ASSESSING THE IMPACTS OF URBANISATION ON GROUND WATER USING REMOTE SENSING TECHNIQUES.

A CASE STUDY OF ARUSHA CITY

BRIAN BLASSY SHIRIMA

A Dissertation submitted in the Department of Geospatial Science and Technology in partial fulfilment of the requirements for the award of Bachelor of Science degree in Geographic Information System and Remote Sensing of Ardhi University.

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University as dissertation titled: **"Assessing the Impacts of Urbanization on Ground Water Using Remote Sensing Techniques"** in fulfillment of the requirements for the Bachelor of Science Degree in Geographic Information System and Remote Sensing.

____

Dr. Zakaria Ngereja

(Supervisor)

Date: _______________________

____

Mr. Michael Mavura

(Supervisor)

Date _______________________

DECLARATION AND COPYRIGHT

I, Brian Blassy Shirima, the undersigned, hereby declare that the contents of this dissertation are the results of my own findings, obtained through studies and investigation. To the best of my knowledge, similar work has never been presented anywhere as the thesis award of the diploma, degree of any other profession in higher learning institution.

____

BRIAN BLASSY SHIRIMA

25461/T.2020

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Almighty God for blessing me with knowledge, good health throughout my study period, and the ability to successfully complete my research. "*Not by might nor power, but my spirit, says the Lord Almighty" **Zachariah 4:6b.***

I deeply appreciate the support offered by my supervisors; Dr. Zacharia Ngereja and Mr. Mavura whose sincerity, inspiration, guidance and vast knowledge have greatly influenced me throughout the entire dissertation I also extend much appreciation to Dr. Dorothy Deus, Dr. Beatrice Tarimo, Ms. Latifa Litwe, the panel members and the staffs of Geospatial Sciences and Technology Department (DGST) for their constructive comments, encouragement and support.

My gratitude would not be complete if I do not mention my GIS classmates, Jacqueline Maleko, Joel Zablon, Sarah Paul, Emmanuela Charles, Neema Magele and the rest of my colleagues- the company and support offered will not be forgotten.

The completion of this research could not have been possible without the participation and assistance of so many people who might have not been mentioned in this page, whose contributions are sincerely appreciated and gratefully acknowledged.

DEDICATION

To my parents Blassy Shirima and Mary Shirima, who have raised and educated me since I was a child to a person I am today. I am grateful for everything you have done for me. You have my undying love and gratitude, and I will never be able to express how much I value and love you. I am grateful to my sister Frida Shirima and my brother David Shirima for youR advice and always motivating me to keep on going forward. I Thank you and love you all.

ABSTRACT

This study aimed to assess the impacts of urbanization on groundwater resources in Arusha Urban using remote sensing techniques. The analysis employed supervised classification with the National Land Cover Database (NLCD) classification scheme, specifically distinguishing urban built-up areas, suburban built-up areas, agricultural land, and rural open land. The Random Forest algorithm was utilized for the classification process. Accuracy assessment was conducted for the years 2016, 2019, and 2022 to evaluate the reliability of the classification results. The study focused on two key outputs: mapping of groundwater potential zones and analyzing the extent of urbanization in Arusha Urban.

The findings revealed significant changes in land cover patterns due to urbanization. Urban and suburban built-up areas expanded over the study period, resulting in the conversion of agricultural land and rural open areas. The Random Forest algorithm demonstrated satisfactory accuracy in classifying land cover types. The groundwater potential zone mapping provided valuable information on areas with high or low potential for groundwater availability. The study also highlighted the implications of urbanization on groundwater resources, emphasizing the need for sustainable management and conservation strategies.

Overall, this research contributes to a better understanding of the relationship between urbanization and groundwater resources in Arusha Urban. The remote sensing-based approach combined with supervised classification and the NLCD classification scheme offered an effective means to analyze land cover changes and assess the impacts on groundwater. The outcomes can assist urban planners and policymakers in making informed decisions regarding land use management, water resource allocation, and sustainable urban development in Arusha Urban and similar contexts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AOI	**Area of Interest**
DEM	**Digital Elevation Model**
IR	**Infrared**
LULC	**Land Use Land Cover**
NIR	**Near Infrared**
OLI	**Operational Land Image**
RS	**Remote Sensing**
TM	**Thematic Mapper**
UTM	**Universal Transverse Mercator**
WGS	**World Geodetic System**
NLCD	**National Land Cover Database**
TWI	**Topographic Wetness Index**
TRI	**Topographic Roughness Index**

CHAPTER ONE

INTRODUCTION

1.1 Background

Groundwater plays a fundamental but often unappreciated role in the economic and social well-being of urban areas. More than 50% of the African population relies on groundwater for domestic, agricultural and industrial use. In many situations, without groundwater there would be a deficit in water supply. Groundwater is more readily available at or close to the demand point and is often potable at the source. Groundwater accounts for over 80% of the daily water supply in Arusha (EWURA, 2015). Recharge into the unconfined aquifer is mainly from infiltration of excess rainfall, with a significant amount coming from the slopes of Mount Meru (GITEC, 2011; Kashaigili, 2010).

Urbanization refers to the process of population growth and the expansion of urban areas, including cities and towns. Urbanization has been on the rise globally, with more than half of the world's population now living in urban areas. The growth of cities and towns has had significant impacts on natural resources, including groundwater, which led to increased water demand, land use changes, and pollution. Rapid urbanization in most region has led to increased pressure on groundwater resources, which are critical for the city's residents and economic activities. Remote sensing techniques have emerged as a powerful tool to study the impacts of urbanization on groundwater.

Arusha region, located in northern Tanzania, has experienced rapid urbanization in recent years, which serves as a hub for tourism and trade in the region. The city has grown significantly, leading to increased pressure on natural resources, including groundwater. The development between 2016 and 2022 was very rapid, and this had consequences for water supply and availability (Agwanda & Amani, 2014). The Arusha Urban Water and Sanitation Agency (AUWSSA), the local public water supply agency, has been unable to meet the growing demand of different sectors (EGIS, 2017). The infrastructural, social and developmental WATER INTERNATIONAL 499 changes needed to dampen the effects of rapid urbanization and climate change are either not in place or happening at a very slow rate. Groundwater is a critical resource in Arusha, providing drinking water for the city's residents and supporting agriculture and other economic activities.

Arusha being a developing city, some changes were examined in land use and vegetation cover over a period of time, and relate these changes to variations in groundwater levels and quality. By doing so, we aim to provide a better understanding of the relationship between urbanization and groundwater resources in Arusha, and to identify potential risks and challenges that may arise from continued urban growth in the region. The results of this study can inform policy and planning decisions, and help to ensure the sustainable use of groundwater resources in Arusha and other rapidly urbanizing areas.

However, the impact of urbanization on groundwater resources in Arusha is not well understood, and there is a need to assess the potential risks and impacts of continued urban growth on this valuable resource. Remote sensing techniques have emerged as a powerful tool for studying the impacts of urbanization on groundwater. By using remote sensing techniques, it is possible to assess changes in land use and vegetation cover over time, and to relate these changes to variations in groundwater levels and quality.

