University of Nairobi

School of Engineering

DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

GIS- BASED MULTI-CRITERIA DECISION ANALYSIS OF URBAN PIPED WATER DEMAND:

A CASE STUDY OF LODWAR TOWN TURKANA COUNTY, KENYA

BY

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A project report submitted in partial fulfilment of the requirements for the Degree of Master of Science in Geographic Information Systems, in the Department of Geospatial and Space Technology of the University of Nairobi

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Dedication

I dedicate this project to my parents, the late Mr. James Wanguba, my mother Mrs. Hellen Amisi for their tireless effort in educating me, my brothers & sisters for encouraging me to work hard in my education.

Acknowledgement

I take this opportunity to thank my lecturer Mr. B.M. Okumu for his guidance, corrections and critique he offered me as the supervisor during the entire project period.

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Lastly, I would like to express my gratefulness to the Almighty God for the far He has brought me.

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List of Acronyms and Abbreviations

AHP – Analytical Hierarchy Process

ASAL – Arid and Semi-Arid Lands

BWR – Basic Water Requirement

CAD – Computer-Aided Design

CBD – Central Business District

CIP – County Investment Plan

COK – Constitution of Kenya 2010

CI – Consistency Index

CR – Consistency Ratio

DEM – Digital Elevation Model

FAO – Food and Agricultural Organization

GIS – Geographic Information Systems

GIS-MCDA – Geographic Information Systems Multi-Criteria Decision Analysis

GloVis – Global Visualization

GPS – Global Positioning System

GWR – Geographical Weighted Ratios

HDD – Hard Disk

Hh – Household

IDP – Integrated Development Plan

ILRI – International Livestock Research Institute

JICA – Japan International Cooperation Agency

LULC – Land Use & Land Cover Classes

LOWASCO – Lodwar Water and Sanitation Company

MCDA – Multi-Criteria Decision Analysis

NGO – Non- Governmental Organization

NRW – Non-Revenue Water

OLS – Ordinary Least Squares

RI – Ratio Index

SoK – Survey of Kenya

SRTM – Shuttle Radar Topography Mission

TB – TeraByte

UNDESA – United Nations Department of Economic & Social Affairs

USGS – United States Geological Survey

UTM – Universal Transverse Mercator

UN-Water – United Nations Water

WSTF – Water Sector Trust Fund

WGS – World Geodetic System

WASREB – Water Services Regulatory Board

Abstract

Water scarcity has become a global problem as a result of the ever-growing demand for water. The rapid urbanization, the population explosion and the growth of new settlements in small towns have increased the demand for water resources thereby leading to scarcity of available water resources. The water service providers are currently facing a bigger challenge of maintaining a stable and safe water supply of such towns to satisfy the growing demand.

Lodwar town in Turkana County Kenya which largely depends on groundwater as the main water source is one such small town in a fragile environment facing such a high-water demand. The water service provider (LOWASCO) runs about 11 boreholes situated along the Turkwel River within a radius of about 10km. In this study, the Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) methods were utilized in the mapping of residential piped water demand for the urban area for the period 2017 to 2019. The datasets used in this research included topographic maps, population data, urban spatial plan, area slope, Land use /Land cover change map as well as the detailed water utility infrastructure map. The methodology included the processing of satellite imageries for further land use analysis, Digital Elevation Model (DEM) was used to extract slope information. The resultant layers together with other data collected were projecting into the study area coordinate system WGS UTM Zone 36N. Saaty's Analytic Hierarchy Process (AHP) method was applied in the calculation of respective weights for each factor influencing water demand as identified by the officers at LOWASCO and from the fieldwork.

The analysis of the final Land use results indicated that the built-up areas are within the town centre and some parts of Kanamkemer area to the South forming two business centres with high water demand. Subsequently, areas around the proposed CBD/Town Centre have the highest population densities per km^2 i.e. range (22555 – 37789) for respective unit areas within a range of (0.013833 - 0.014317) km^2. The resultant water demand maps from records for the LOWASCO zones within period 2017 to 2019 indicated that Town B has the highest average annual water per capita demand of 86.595M^3 whereas Nakwamekwi zone has the lowest average annual per capita demand of 8.497M^3. The combination of main demand factors in the model produced a resultant map with different demand priority areas. The expanding urban areas/settlements to the South West (Kanamkemer) from the Town Centre and to the South East (Nawoitorong) should be given high priority in the future expansion of water distribution system.

1. CHAPTER ONE: INTRODUCTION

1.0 Introduction

This chapter focuses on the background to the study which leads to the problem statement detailing the issue under investigation. The objectives of the study are highlighted followed by the justification on why the research is crucial at the moment and its contribution to the solution problem at hand. The chapter ends by describing the scope of work that was carried out.

1.1 Background

The world is currently off-track towards solving the global water crisis with approximately 2.1 billion people experiencing inadequate safely-managed drinking-water (UN World Water Assessment Report, 2018). According to FAO (2018), global water demand is growing with changing consumption patterns, rapid population growth, and economic development. This accelerating urbanization has exacerbated water management challenges for many large cities across most regions in the world. Even though Asia and Africa's population remains mostly in the rural, these regions have started to experience the most rapid urbanization rates which are evaluated at 1.5% and 1.1% per year, respectively (UN DESA, 2017).

In the Kenyan context, a comparative analysis of Kenya urbanization trends by UN DESA 2018 shows rising populations as shown in Figure 1.1. Consequently, it has been established that the water demand in most towns is higher than production (WASREB, 2018). Lodwar town, located in North-Western Kenya's arid environment depends largely on groundwater resources. The water potential report by the JICA team (2013) indicated that the water demand for Lodwar town is very high. Most of the peri-urban areas of the town have no reliable water resources, the people living there depend largely on portable water supplied by water tankers and trucks from the town centre. The town's existing water and sanitation facilities are old and in a dilapidated state (inherited from the colonial government) thus unable to meet the present and future demands of the growing urban population. The Turkwell River which is an alternative water source has been affected by uncontrolled human activities such as enormous sand harvesting and irrigation upstream resulting in severe environmental degradation. This has led to the river regime changes and reduced retention capacity (CIP, 2016). The discovery of alluvial aquifers at the Napuu basin (UNESCO, 2013) has been a big relief for the water situation in Lodwar town but not until when the supply works are complete that town will have sufficient water. The main water service provider for the town, Lodwar Water and Sanitation Company LOWASCO (founded in 2007) runs about 11 solar/electric powered boreholes situated along the Turkwell River within a radius of 10km which serve most of the town population. Some areas of the town areas (especially the peri-urban villages) do not get enough water and rely on water from the kiosks and elevated tanks and mostly from hand-pumps built by Non-Governmental Organizations (NGOs) in partnership with LOWASCO. Consequently, the urban population connected to piped water is facing problems such as the inadequate supply of water due to low pressure, frequent pipe burst, excessive leakages due to dilapidated supply network among others (REACH, 2015)**.** The expanding urban settlement areas far from the town, even though they have water pipe network coverage but lack a steady water supply most of the time.

There is a need to mitigate this challenge of high-water demand to ensure all areas and zones within the town have even distribution of reliable water. To ensure an equitable water distribution system is developed, the reliable information on water demand is necessary for the water service provider. The spatial modelling of urban water demand can generate such crucial information for the water service providers and top-level decision-makers in the County Government Ministry of Water and Irrigation. This will in-turn play a major role in the efficient planning, development, and distribution of the water supply system to cover all the urban zones. The spatial demand modelling can also help the water utility managers in the planning for cost-effective and reliable infrastructure expansion plans of available water supply sources besides incorporating water demand management programs (House-Peters & Chang, 2011). It is against this background that the study aimed at assessing and mapping the piped water demand by applying geoinformation methods and multi-criteria decision analysis to provide in-depth knowledge of the long-term dynamics of demand in Lodwar town. The study focused on Lodwar town in Turkana County as an emerging urban area in Northern Kenya fragile environment currently experiencing population pressure. The extreme location of the town and its strategic importance to the Turkana County calls for proper planning of water infrastructure among other critical infrastructure to effectively serve its functions as the county headquarters.

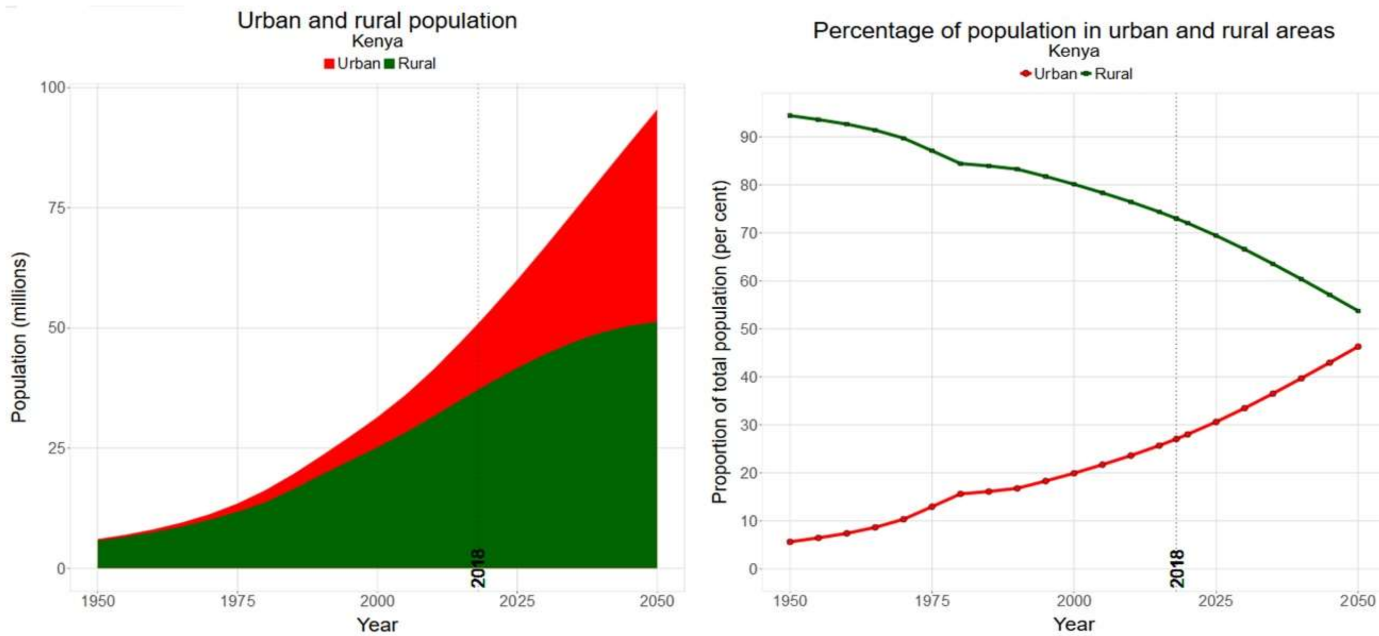

Figure 1.1: Urbanization Trends-projections, Town Scales, Rural-Urban Growth Projection.

Source © 2018 United Nations, DESA, Population Division.

1. 2 Problem Statement

Kenya is classified as one of the most water-scarce countries in Africa which receive 647m^3 of freshwater per capita per year (Mogaka et. al, 2006). The imbalances in the water supply can affect the natural patterns of growth in urban areas and or small towns. Water resource valuation and management are fundamentally geographical activities which require the handling of multiple forms of spatial data. The various combinations of geographic information systems mapping and simulation models can provide decision-makers and water managers with interactive analysis tools that can help in arriving at management actions which might positively affect that water distribution system.

Lodwar town is facing an increased water demand due to rising urban population and emerging sectors which have spurred rapid urbanization. WASREB 2018 performance report ranked the town's water utility company LOWASCO among the bottom ten in the country during the period 2016 to 2017. The consecutive reports still indicate underperformance by the water utility company and with little improvements. Subsequently, among other major challenges of the company is the percentage of unaccounted for water which is still high at 37% (LOWASCO Audit Report, 2016), inadequate funds and human resource capacity especially the qualified experts at both the managerial as well as field level. Water distribution planning and water utility management remain a challenge to some extent as the successive audit reports have noted. However, the improvement of water service provision to meet the needs of the growing urban population remains a top priority by the management. Some of these constant problems can be managed effectively if proper information is made available to the management. The need to analyze the long-term water demand in a spatial context and availing this information to managers can play a major role in informing reliable policy implementation towards improved service provision.

1.3 Objectives

1.3.1 General Objective

The general objective of the study was the analysis and mapping of urban piped water demand for Lodwar town Turkana County using GIS-based Multi-Criteria Decision Analysis methods.

1.3.1 Specific Objectives

The specific objectives for the study included the following:

1) To develop spatial water demand maps for the study area.
2) To map the zones experiencing rapid urban growth.
3) To identify the priority zones/areas for consideration in future water distribution system planning.

1.4 Justification for the Study

The large-scale irrigation schemes to be implemented along the River Turkwell of about 10,000 hectares and increasing water demand as a result of growing urban population, commercial and emerging oil activities are presenting an anticipated demand for huge supplies of water in Lodwar town and the nearby regions (Olago, 2018). The water service providers are required to supply water to residents and other customers with a certain level of reliability (COK Section 43(I)(d), 2010). Uneven distribution of water within a town or a city can result in both scarcity and excess supply in other areas. Over time, if this condition is not mitigated it becomes a prerequisite for uneven urban growth.

To plan or develop for a proper water distribution system, managers at water utility companies need to establish the spatial dimensions of water demand. Spatial water demand evaluations ensure an even distribution water system is implemented to cater to all the town zones. The other advantage is that it safeguards the water distribution system against the risk of failure due to uneven pressure and lastly, it ensures a complete distribution system is running in an optimally cost-effective manner (Durga, 2005). The visualization of water demand can, therefore, give a clear picture of the inequalities in water distribution in an urban area.

1.5 Scope of Work

The study was conducted in the current Lodwar municipality of Turkana Central sub-county with a focus on the piped water network managed by Lodwar Water and Sanitation Company (LOWASCO). The focus was on mapping the piped water demand within the area for the period 2017 to 2019. During the study, other water sources such as rivers, shallow wells, and hand pumps located in the study area which influence the supply and demand of water were not considered. Subsequently, water consumption for the water kiosks operated by LOWASCO was excluded from this study. The data in question is held by third parties and stakeholders (data on Water ATM Kiosks), while the other data had gaps (kiosks run for short periods and most were not functional for the last few years) hence not reliable. The study, therefore, relied mainly on the water supply network available consumption records from the water utility company which can be verified. The other data compiled from various sources and fieldwork from in the area/zones served by the company as well as the proposed expansion plans were all considered in the scope of the study.

As a result of the upgraded Lodwar Town status into a Municipality in late 2018, the word “Lodwar Town” and “Lodwar Municipality”, the “Town centre) and CBD was used synonymously in this study to refer to the same thing.

1.6 Organization of the Report

The project report consists of five chapters namely: Introduction, Literature review, Methodology, Results and Discussions and lastly Conclusion and Recommendations.

Chapter one focuses on the background to the research which leads to the problem statement detailing the issue that was investigated. The objectives of the study are highlighted followed by the justification on why the research is crucial at the moment. The chapter ends by describing the scope of work that was undertaken and the organization of the entire report.

Chapter two deals with an overview of water demand from a global perspective, the current situation of water demand in different areas of Kenya comparing the urban regions. The major factors affecting water demand are also discussed, and lastly, the case study application of GIS in modelling water demand both on a short-term and long-term basis.

Chapter three covers the methodology used to achieve the objectives of the study. It also highlights the study area, the materials and or equipment used in the data collection and the data obtained from different sources to achieve the objectives.

Chapter four touches on the results obtained based on the data collected from the field and relevant organization in the county and national agencies. It also presents the discussions of the results based on the data analyzed as well as their interpretation.

Chapter five highlights the conclusions and recommendations from the entire study based on the results obtained from the data analysis and interpretation.

2. CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

In this chapter, an overview of water demand from a global perspective was briefly discussed, the current situation of water demand in Kenya comparing the different areas. Major factors affecting water demand from a general point of view was also discussed, the science behind GIS-MCDA methods and lastly, the case studies on the application of GIS in modelling water demand.

2.1 Global Water Demand

The deficiency of enough water resources to meet the water demand in a region is referred to as water scarcity. It affects every continent thus being listed as one of the largest risks globally in terms of potential impact in the next decade by the World Economic Forum 2019. Water demand is equivalent to water use which is usually the volume rate of flow applied to some beneficial purpose. Water demand types can be classified as either domestic demand, industrial or public demand. In developed countries, the water supplied to houses, commerce and industry are all of the drinking water standards. The complex nature of water supply can be portrayed through the use of maps and in particular water to indicate different water supply and demand scenarios. Global water use has increased by a factor of six for the past 100 years (Wada et al., 2016). The water use is expected to continue increasing as a function of population growth, economic development and changing consumption patterns, among other factors. The agricultural and energy production demands, all of which require large amounts of water, are likely to increase water requirements by about 60 % and 80 % by the year 2025 (Alexandratos et al, 2012). On the other hand, the global water cycle is intensifying as a result of global warming (IPCC, 2014). Burek et al., (2016) noted that the global water demand has been projected to be about 4,600 km^3 annually and the anticipated percentage rise will be between 20–30% (5,500 and 6,000 km^3) annually by the year 2050. However, these global assessments are complicated due to limitations in the available data and the various interactions of an amalgamation of economic, social, environmental and political factors. Due to such interconnections, the local water management leads to global impacts, while international changes and or developments tend to have impacts on the local water management (Wada et al., 2016). These change aspects change at a global scale demonstrate the necessity for immediate development and implementation of tactical, realistic and proper management as well as countermeasures towards the declining water security situation (Burek et al., 2016).

2.2 Water Sector Situation in Kenya

Kenya, with about 50 million people, around 41% rely on unimproved water sources. Such include shallow wells, ponds, rivers whereas approximately 71% use unimproved sanitation solutions (Water.org, 2019). The above challenges remain evident in the rural areas as well as urban slums of major towns. Kenya has been categorized as a water-scarce country and thus the achievement 2030 goals on water and sanitation under the social pillar remains a mirage for now. To achieve this goal deliberate effort is required towards the development and expansion of the entire water sector to improve service provision. The renewable water per capita in Kenya stands at around $647m^3$ (Mogaka et' al, 2006) of which is in contradiction of the required minimum of $1000m^3$ by the United Nations. The management of water resources in Kenya is still crucial in achieving the targets which are under the three pillars of Vision 2030. In the political pillar, rural-based conflicts are noted to have been largely resource-based. Likewise, on the social pillar, the targets are below the health sector, tourism which still depends on water to be fully realized. The access, as well as quality, is a significant contributor to the infant mortality rates. The country's economic pillar which consists of industrial development has a heavy reliance on water. This altogether indicates that water resources management and development cannot take a back seat but rather a front seat in the overall development of various sectors in the country as envisioned in both the Vision 2030 as well as the Big Four Agenda (Budget Watch, 2018). The development of most upcoming and other towns serving different areas relies on water. However, most towns in Kenyan counties have accumulated huge deficits in the provision of basic services, a situation that has been escalated by their related unplanned growth and informal developments (UN Habitat, 2019). This is overwhelming their potential to offer quality life to the residents thus slowing local economic development. The report further noted that the technical considerations to services configuration and delivery need to feature more prominently in county policy and public investment programs to offset the deficits. Approximately nine out of about fifty-five water service providers in the country supply a steady and continuous water supply to residents. This situation leaves most people to find their ways to meet these basic needs (Water.org, 2019).

The water resources management has been a challenge in Kenya from time immemorial. A major challenge is from the fact that most cultural practices view that the government should provide water for free. This perception has created the unwillingness to contribute or rather pay for water thus being the main causes in the increase in Non-Revenue Water (NRW) in the country. This continued scenario for some time has led to a situation of untenable water institutions which have inadequate incomes and or revenue from the water service provision they offer to citizens. Literature materials (WASREB) indicate that NRW relates to approximately 42% of the water in Kenya. This shortage is mainly obvious in the Kenyan rural areas and more pronounced in the ASAL areas like Turkana County. This water shortage situation has forced women and children to walk for long distances in search of water for domestic uses. Consequently, water has greatly affected education status in some of these ASAL regions since most of the school critical time is to spend searching and fetching water from far areas to schools. The other main issues around the water demand are water quality, constant water supply and the wastewater treatment. During failed rain seasons, major urban areas like Nairobi and Mombasa have frequent water shortages.

The management of water resources has been for a long time a reservation of the national government until recently when private entities emerged in the water sector particularly in the provision of water in gated societies and or communities. The private entities operate where they have boreholes and are capable of distributing water to several households. Before the enactment of the Water Act 2002, the water services were centralized under the National Water Conservation and Pipeline Corporation. In the year 2016, a new Water Act was again enacted paving way for further decentralization of water services to the current 47devolved government units also referred to as counties in the new Constitution of 2010. This saw the creation of various institutions: Water Services Regulatory Board (WASREB), charged with the development of rules and enforcement of the rules within the water sector geared towards ensuring the access to efficient, affordable and sustainable services.); Water Sector Trust Fund (WSTF) reconstituted from the other institutions with aim of financing water and sanitation services across the country. They were established to organize the water sector and ensure the achievement of access to water by all parties is realized.

2.3 Factors Affecting Water Demand

General water demand is affected by several factors which vary in different areas in the world. Some of the major factors include Climate/weather; Demographics and land use; water supply systems; water use practices and or water use equipment/appliances; water source substitution among others as detailed in Figure 2.1 below. These factors may affect demand for water depending on other factors within the locality which makes them variable from one urban area to another and from one country to another.

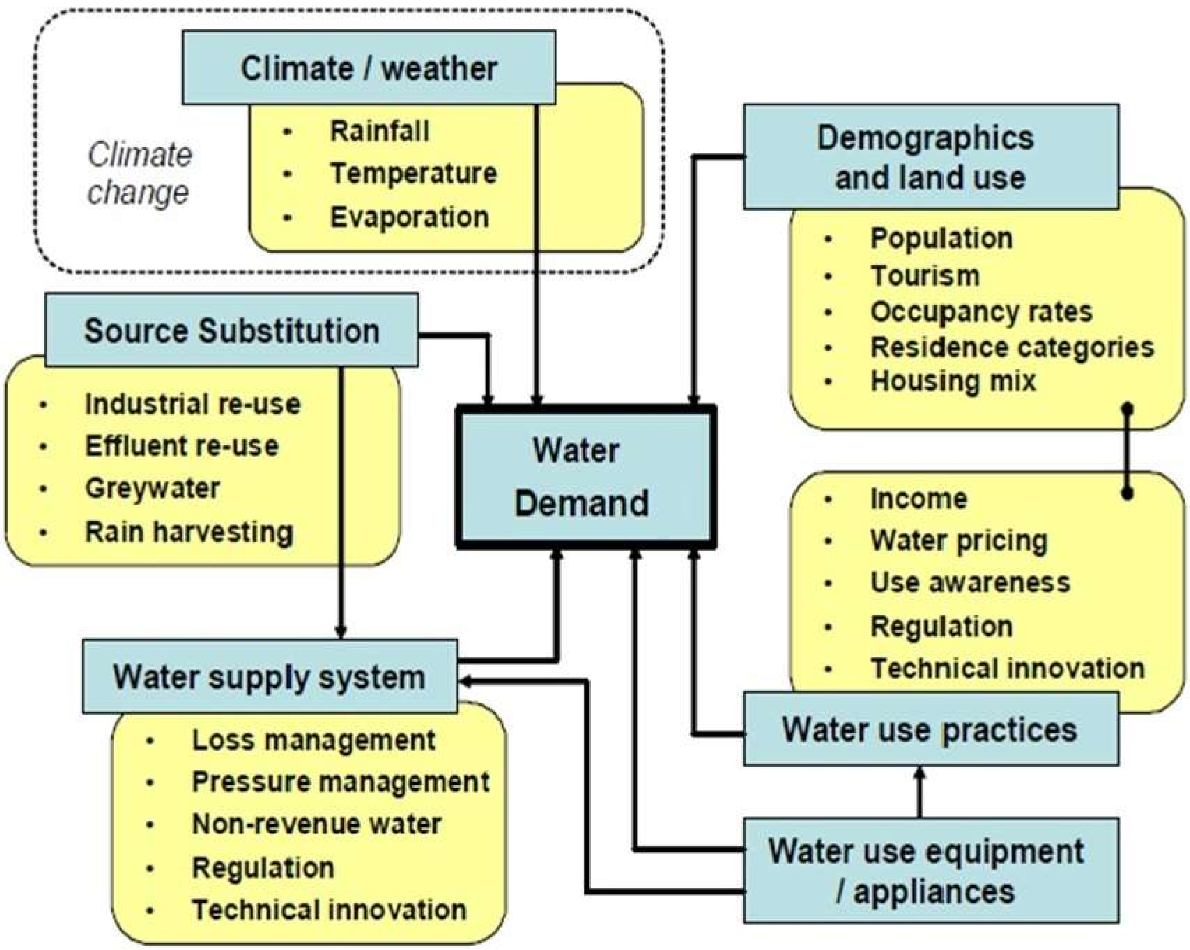

Figure 2.1: Direct and Indirect Factors Influencing Urban Water Demand.

