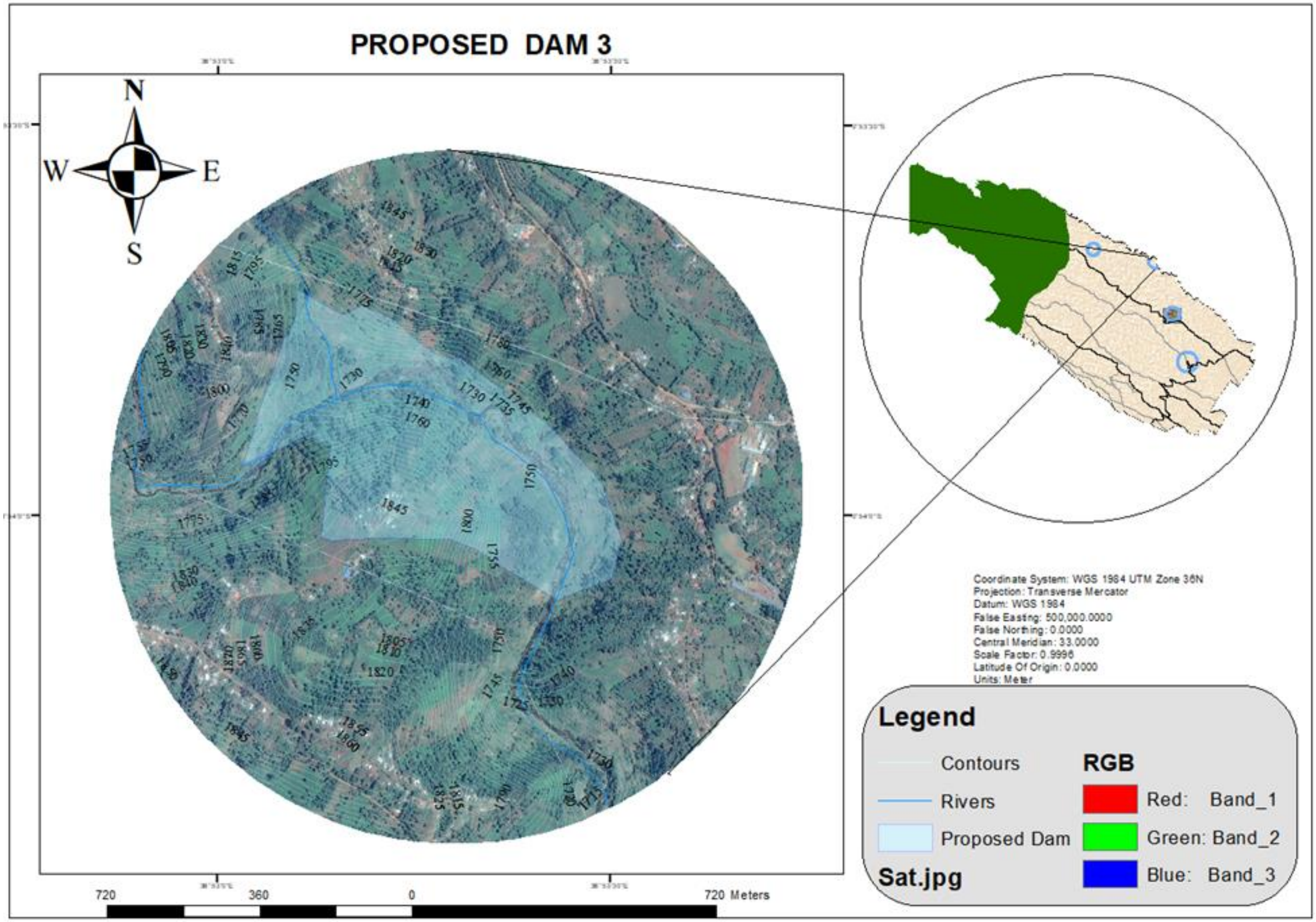


Figure 43: Proposed Site for Dam 3 along Chania River

Source: Author 2019

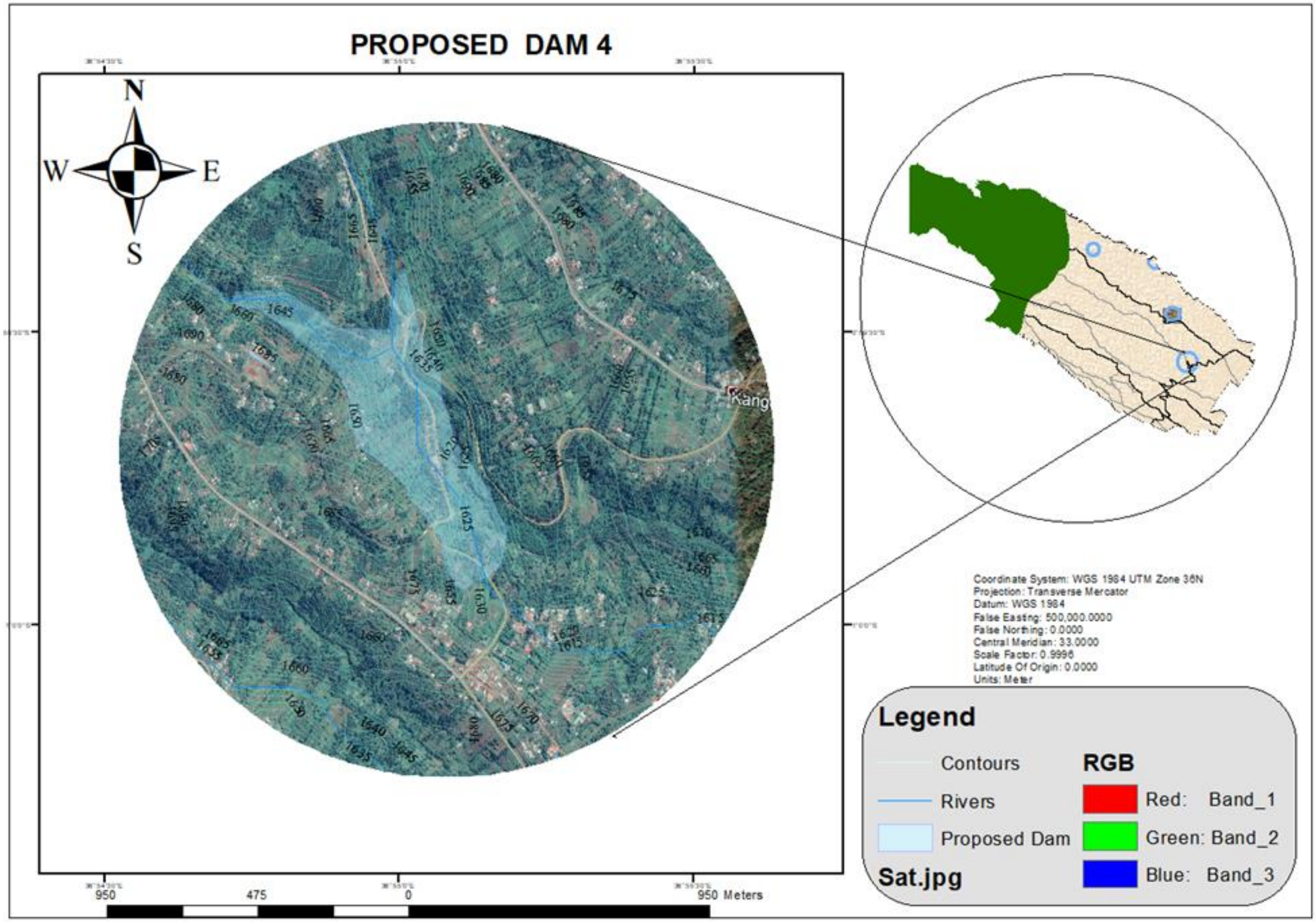


Figure 44: Proposed Site for Dam 4 along Ndarugu River

Source: Author 2019

v. Expansion of irrigated agriculture

To enhance agricultural productivity and production, irrigation should be extended in rain-fed agricultural regions in the research area. Farmers face a variety of difficulties as a result of unreliable and inadequate water delivery, including a lack of water supply, which leads to poorer yields and lower earnings, as well as a drop in the amount of area under irrigation. Water-saving irrigation should be adopted to increase water productivity in all irrigation regions in order to fully utilize available water resources effectively for the long-term sustainability of irrigation development.

vi. Scheduling irrigation

Poor management is one of the primary causes of decreased water efficiency in irrigation. Water-saving irrigation should be adopted to increase water productivity in all irrigation regions in order to fully utilize available water resources efficiently for the long-term sustainability of irrigation development.

6.3 Areas of Further Research

A detailed topographic analysis is also necessary to decide if the reservoir water can be supplied by gravity or by a pumping system..

Determination of rivers with the highest potential for construction of mega dams to support irrigated agriculture and flood areas for construction of water pans.

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Appendices

Appendix 1: Household Questionnaire

DECLARATION: *The information supplied herein will be used for academic purposes only and will be treated with utmost confidentiality.*

Name of Ward:

Name of Village:

Name of Interviewer:

Phone No.:

<table>
<tr><th>No.</th><th>Question</th><th>Answer</th><th>Code</th></tr>
<tr><td colspan="4">Respondent Information</td></tr>
<tr><td>1)</td><td>Name(optional)</td><td></td><td></td></tr>
<tr><td>2)</td><td>Gender</td><td>(1) Male (2) Female</td><td></td></tr>
<tr><td>3)</td><td>Age(years)</td><td></td><td></td></tr>
<tr><td>4)</td><td>How many people live in your house including yourself?</td><td></td><td></td></tr>
<tr><td>5)</td><td>What is your highest level of education?</td><td>(1) University (2) College (3) Secondary (4) Primary
(5) ECDE (6) None (7) Others(specify)</td><td></td></tr>
<tr><td colspan="4">B. Status of Irrigated Agriculture / Adequacy of Water Storage</td></tr>
<tr><td>6)</td><td>Size of land in acreage</td><td></td><td></td></tr>
<tr><td>7)</td><td>Acreage under agriculture (crop)</td><td><table><tr><th>Type of Crop</th><th>Acreage</th></tr><tr><td></td><td></td></tr><tr><td></td><td></td></tr><tr><td></td><td></td></tr></table></td><td></td></tr>
<tr><td>8)</td><td>Source of Water (approximate distance- Interviewer to equate 15min walk to a kilometer)</td><td><table><tr><th>Source</th><th>Approx. Distance/ walking time</th></tr><tr><td></td><td></td></tr><tr><td></td><td></td></tr></table></td><td></td></tr>
</table>

<table>
<tr><th>No.</th><th>Question</th><th>Answer</th><th>Code</th></tr>
<tr><td></td><td></td><td><table><tr><td></td><td></td></tr></table></td><td></td></tr>
<tr><td>12)</td><td>Do you have any onsite water storage facility</td><td>Yes
No</td><td></td></tr>
<tr><td>13)</td><td></td><td></td><td></td></tr>
<tr><td>14)</td><td>a. Do you practice Irrigated Agriculture?</td><td>Yes
No</td><td></td></tr>
<tr><td></td><td>b. If no to a. above, why?</td><td>______________________________________
____
________________</td><td></td></tr>
<tr><td></td><td>c. If yes to a. above, what size of your land is under Irrigation agriculture in acres?</td><td></td><td></td></tr>
<tr><td>15)</td><td>Is the water enough for your cultivation needs</td><td>Yes
No</td><td></td></tr>
<tr><td>16)</td><td>If no how do you supplement your irrigation?</td><td></td><td></td></tr>
<tr><td>18)</td><td>What crops do you cultivate?</td><td>Cash crop
Food crop
Both</td><td></td></tr>
<tr><td>23)</td><td>Do you keep livestock?</td><td>Yes
No</td><td></td></tr>
<tr><td>24)</td><td>If no why?</td><td></td><td></td></tr>
<tr><td>25)</td><td>If yes which ones?</td><td><table><tr><th>Livestock</th><th>No.</th></tr><tr><td>Cattle</td><td></td></tr><tr><td>Goats</td><td></td></tr><tr><td>Sheep</td><td></td></tr><tr><td>Pigs</td><td></td></tr><tr><td>Poultry</td><td></td></tr></table></td><td></td></tr>
</table>

No.	Question	Answer	Code
		Others(*specify*)		
26)	Where do you get water for your livestock needs and how far is the source?	**Source** / **Approx. Distance.**	
27)	Is the water supply sufficient?	Yes No	
28)	If no, how do you supplement for your livestock water needs?		
	C. Suitable Locations for Water Storage Facilities		
29)	Would you support construction of a water storage facility to supplement your water needs?	Yes No	
30)	If yes, how would you support?	Financially Free labor Land Others (*specify*)	
31)	If no, why?		
	G. Strategies to be put in Place		
32)	What strategies do you think should be put in place to ensure adequate water storage facilities for irrigated agriculture?		

No.	Question	Answer	Code
	____ ____ ____ ____ ____ ____		
34)	**H. Comments/observations** ____ ____ ____ ____ _______________________________________		

Thank you for your time!

Appendix 2: Key Informant Interview Schedule

DECLARATION: *The information supplied herein will be used for academic purposes only and will be treated with utmost confidentiality.*

Sub-location………………………………………...………..…………………….

Name of Informant……………………….……………….…….……………….….…

Designation of Informant………………………………………………………….

Date of Interview……………………………….……………………..…………….

Interview Guide Questions

1) What are the main water harvesting methods in Gatundu North and South Sub-counties?
2) Please state the limitations of each water harvesting method
3) What water storage facilities exist for irrigated agriculture in Gatundu North and south sub- counties?
4) Please indicate their location?
5) What are their capacities and distribution?
6) Which are the suitable locations for new water storage facilities for irrigated agriculture?

Please find attached tables to comment on the distribution of the water storage facilities

Earth Dams

s/no	Name of water pan	Location	Capacity /Size	Purpose	Source of Water	Ownership	Date of Completion	Suitable locations for new water Dams
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								

Water Pans

S/no	Name of water pan	Location	Capacity /Size	Purpose	Source of Water	Ownership	Date of Completion	Suitable locations for new water Dams
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								

Storage Tanks

s/no	Name of water pan	Location	Capacity /Size	Purpose	Source of Water	Ownership	Date of Completion	Suitable locations for new water Dams
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								

Limitations of Each water storage method

S/No	Method	Limitation
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		