1.2 Statement of the Problem.

Arusha region is one among the big cities in Tanzania with increase in urbanization due to population growth leading to the increase in the demand of water causing effects in groundwater resources. The increase in urbanization has led to decline in ground water since it prevents infiltration of water and hence cause surface runoff. Water demand for domestic, agriculture and industrial activities has outpaced the supply from unconfined Arusha aquifer. The impact of urbanization is not well understood especially in rapid urbanizing regions like Arusha leading to the need of assessing the impacts of urbanization on ground water to identify the potential risks and challenges that may rise from continue urban growth in Arusha region.

1.3 Research Objectives

1.3.1 Main Objectives

To assess the impacts of urbanization on groundwater in Arusha region.

1.3.2 Specific Objectives

1. Determine the land use and land cover changes over time in the area
2. Determine the ground water model
3. Examine the relationship between the ground water model and the land use and landcover changes.

1.4 Research Questions

- What changes have occurred on the land cover in Arusha?
- How will the groundwater be modeled?
- What is the relationship that exists between the groundwater model and landcover?

1.5 Importance of The Study

i. This study will help to provide the update information concerning with the urban LULC changes and urban expansion.
ii. The output of this study is essential for decision makers and urban planners for proper planning and utilization of the ground water resources.
iii. The output helps to ensure sustainable water supply and avoid over exploitation of groundwater
iv. Identifies ecological risks, prioritize conservation effort and maintain the health of ecosystem that rely on groundwater resources.

1.6 Beneficiaries

Users of result of this research includes;

1. Water Resource Managers and Planners

   The research findings will provide valuable insights into the impacts of urbanization on groundwater resources. Water resource managers and planners can use this information to develop effective strategies for sustainable water management in urban areas. The research can help identify areas at risk of groundwater depletion or contamination, allowing for targeted interventions such as groundwater recharge projects, land use planning, and infrastructure development to ensure the long-term availability and quality of groundwater resources.

2. Urban Planners and Policy Makers

   Urbanization poses numerous challenges to city planners and policymakers, including the management of water resources. The research outcomes can guide urban planners and policymakers in making informed decisions regarding land use zoning, infrastructure development, and urban expansion. By understanding the impacts of urbanization on groundwater, they can implement measures to mitigate negative effects, such as implementing green infrastructure, optimizing stormwater management systems, and promoting water-sensitive urban design.

3. Community and Residents

The research directly benefits the local community and residents in urban areas. By assessing the impacts of urbanization on groundwater, the research can raise awareness about the importance of sustainable water management practices among the general public. The findings can also help communities understand the potential risks associated with groundwater depletion or contamination, empowering them to engage in informed discussions and participate in decision-making processes related to water resource management. This knowledge can lead to community-driven initiatives.

1.7 Scope And Limitations Of The Research

This study aims to assess the impact of urbanization on groundwater using remote sensing techniques, focusing on changes in land use, infrastructure development, and urban expansion. It analyzes groundwater levels, quality, and availability, considering factors such as recharge rates, aquifer depletion, and contamination. Remote sensing technologies, including satellite imagery and GIS, are employed to gather spatial data for analysis. Data limitations, including availability and quality of remote sensing data, may affect the accuracy of the analysis. The findings may be specific to the study area and may not be easily generalized to other locations.

1.8 Dissertation Structure

This dissertation is divided into five (5) chapters that explain the assessments of the impacts of urbanization on ground water using remote sensing techniques in order to focuses on understanding the spatial patterns of urbanization and their influence on groundwater dynamics.

Chapter 1

This chapter introduces the research by describing relevant background information, the statement of the problem that influences the research, the main and specific objectives that provide an overview of the research results, significance, beneficiaries, scope and limitation to show the research extent based on the specific objectives provided, and the research questions derived from specific objectives.

Chapter 2

The Literature Review chapter describes information from several literatures about various studies examining the relationship between urbanization and groundwater dynamics are reviewed. This chapter's review, investigates the sources and characteristics of groundwater contamination resulting from urban activities, such as industrial discharges, sewage systems, and chemical usage. Furthermore, this chapter provides relevant studies that have attempted to utilize the same approaches.

Chapter 3

This chapter contains a description of the methodology utilized to achieve the research objectives, as well as a flow chart that explains the entire process of reaching the study goals. The methods for data collecting and processing are detailed in this chapter.

Chapter 4

This is the results, analysis and discussion chapter, which provides a path to achieving the research objectives. The chapter provides a detailed review of the research findings and results through the use of maps and graphs for analysis.

Chapter 5

This chapter contains the conclusions and recommendations. It includes a conclusion based onthe research objectives as well as recommendations based on the research findings

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview

This chapter reviews different literature relating to assessment of the impacts of urbanization on groundwater, a review of factor influencing the urbanization of the cities and the change in the ground water pattern in influencing the groundwater to be drained rather than surface runoff.

2.2 Urbanization

Urbanization is a global phenomenon characterized by rapid population growth and the expansion of urban areas. The increasing urbanization has significant implications for groundwater resources, which play a crucial role in supporting human and ecological needs. Remote sensing techniques have emerged as valuable tools for assessing the impacts of urbanization on groundwater dynamics. This literature review aims to provide an overview of existing research on the topic, focusing on the utilization of remote sensing techniques to understand the relationship between urbanization and groundwater resources.

Urbanization and Groundwater Interactions: Numerous studies have highlighted the complex interactions between urbanization and groundwater. Urban development alters land use patterns, resulting in increased impervious surfaces and reduced natural infiltration rates. This process disrupts groundwater recharge mechanisms and modifies the hydrological balance. Remote sensing techniques, such as satellite imagery, have been used to quantify changes in land use and impervious surface coverage, enabling a better understanding of the spatial extent of urbanization and its impact on groundwater resources.

Remote Sensing Applications in Assessing Urbanization Impacts: Remote sensing techniques offer unique capabilities to monitor urbanization and its impacts on groundwater. Satellite-based sensors provide high-resolution imagery, allowing for the identification and characterization of urban land use patterns, urban heat islands, and changes in vegetation cover. This information aids in assessing the spatial distribution of urbanization and its effects on groundwater recharge and discharge zones. Furthermore, remote sensing data integrated with Geographic Information Systems (GIS) facilitates the analysis of land surface characteristics and their relationship with groundwater dynamics.

Quantifying Groundwater Changes using Remote Sensing: Several studies have successfully utilized remote sensing techniques to quantify changes in groundwater levels and availability. By combining satellite-based data with ground-based measurements, researchers have developed models to estimate groundwater storage variations, recharge rates, and aquifer responses to urbanization. Remote sensing data also aids in identifying regions with groundwater depletion or rising water tables, enabling effective management of water resources in urban areas.

Assessing Groundwater Quality Impacts: Urbanization often leads to contamination of groundwater due to anthropogenic activities. Remote sensing techniques provide valuable insights into the sources and extent of groundwater pollution in urban areas. Satellite imagery, combined with spectral analysis, helps identify land use practices that contribute to groundwater contamination, such as industrial areas, sewage systems, and agricultural practices. This information aids in understanding the spatial distribution and extent of pollution, supporting targeted remediation efforts.