Source: Integrated Water Resources Management Document Series (2010).

2.4 Basic Water Requirements

In the past 20 years, many water scarcity indices have been advanced to evaluate water scarcity quantitatively. Freshwater scarcity is usually described as a function of available water resources and the human population. The resultant figures are expressed in terms of annual per capita. The different sectors of societies in diverse regions of the world use water for varied purposes. It may include producing manufactured goods, drinking, diluting wastes, irrigation, hydro-power generation among other many uses. Water required for each of these purposes varies with climatic conditions, culture, lifestyle, technological advancements etc. The minimum water requirement for humans, without aspects of lifestyle and or culture, can only be defined for maintaining human survival. In the year1970 at Mar Del Plata Conference, among the concepts i.e. one of the earliest global efforts to address worldwide water problems was that of "basic needs" It stated clearly that "…all persons, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of a quality equal to their basic needs.." (United Nations, 1977). This concept has been reinforced by the 2010 Kenyan Constitution section 43(1) (d) for the citizens' rights to access water for basic need. The Basic Water Requirement (BWR) index was developed in 1996 as a measure of the ability to meet the water requirements for basic human needs. In his report 'Basic Water Requirements for Human Activities: Meeting Basic Needs', Gleick. P.H, (1996) further identified the basic human needs as follows:

- Drinking water for survival
- Water for sanitation services
- Water for human hygiene,
- Water for modest household needs for preparing food

Table 2.1: Recommended Basic Water Requirements for Human Needs. Source: (Gleick, 1996)

Basic Human Need	**Daily Minimum Water (Litres)**
Drinking water for survival	5
Waste disposal and related hygiene	20
Water for bathing	15
Water for modest household needs for preparing food	10
Total	**50**

Other water scarcity indices used for various measures in different applications include:

- The Falkenmark Indicator
- The Water Poverty Index
- The Water Resources Vulnerability Index

2.5 Water Demand Analysis

Matching water availability and water demand are some of the major challenges' policymakers are currently facing worldwide. The multidisciplinary modelling approaches involving hydrology, economy, ecology, or socio-politics have been applied widely as tools for selecting proper measures to solve water-related problems (Bouraoui and Grizzetti, 2014). The water management framework is important when estimating the present and future urban water demands which can either be short term or long term for proper development planning and water resources management. The focusing on target areas or areas of interest in geographic water demand analysis is referred to as geographic targeting. The assumption for geographic targeting emanates from the thought that poverty tends to exist in pockets precipitated by an amalgamation of individual and structural factors, (Cullis and O'Regan, 2003). Such pockets are usually identified both rural and urban areas of a country. Naturally, water poverty tends to have a noticeable geographic nature due to the significance of environmental factors and the level of local infrastructure development that defines the availability of the water resource and peoples' accessibility to the resources.

2.5.1 Geographic Information System GIS

A Geoinformation Information System (GIS) is described as "...A computerized information system with functions for collection, storage, processing, analysis and visualization of spatial data" (Harrie, 2008) used in describing and analyzing spatial and relations over time and space (Eklundh, 2003).The geographical phenomenon can be presented as single objects i.e. vector format and or as continuous surface (raster format) (Eklundh, 2003). GIS is most commonly used to visualize characteristics of a landscape or an environment and could be used as a tool for analyzing data, optimizing activities, performing risk analyses and test different scenario (GIS Centre, 2003). The ability to display separate information in layers, and sometimes combine the spatial data with other forms and or layers of information differentiates GIS from other information systems hence a great tool for high-level decision-making tool. A Geographic Information System is currently applied extensively in government agencies, and research purposes for a wide range of applications including land use planning, environmental resource analysis, suitability analysis, utility and infrastructure planning, demographic analysis real estate analysis, marketing purposes, natural resources studies among many other applications (Longley et' al., 2006). Nevertheless, GIS is highly suitable for analyzing all forms of data in water utility companies thereby revealing trends and inter-relationships that would be more difficult to discover if the same data would have been in tabular format.

2.5.2 Multi-Criteria Decision Analysis MCDA

Multi-Criteria Decision-Analysis (MCDA) is one of the approaches used in facilitating the consideration of various conditions by managers and or decision-makers. MCDA has been used to logically evaluate and compare numerous situations a that are often inconsistent thereby making the best decision out of them. The method is useful predominantly whereby a varied range of stakeholders have conflicting values, interests and or goals. An MCDA is applicable in fields where a wide range of issues and or problems exist and with favourable solutions (Eastman et al.,1995). Such applicable areas have been like in the health care system like disease treatment, choosing a new car processing options, the transportation sector, energy, risk assessment as well as site selection and land use among others.

A comprehensive structure on MCDA methodologies as developed by Figueira et al., 2005 is presented in Figure 2.2. The Multi-Criteria Decision Analysis techniques can, therefore, be classified in groups such as outranking methods, multi-attribute utility and value theories (MAUT and MAVT), pairwise comparison methods, distance-based methods, and fuzzy set theory. Several MCDA techniques provide decision-makers with the opportunity to effectively address decision problems. MCDA has been extensively applied worldwide to support decision-making processes for issues related to the management and planning of water resources. In several urban water supply studies, over 500 studies have published MCDA methodologies for infrastructure management from mid-1990 to present. These publications have included an extensive distribution of methods, ranging from ELECTRE, PROMETHEE, MAUT, Analytic Hierarchy Process (AHP), the Technique for Order of Preference by Similarity to Ideal Solution

(TOPSIS), Compromise Programming (CP) and other combined methods. In the literature material reviewed, one of the most widely used pairwise comparison methods is AHP.

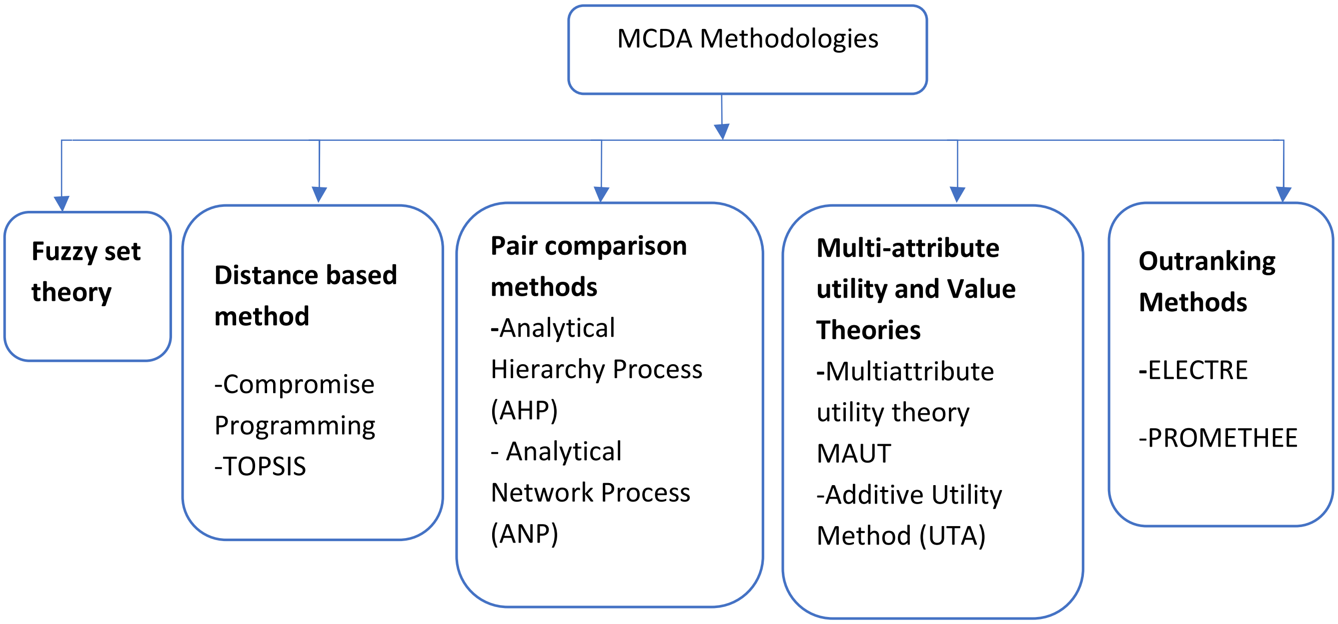

Figure 2.2: General MCDA Technique Classification. Source: Figueira, Greco & Ehrgott (2005).

This study, therefore, adopted the Analytical Hierarchy Process (AHP) which is a pair-wise comparison method as one of the widely used MCDA to advance its objectives.

The Analytical Hierarchy Process (AHP)

Developed by Thomas Saaty in 1980, the Analytical Hierarchy Process (AHP) is a pairwise comparison method that is used on the MCDA criteria concerning the problem and objective under investigation. The pairwise comparisons are evaluated for all the relevant factors within an investigation. They are usually not more than seven as in Table 2.2 below.

Table 2.2: Comparison Matrix (Saaty, 1980).

Relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to objective
3	Weak importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	One activity is strongly favoured and demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed between two adjacent judgments

Once the criteria have been combined and categorized within the MCDA guidelines, the Analytical Hierarchical Process is then used to compute relative weight sand or value of each factor that is relevant to the objective under investigation. Upon assigning relative weights, the calculation of a priority vector is usually the next step which gives the overall relevance modifier value for the individual factor which is then used in the GIS calculations.

A pairwise comparison matrix is derived using Saaty's nine-point importance scale based on thematic layers as in Table 2.2 above. The AHP has been known to capture the idea of uncertainty in the judgments which is usually through the principal eigenvalue as well as the Consistency Index (CI). A measure of consistency (CI) as given by Saaty is given as a deviation or degree of consistency using the equation below.

$$CI = \frac{\lambda_{max} - n}{n-1}$$

λmax = the largest eigenvalue of the pairwise comparison matrix evaluation.

n is the number of classes and or criteria used in the analysis.

A Consistency Ratio (CR) is then calculated to measure how dependable or consistent the findings have fared on in relative to large samples of purely random judgements. Where the CR is above 0.1, the judgements are taken to be unreliable thus the need to revise the subjective judgment.

$$CR = \frac{CI}{RI}$$

RI = Ratio Index.

The value of RI is for different 'n' values that are obtained in the analysis.

The advantages of using AHP method include a structured approach in measuring suitability through breaking the problem into hierarchical conditions known as criteria. With AHP, there is a more systematic and or in-depth examination of the main factors leading to better understanding especially when looking at lower and more specific forms. The method also allows for the involvement of a wide range of experts and or stakeholders during the process of giving their ideas. This context, therefore, allows the incorporation of both qualitative and quantitative conditions or the information given as well as expert knowledge.

2.5.3 GIS - MCDA

Several problems faced by humans happen to be geographical and thus connecting GIS with MCDA has become a necessity. The common spatial problems are characterized with large sets of practicable alternatives and multiple, contradictory and unequal evaluation conditions or criteria. The application of Geoinformation methods and MCDA is, therefore, a process that combines and converts geospatial data coupled with value judgements to solve existing spatial problems faced by managers in day to day operations in a different profession. To effectively achieve the goals, the GIS-MCDA considers geospatial data models. Spatial dimensions of the valuation conditions as well as result alternatives in the whole criteria evaluation (Malcweski, 1999 and Eastman et al.,1995). The GIS-MCDA applications areas in the real world include site selection, vehicle routing, situation evaluations, transportation scheduling, land suitability, location-allocation to a variety of sectors and impact assessments among other scenarios.

The GIS-MCDA involves several steps which include the following (Malcweski, 1999).

- Problem definition, goal or objective. In this step, the researcher should try to understand and formulate the problem as comprehensively as possible depending on his/her knowledge in the subject area.
- Criteria and the constraints determination. Using a combination of opinion from different experts' and information from different sources. It can be acquired from interviews, discussions with managers and or experts in the relevant fields, literature survey the analysis of various historical data in the area under investigation
- Value transformation onto a comparative/relative scale. It is done to allow for evaluation and or comparison between the criteria chosen, and subsequently in the representation of the judgments' vis-a-vis the expert information with meaningful facts or figures.
- Criteria weighting. The importance of separate criteria is determined with regards to the objective, and in respect, other criteria selected for evaluation.
- The combination, synthesis and or aggregation of the layers/criteria generated altogether.
- Analysis and then validation of your results

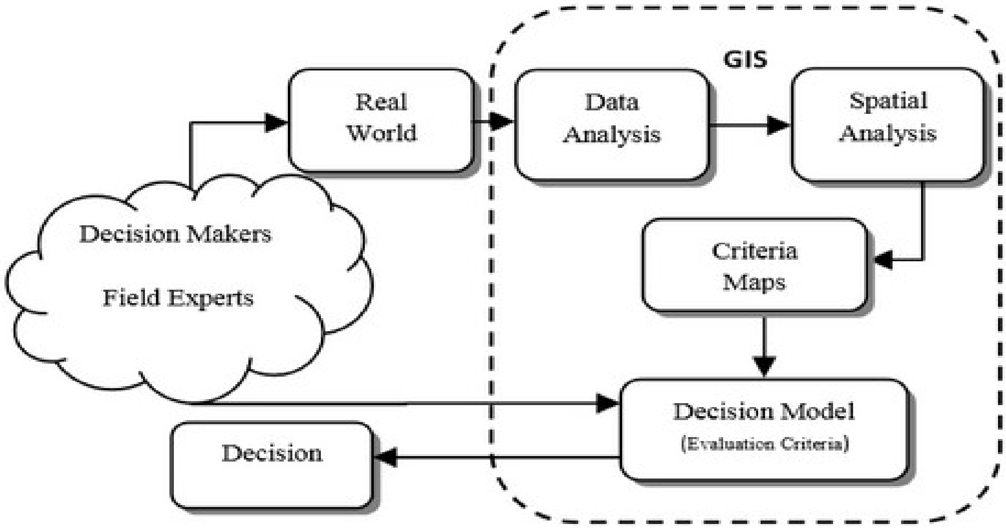

Figure 2.3: Integrated GIS-MCDA Approach. Source: (Malcweski, 1999).

2.6 Demand Modelling Tools

Urban water demand can be estimated by several methods. Forecasting methods are simply the steps, procedures and or conventions employed in the analysis of past water use then project the resultant knowledge to the future demand for water in a given area. These methods usually render estimated values of an individual or more explanatory factors like population, water price, income among others into estimates of future water requirements (Froukh, 2001). The developed methods are founded on either analytical or mathematical approaches whereas others for short-term estimations employ a heuristic approach (Rahman and Bhagnagar, 1988). These techniques include the long-term forecast methods as well as short-term forecast methods:

Table 2.3: Summary of Water Demand Modelling Techniques. Source: (Froukh, 2001)

Long-term forecast methods	Short-term forecast methods
▪ Single-coefficient method ▪ Disaggregate end-uses method ▪ Multiple-coefficient method ▪ Time-extrapolation method	▪ Probabilistic method ▪ Memory-based learning technique ▪ Time-series models such as Box Jenkins and Arima Models ▪ Artificial Neural Network

In the process of selecting any given technique for a given application, it is important to consider both planning needs and the stability arising from accepting a sophisticated technique against data acquisition cost and analysis. The linear regression, scenario approaches, artificial neural networks, time series analysis, fuzzy neuro-fuzzy models, simulation and agent-based models have been applied in predicting water demand in past studies in Europe (Panagopoulos et al, 2012).

2.7 Case Studies

In the study to map water demand for the Mytilene town of Lesvos Island in Greece, the researchers (Panagopoulos et al, 2012) applied Geoinformation methods and MCDA to estimate the present and near future water demands of the town. Several factors influencing demand were identified as well as those limiting demand for water in the town. The AHP method was used to cross-relate the factors and in the process of deriving weights. The findings classified almost 33% of the study area to high and very high priority zones of the potential urban water demands. The validation of the results indicated that the proposed methodology was able to give reliable results which were useful to the water managers of the town in implementing their policies. In the selection of best management operation alternatives for a new water supply scheme in Offa City, Nigeria, researchers (Okeola and Sule, 2012) employed the AHP method. Their study concluded that the best management option for the water supply scheme was public ownership and operation. Similarly, in the evaluation of non-conventional water resources supply alternatives for water availability and sustainability in Jordan, researchers (Jaber and Mohsen, 2001) implemented an AHP method in their research. Their study concluded that desalination and water harvesting were superior to treated wastewater and water importation as potential solutions for water scarcity in the country.

In the application of MCDA methodology for the selection of new water supply infrastructure in the city of Santa Marta Columbia, (Daza, H., et al 2019) the study integrated a hierarchy of non-economic benefits and the future expected costs into a global index alongside geoinformation methods. The MCDA treated economic criteria separately from non-economic criteria which had been previously proposed to address the same problem. The decision-making theory enabled various stakeholders to systematically evaluate alternatives to the multifaceted water supply problem. The study concluded that the implementation of the best alternatives for addressing the city's water supply problem should be by considering stakeholder's preferences.

In Kenya, while modelling the supply and forecasting the water demand for Nairobi West area and Athi river town using GIS, the researchers (Wafula & Ngigi, 2015; Manetu et' al, 2019) both employed GIS-based regression model (Geographically Weighted Regression - GWR and Ordinary Least squares - OLS) to estimate the future water demand of the two towns. A comparison of the GWR and OLS revealed that the GWR was more capable of estimating demand than the OLS. The studies concluded that spatial effects have greater importance in influencing water demand among other variables. The GWR model outcomes recommended that water resource manager should consider spatial and neighbourhood effects in the process of managing limited water resources. Nevertheless, upgrading of GWR over OLS confirmed that it can be preferred in projecting water demand accurately than the OLS model.

In the above studies done in Kenya, the mapping of water demand attempted to model the spatial demand for urban areas on a short-term basis even though some crucial factors were not included owing to the models applied. The model variations are a result of different factors influencing the demand for water in the respective urban areas. Further analysis of the literature on water demand mapping in Kenya reveals a special interest in Kenya's major towns and the cities, there is little attention to upcoming and small towns in ASAL regions. Given the importance of the water resource management and the variety of criteria involved in the decision-making process, a suitable tool such as multi-criteria decision analysis (MCDA) is essential to guarantee the success and efficiency of water distribution systems (Garfí & Ferrer-Martí, 2011). Different MCDA methods as proposed in the literature have been used but regardless of any of the methods applied, it narrows down to the ranking and weighting of the criteria influencing the decision-making process depending on their importance. The Analytical Hierarchy Process (AHP), a weighted evaluation method and sometimes referred to as "one of the most promising techniques" is a multi-objective, multi-criteria methodology, developed by Saaty in 1977 for decision making. It embraces the systematic hierarchy of the aspects and the contrasts among the several sets of these aspects during the assigning of an appropriate ratio for individual aspect or factor (Panagopoulos, G., et al', 2012). The capacity for comparing several aspects makes this AHP a crucial tool in managing water resources. The AHP is used to determine the weights since it ranks the goal on the top, the criteria in the middle whereas the alternatives at the bottom. The experts' input is a pair-wise assessment of the criteria values, which upon multiplication by the performances of the alternatives results in the choice of the best scoring solution.

3. CHAPTER THREE: MATERIALS AND METHODOLOGY

3.0 Introduction

This chapter covers the methodology used to advance the study to achieve the intended objectives. It also highlights the study area, the materials and or equipment used in the data collection and the data obtained from different sources to achieve the objectives.

3.1 Study Area

Founded in the year 1919 as an army base of colonial Government, Lodwar town used to serve as the administrative headquarters of the former Turkana District in early independence years. The town is currently situated in Turkana Central sub-county of Turkana County. Geographically, it ranges from Latitude 35.33°E to 35.62°E and Longitude 3.14°N to 3.8°N at an altitude of about 477m above sea level. The area receives about 217 mm mean annual rainfall. Geologically, the area around Lodwar is characterized by an extensive cover of Holocene alluvial deposits, pebble sheets along the Turkwell River as well as basalt and phonolites (Olago, 2018).

The current town lies within the recently upgraded Lodwar Municipality that covers an area of 706 km^2 combining Kanamkemer and Lodwar Township wards (Lodwar Municipality IDP) as shown in figure 3.1 below. Political and socio-economic changes in recent time have teamed up to spur rapid growth of the town which acts as a major commercial centre in the North-Western region. According to the census results of 2019, the population stood at 82 970, a figure which surpassed the previous projections by about 10,000 putting the town among the top 30 urban areas in Kenya in terms of population. A clear indication of the rapid population growth in the town in recent times. The socio-economic activities include dryland agriculture, livestock keeping, mining, capital investments, commercial activities within the town centre and tourism (Lodwar Municipality Integrated Development Plan, 2018).

In this study, all the available tentative urban spatial plans prepared during the development of "Lodwar Integrated Strategic Urban Development Plan 2011 – 2030", the past town council boundaries and the existing LOWASCO water network as well as designated areas for network expansion were considered in the delineation of the final study area as detailed in Figure 3.2. The suitable area of interest in the Lodwar Municipality covers an area from Latitude 3° 1'38.712" to 3°10'34.968" and from Longitude 35°31'35.63 to 35°39'39.078 as indicated in Figure 3.1 below.

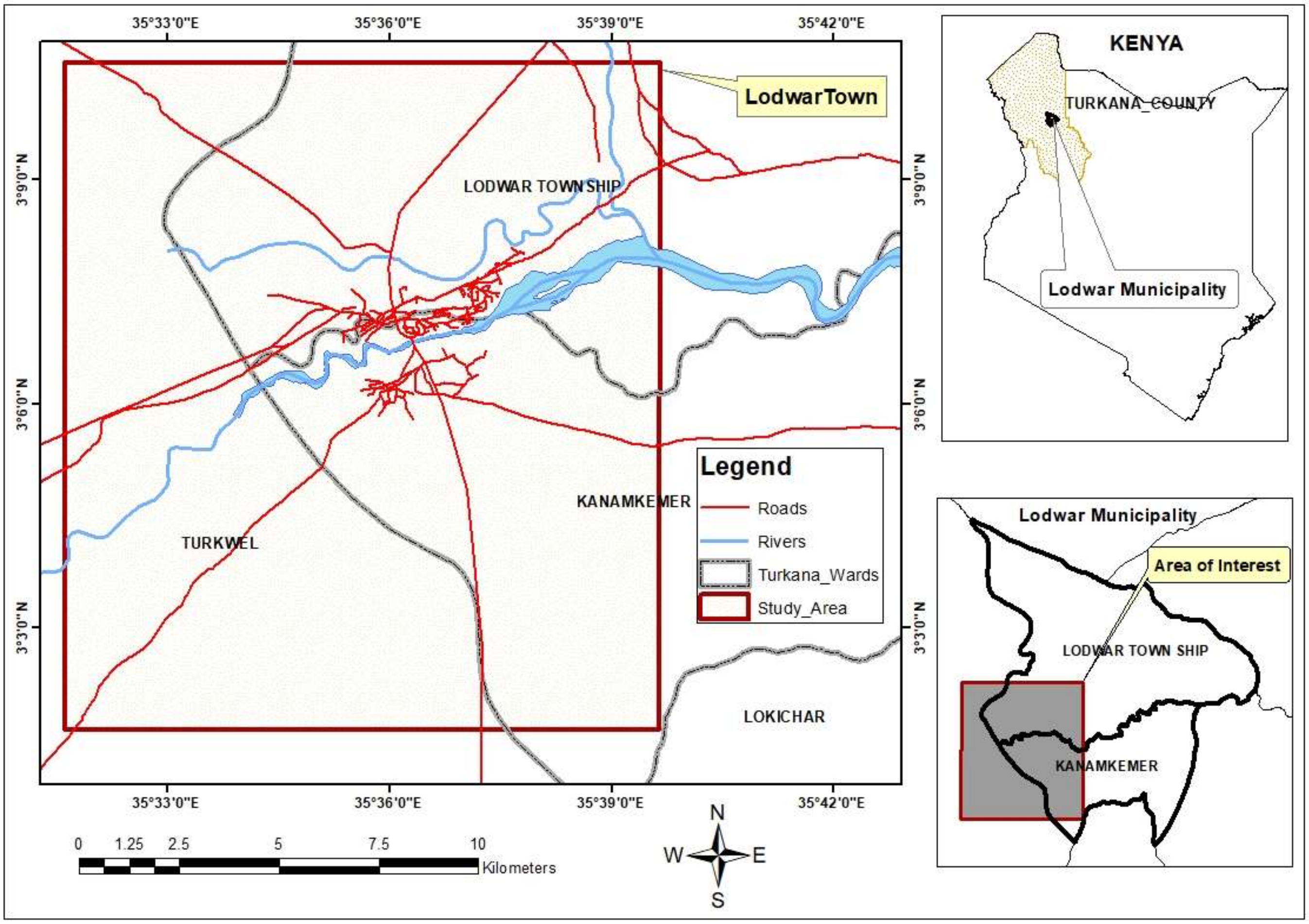

Figure 3.1: Location of Study Area- Lodwar Town.

3.2 Data Sources and Tools

The study obtained data from the relevant sources and utilized the available tools to attain the set objectives. Subsequently, the other data used in the study was obtained from fieldwork conducted in the study area.

3.2.1 Data Sources

The datasets used for this project were obtained from different online sources (satellite imagery, Digital Elevation Model) and the official registered organizations in Kenya. The data and respective sources are detailed in table 3.1 below.

Table 3.1: Data Sources

	Data	Sources
1	Demographic	Kenya National Bureau of Statistics (KNBS)
2	Land use and Land cover classes (LULC)	RCMRD/Landsat 8 satellite USGS Earth explorer/GloVis website http://glovis.usgs.gov; http://earthexplorer.usgs.gov.
3	Annual water consumption records for 2017 - 2019, Metered connections	Lodwar Water and Sanitation Company (LOWASCO) Data office.
4	LOWASCO Infrastructure maps (2014)	Oxfam Turkana Programme and Director of Water Services Turkana County.
5	Municipal boundaries, roads and drainage shapefiles	ILRI shapefiles, Google Earth, Ministry of Lands and Physical planning County Government of Turkana OpenStreetMap https://opentopomap.org/#map=13/3.11806/35.60223
6	Urban spatial plans/Municipality Physical plans	Town Manager/Ministry of Lands and Physical planning County Government of Turkana
7	Slope	SRTM DEM from USGS Earth Explorer & GloVis http://glovis.usgs.gov ; http://earthexplorer.usgs.gov.
8	Topo maps	*Topographische Karten aus* OpenStreetMap https://opentopomap.org/#map=13/3.11806/35.60223
9	Other attribute data	Fieldwork, Observation, Interviews, Discussions.

3.2.2 Tools

To achieve the objectives of this study within the timelines, the study utilized the following hardware and software were utilized:

(a) Hardware:

- A laptop with the following specifications: Model Toshiba Satellite, 500GB HDD, 4GB RAM, corei3. The Laptop was installed with GIS software was used for the processing and analysis of geospatial data.
- The data storage medium (1TB External Hard disk and 16gbflash disk). The gadgets were used mainly for data storage and backup of crucial project data.
- A Handheld GPS receiver: (Garmin 64), A Digital Camera, a GPS enabled smartphone were used in the fieldwork activities such as collecting GPS points of Storage Tanks, Boreholes locations, validation points among other features of interest.

(b) Software:

- ArcGIS 10.6. The GIS software contains the necessary and reliable modules which offer the environment for re-projecting spatial data, the georeferencing capabilities, digitizing and editing of map features as well as the geo-processing and spatial data analysis which will result in the development of the required models and preparation of respective thematic maps.
- Windows Microsoft office tools (Ms Word, Ms Excel, Ms PowerPoint) was used for various tasks during the project like presentation, data analysis, and report writing.

3.3 Data Collection

The data collection process involved some procedures which were used to acquire both spatial and non-spatial data both in the field and through visiting several organizations and government agencies in both Turkana and Nairobi Counties.

Topo maps

The topographic map data used in this study were obtained from the online sources Topographische Karten aus Open Topo Map https://opentopomap.org/#map=13/3.11806/35.60223) which were used as base map and for further reference purposes at various stages in the study.

Slope data

Slope data used in this study was obtained from Shuttle Radar Topography Mission (STRM) Digital Elevation Model (DEM) 30m for Kenya which was obtained from the USGS/Earth Explorer website. The DEM was projected to WGS UTM Zone 36N and clipped to the study area boundaries for further processing.

Satellite imagery

The Landsat satellite imagery was used in this study to analyze the land use and land cover classes within the study area for the year 2019. The data was downloaded from GloVis USGS website. With a spatial resolution of 30m, Landsat imagery is suitable for studying land cover changes in urban areas. The details of the downloaded satellite imagery shown below.

Table 3.2: Landsat 8 Satellite Imagery Details

Year	**Landsat Image (Path/Row)**	**Date of Acquisition**
2019	170/058	2019/03/03

Population data

The population dataset used in this study were obtained from the Kenya National Bureau of Statistics head office Cartographic Unit in Nairobi. The data consisted of the shapefiles for the boundaries (enumeration units) and their related attribute information used in the census exercise clipped to the area of interest.

LOWASCO Water consumption, metered water connections.

The water consumption data for 2017, 2018, 2019 and their respective metered connections were obtained from LOWASCO office water data collection office. The data obtained from were in Excel spreadsheet format as detailed in Tables 3.3, 3.4 and 3.5 below.

Table 3.3: LOWASCO Water Consumption in 2017.

LOWASCO Water consumption for 2017				
	Zones	Active Connection	Consumption M^3	Estimated Population Hh (6pple per connection)
1	D.C area	295	135,420	1,770
2	Town A	429	102,505	2,574
3	Town B	287	131,460	1,722
4	California	534	181,450	3,204
5	Nakwamekwi	984	54,750	5,904
6	Nawoitorong	1144	120,140	6,864
7	Napetet	874	251,980	5,244
8	Kanamkemer	2836	388,825	17,016
	Total	**7383**	**1,366,530**	**44,298**

Table 3.4: LOWASCO Water Consumption in 2018.

LOWASCO Water consumption for 2018				
	Zones	Active Connection	Consumption M^3	Estimated Hh Population (6pple per connection)
1	D.C area	311	155,745	1,866
2	Town A	439	124,750	2,634
3	Town B	287	152,664	1,722
4	California	602	289,450	3,612
5	Nakwamekwi	1232	68,520	7,392
6	Nawoitorong	1144	227,420	6,864
7	Napetet	981	249,656	5,886
8	Kanamkemer	3130	840,427	18,780
	Total	**8126**	**2,108,632**	**48,756**

Table 3.5: LOWASCO Water Consumption in 2019.

LOWASCO Water consumption for 2019				
	Zones	Active Connection	Consumption M^3	Estimated Population Hh (6pple per connection)
1	D.C area	311	125,485	1,866
2	Town A	439	114,780	2,634
3	Town B	287	163,225	1,722
4	California	602	285,980	3,612
5	Nakwamekwi	1232	54,750	7,392
6	Nawoitorong	1332	213,664	7,992
7	Napetet	981	258,440	5,886
8	Kanamkemer	3230	659,043	19,380
	Total	**8414**	**1,875,367**	**50,484**

Urban physical/spatial plan

The urban plans/spatial plans for Lodwar Town prepared in previous development of the strategic plan for Lodwar town were obtained from the Turkana County Government Ministry of Lands and Physical Planning GIS department. The plans were used in delineating the suitable study area as well. A detailed map with several thematic for the tentative urban plan is detailed in Figure 3.2.

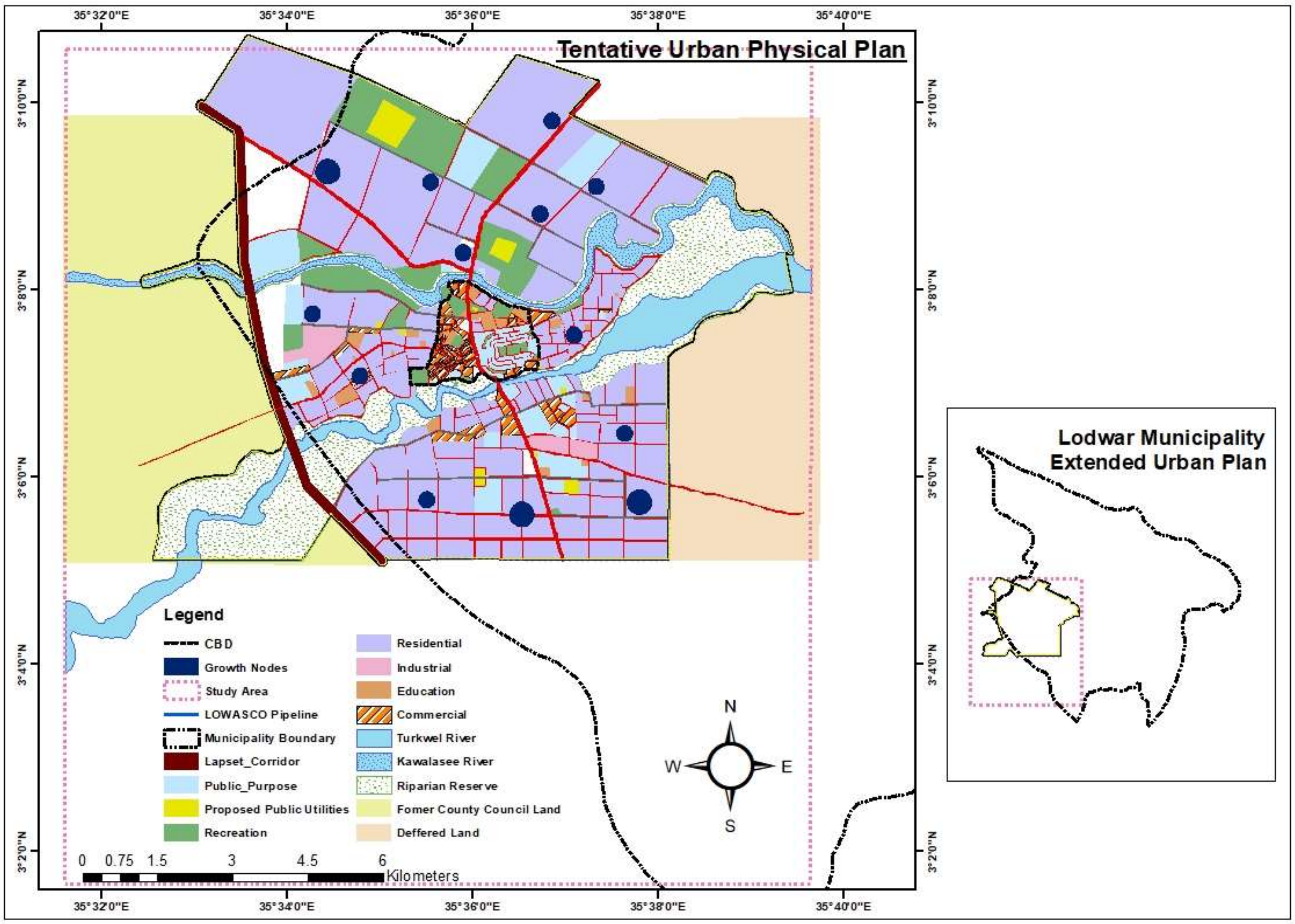

Figure 3.2: Tentative Physical Plan for Lodwar Town.

Source: County GIS Department, Ministry of Lands and Physical Planning

LOWASCO Water infrastructure map

The water utility/infrastructure map was obtained from Oxfam Turkana Programme consultant who was previously hired to survey and map the entire network in the year 2014. The map was in CAD format and was subsequently converted to shapefiles with an appropriate coordinate system for further GIS analysis. A copy of the map containing the water infrastructure mapped by a consultant in late 2014 is shown in Figure 3.3 below

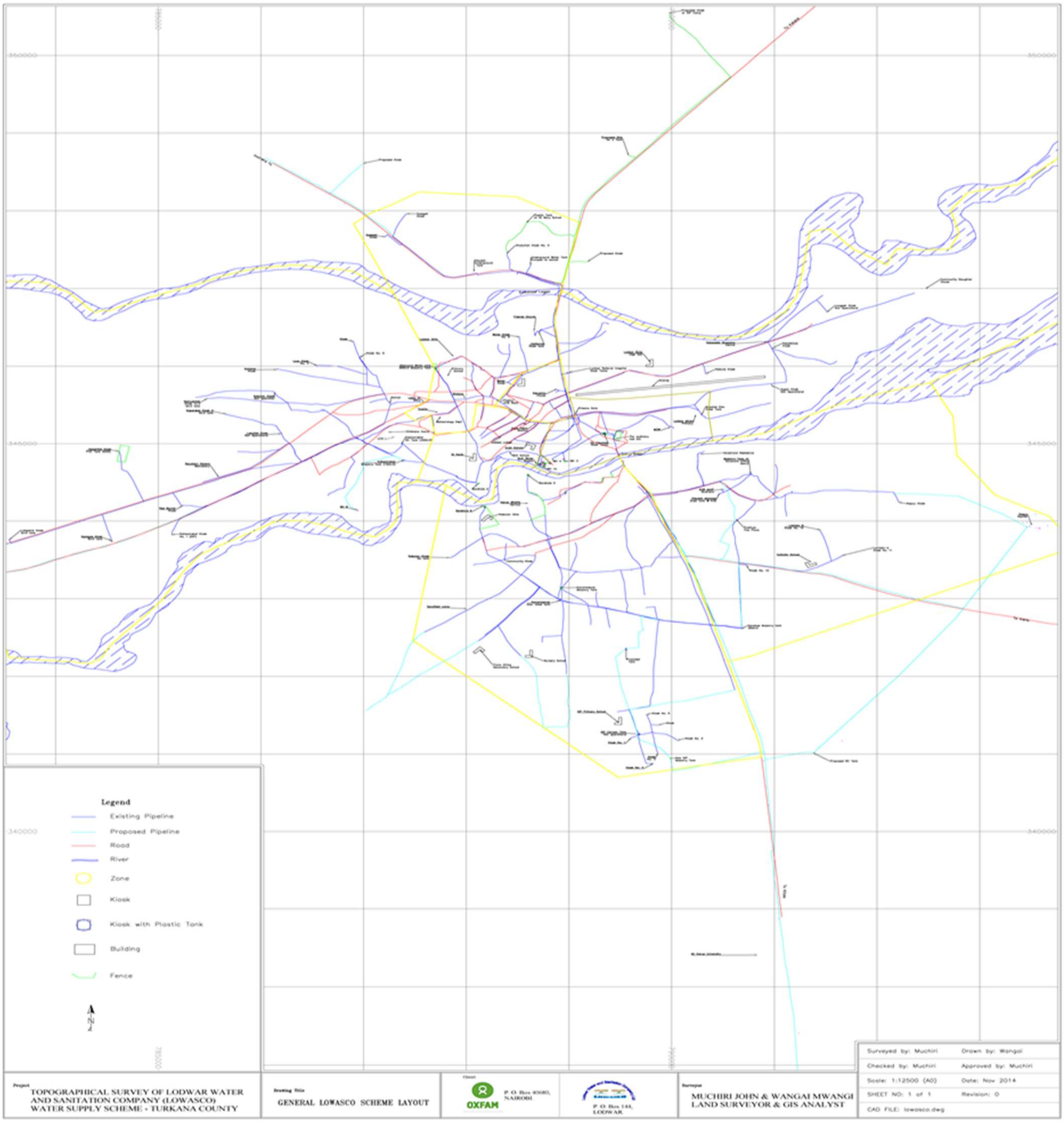

Figure 3.3: LOWASCO Water Supply Scheme Map.

3.4 Data Processing

Several spatial datasets collected from relevant sources for the study were processed using ArcGIS 10.6 software. The downloaded satellite image for the study area had the global reference system: World Geodetic System 1984 (WGS 84) and the projection Universal Transverse Mercator (UTM). Since the study area is located in Northern Kenya, the image was projected to WGS UTM Zone 36N which is the suitable zone for the study area. The Landsat 8 composite bands 7,6,4 (false urban colour) was used in the urban land cover analysis. The study adopted maximum likelihood supervised classification in classifying the satellite image for different land uses and land cover classes in the area.

The slope information was extracted from the Digital Elevation Model (DEM) using the Spatial Analyst Tool of the Arc GIS 10.6. Subsequently, the other data obtained in Excel spreadsheet from other organization were converted to GIS shapefiles and assigned an appropriate coordinate system for further analysis and merging with other relevant layers.

3.4.1 Annual Water Per Capita

The study used population estimates by LOWASO based on the active connections for each year (2017-2019) and the annual water supply for each of the LOWASCO zones, resultant figures for the water per capita supply were computed as shown in Table 3.6.

Table 3.6: Computed Annual Per Capita Demand for 2017 to 2019

	Zone	Water Per Capita 2017(m^3)	Water Per Capita 2018(m^3)	Water Per Capita 2019(m^3)
1	D.C area	76.508	83.465	67.248
2	Town A	39.823	47.361	43.576
3	Town B	76.341	88.655	94.788
4	California	56.632	80.136	79.173
5	Nakwamekwi	9.273	9.269	7.407
6	Nawoitorong	17.503	33.132	26.735
7	Napetet	48.051	42.415	43.908
8	Kanamkemer	22.851	44.751	34.006

The LOWASCO zones map layer and the computed annual water per capita supply Excel spreadsheet were combined using ArcGIS *Spatial join tool*. The resulting layer then used to create choropleth maps to enable visualization of supply in the areas. Thereafter a comparison was made between water per capita supply against the annual basic water requirements of 18.25m^3. Using proportional symbol maps with a bar chart, a comparison was carried out.

3.5 Methodology

In this study, the main procedure of GIS-MCDA (Malcweski, 1999 and Eastman et al.,1995) was adopted as follows:

a) Determination of the objective.
b) Definition of criteria affecting urban water demand.
c) Criteria standardization for procedure two above.
d) Assigning of weights for each criterion using AHP.
e) Combination of all criteria.
f) Validation of the results.

The mapping of urban water demand was the objective of this study, the criteria influencing water demand were selected which were the main factors that are influencing water demand. In multi-criteria decision analysis, the number of the criteria applied are usually unlimited, nonetheless, those criteria must be able to recognize objectives in question (Eastman, 1999). In the process of mapping urban water demand, the criteria used included: proximity to the water pipeline network or water infrastructure (storage tanks), proximity to the town centre, the population growth of the town, distance to local business centres, urban growth among others. On the other hand, the constraints may be criteria hindering access to water services in the area which included the slope of the area. The MCDA approach gives room for water utility managers/stakeholders to have an impact on decision making regarding the development that was to be undertaken. The fieldwork and discussions with officers at LOWASCO led to the identification of some factors influencing the water demand in the town to be used in the research. The following factors were considered: Slope; Land-use; population density; water supply system boreholes; distance to water network; distance to business centres, distance to the town centre, distance to main water storage facilities

The methodology used in line with the objectives is detailed in Figure 3.4 below.

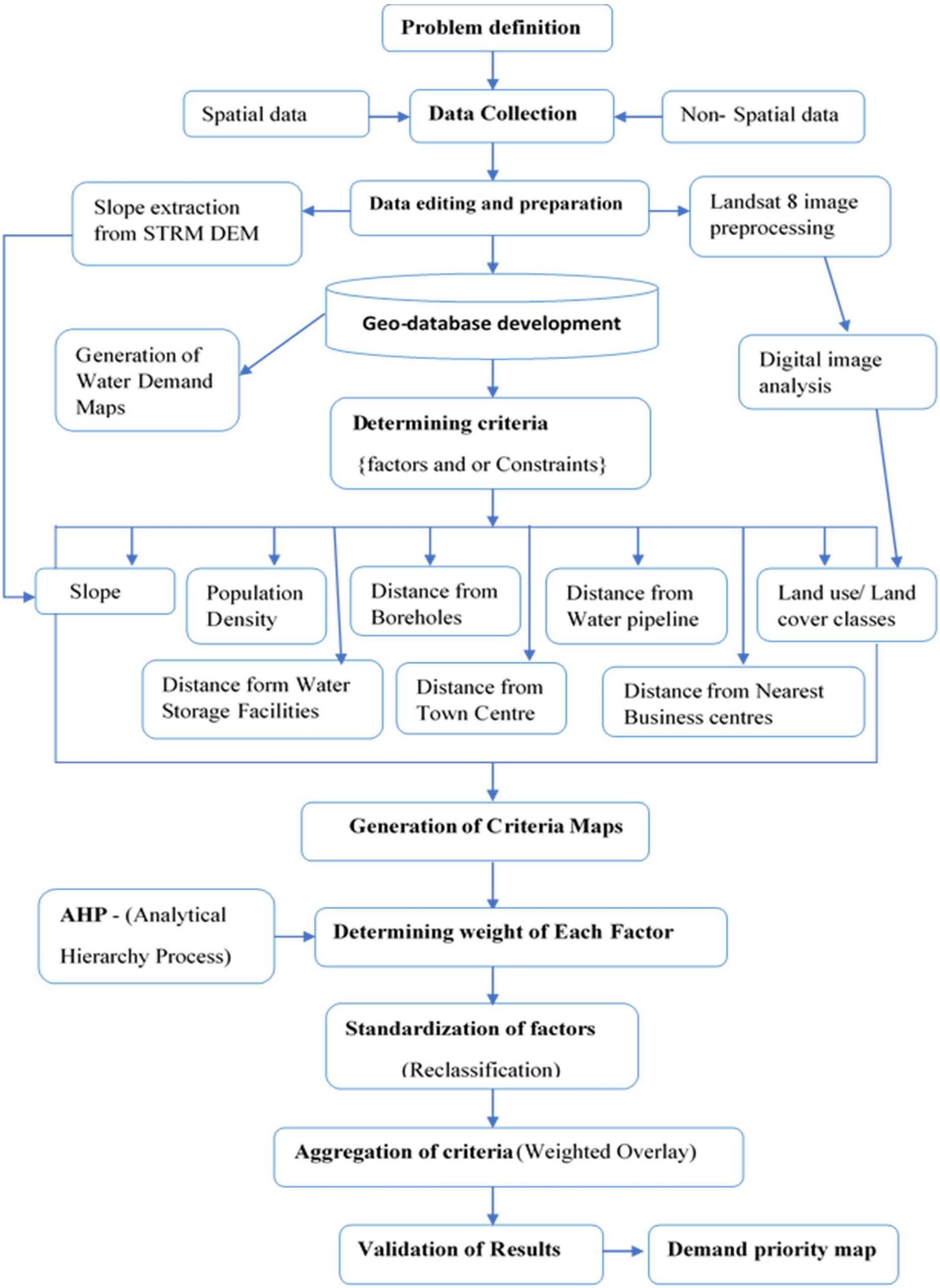

Figure 3.4: Methodology Flowchart.

3.6 Generation of Criteria Maps

3.6.1 Slope

The slope data was obtained from an STRM DEM analysis using the Spatial Analyst Extension to clip the Kenya DEM to the study area boundaries and projected to WGS UTM Zone 36N. The area slopes from North-West towards the Eastern areas which are on a relatively low-lying area. The highest areas are in the North West where the terrain consists of mountains/hills/rock outcrops. These features have been exposed as a result of years of continuous denudation processes within the area. The River Turkwell divides the area into Northern and Southern parts with some parts toward the South partially rising. Most of the LOWASCO water storage facilities are situated on elevated grounds (rock outcrops/hills).

The resultant slope map is presented in Figure 3.5 below.