Conclusion: The literature review demonstrates the value of remote sensing techniques in assessing the impacts of urbanization on groundwater resources. Remote sensing, through satellite imagery and GIS integration, enables the quantification of land use changes, estimation of groundwater availability, and identification of groundwater quality issues in urban areas. By providing a spatially explicit understanding of urbanization impacts, remote sensing techniques can support informed decision-making for sustainable urban development and effective groundwater resource management. Further research is required to advance the application of remote sensing in assessing the dynamic and complex interactions between urbanization and groundwater resources. It also involves migration of people from rural to urban areas resulting to the expansion of cities, increased infrastructure development and changes in land use pattern. Though sometimes urbanization maybe caused by population growth and social factors like education, healthcare facilities(Tacoli,2020).Urbanization affects the social dynamics including changes in lifestyles, social networks and cultural practices(Brueckner&Rosenthal,2020).

When the population grows leads to increase in demand of water which lead to much pressure on the available groundwater for different purposes and these purpose can cause pollution of the groundwater(Angel et al.,2021).The expansion can also be the improvement of infrastructure which lead to the construction of impervious surfaces like roads, buildings and pavements which hinders infiltration of rainwater into the ground reducing the recharge of the groundwater hence disrupt the natural hydrological cycle by altering the patterns of rainfall runoff and infiltration.

2.3 Image Classification

Refers to the techniques of which information classes from remotely sensed multiple band is transformed into thematic map of land cover (Mather & Koch, 2011).It tends to assign each pixel in an image to particular class based on statistical characteristics of the pixel values. Digital image classification is the technique used to derive a thematic classes from RS images and the input are the multiband images and output being the file containing thematic classes.

The principle behind classification is that Pixel is assigned to a class based on its feature vector, by comparing it to predefined clusters in the feature space. Doing this for all image pixels results in a classified image. The crux of image classification in comparing it to predefined clusters, which require definition of clusters and methods of comparison Definition of clusters is an interactive process and is carried out during the training process. Comparison of individual pixels with the clusters take place using classifier algorithms (Rehna & Natya, 2016)

2.3.1 Classification Methods

Computer assisted classification is one among the classification methods, the other ones be manual and object-oriented method (Rehna & Natya, 2016). Depending on the interaction between the analyst and the computer during the classification, there are two types of classification which are supervisedclassification and unsupervised classification.

2.3.2.1 Supervised Classification

In supervised classification the operator defines the spectral characteristics of the classes by identifying sample areas (training areas). Supervised classification requires that the operator to be familiar with the area of interest. The operator needs to know where to find the classes of interest in the area covered by the image. This information can be derived from the general area knowledge of from dedicated fields of observations (Eastman et al, 1993).

It involves some steps for image to be classified like training sample generation in which the analyst identifies representative training sites and develops a numerical description of the spectral attributes of each feature imaged (Rehna & Natya, 2016).It is important as it help to produce quality results of classification. Then the training sample generated are used for classification in which their different methods like maximum likelihood, random forest which make use of the training sample by creating signature file then apply the signature file to produce a classified image which is the output.

The output must effectively convey the interpreted information to its end user. The output might be in the formof Graphic files, Tabular data, and Digital information file. It is in this place where Accuracyassessment is done. Accuracy assessment determines the correctness of a classified image based on pixel groupings. Example the categories of real-world features presented. The resultsof classification are assessed using a confusion matrix.

User accuracy Probability that a certain reference class has also been labelled as that class. In other words, it tells us the likelihood that pixel classified as a certain class represents that class.

Producer accuracy. Probability that a sample point on a map is that class. It indicates how well the training pixels for that class have been classified (Rehna & Natya, 2016).

2.3.2.2 Unsupervised Classification

In this method large number of unknown pixels are examined and divides into number of classes based on natural grouping present in the image values unlike supervised classification, unsupervised classification does not require analyst specified training data. The basic premise is that values within a given cover type should be close together in the measurement space that is have similar gray level whereas data in different classes should be comparatively well separated that is have very different gray level(Eastman et al,1993). The classes that result from unsupervised classification are spectral classes which based on natural grouping of the image values the identity of the spectral class will not be initially known must compare classified data to some form of reference data and informational values of spectral classes.

2.4 Land Cover

Land cover to the surface cover on the ground, whether vegetation, urban infrastructure, water, baresoil or other; it does not describe the use of land, and the use of land may be different for lands withthe same cover type. For instance, a land cover type of forest may be used for timber production,

For this study, LULC data were based on Landsat 8TM multispectral data covering 2016, 2019 and 2022. LULC classification was performed by a multi-temporal maximum-likelihood classification (Congedo, 2017) at a resolution of 30 m. The classification scheme was based on an adapted version of the NLCD land cover class definitions (Homer et al., 2004), emphasizing classes for built-up areas. Projections of the greater Arusha urban area were developed for 2022–2050 at 10-year intervals. To obtain an expressive characterization of the trends in the growth projections, the maps were post-processed using a methodology developed by Angel et al. (2007) in which the projected built-up areas and urban development were classified into meaningful components (e.g. infill, urban extension and leapfrogging development). This ensured consistency when delineating the urban footprint anSd the associated descriptive statistics wildlife management or recreation; it might be private land, a protected watershed, or a popular statepark (Ryan Coffey, 2013)

Land cover is commonly defined as the vegetation (natural or planted) or man-made constructions (buildings, etc.) which occur on the earth surface. Water, ice, bare rock, sand, and similar surfaces also count as land cover.

2.4.1 Change Detection

Change Detection can be defined as the process of identifying differences in the state of an object or phenomenon by observing it at different times. This process is usually applied to earth surface changes at two or more times. The primary source of data is geographic and is usually in digital format (e. g. satellite imagery), analog format (e. g. aerial photos), or Ancillary data (e. g. historical, economic, etc.) can also be used (Lunetta, R.S and Elvidge, C.D, 1998).

Techniques used change detection.

a) Image algebra methods which use a reference/threshold to detect change and involve some techniques such as image differencing, image regression, image rationing and vegetation index differencing.
b) Classification methods which based on the classified images and some of the techniques used are post-classification comparison and artificial neural networks.
c) Advanced models which convert image reflectance values into physically based parameters or fractions which are easy to interpret and some of the techniques used is the spectral mixture analysis YYJK, T6.
d) Transformations method which reduces data redundancy and some of the techniques used are Principal component analysis (PCA) and tasseled cap transformation.

Procedures for performing change detections

a) Image selection.
b) Image registration

c) Radiometric corrections

d) Multi temporal analysis

Land Cover types	Area in 2016 (Km^2)	Area in 2019 (Km^2)	Area in 2022 (Km^2)
Urban Builtup	37	30.5	31.6
Suburban Builtup	119.8	166.1	170.3
Agriculture	22.5	17.5	21.1
Rural Openland	88.6	53.8	44.8
Total footprints	305.4	267.9	267.8

Table 2 .1: NLCD assessment

2.4.2 Prediction

Prediction is the type of modelling that uses simulation to project, a given geographical phenomenon,into a given duration of time. That is to say, the phenomenon in question is being projected from theusing the change analysis results upon a given base map or a dataset. There must be a set of changesfrom which the prediction model can be generated, and also be used to predict how the entity will look like after a given duration of time has passed. One of the most projected scenarios is land cover,as most decision-making processes needs, sufficient information on these datasets for different planning and implementations.