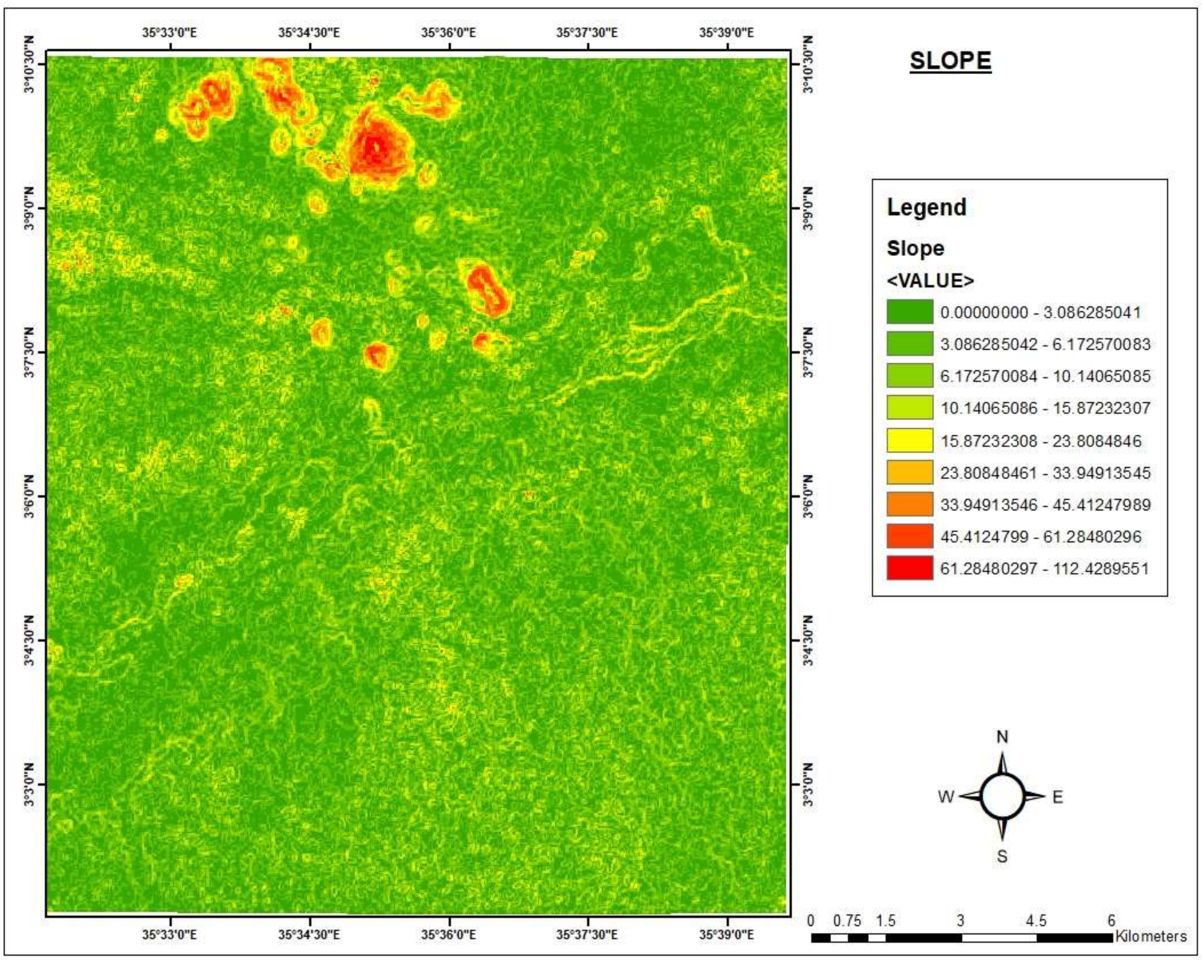

Figure 3.5: Slope Percentage Rise

3.6.2 Population Density

The study area population density per square kilometres for each enumeration unit was obtained from the Kenya National Bureau of Statistics shapefiles and is as presented in Figure 3.6 below.

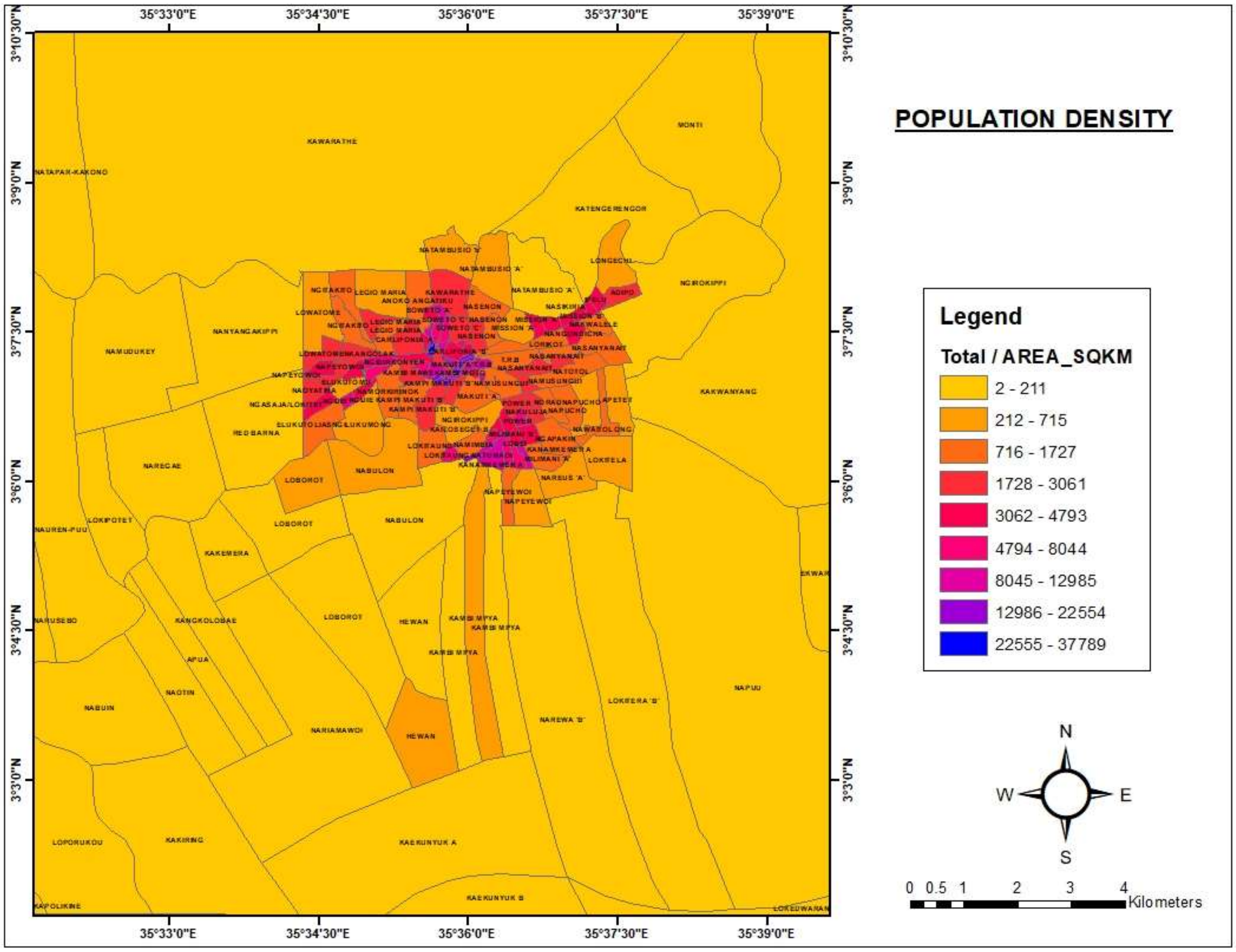

Figure 3.6: Population density of the area per square kilometre.

3.6.3 Distance from Water Pipeline Network

The distance from LOWASCO Water pipeline which was one of the criteria affecting the water demand was computed using the Spatial Analyst extension *Euclidean Distance Tool.* The resultant distances are shown in Figure 3.7 below.

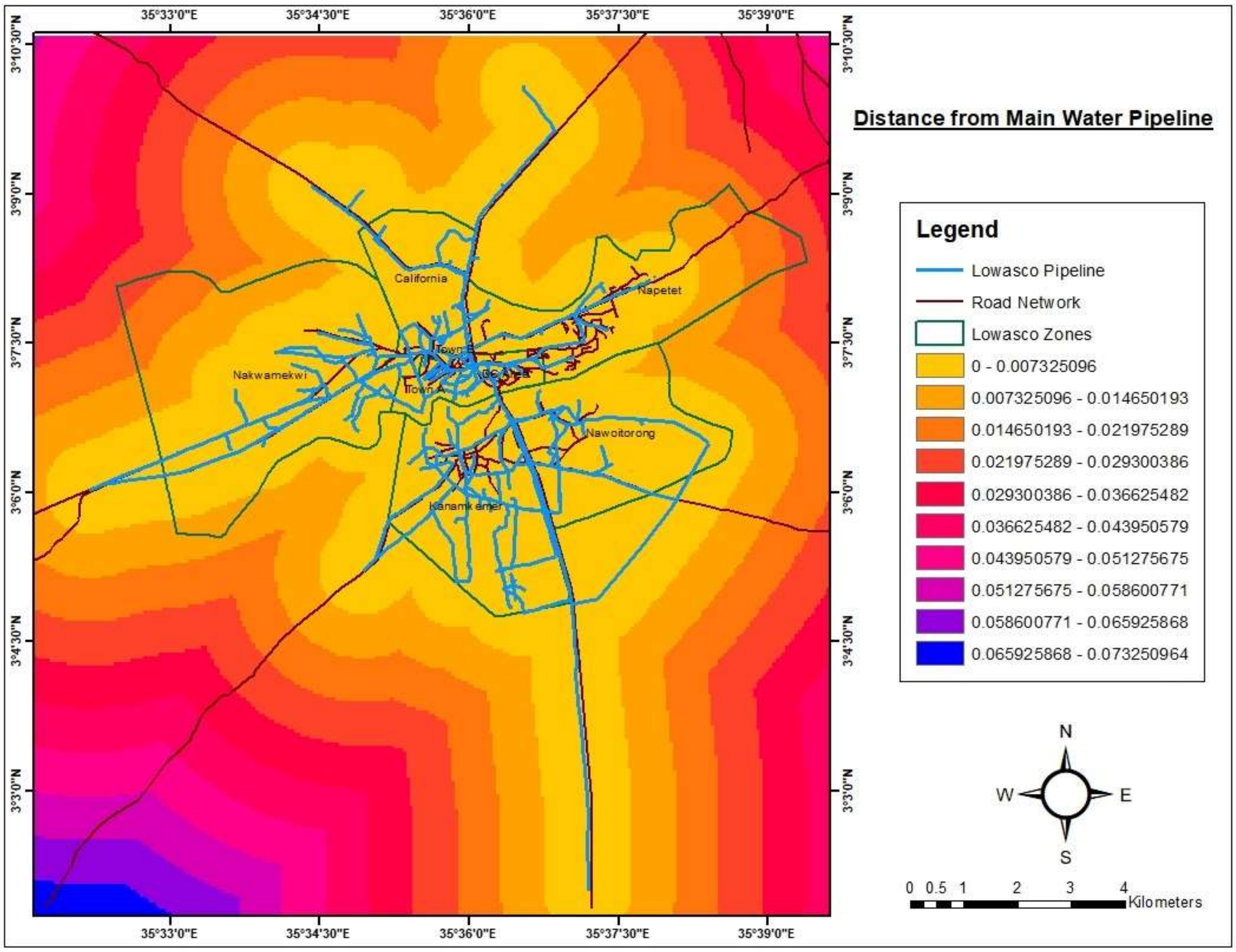

Figure 3.7: Distance from the Water Pipeline Network.

3.6.4 Distance from Town Centre

Access to water is also influenced by the location of households from the town centre. The water provision services near the town are much efficient when compared to areas far away from the town centre especially the peri-urban. This has been made easy by the already existing connection as well as business auxiliary services. The computed distance from the town centre is presented below.

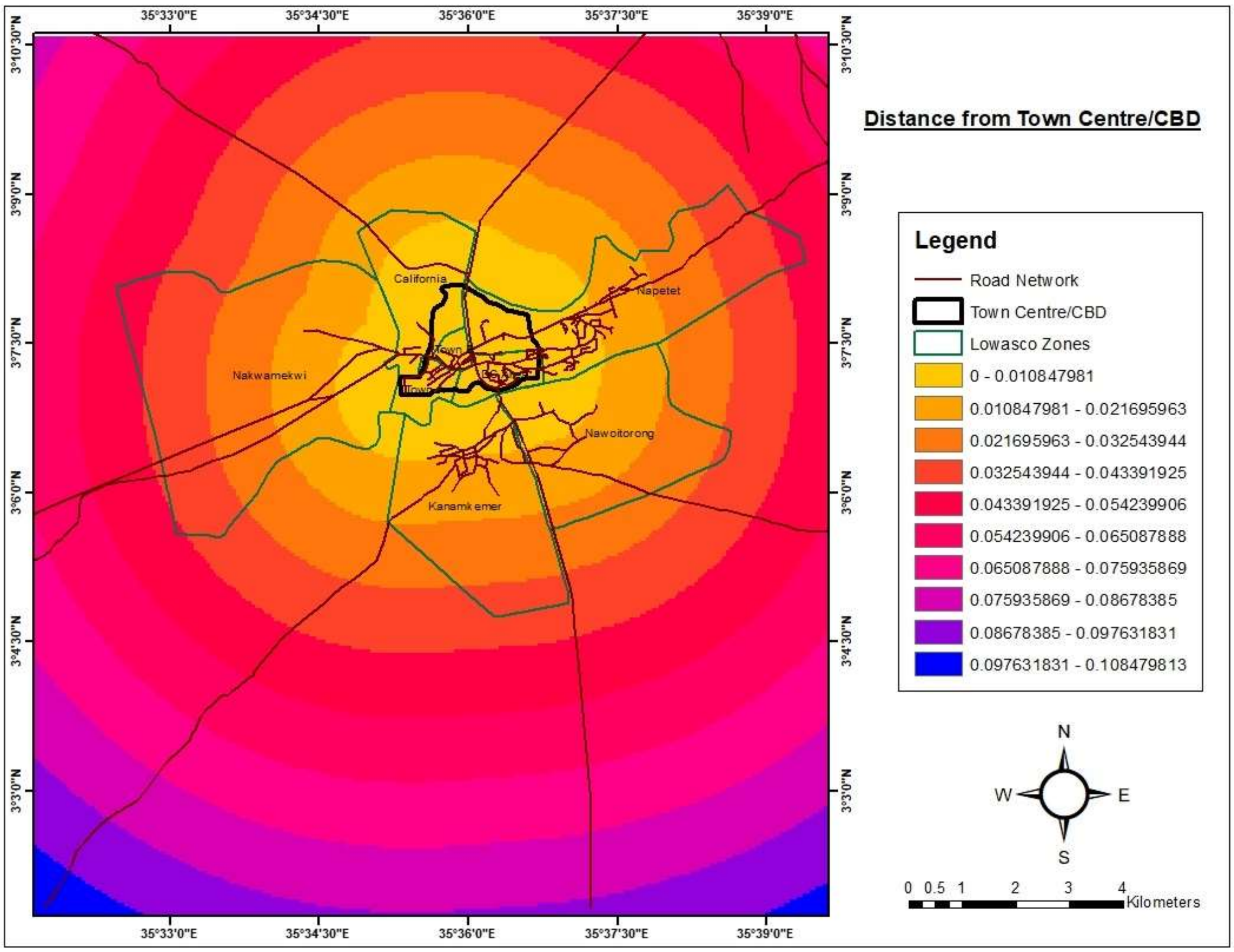

Figure 3.8: Distance from the Town Centre.

3.6.5 Distance from Nearest Business Centres

There exist two main business centres within the area with auxiliary services that has led to huge investments thus improved service provision. In such centres, the water service provision is much better than areas far away from business centres. The business centres were identified as a factor influencing the water demand. The varying distance from the nearest centres was computed as indicated in Figure 3.9 below.

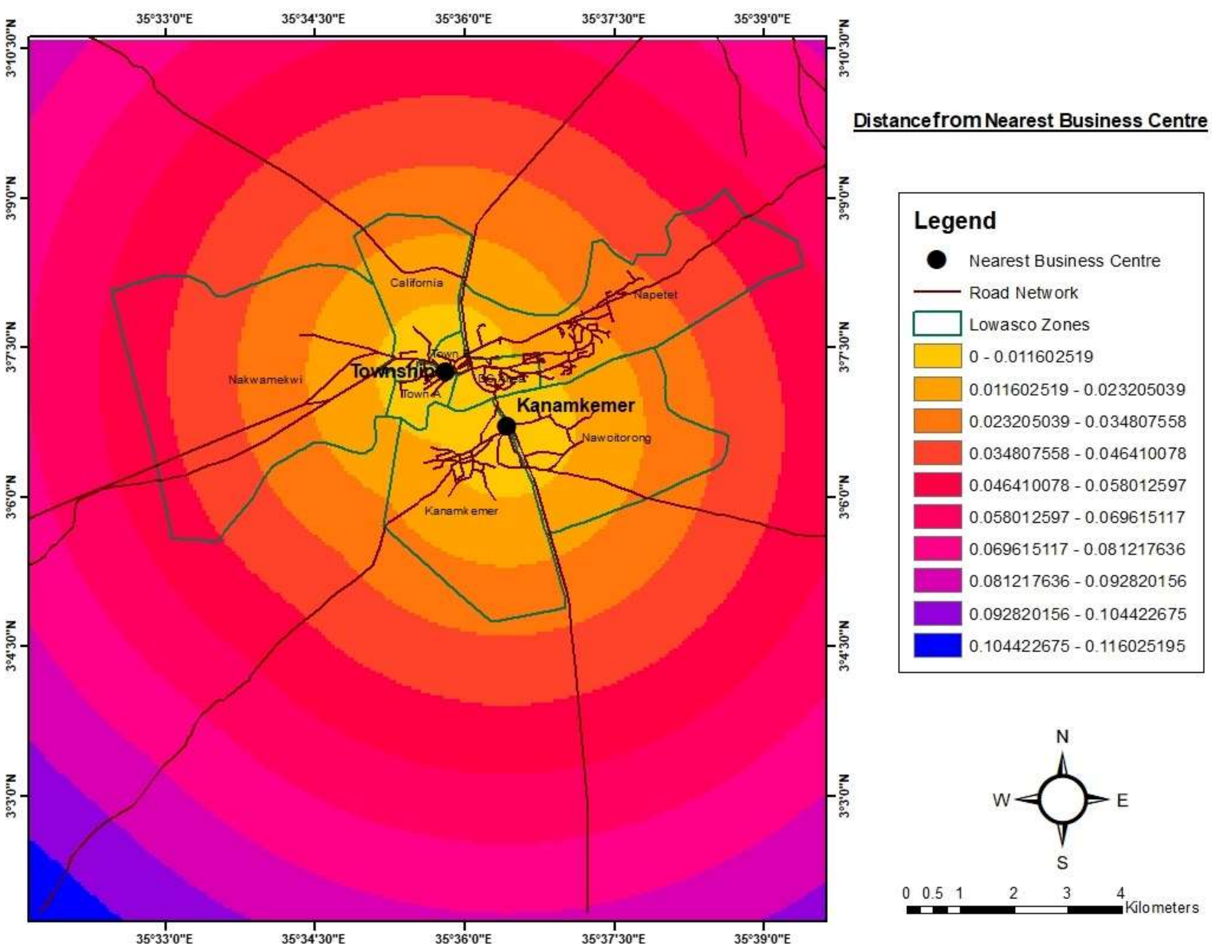

Figure 3.9: Distance from the Nearest Business Centres

3.6.6 Distance from Boreholes

The boreholes operated by LOWASCO were identified as one of the factors affecting the supply of water within the area. They are located near the Turkwel River or within a walking distance from the same river. Households located far away from the boreholes are not efficiently supplied with water due to varied reasons related to the entire water supply network. This distance, therefore, reduces the chances of connection to the supply network. The distance from the boreholes was also computed as presented in Figure 3.10 below.

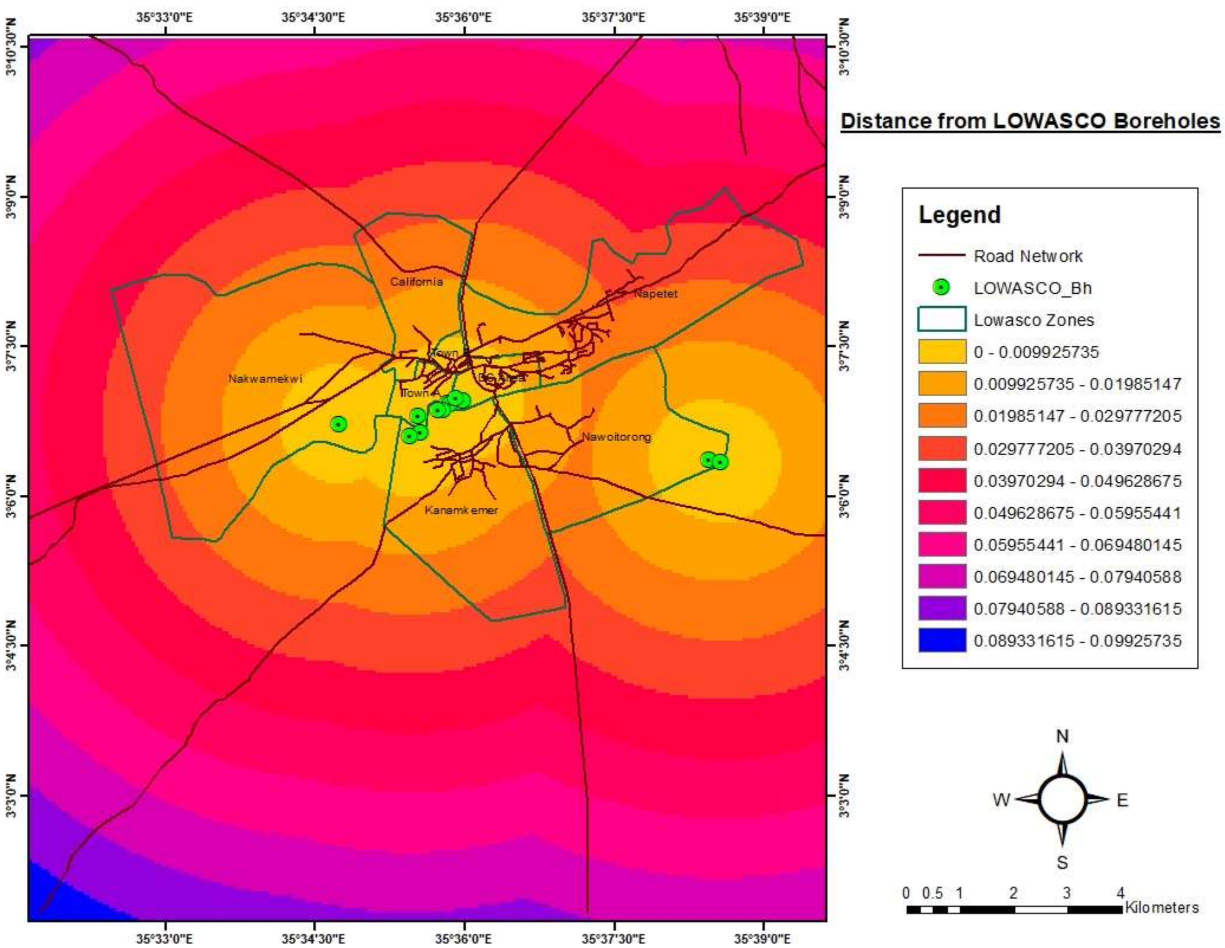

Figure 3.10: Distance from the LOWASCO Boreholes.

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3.6.7 Distance from Storage Tanks

The main storage tanks/facilities within the water supply network serve a crucial function in distributing water to the households located within several areas within the network. Areas far away from the tanks are forced to access water through other means such as water trucking. The distance to the main storage facilities was thus considered to have an influence on the demand for water in the area thus considered as one of the factors.

The distance to identified major storage facilities was computed as shown in Figure 3.11 below.

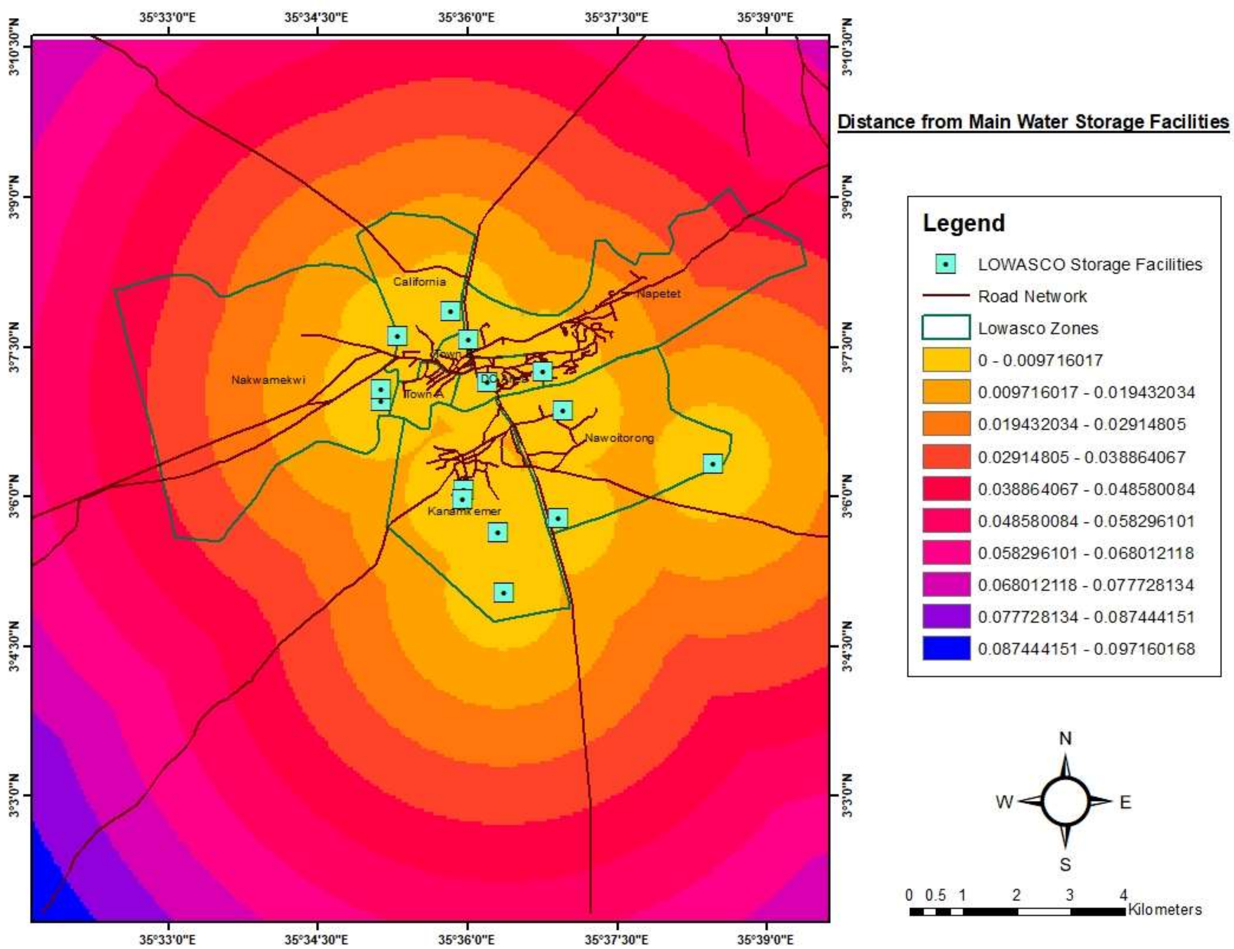

Figure 3.11: Distance from LOWASCO Main Storage Facilities.