Cellular automata- Markov chain method there are various that have been applied so far, so as to be able to do prediction on land cover for various purposes such as planning. The most used method in prediction is the cellular automata- Markov chain which is a combination of the two methods entailing the stochastic Markov with cellular automata. (Mishra & Rai, 2016) Numerous research have applied different models to simulatefuture LULC changes. Markov Chain (MC) model is the most commonly used technique in modellingand simulating LULC changes. The MC-based simulation is stochastic modelling approach that considers certain time large-scale datasets from previous years and uses the data sets to develop a transition matrix, as well predicting land cover of the given locality per simulated time.

2.5 Ground Water

Groundwater is a precious resource that covers wide geographical extent. Proper evaluation is required to ensure prudent use of groundwater resources. Lack of proper knowledge accounting distribution of groundwater potential zones (GWPZS) has a negative implication on groundwater exploitation and management as the area will be explored with higher uncertainties. (Fischer & Getis,2010).

2.5.1 Slope

The Slope tool determines the steepness at each cell of a raster surface. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. (Fotheringham & Rogerson,2009)

The Slope tool uses a 3 by 3 window of cells to compute the value, while the Surface Parameters toolallows window sizes from 3 by 3 to 15 by 15 cells. Larger window sizes are useful with high resolution elevation data to capture land surface processes at an appropriate scale. Surface Parametersalso provides an adaptive window option that evaluates the local variability of the terrain and identifies the largest appropriate neighborhood size for each cell. This can be useful with gradual homogeneous terrain interrupted by streams, roads, or sharp breaks in slope.

The output slope raster can be calculated in two types of units, degrees, or percent (percent rise). Thepercent rise can be better understood if you consider it as the rise divided by the run, multiplied by

100. Consider triangle B below. When the angle is 45 degrees, the rise is equal to the run, and the percent rise is 100 percent. As the slope angle approaches vertical (90 degrees), as in triangle C, the percent rise begins to approach infinity. (Fischer & Getis, 2010)

Slope calculation

Slope as degrees= $tan^{-1}({}^{a}/_{b})$

Slope as percent =${}^{rise}/_{run} * 100$

2.5.2 Aspect

Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. (Heng, 2009) The values of each cell in theoutput raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas havingno downslope direction are given a value of -1. The value of each cell in an aspect dataset shows thedirection the cell's slope faces.

Aspect calculation

A moving 3 x 3 window visits each cell in the input raster, and for each cell in the center of the window, an aspect value is calculated using an algorithm that incorporates the values of the cell's eight neighbors. The cells are identified as letters a to i, with e representing the cell for which the aspect is being calculated. Figure 2.1 shows how aspect is calculated using 3x3 window

Table 2. 1 Surface window

a	b	c
d	e	f
g	h	i

The rate of change in the x direction for cell e is calculated with the following algorithm:

$$\left|\frac{dz}{dx}\right| = \frac{(c + 2f + i) - (a + 2d + g)}{8}$$

The rate of change in the y direction for cell e is calculated with the following algorithm:

$$\left|\frac{dz}{dy}\right| = \frac{(g + 2h + i) - (a + 2b + c)}{8}$$

Taking the rate of change in both the x and y direction for cell e, aspect is calculated using:

Aspects=$57.29578 * atan2(\left[\frac{dz}{dy}\right] - [\frac{dz}{dx}$

The aspect value is then converted to compass direction values (0-360 degrees), according to thefollowing rule:

If aspect <0, then Cell = 90 - aspect else

If aspect >90, then Cell = 360 – aspect + 90

Else, Cell = 90 - aspect (Longley, Goodchild, & Smith, 2011)

2.5.3 Hill shade

The Hill shade tool obtains the hypothetical illumination of a surface by determining illumination values for each cell in a raster. It does this by setting a position for a hypothetical light source and calculating the illumination values of each cell in relation to neighboring cells. It can greatly enhancethe visualization of a surface for analysis or graphical display, especially when using transparency. By default, shadow and light are shades of gray associated with integers from 0 to 255 (increasing from black to white). The primary factor when creating a hill shade map for any location is the location of the sun in the sky (Fotheringham & Rogerson, 2009).

Calculations of hill shade

To calculate the hill shade value, the altitude and azimuth of the illumination source are required. These values will be processed with calculations for slope and aspect to determine the final hill shadevalue for each cell in the output raster.

The algorithm for calculating the hill shade value is as follows:

Formula

Hill shade = 255 * ((cos (Zenith_rad) * cos (Slope_rad)) +(sin(Zenith_rad) * sin (Slope_rad) * cos (Azimuth_rad - Aspect_rad))) 2.3

Note that if the calculation of the hill shade value is < 0, the output cell value will be = 0. (Fotheringham & Rogerson, 2009)

Wells and well field Information's

Wel lNo	Well Name	X	Y	rface level a.m.s.l	tial water table	quifer base (a.m.s.l)	ells capacity (m3/hr)	ischarge Rate
1	Moivo II	4264	4653.8	1437.0	1338.0	1333.48	85	31
2	Sanawari	3604	4653.9	1430.2	1370.7	1288.68	130	91
3	Moivo I	4000	5653.8	1458.7	1380.0	1325.00	80	21
4	Loruvani New	4190	6264.0	1499.9	1399.9	1295.80	100	60
5	Ilkilorit	3385	5423.0	1443.8	1399.8	1262.28	85	40
6	Ilboru	3012	6000.0	1472.8	1413.0	1330.34	185	119
7	Mianzini	2346	4615.4	1437.3	1359.0	1295.79	65	43
8	Oltulelei	1808	5846.2	1472.1	1388.1	1288.58	215	164
9	Emco	4050	1862.0	1335.4	1300.0	1181.64	120	44
10	Sakina	385	4192.3	1410.0	1359.9	1318.56	30	26
11	Sekei	4846	4615.4	1445.0	1380.9	1289.07	20	18
12	Old Sanawari	3808	5384.6	1461.8		1387.91	42	42
13	Loruvani Yard	3923	6384.6	1500.0	1420.1	1378.95	30	24
14	Loruvani Bondeni	3377	6623.0	1520.0		1436.00	90	80
15	Kiranyi	1000	6000.0	1433.0	1383.0	1233.00	320	39
15	Ngarendolu Spring	1886	4544.5	1394.0	1394.0	1200.00	166	
16	Oliglai Spring	6656	5591.4	1582.0	1582.0	1380.00	1083	
17	ATC	4000	4653.9	1430.2	1370.7	1288.68	130	91

Table 2 Data of wells and wells information

CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter describes overall workflow ranging from data collection to methods used. It includes the data collection, data pre-processing and data analysis methods that were used in obtaining the results.

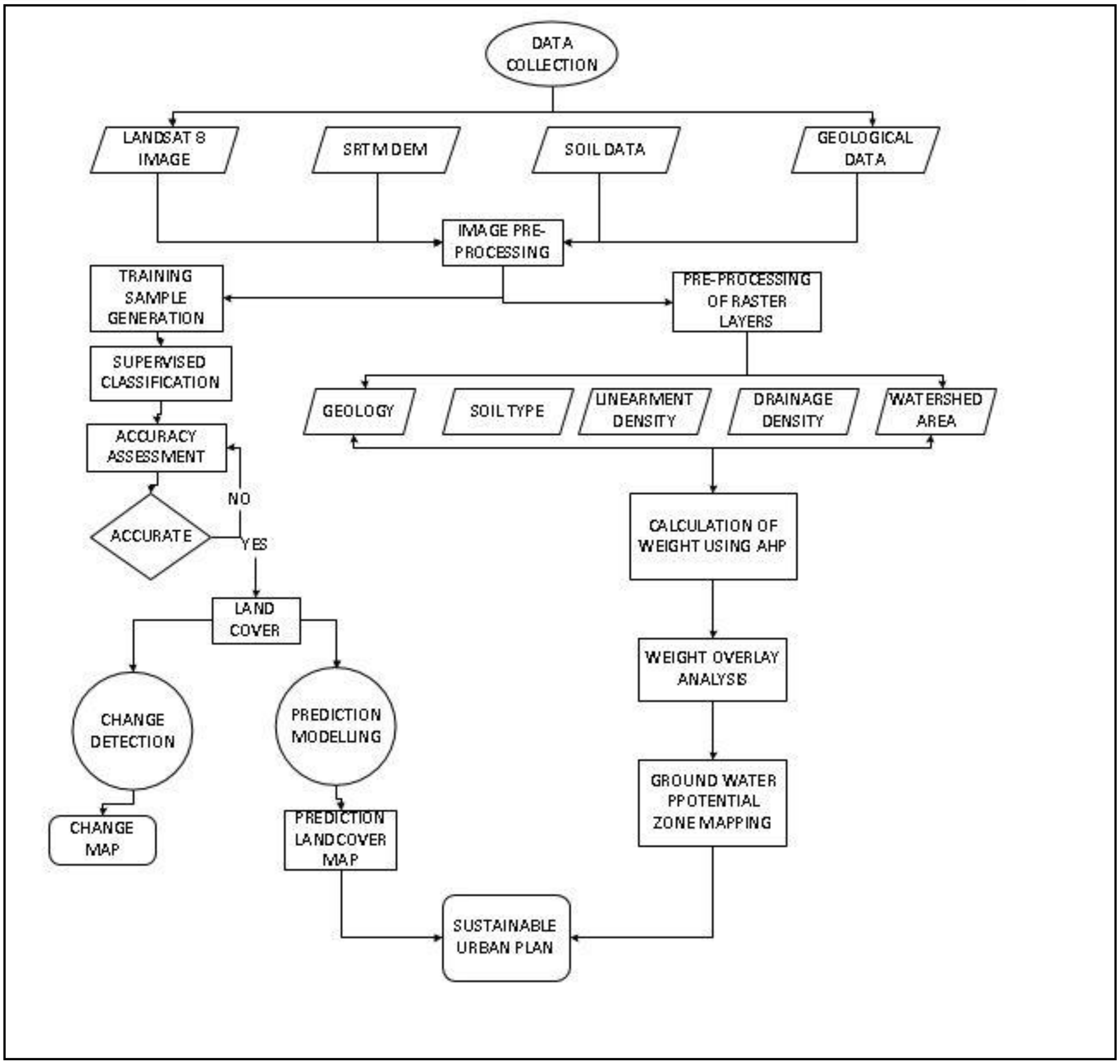

Figure 3.1 The Workflow

3.2 Description Of The Study Area

Arusha region is located in the Northern part of Tanzania between 34ºE to 37ºE and 2ºS to 4ºS of Greenwich Meridian. Its altitude is about 1400m from the sea level on the Southern foot slope of an ancient volcano namely Mount Meru (4565 a.m.s.l). Its population as of 2016 census was over 453,000 inhabitants with a growth rate of 2.26% per annum. With this trend it is expected by 2035 there will be over 886,000 inhabitants assuming net migration. Also, as industries and other water demanding activities are increasing current source of water not equal the demand. In Arusha urban, there are three sources of water namely springs, boreholes and rivers, the spring include Olesha-Masama springs along Themi River located 4km north of the Municipality and Ngarendolu springs located in the northern part of the Municipality In Arumeru districts and two boreholes located one within the Municipality area and the other near Nduruma River along Moshi Arusha Highway in Arumeru district.

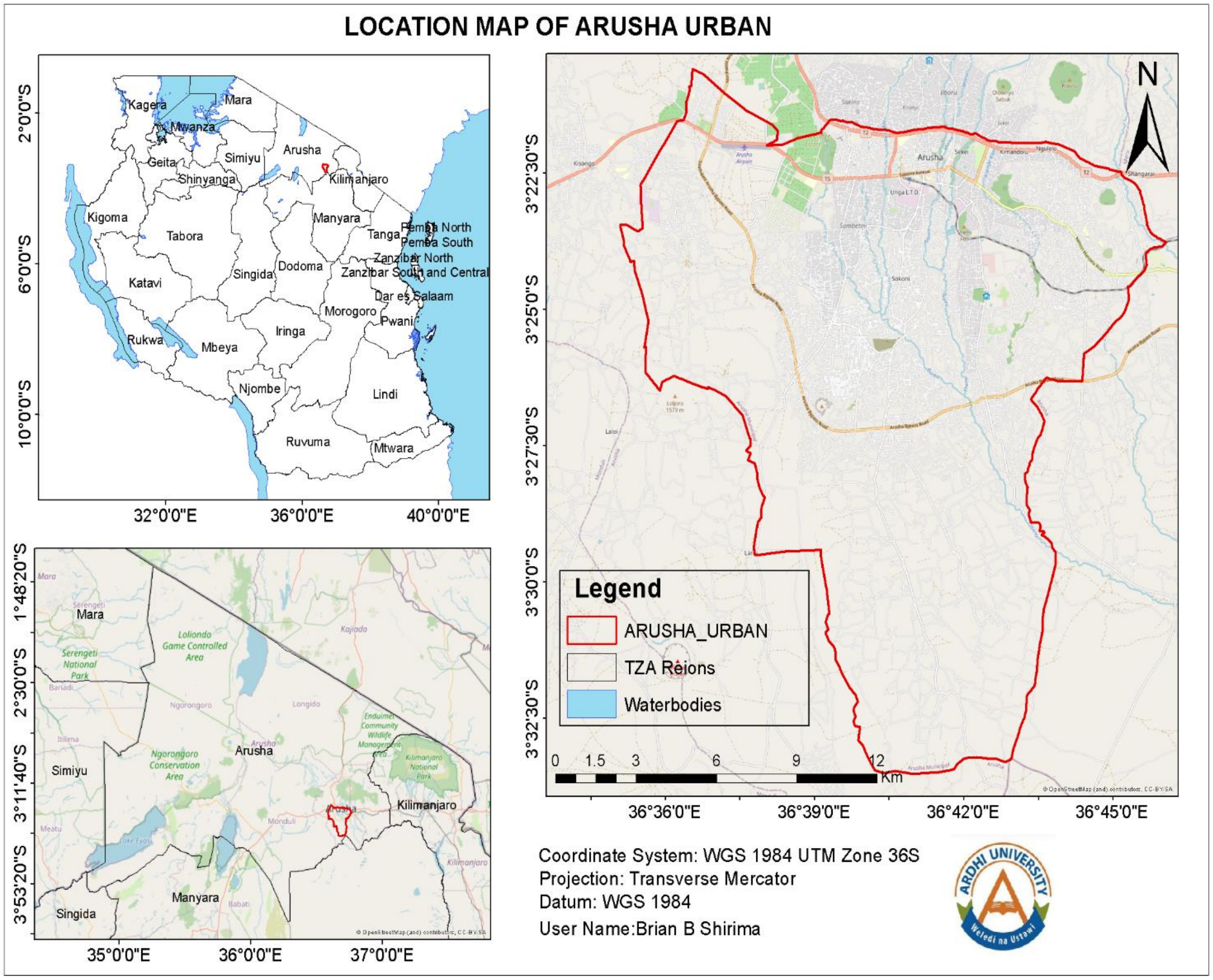

Figure 3.2 Location map

3.3 Data Collection And Description.

The data used in the study were collected from various sources and in different format, and are summarized in the table 3.1