3.6.8 Land use Landcover classes

Landsat 8 satellite image was used in the analysis of land use land cover classes in the study area for 2019. The results in the urban land cover change for the 9 dominant classes are presented below.

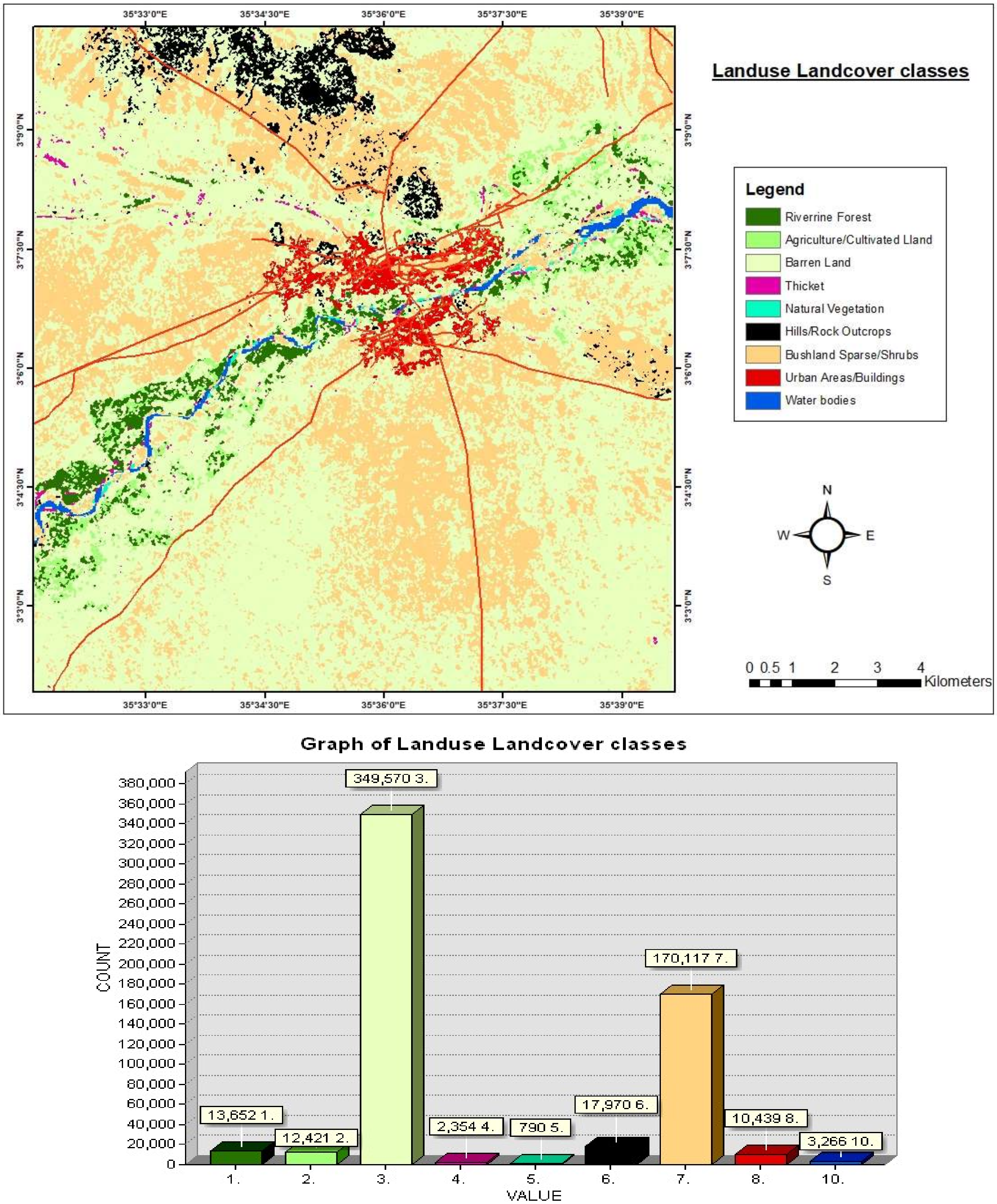

Figure 3.12: Land use Landcover Classes for 2019.

3.7 The Analytic Hierarchy Process

The factor/constraints identified were assigned respective weights using the AHP process. The factor with high influence had high weights as compared to the factors with the least influence on the water demand. The AHP comparison matrix framework is shown in the table below.

Table 3.7: AHP Comparison Matrix Framework and Principal Eigen Vector.

		Population Density	Land use/Landcover	Slope	Distance from Water Pipeline	Distance from Water Storage	Distance from Boreholes	Distance from Town Centre	Distance from Business Centre	Eigen Vector
		1	2	3	4	5	6	7	8	
1	**Population Density**	1.0000	2.0000	1.8571	2.8333	3.1250	2.7779	5.3750	3.2222	**26.5%**
2	**Land use/Landcover**	0.5000	1.0000	2.7779	2.7143	3.7143	3.5000	5.1429	2.5000	**23.7%**
3	**Slope**	0.5000	0.3333	1.0000	0.8333	1.5000	1.0000	3.5000	0.6667	**9.7%**
4	**Distance from Water Pipeline**	0.3333	0.3750	1.2000	1.0000	0.6000	0.6667	3.0000	1.0000	**8.5%**
5	**Distance from Water Storage**	0.3333	0.2500	0.8333	1.6667	1.0000	1.4000	3.4000	0.8333	**9.6%**
6	**Distance from Boreholes**	0.3333	0.2857	1.0000	1.5714	0.7143	1.0000	1.6667	1.2000	**8.7%**
7	**Distance from Town Centre**	0.2000	0.2000	0.2857	0.3333	0.2857	0.6000	1.0000	0.6667	**4%**
8	**Distance from Business Centre**	0.3333	0.4444	1.5714	1.0000	1.2000	0.8333	1.5714	1.0000	**9.3%**

3.8 Standardization

Before the weighted overlay process, the identified criteria are required to be reclassified into the same units hence the standardization process. The process(standardization) unifies the units and the scores lose their dimension along with their measurement unit (Malcweski, 1999 and Eastman et al.,1995). All the other vector layers were converted into raster format and reclassified accordingly to be used in the weighted overlay analysis for the final suitability map. In the Arc GIS Extension (Spatial Analyst) the Reclassify tool standardized the value of all criteria for comparison.

3.8.1 Standardized Slope

The slope rise categories were reclassified using the *Reclass Tool* into 5 categories based on slope suitability. Slope percentage rise is the incline and or gradient of a surface commonly expressed as a percentage. Slope gradient of any given land surface has a great influence on the pipeline construction among other utilities related to water infrastructure in a water utility company thus having an impact on the supply of water to an area. The reclassified slope as presented in Figure 3.13 below.

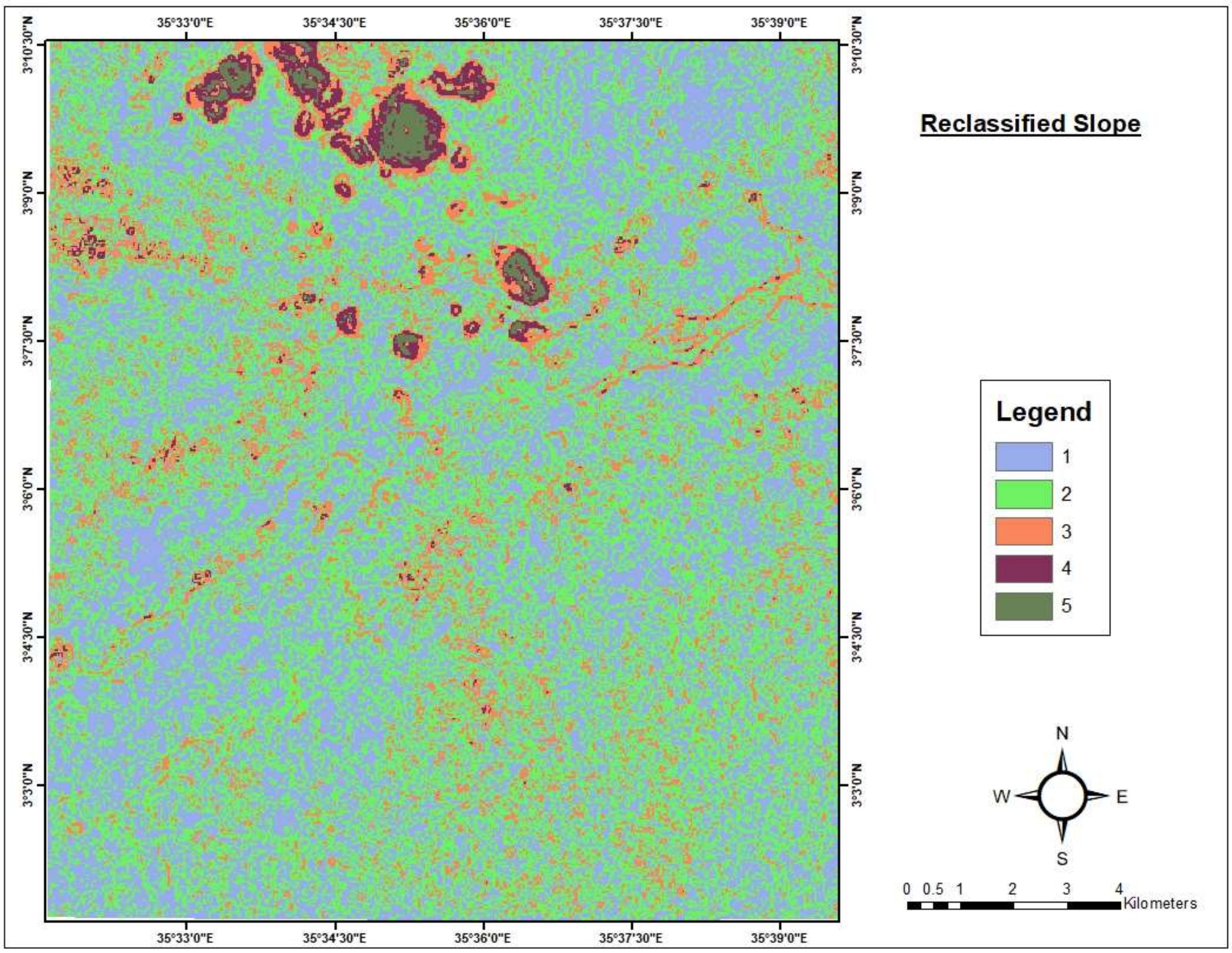

Figure 3.13: Reclassified Slope.

Table 3.8: Criteria for Slope Suitability Classification.

Class (%)	Legend	Weight	Description
0 – 5	1	5	High
5 – 15	2	4	Moderate
15–25	3	3	Low
25 – 45	4	2	Very Low
< 45	5	1	Extremely Low

3.8.2 Standardized Population Density

The population density of each enumeration units in the area was reclassified into 5 classes as presented in Figure 3.14 below.

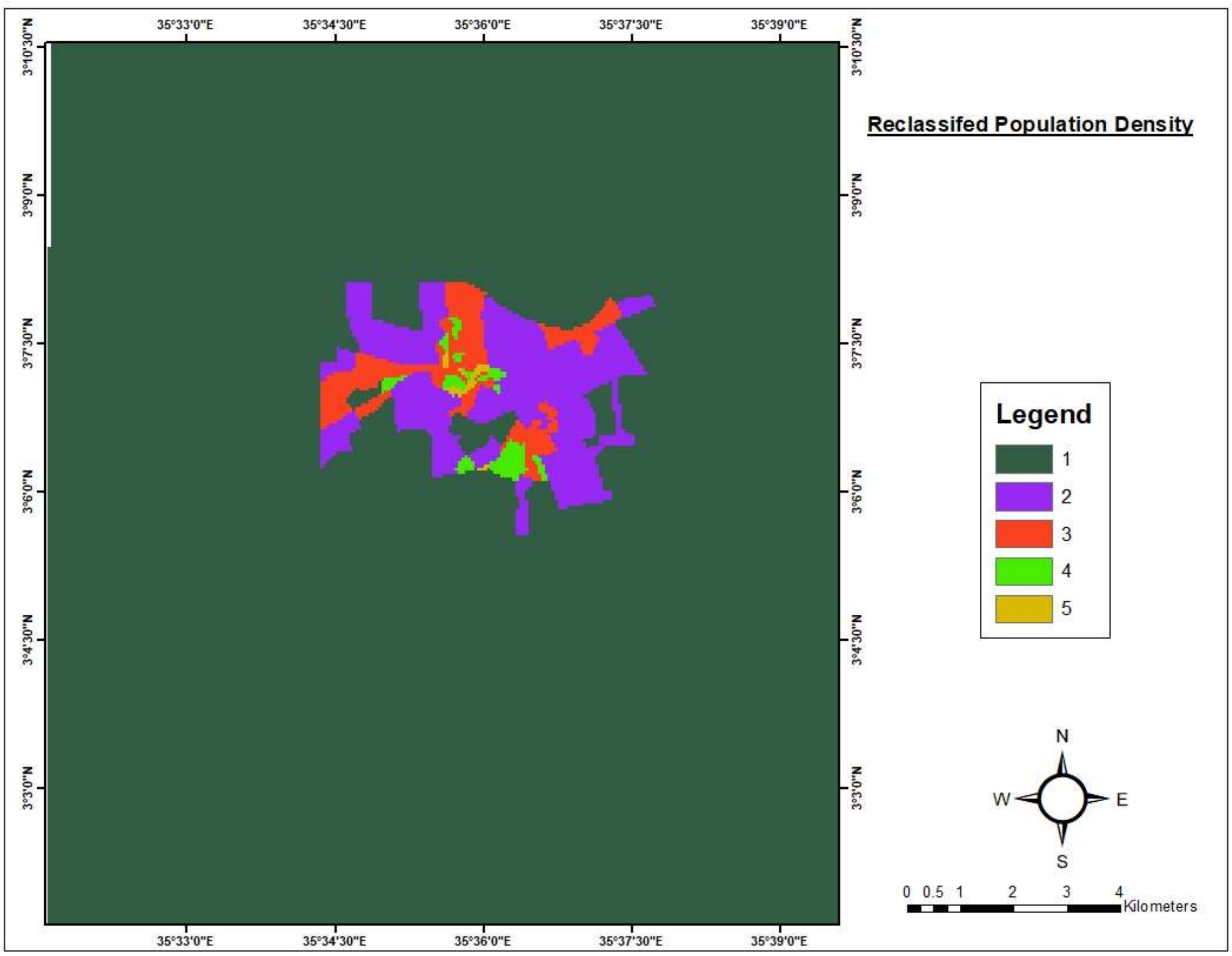

Figure 3.14: Reclassified Population Density.

Table 3.9: Criteria for Population Density Classification.

Class (Inhabitants per Km^2)	Legend	Weight	Description
2 – 594	1	3	Low
595 – 2520	2	4	Moderate
2521- 6373	3	5	High
6374 - 12893	4	6	Very High
12894 - 37787	5	7	Extremely High

3.8.3 Standardized Distance from Water Pipeline Network

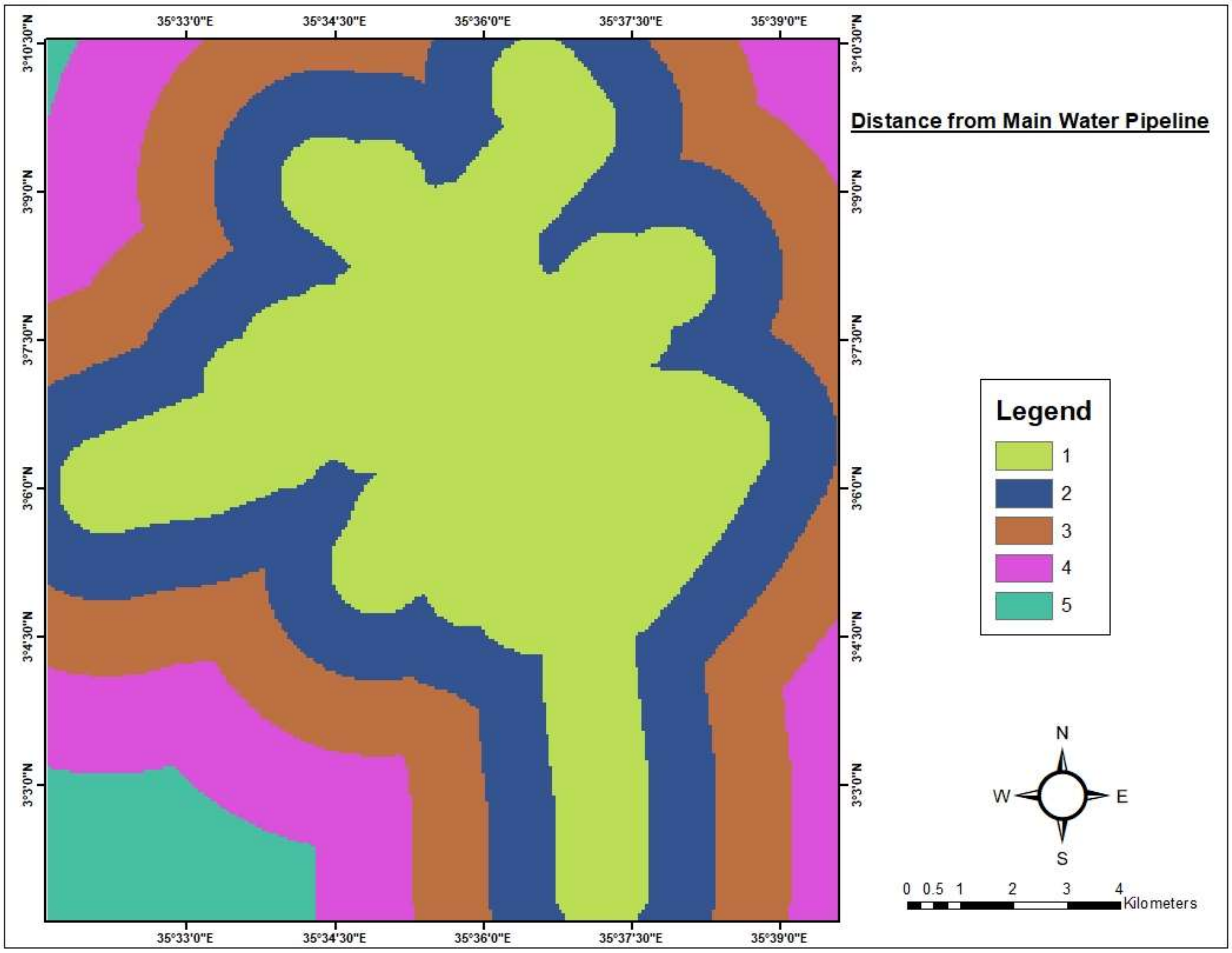

Figure 3.15: Reclassified Distance from Water Pipeline.

Table 3.10: Criteria for Distance from Water Pipeline Classification.

Class (Distance in Km)	Legend	Weight	Description
0 - 2	1	7	Extremely High
2 – 4	2	6	Very High
4 – 6	3	5	Moderate
6 – 8	4	3	Low
< 8	5	2	Very Low

3.8.4 Standardized Distance from Boreholes

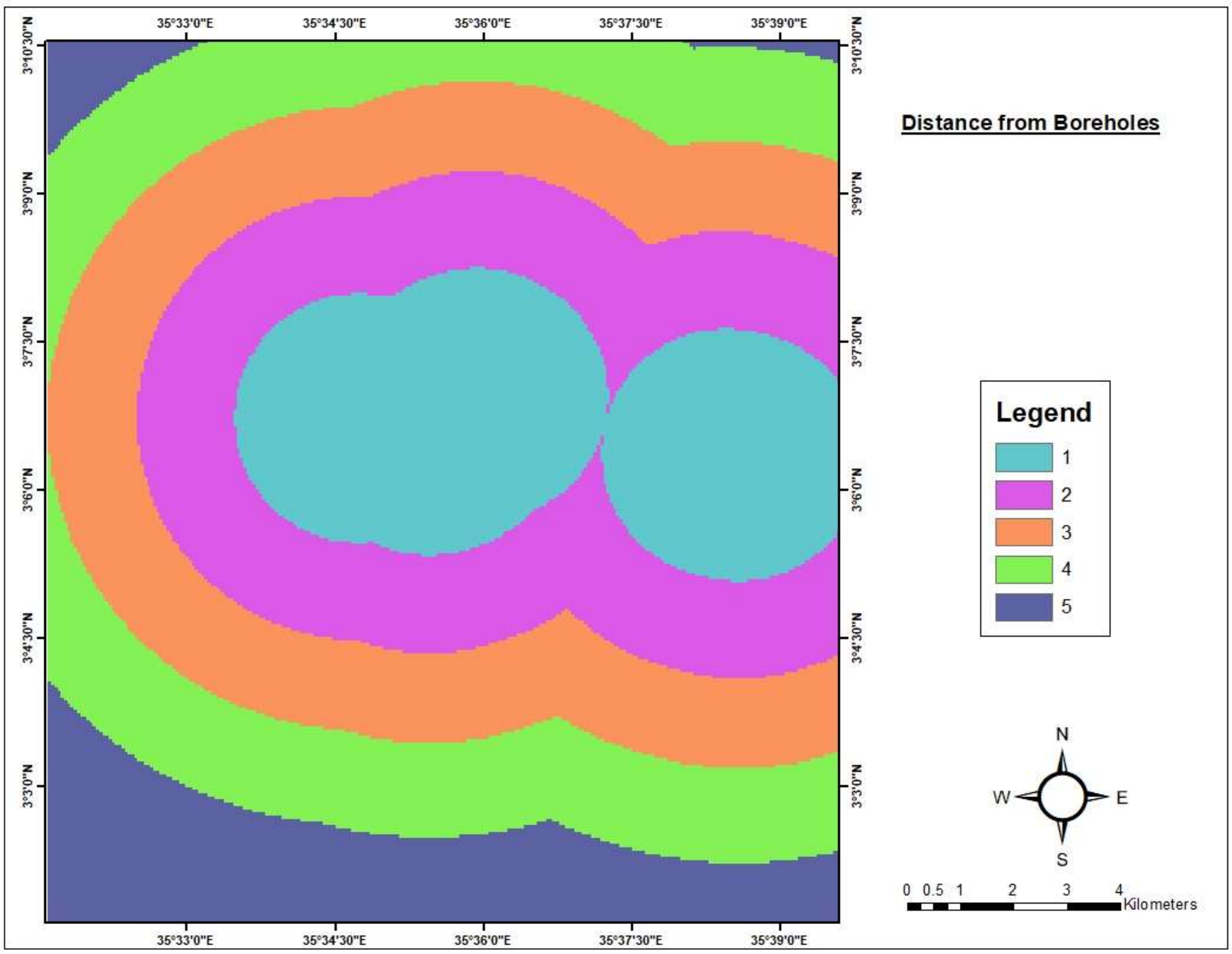

Figure 3.16: Reclassified Distance from Boreholes.

Table 3.11: Criteria for Distance from Borehole Classification.