	NAMES	SOURCE	FORMAT	PURPOSE
1	Elevation (DEM)	USGS	Tiff.	Modelling
2	Soil Data	ISRIC	Tiff.	Modelling
3	Temperature (Tmax & Tmin)	TerraClim	Tiff.	Modelling
4	Precipitation	TerraClim	Tiff.	Modelling
5	Boundary Data	GADM	Shp.	Modelling

Table 3.3 Data and sources

3.3.1 Landsat 8 Operational Land Image (OLI).

The Landsat 8 image consists of nine spectral bands with a spatial resolution of 30 meters 1 to 7 and 9. New band 1 (Ultra-blue) is useful for coastal and aerosol studies. New band 9 is useful for cirrus cloud detection. The resolution for Band 8 (panchromatic) is 15 meters. Thermal bands 10 and 11 are useful in providing more accurate surface temperatures and collected at 1000 meter and the data were acquired from USGS website. Their resolution properties were summarized in Table 3.3 for Landsat 8 OLI.

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1-Coastal aerosol	0.43 – 0.45	30
Band 2-Blue	0.45 – 0.51	30
Band 3-Green	0.53 – 0.59	30
Band 4 -Blue	0.64 – 0.67	30
Band 5 -Near Infrared (NIR)	0.85 – 0.88	30
Band 6 -SWIR 1	1.57 – 1.65	30
Band 7 -SWIR 2	2.11 – 2.29	30
Band 8 -Panchromatic	0.50 – 0.68	15
Band 9 -Cirrus	1.36 – 1.38	30
Band 10 –Thermal infrared (TIRS 1)	10.60 – 11.19	100
Band 11- Thermal Infrared (TIRS 2)	11.50 – 12.51	100

Table 3.4 Bands resolution

3.4 Image Pre-Processing

3.4.1 Layer Stacking

Layer stacking is a technique used in remote sensing and GIS to combine multiple raster layers into a single composite image or dataset. It integrates information from different variables or attributes to provide a comprehensive view of the study area. Layer stacking helps identify relationships and patterns between variables and enables more robust data analysis and modeling. By consolidating multiple layers into a single dataset, layer stacking enhances data visualization and supports various applications in fields like environmental monitoring and land management.

3.4.2Band-selection

Band selection is a crucial pre-processing step in analyzing urban footprints in Arusha urban using remote sensing data. It involves choosing specific spectral bands from the available multispectral imagery that are most relevant for distinguishing urban features. In the case of Arusha urban, bands sensitive to urban characteristics such as building materials, vegetation, and impervious surfaces are typically selected. By carefully selecting the appropriate bands, analysts can enhance the accuracy of urban footprint extraction and improve the overall quality of the analysis results.

3.4.3 Re-projection of soil data

The soil data from ISRIC was in a different coordinate system compared to the study area shapefile hence it was re-projected from lambert equal area projection to geographic coordinatesystem (GCS WGS84) so as it can correspond to other datasets and easier the further steps of processing.

3.4.4 Subsetting

This process involves extracting smaller area that covered the study area from the large downloaded Landsat image. From the images obtained the area of interest was then extracted which help to achieve the objectives of the research and speed processing since the size of the image is reduced and manage storage memory in computer.

3.5 Data Preprocessing

The acquired images were then preprocessed, to remove several radiometric errors. As the imageries collected were correct in other radiometric aspects, such as noise, atmospheric correction was done. The images of 2016, 2019 and 2022, were converted from digital number representation to surface reflectance. In other words, the images were converted from top of the atmosphere to the bottom of atmosphere, to make the images free of these errors that are due to atmospheric interferences.

3.5.1 Data Preparation.

The images of 2016, 2019 and 2022, were prepared for the preprocessing and processing to be proceed.The preparation steps were layer stacking, mosaic, or merging, projection and subset. On the part of layer stacking, 2, 3, 4, and 8 of each image, were stacked, so as to give multispectral image for each year. The bands selected, were chosen as they had the same resolution, which was 10m. After each images bands were stacked, the scenes of the images were put together. As there were, three scenes for each year, the scenes were merged to give a composite image for each year. When the merging process was cleared, the images of 2016, 2019 and 2022, were subsisted, to acquirethe area of interest on the sentinel images, which is Dodoma urban.

3.5.2 Supervised Classification

After the affirmation, that the class were separable, classification, followed which in specificity, was supervised approach. On which the classification was not based on the computer, but supervisor based. The algorithm used in this procedure was machine learning algorithm, random classification algorithm.

The images of 2016, 2019, and 2022 were classified, using the random classifier, basing on the training signatures generated during training step, hence the samples for each classes were used so asthe algorithm to classify.

3.5.3 Accuracy Assessment

The classified images of 2016, 2019, and 2022 were then assessed to see if there were accurate. Theintended accuracy was set 75% for all images, and this value was used, it is most preferred one, in different cases.

3.5.4 Change Detection

The method used in this step, was post classification, and this was done, as there were already classified images, which for the given method are required. Post classification serves well, as the changes that will be found in the land covers, will show the changes in the land cover maps and not only on the images that have not been classified, like how other methods, such as image algebra result.

3.6 Reclassification thematic layer

To generate groundwater potential zones, the following steps were involved:

Conversion of the generated thematic layers (i.e., lineament density, drainage density, slope and LULC) into the raster format (reclassification) and the overlay analysis. Groundwater potential zones were obtained by the weighted overlay analysismethod using spatial analysis tools. During weighted overlay analysis, a rank was given for each individual parameter of each thematic layer map, and weights were assigned according to the outputof the MCDM (AHP) technique to that feature on the hydro-geological environment of the study area. The relationship between the five thematic layers and their respective classes was derived usingthe MCDM by computing the relative importance of theme and its classes. Two main steps in computing the AHP method are:

Step 1: Construction of model based on a literature review many models has been identified for mapping groundwater potential zones. For the construction of a model, the pro should we clearly defined and then decomposed into various thematic layers containing the different features/classes of the individual thematic map to form a network of the model.