Class (Distance in Km)	Legend	Weight	Description
0 - 2	1	5	High
2 – 4	2	4	Moderate
4 – 6	3	3	Low
6 – 8	4	2	Very Low
< 8	5	1	Extremely Low

3.8.5 Standardized Distance from Storage Tanks

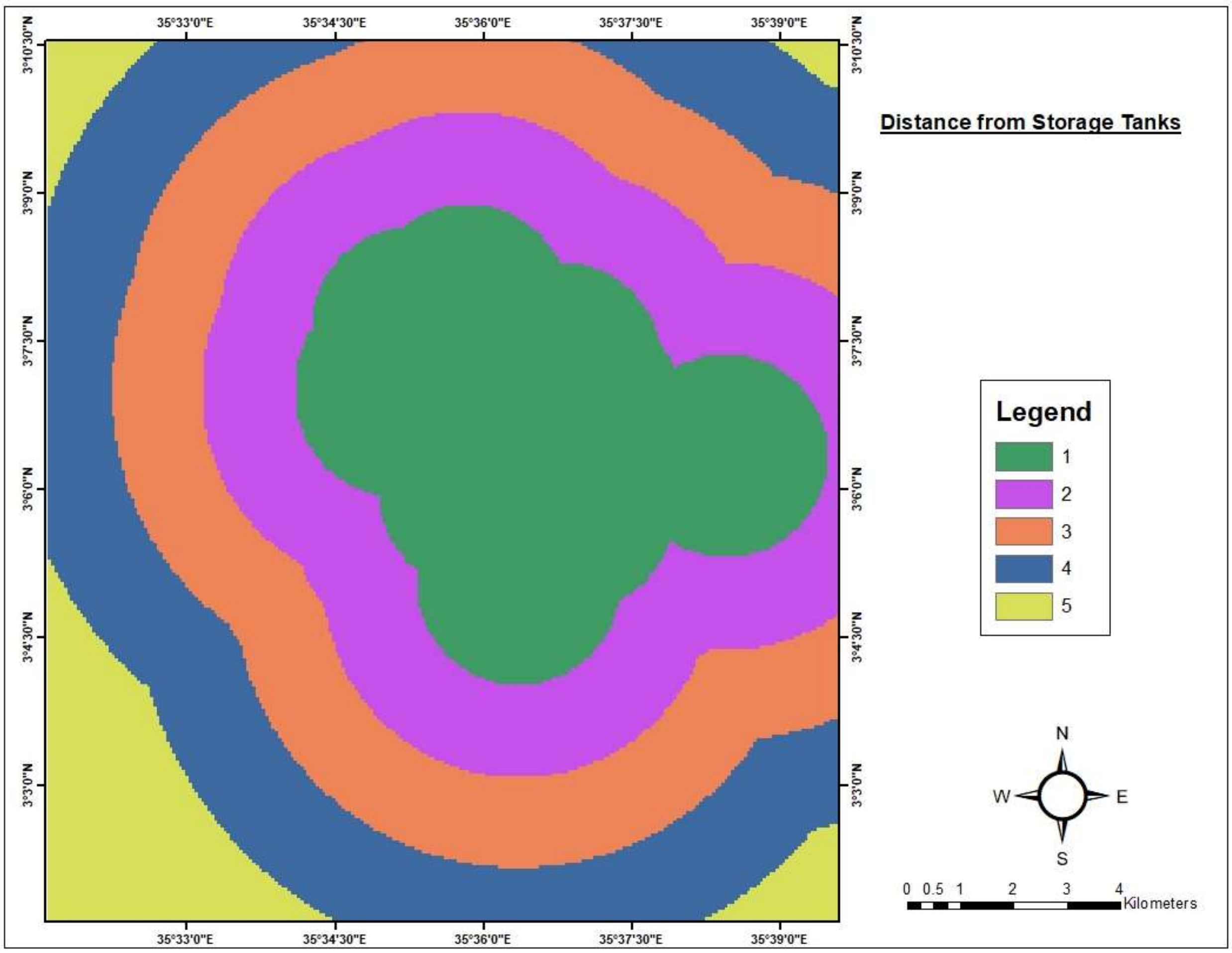

Figure 3.17: Reclassified Distance from Storage Tanks.

Table 3.12: Criteria for Distance from Storage Tanks Classification.

Class (Distance in Km)	Legend	Weight	Description
0 - 2	1	7	Extremely High
2 – 4	2	6	Very High
4 – 6	3	5	High
6 – 8	4	3	Low
< 8	5	2	Very Low

3.8.6 Standardized Distance from Town Centre

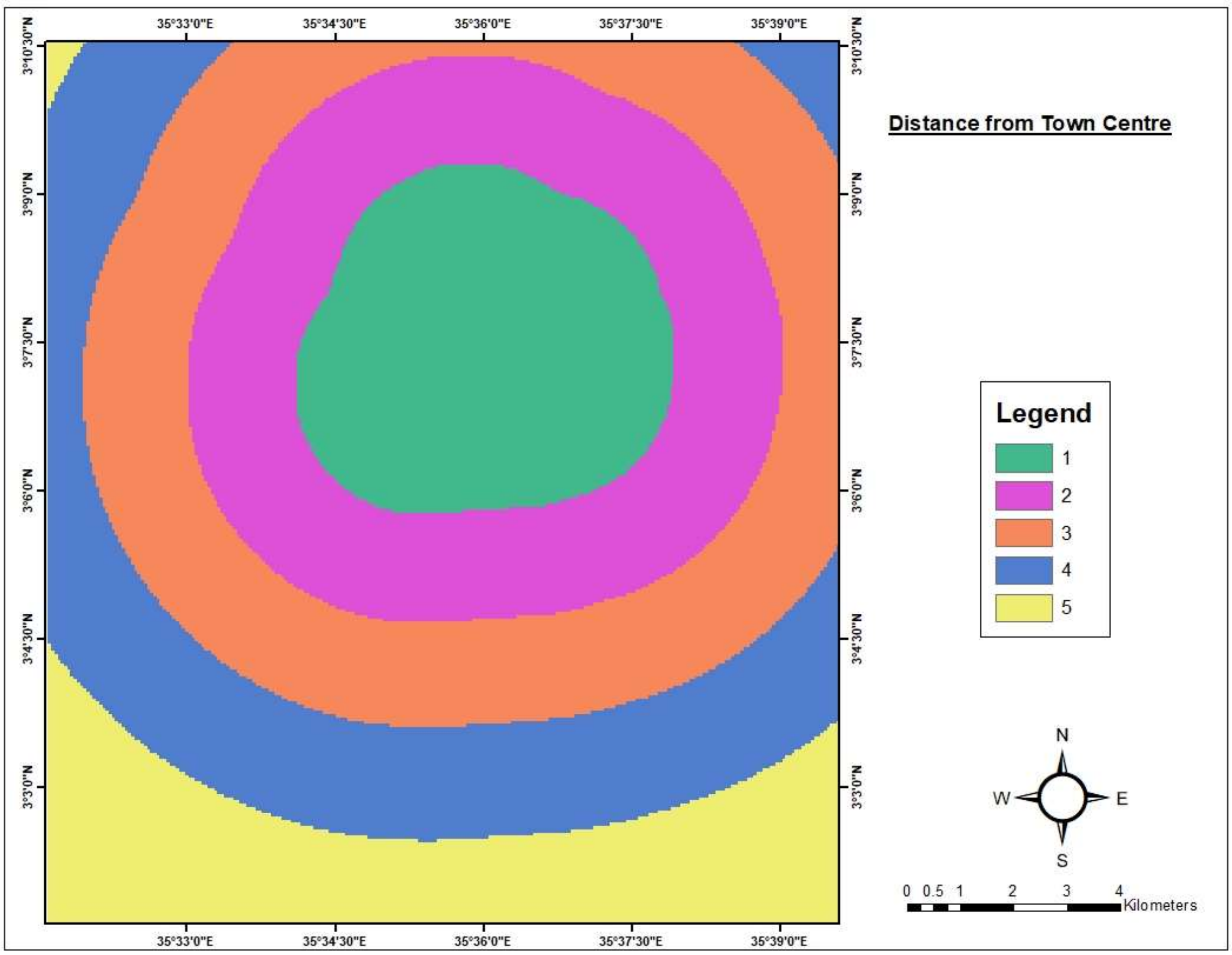

Figure 3.18: Reclassified Distance from Town Centre.

Table 3.13: Criteria for Distance from Town Centre Classification.

Class (Distance in Km)	Legend	Weight	Description
0 - 2	1	7	Extremely High
2 – 4	2	6	Very High
4 – 6	3	4	Moderate
6 – 8	4	3	Low
< 8	5	1	Extremely Low

3.8.7 Standardized Distance from Nearest Business Centres

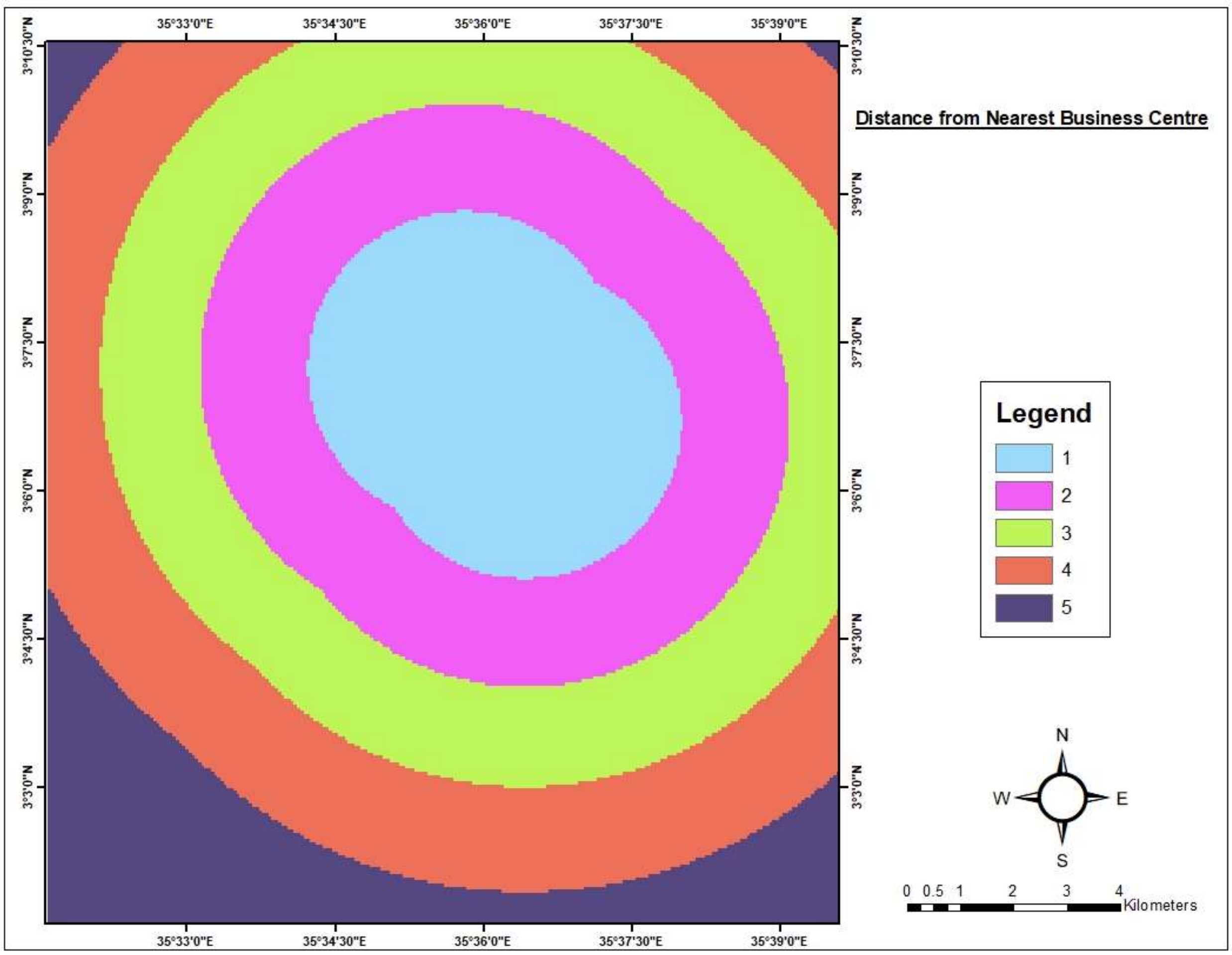

Figure 3.19: Reclassified Distance from Nearest Business Centres.

Table 3.14: Criteria for Distance from the Nearest Business Centres.

Class (Distance in Km)	Legend	Weight	Description
0 - 2	1	7	Extremely High
2 – 4	2	6	Very High
4 – 6	3	4	Moderate
6 – 8	4	3	Low
< 8	5	1	Extremely Low

3.8.8 Standardized Land use Landcover classes

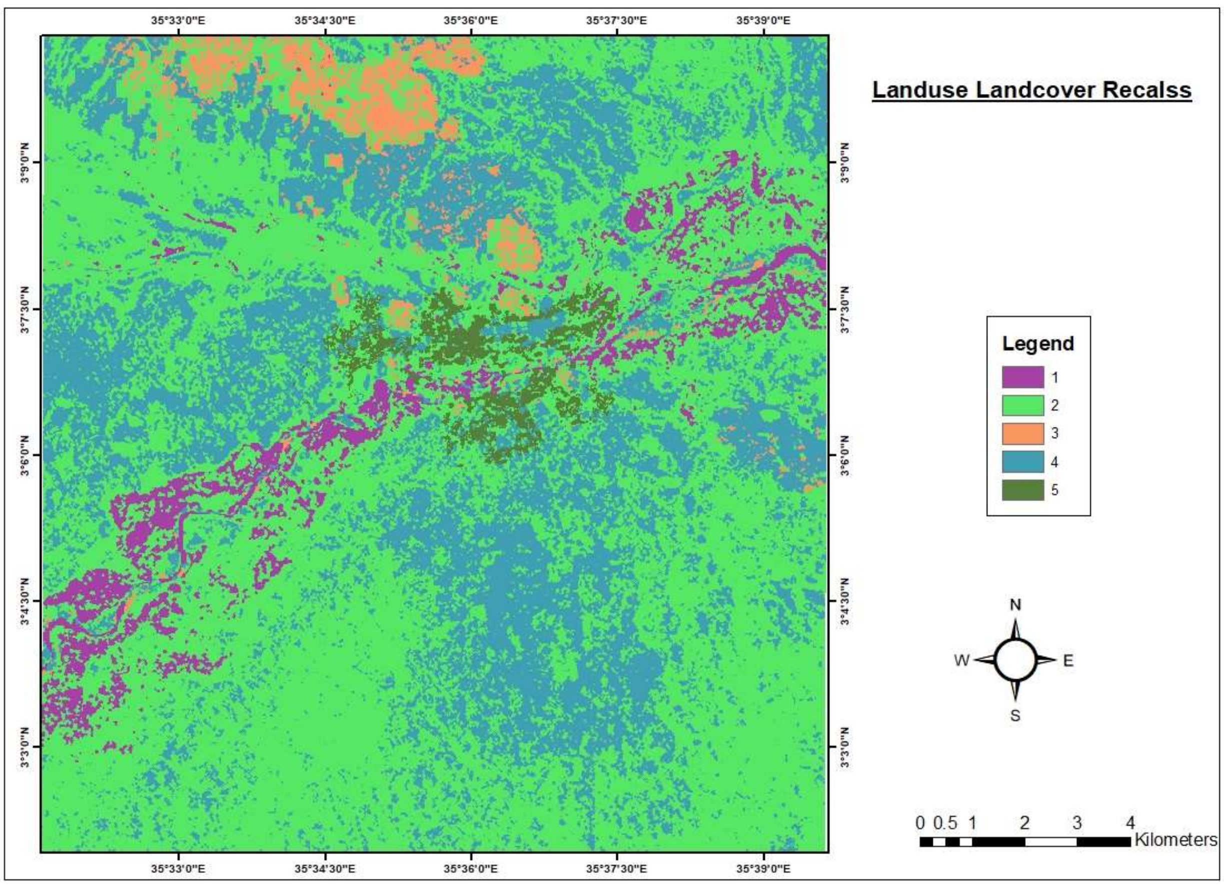

Figure 3.20: Standardized Land use Land cover classes

Table 3.15: Criteria for Land use Classification.

Land use Class	**Legend**	**Weight**	**Description**
Waterbodies /Agricultural land	1	6	Very High
Not covered (Bushland)	2	3	Low
Not covered (Rock Outcrops/hills)	3	2	Very Low
Urban outskirts	4	5	High
Urban Built-up areas	5	7	Extremely High

Table 3.16: Assigned Weights to Factors Based on their Suitability.

Scale	Suitability
1	Extremely Low
2	Very Low
3	Low
4	Moderate
5	High
6	Very High
7	Extremely High

3.9 Weighted Overlay Process

The *Overlay Tool* in ArcGIS was used in the combining of the resultant criteria generated from the resultant suitability maps in the previous section into one suitability map. Weights and or scale values were assigned to each of the factors/criteria affecting the water demand and supply in the areas using the AHP process as detailed in the previous section.

The reclassified datasets are then combined to generate a potential water demand priority map indicating areas that can be served efficiently by the water service provider. The values of the reclassification datasets representing slope, distance to boreholes, distance to water pipeline, land use land cover, distance to storage facilities, distance to business centres, distance to town centre reclassified to a common measurement scale.

The different layers/factors had varied influence were weighted, assigned a percentage of influence based on the results of the AHP process. Factors with a higher percentage have a higher influence in the suitability model.

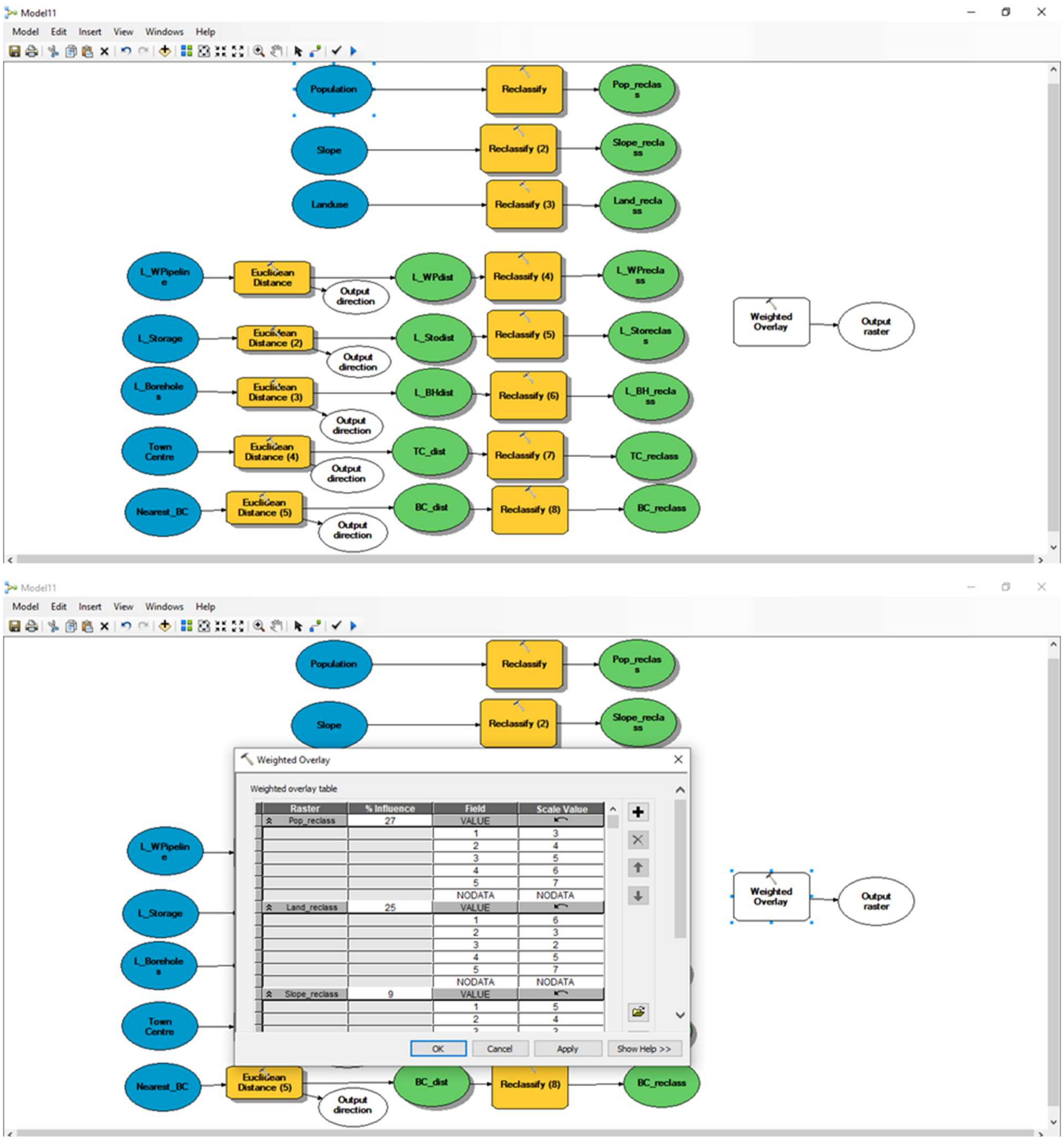

Figure 3.21: Weighted Overlay Process in Arc GIS Model Builder.

4. CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Introduction

Chapter four discusses the study results based on the data collected from the field and relevant organization. It also presents the discussions of the results deduced from the data collected and analyzed.

4.1 Results

4.1.1 Water Per Capita Demand Resultant Maps

The water consumption data for 2017, 2018 and 2019 from the records for the respective LOWASCO zones were analyzed and the annual per capita demand was computed as presented in the following maps.

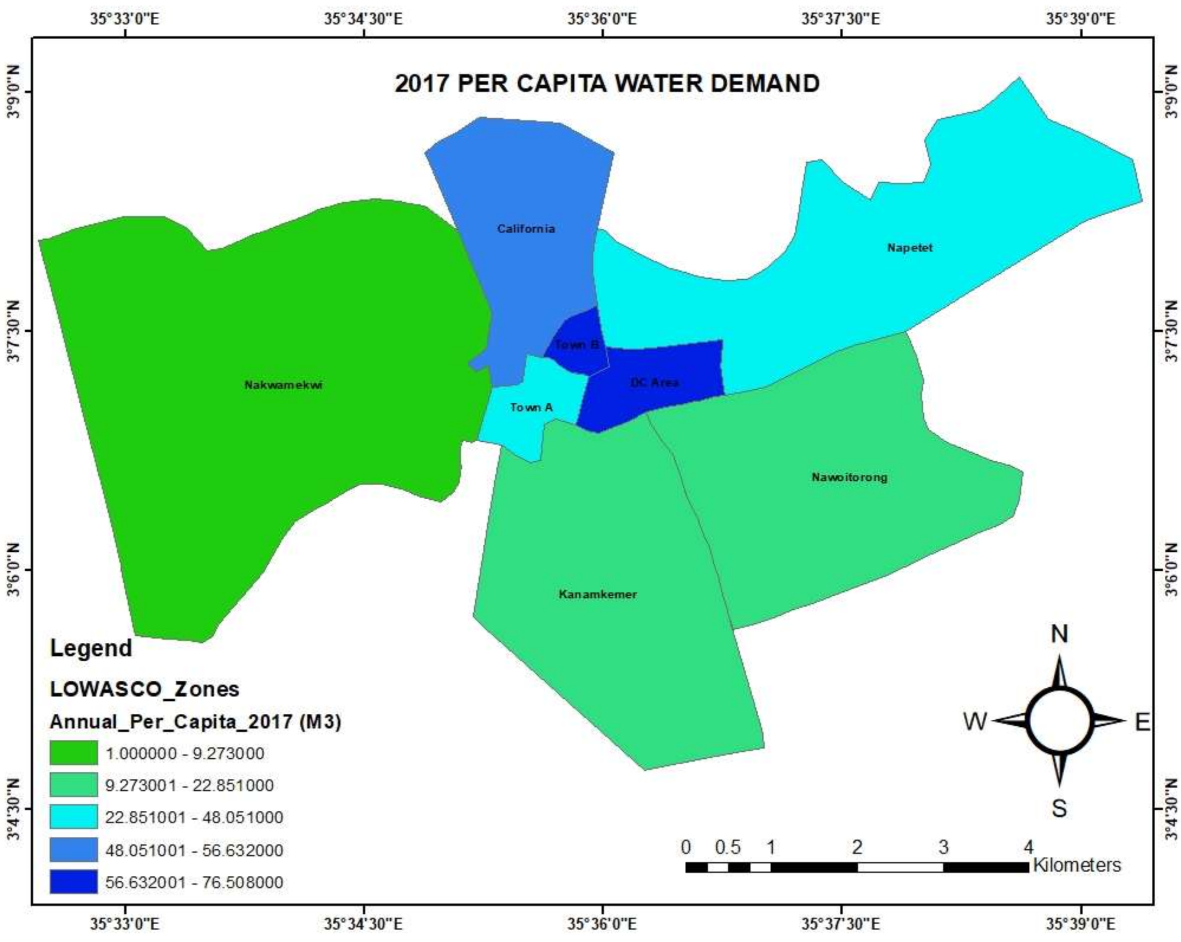

Figure 4.1:2017 Per Capita Water Demand.

The 2017 per capita water demand in LOWASCO zones indicate that Town B and DC Area zones had the highest water capita ranging between 56.632 – 76.508 M^3 which translates to a daily per capita of 155 – 209 litres. Nakwamekwi zone had the least annual per capita ranging from 1 to 9.273 M^3 which is equivalent to a daily per capita demand of 1 to 25 litres. A figure which is roughly half of the Basic Water Requirements (BWR) of 50 litres per day or annual per capita demand of 18.25 M^3. Several factors such as the state of the water supply network in respective zones, the status of boreholes serving the zone, population density and varying water use play a major in the amount of water used hence differences in annual per capita as reflected in the map.

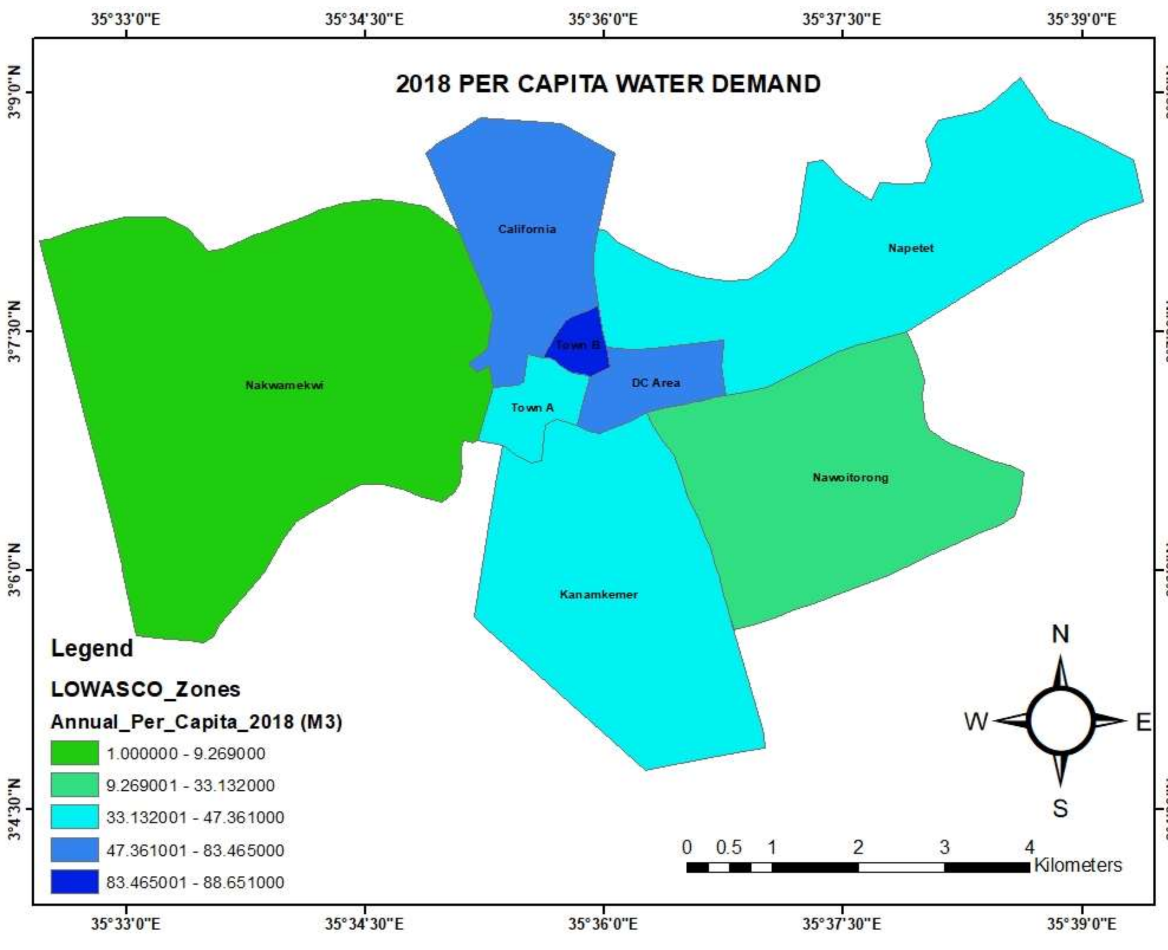

Figure 4.2:2018 Per Capita Water Demand.

In 2018, Town B zone still had a higher annual water per capita demand of between 83.465 – 88.651 M^3 relating to daily water per capita demand of 229 to 243 litres. This figure is much higher than the recommended BWR of 50 litres daily or annual per capita demand of 18.25M^3. Nakwamekwi zone in the second consecutive year had the lowest annual water per capita ranging from 1 to 9.269 M^3 which is an equivalent of 1 to 25 litres daily water per capita. This is still lower than the BWR of at least 50 litres daily and or annual per capita demand of 18.25M^3.

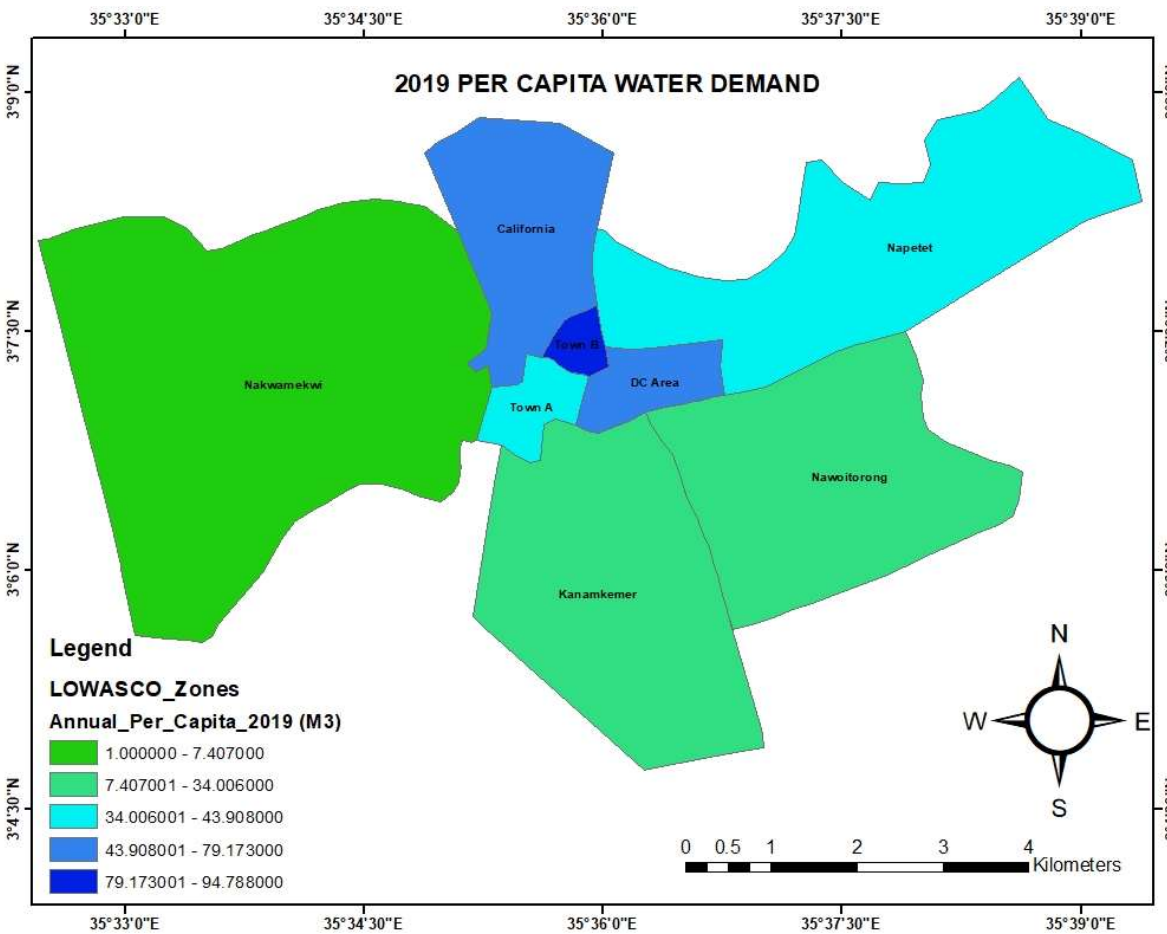

Figure 4.3: 2019 Per Capita Water Demand.

In 2019, the third consecutive year, Town B zone had a higher annual per capita water demand of between 79.173 to 94.788 M^3 which is an increase compared to years 2017 and 2018. The figure translates to 217 to 260 litres daily per capita demand which is far much higher than the recommended BWR of 50 litres of annual per capita demand of 18.25 M^3. Nakwamekwi zone had an annual per capita ranging from 1 to 7.407 M^3 a figure which is much lower compared to

2017 and 2018. This translates to 1 to 20 litres daily water per capita that is lower than the required standards of daily BWR of 50 litres or annual per capita demand of 18.25 M^3.

4.1.2 Comparison in Annual Per Capita Water Demand from 2017 to 2019

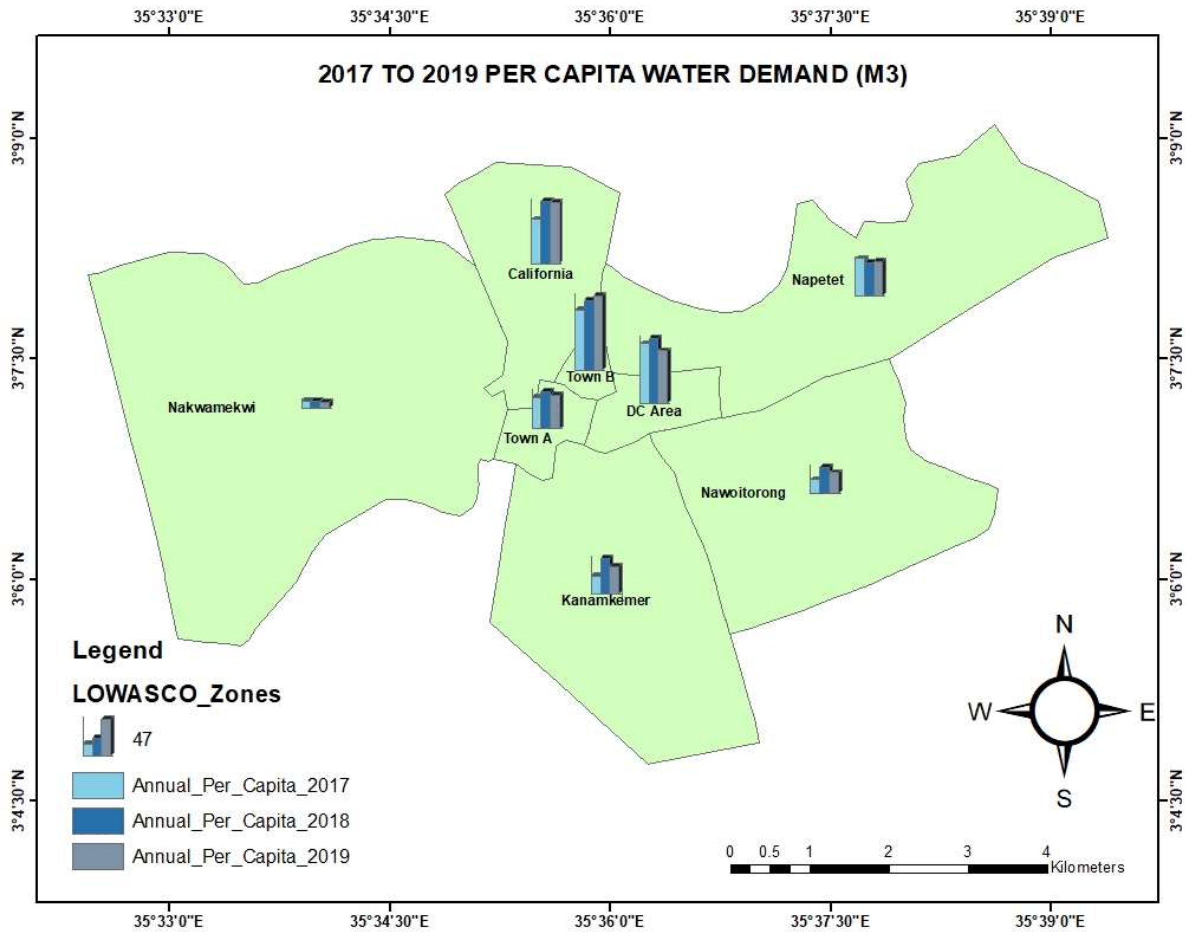

Figure 4.4: Per Capita Water Demand Comparison from 2017 to 2019.

A comparison of the LOWASCO zones water consumption from 2017 to 2019 as shown in Figure 4.4 indicates that Town B zone had the highest average annual per capita demand of 86.595M^3 while the Nakwamekwi zone has the lowest average annual per capita demand of 8.497M^3 for the three consecutive years. Other zones such as Kanamkemer and Nawoitorong have a medium-range in the three consecutive years. The zones: DC Area, Napetet, California and Town A have medium towards high range annual per capita demand in the three consecutive years.

The zones inside and near the town centre (DC Area, Napetet, California, Town B and Town A) have varied water use, their proximity to water storage facilities, population density, human activities, the state of water supply network among other factors have led to varying high annual water per capita. Some zones such as Town A, Town B, DC Area and California are inside the town centre where most service industries, retail shops, county and national government agencies, vital public institutions and commercial investments are situated/concentrated thus increased consumption of water. Nakwamekwi zone is less developed in terms of retail shops, service industries, less concentration of county government offices as compared to other zones in the municipality. Its location concerning the town centre has attracted medium human activities but with increased households/settlement leading to increased active metered connections with low consumption (mostly domestic purposes). The other reason is attributed to frequent waterpipe leakages due to its dilapidated condition and frequent borehole breakdowns serving this zone. A combination of these factors among others have denied the area/zone a constant and steady supply of water thus the lowest annual per capita demand which in some year is below the basic water requirements.

4.1.3 Comparison in Annual Per Capita Water Demand 2017 to 2019 Against BMR

A comparison of the annual water per capita against BWR as indicated in Figure 4.5 below revealed that Nakwamekwi zone is falling short of meeting the required standards of basic water requirements. Nawoitorong zone is following in terms of achieving the basic water requirements but with a slight improvement in the last two consecutive years. Some of the accessed annual audit reports (2016/2017 onwards) of the water service provider have indicated that the percentage of unaccounted for water is about 30% of the total water produced and supplied to the customers. Other losses occur through frequent pipe leakage as a result of the ageing pipe network and the persistent problem of illegal connections which are yet to be reduced.

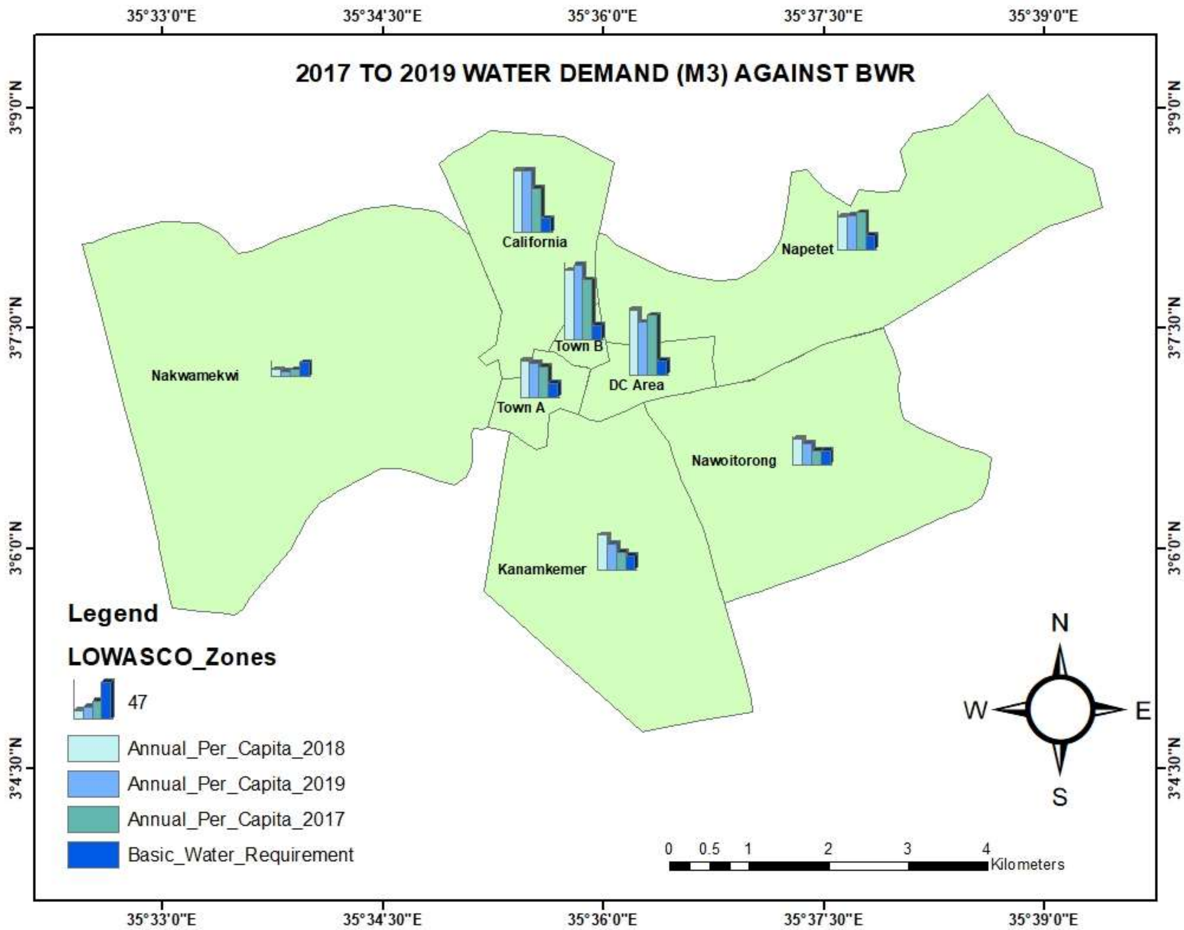

Figure 4.5:2017 to 2019 Per Capita Water Demand Against BWR.

4.2 Land use Land cover Results.

The analysis of Landsat 8 satellite image classification resulted in different 9 classes. The classes were from the land use and land cover classes which were captured by the satellite in the year 2019. The application of both supervised image classification technique ensured that all the existing classes are identified with the help of ground-truthing data. The final results of the image are presented in Figure 4.6 below.

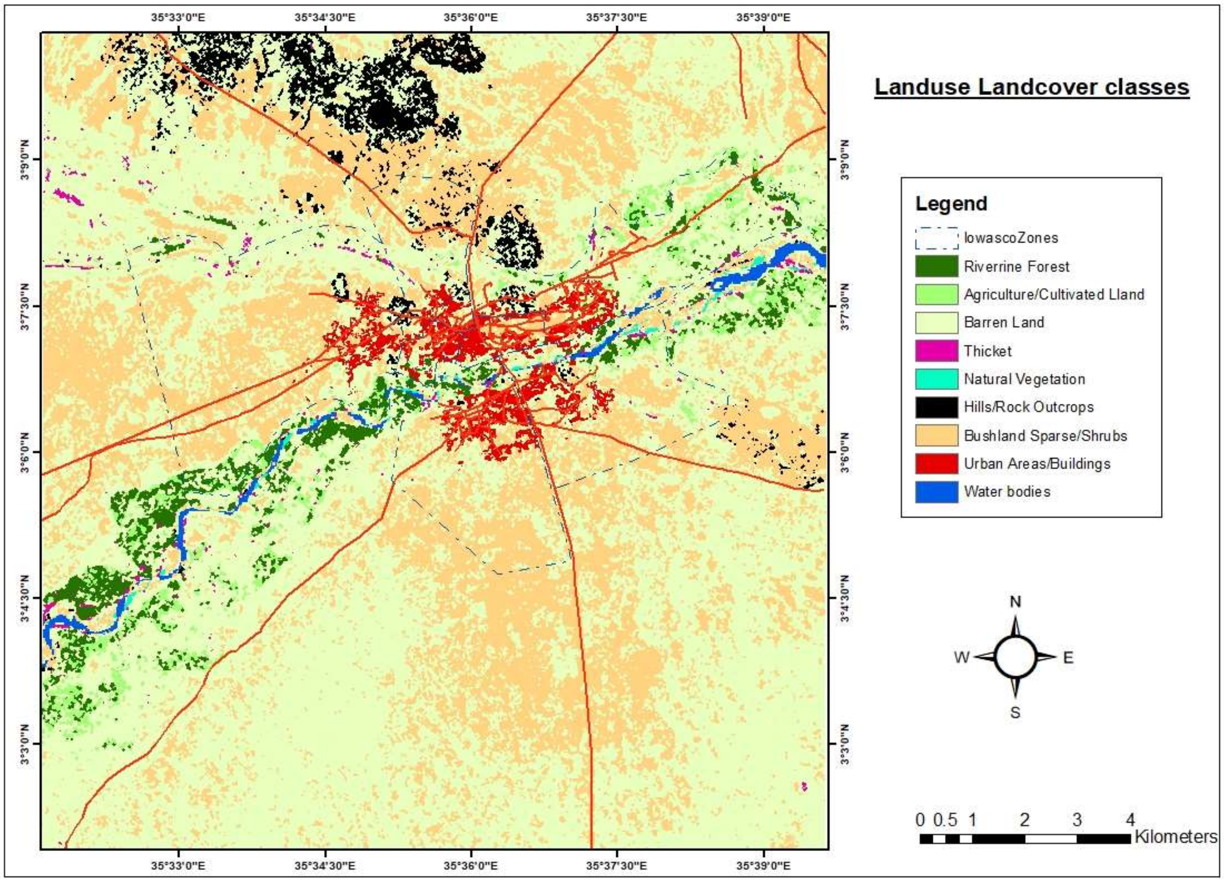

Figure 4.6: Land use/Land cover Classes

4.3 Population Density

The population density for the area was based on the enumeration units used by KNBS in conducting census which was the most suitable units. The population density of individual enumeration units was computed based on the size of the unit in square kilometres. The enumeration units with the highest density were ranging between 22555 – 37789 for the units with an area of between 0.013833 - 0.014317 km^2 respectively. The population density for the study area is represented in the map in Figure 4.7 below.