Step 2: Generation of pair-wise comparison matrices. The relative importance values are determinedusing Saaty's – scale, where a score of represents equal influence between the two thematic maps, and a score of 9 indicates the extreme influence of one thematic map compared to other one. In the current study the nine points of the Saaty's scale values to each thematic map and their respective classes were assigned according to their importance of influence in groundwater potential (Saaty, 1980). The Saaty's nine points values were obtained from interview and group discussion with groundwater experts who are working for Government of Tanzania, Panel of Arusha Urban Water Supply and Sewage Authority (AUWASA), Groundwater experts of GST and Department ofGeology, The University of Dodoma.

The AHP captures the idea of uncertainty in judgments through the principal eigen value and the consistency index (Saaty, 1977). Saaty gives a measure of consistency called the Consistency Index(CI) as a deviation or degree of consistency using the following Eq. (1):

$$\mathrm{CI} = \frac{(\lambda - \mathrm{N})}{(\mathrm{N} - 1)} \;\ldots\ldots\; (1)$$

Where λ is the largest eigen value of the pair-wise comparison matrix, and n is the number of classes or features. To control the consistency analysis and scale judgment, the Consistency Ratio (CR) which is a measure of consistency pairwise comparison matrix is calculated by Eq

(2):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \;\ldots\ldots\; (2)$$

Where RI is the Ratio Index. The value of RI for different n values is given, which in this research isequal to 1.12 (n = 5). If the value of the CR is less than or equal to 0.1, the inconsistency is acceptable,or if the consistency ratio CR is equal to 0.00, it means the judgment of the pair-wise comparison matrix is perfectly consistent. If the CR is greater than 0.1, we need to go back to the step pair-wise comparison matrix to rank the judgment value carefully with regard to the dominant factor that influences groundwater occurrences in the overall thematic layer map. The relative weights obtained from AHP were assigned to each thematic map to generate a cumulativeweight of the respective thematic maps and the weight value of each map with the highest or lowestweight was assigned in accordance with the real situation on the field. The summary of the assignedand normalized weights of the features/classes of the different thematic layers and the consistency ratio of its thematic map were also computed and assigned for respective thematic map. Then, the five different thematic maps were integrated as a summation of overall groundwater influencing factors to generate the groundwater potential map (GPM) for the study area.

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Overview

The results and analysis clarify a path to achieving the research objectives, thus the outputs forthe entire study are described in this chapter utilizing maps and graphs. The chapter provides adetailed review of the research findings and results through the use of maps and graphs for analysis.

4.2 Pre-processing Results

Pre-processing refers to the initial stage of data preparation and transformation before conducting analysis or modeling. It involves a series of steps to clean, organize, and enhance the quality of raw data, ensuring its suitability for further analysis.

4.2.1 Population Distribution Results

The population distribution of Arusha urban is characterized by concentrated settlements in specific areas in the city. The central business district and surrounding commercial zones are densely populated, serving as hub for economic activities, services and administrative. Residential neighborhoods are predominantly found in the outskirts along major roads leading to city center. These residential areas vary in terms housing type, from formal residential estates to informal settlements. Additionally, population density tends to decrease as one moves from the city center, with more sparsely populated areas observed in the suburban and rural fringes of Arusha Urban.

Year	Population	Growth Rate (%)
2016	453,000	2.26
2019	483,000	2.11
2022	519,000	2.75

Table 4.1 Arusha Urban Population

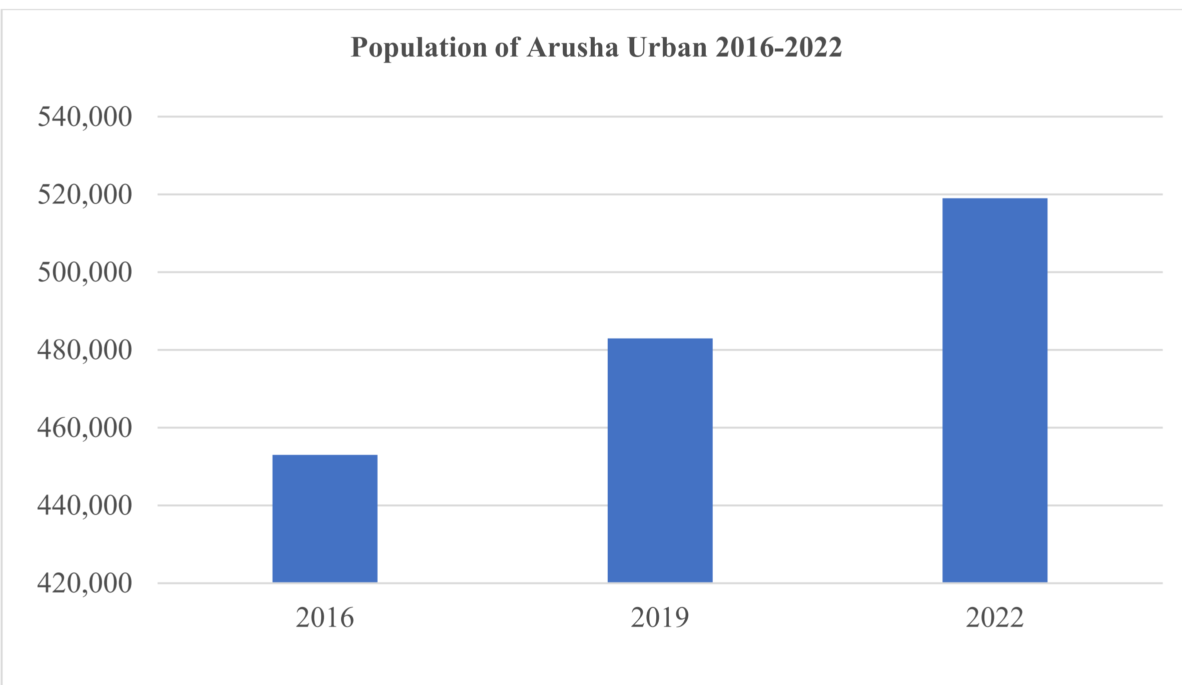

Figure 4.1 Population Distribution Of Arusha Urban 2016-2022

4.2.2 Urban Builtup Area Distribution Results.

The figure 3 below show the area variation in the class of Urban Builtup which represents densely developed areas. The graph show the slow growth or expansion of urban builtup.

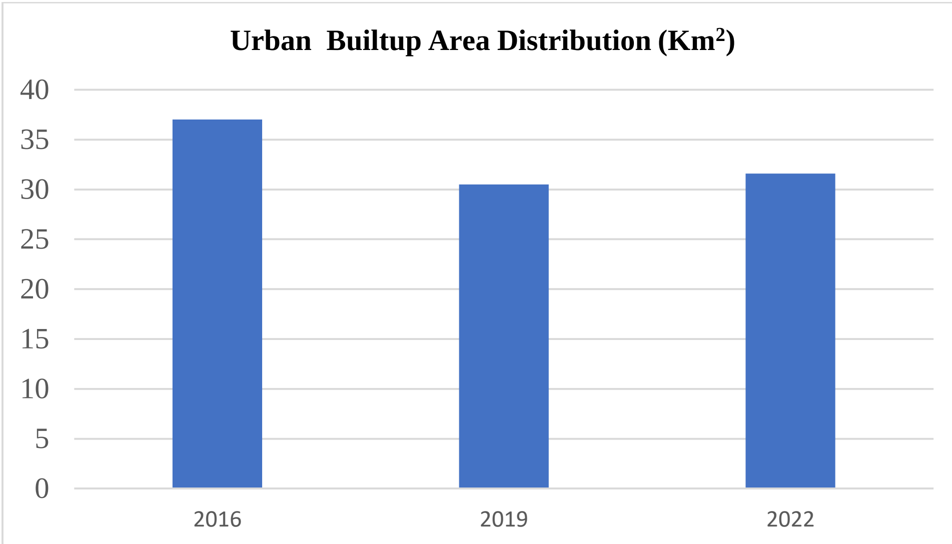

Figure 4.2 Urban Built-up Area Distribution Graph

4.2.3 Suburban Builtup Area Distribution Results.

The figure 3 below show the area variation in the class of Suburban Builtup which represents moderately developed areas. The graph show the slow growth or expansion of urban builtup.