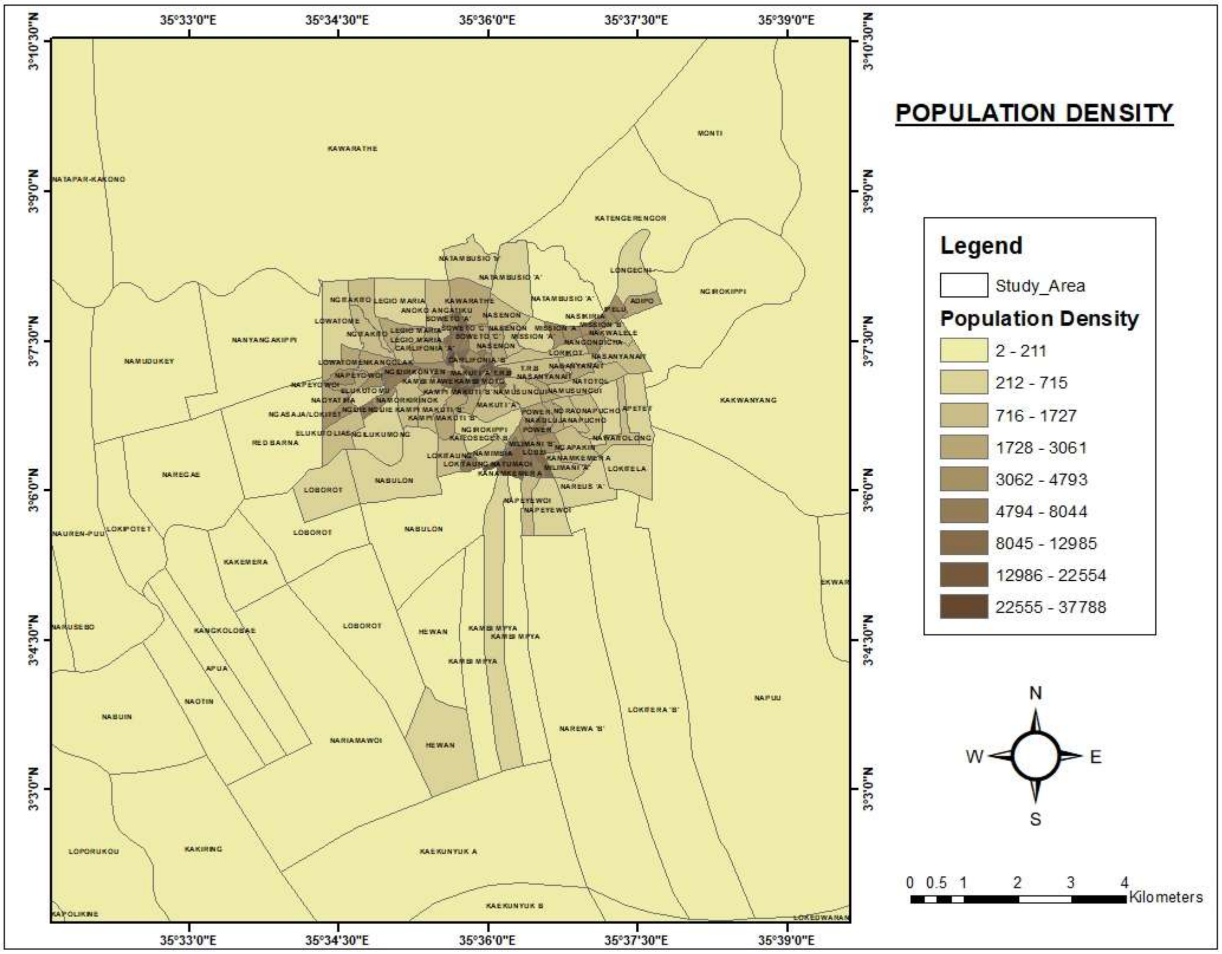

Figure 4.7: Population Density based on the KNBS enumeration Units.

4.4 Weighted Overlay Results.

The demand priority model that resulted from the combined 8 factors influencing water demand using the Arc GIS Weighted Overlay Analysis tool is presented in the figure below.

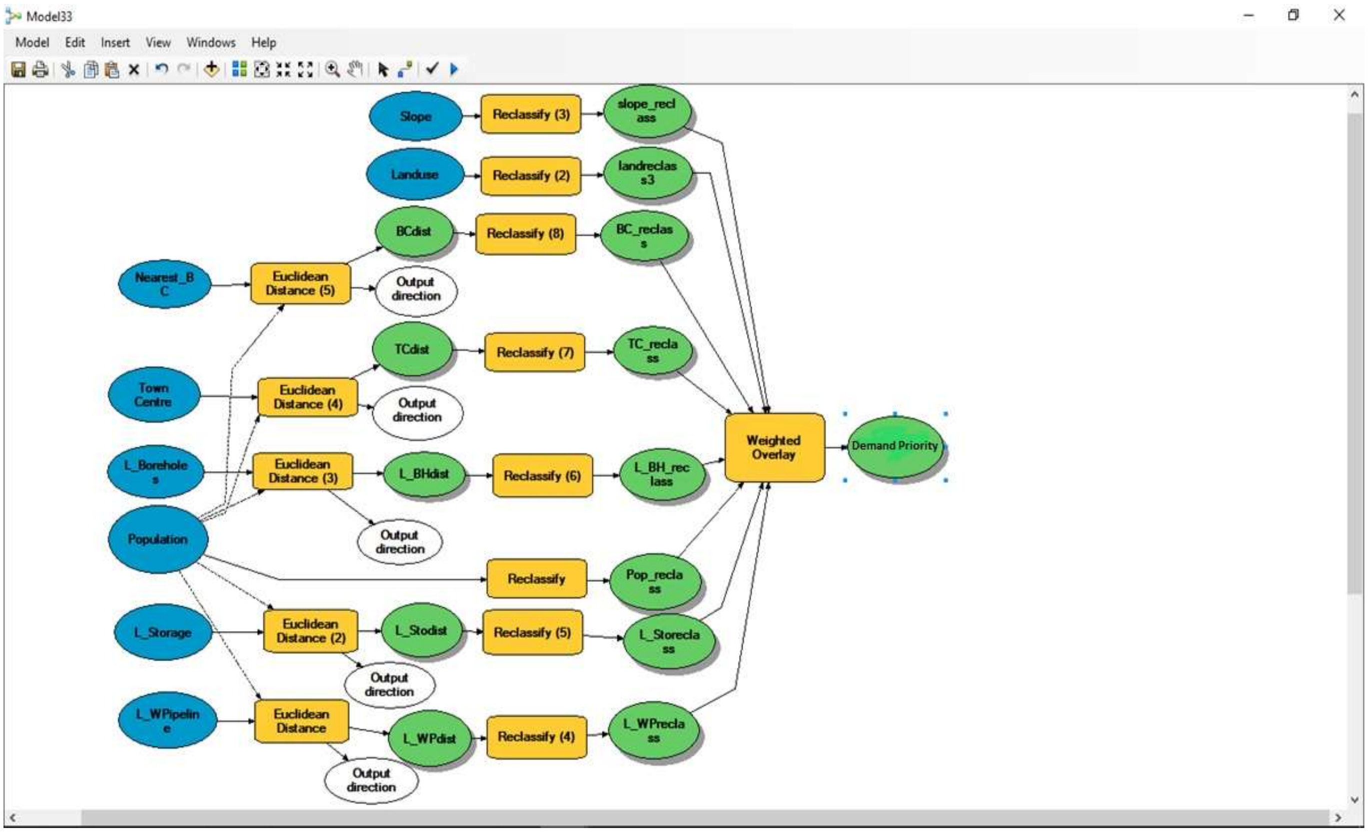

Figure 4.8 Demand Priority Model.

4.5 Final Results

The demand priority map from the weighted overlay analysis results was categorized into three priority demand priority areas, as well as one unsuitable, are which included the restricted areas (riverine forest reserve area), mountainous/hilly/rock outcrop areas based on the land use land cover classes identified and subsequently reclassed. These areas are designated as protected areas (riverine forest) in the tentative urban physical plan for Lodwar Town whereas the mountainous/hilly and outcrops to the North are not occupied by humans at the moment.

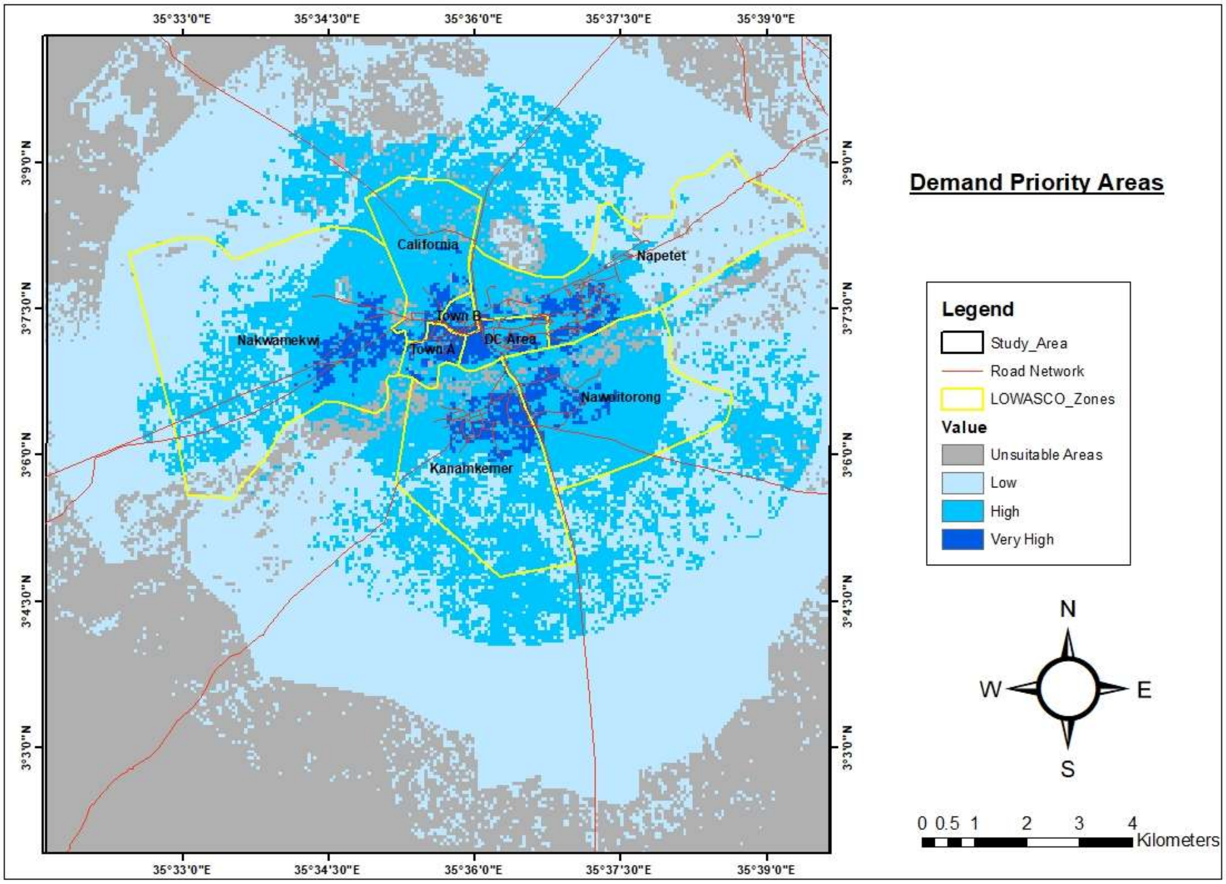

Figure 4.9: Demand Priority Areas.

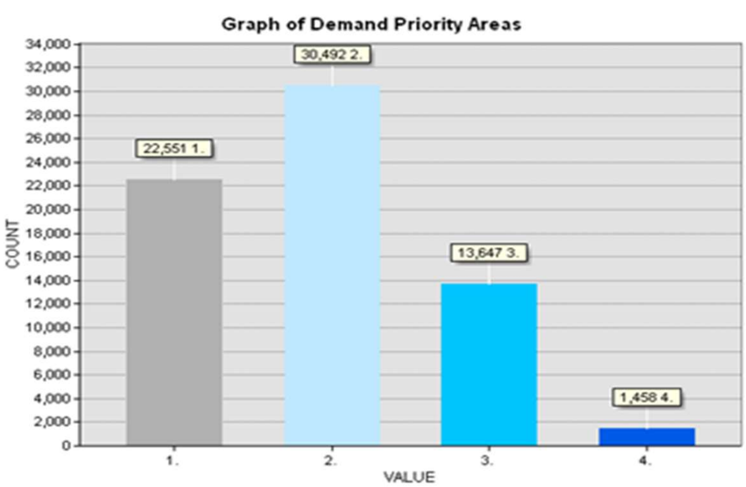

Figure 4.10: Demand Priority Areas Graph.

The areas around the Town Centre/proposed CBD have “Very High” priority in terms of water demand, a fact which was well captured in the water consumption records for 2017, 2018 and 2019. The expanding areas near the town have “High” priority due to the emerging service industries and commercial activities in the nearby areas to the CBD. The situation has been precipitated by the town upgraded status to be the headquarters of the Turkana County thus attracting investments. There is increasing development of settlements in the Southern region from the Town Centre in the current Kanamkemer ward as observed during the fieldwork.

4.6Model Results Validation

The results of the demand priority model were verified using the water utility infrastructure map for LOWASCO as well as field GPS points data from ground-truthing data. The areas having high annual water per capita based on the previous analysis of consumption data from LOWASCO zones were found to be in the "Very High" priority area of the model results.

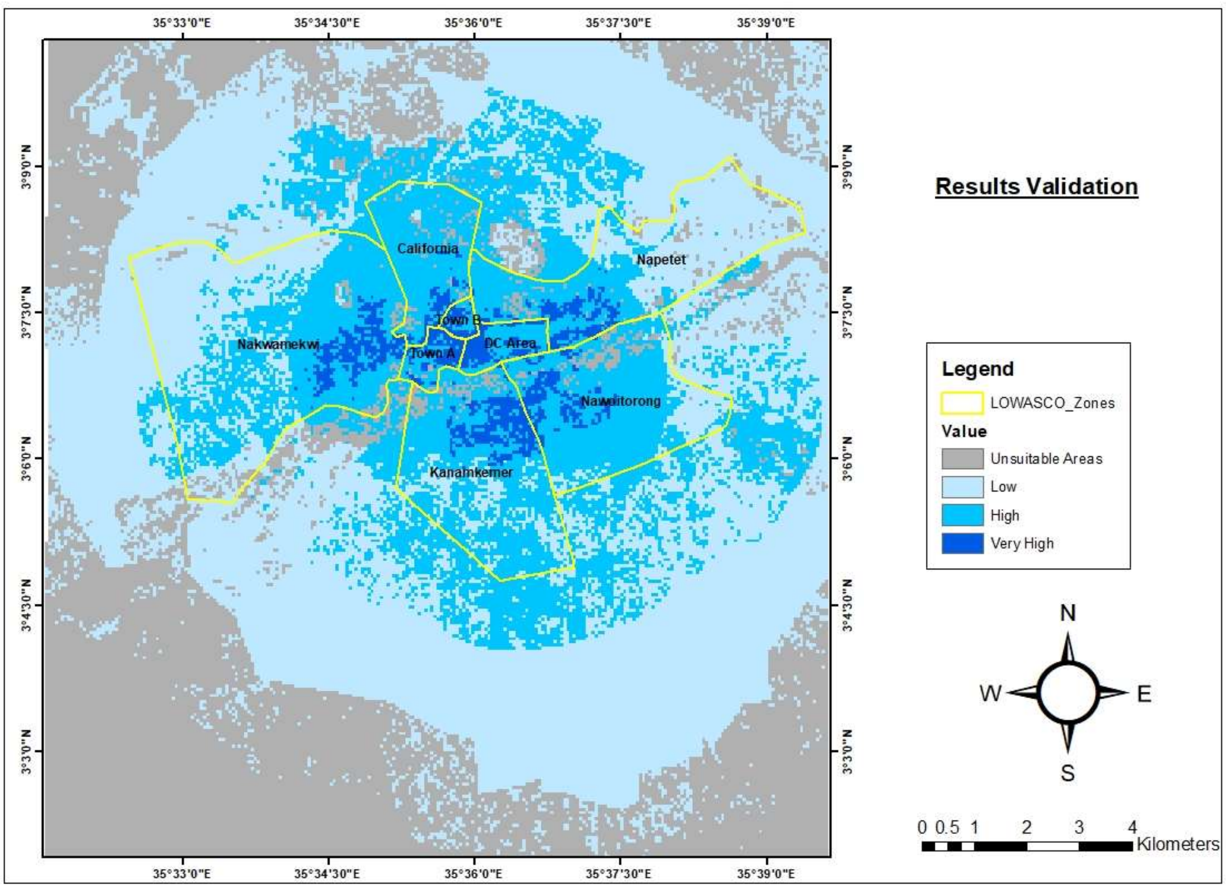

Figure 4.11: Model Results Validation Based on LOWASCO Supply Zones.

The model results indicated that some areas with high priority in water demand are falling outside the current LOWASCO zones. The management of the water utility company (LOWASCO) should consider adjusting the current zones to include all the areas with 'High Priority" to maximumly serve the population. The uniform distribution is key to efficient water service delivery which will relate to even urban growth being realized in these emerging areas and thus reduce their reliance on water trucking, kiosks and water bowsers. Nevertheless, the water storage facilities which are vital in feeding the water pipeline and to the customers should be uniformly distributed to all potential water demand areas especially the town peripheries within the "High" demand priority. This will ensure efficient access to water by the population in such areas. This can, in turn, reduce the uneven increase in the water consumption witnessed in some zones with high annual per capita as opposed to others experiencing increased connection each year but with lowest annual water per capita.

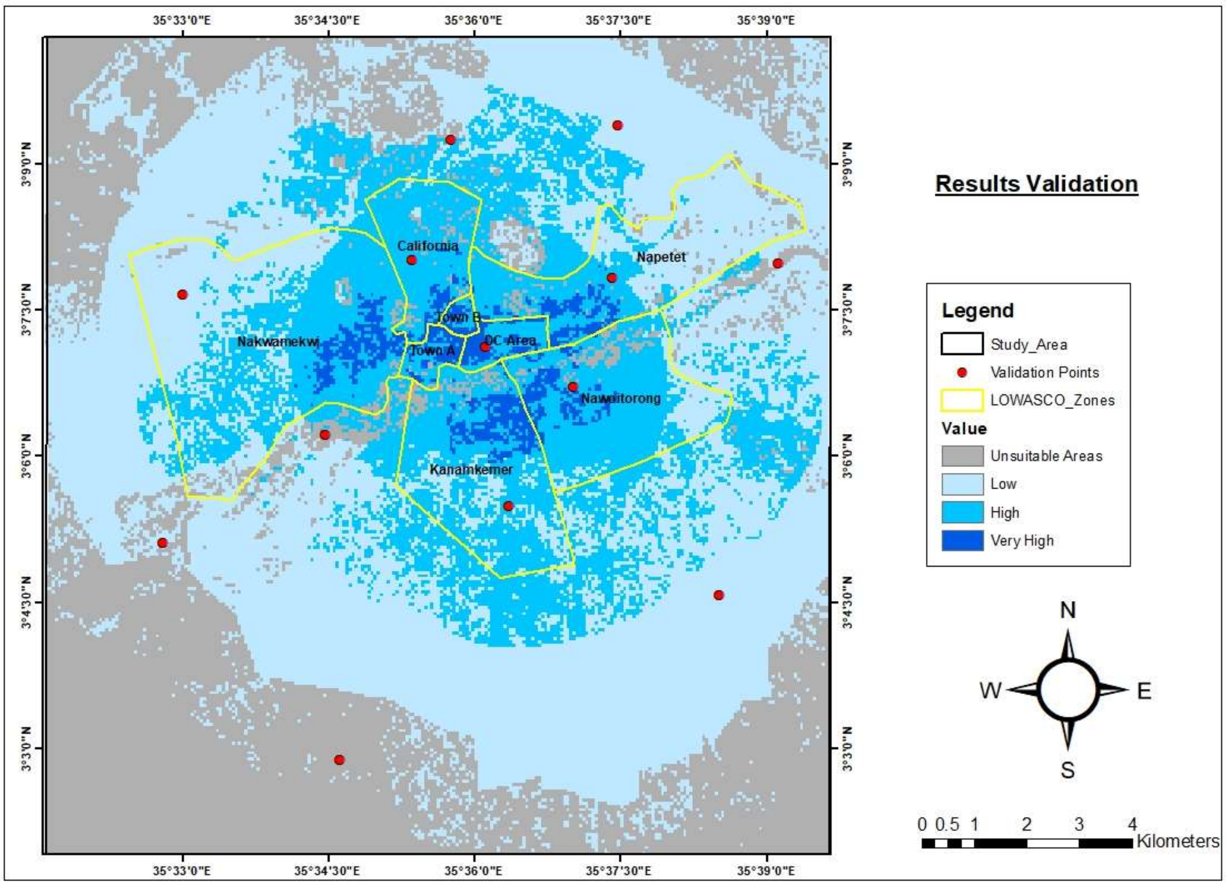

Figure 4.12: Model Results Validation Based on Validation Points

Ground truthing validation points were also used in the verification and adjustment of the model to reflect the current situation in the study area. Out of the 13 validation points mapped from the study area, 10 matched the results of the model while 3 points were slightly out of the range in line with the model priority results. The cross-referencing of the points with ground data proved the accuracy of the model.

5. CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

6.0. Introduction

This chapter highlights the conclusions and recommendations from the entire study based on the results obtained from the data analysis and interpretation.

The study main objective was to map the water demand in the area of interest the following conclusions and recommendations were made.

6.1. Conclusions

The study employed geoinformation methods and multi-criteria decision-making analysis in mapping the demand and supply of urban piped water in the study area. Through field data collection, analyzing different spatial and non-spatial data and presenting the results via a methodology using Arc GIS software, the results generated valuable information. Based on eight main factors identified to influence the demand for water in the town, a model was generated whose final results classified the town into three demand priority areas.

The study area was classified into nine land use/landcover classes using satellite imagery which indicated that the urban /built-up area is at the centre covering some parts of current Lodwar Township and Kanamkemer wards separated by the Turkwel River. The built-up areas/settlements to the southern part are expanding rapidly in contrast to the Northern area characterized by mountainous terrain with rock outcrops, hills as well as the Kawalase River which floods periodically during the rainy season thus a hindrance to development. The proposed urban physical plan for the town thus opted to designate most areas to the South for residential purposes while the Town Centre is mostly for commercial purposes.

The study also established that among the LOWASCO zones, Town B has the highest average annual water per capita demand of $86.595M^3$ whereas Nakwamekwi has the lowest average annual per capita water demand of $8.497M^3$. The status is well captured in Figures 4.1, 4.2 and 4.3 for three consecutive years (2017, 2018 and 2019) based on the water consumption data form LOWASCO records. On the contrary, Nakwamekwi zone has the lowest annual water per capita demand in the 3 consecutive years despite having an increasing number of active metered connections. The water per capita demand mapped against BWR have also shown that the same area is receiving water below the international required standards followed slightly by Nawoitorong zone although the situation for this zone is slightly improving in preceding years.

This worrying trend in the two zones (Nakwamekwi and Nawoitorong') needs to be improved to be at par with the other zones. The situation for Town B of high capita demand is reinforced by the model results which classified it under "Very High" priority for water demand.

The study has also demonstrated that the currently established zones are in the right priority zone in so far as water demand factors are concerned. However, the LOWASCO zones are not fully covering the suitable areas which can be efficiently served. Some areas which have "High" priority demand are not falling inside the established zones thus under-served. The future planning should thus incorporate all these areas within "High" priority for the expansion of water infrastructure services to reduce the current situation where such areas are relying on private water truckers.

6.2. Recommendations

Based on results obtained from the study and having interacted with different personnel from LOWASCO (while on fieldwork and in the office during the data collection stage), the following is a set of recommendations by the researcher:

Mapping and harmonization of all the existing infrastructure

Given the fact that last reliable mapping of water infrastructure was done in 2014, it will be of great importance if all the current/existing infrastructure from 2015 onwards be exhaustively mapped and be constantly updated to bridge the existing information/data gaps on some of the maps. This will make the maps reliable in decision making as well as the normal field activities.

The crucial data for LOWASCO hitherto is held by different entities and or major stakeholders. For instance, the infrastructure map, consumption data on Water Kiosks among others are in the custody of partners associated with the company making it difficult for easy access by researchers and interested groups for research purposes. For the best interest of the company operations, all the crucial data should be consolidated into a well-managed centralized geodatabase for easy access and management of the company utilities. The current situation (lack of geo-database) has made the key decision-makers in the company to lack an adequate basis on which to formulate informed decisions. Similarly, the water consumption data should be categorized based on their relevant use from different customers in respective zones for easy identification and separation of data from commercial activities and household consumption thus understand the disparities in water consumption.

Collaboration with County GIS department

The management of the water utility company spatial data is fundamental to managerial decision making and its core operations. LOWASCO should consider setting up a GIS department in collaboration with the County GIS department at the Ministry of Lands and Physical Planning so that all joint activities related to water infrastructure mapping in the area can be implemented. Since the said ministry already has information on water utilities within the town used in the development of urban physical plans, it will be effective to integrate similar functions and update their data to facilitate resourceful management of company assets. Such collaborations' if well laid out can help in the long run in managing the company's geospatial data and reduce over-reliance on consultancies.

LOWASCO should also consider hiring a competent GIS Analyst who will be responsible for consolidating the company vital geospatial data currently held by various stakeholders into a geodatabase accessible to appropriate persons. Working closely with the Technical Manager, Operations Manager and Field Assistants among others. The pair can then build the capacity of the entire staff in matters geospatial technology so that the staff can be utilized in routine data collecting in the respective zones/areas. This will also reduce operating costs and over-reliance on consultants.

Incorporate emerging technologies

Given emerging technologies in water infrastructure management planning, the maps, as well as the analytical approach presented in this research, can be used as a means for monitoring future annual, monthly or even daily disparities in the town's piped water demand and or supply. Besides the adoption of Water ATMs, it is recommendable that LOWASCO should consider embracing emerging technologies such as GIS and Information Technology by fully incorporate them into their operations.

Future mapping of water demand/supply can greatly be improved by basing the analysis on smaller geographic units like zones rather than the entire town since water supply and demand may vary markedly within a wider geographical area. For instance, large water quantity users should be isolated and analyzed separately since such consumers are likely to distort the average per-capita water demand where other residents within the area are not using such large quantities.

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