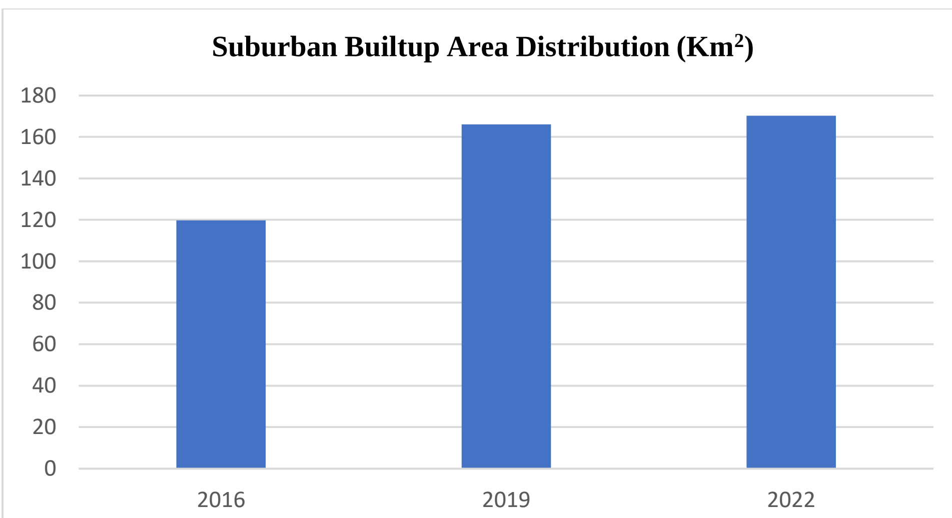

Figure 4.3 Suburban Built-up Area Distribution Graph

4.2.4 Agriculture Area Distribution results.

The figure 3 below show the area variation in the class of Suburban Built-up which represents area which there is farming or any agricultural activities. The graph show the slow growth or expansion of urban built-up.

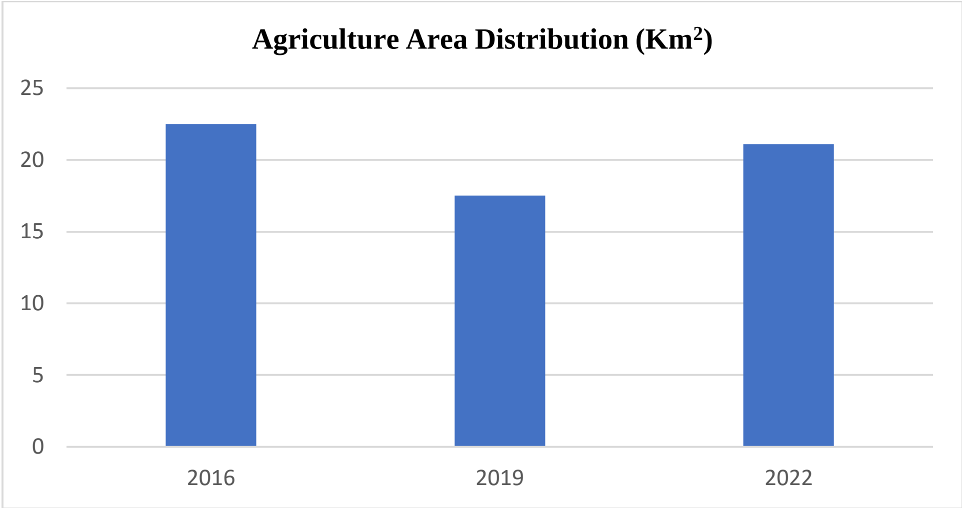

Figure 4.4 Agriculture Area Distribution Graph

4.2.5 Rural Openland Area Distribution results.

The figure 3 below show the area variation in the class of Suburban Builtup which represents areas outside urban and suburban. The graph show the slow growth or expansion of urban builtup.

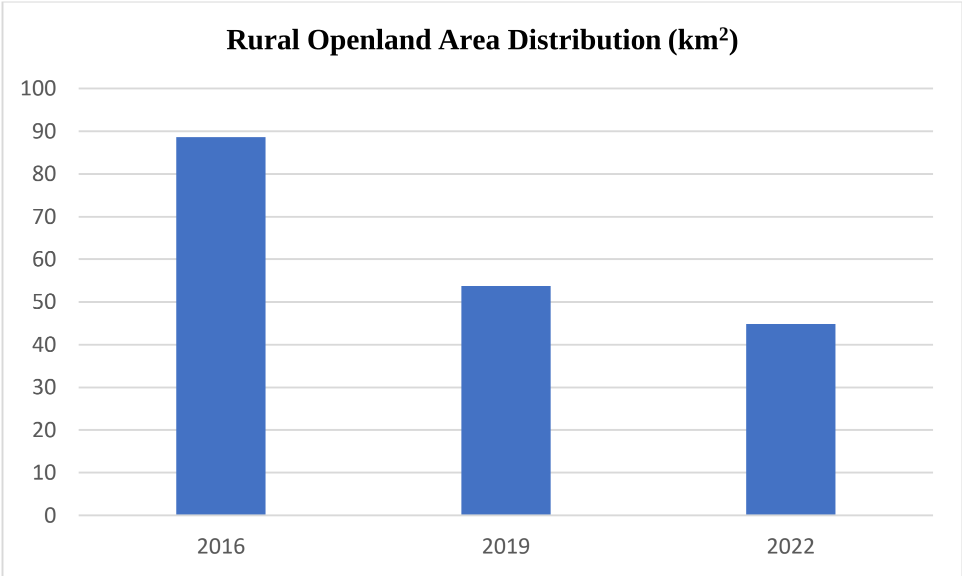

Figure 4.5 Rural Openland Area Distribution Graph

4.3 Urban Footprints of Arusha Urban

4.3.1 Urban Footprints of 2016

In this class of 2016, the classes under the classification scheme of NLCD it show that the, Urban built-up, suburban built-up, the rural open land and the Agriculture class. The distribution from the map show that the urban built up is less compares to the suburban built-up, and less or equal to the agriculture class. The results depicts that in 2016 the population growth rate of Arusha urban 2.26% in which the Urban Built-up class show the normal distribution of Arusha urban but the instinct of migration is considered to be the driving factor of population increase in the center of Arusha urban.

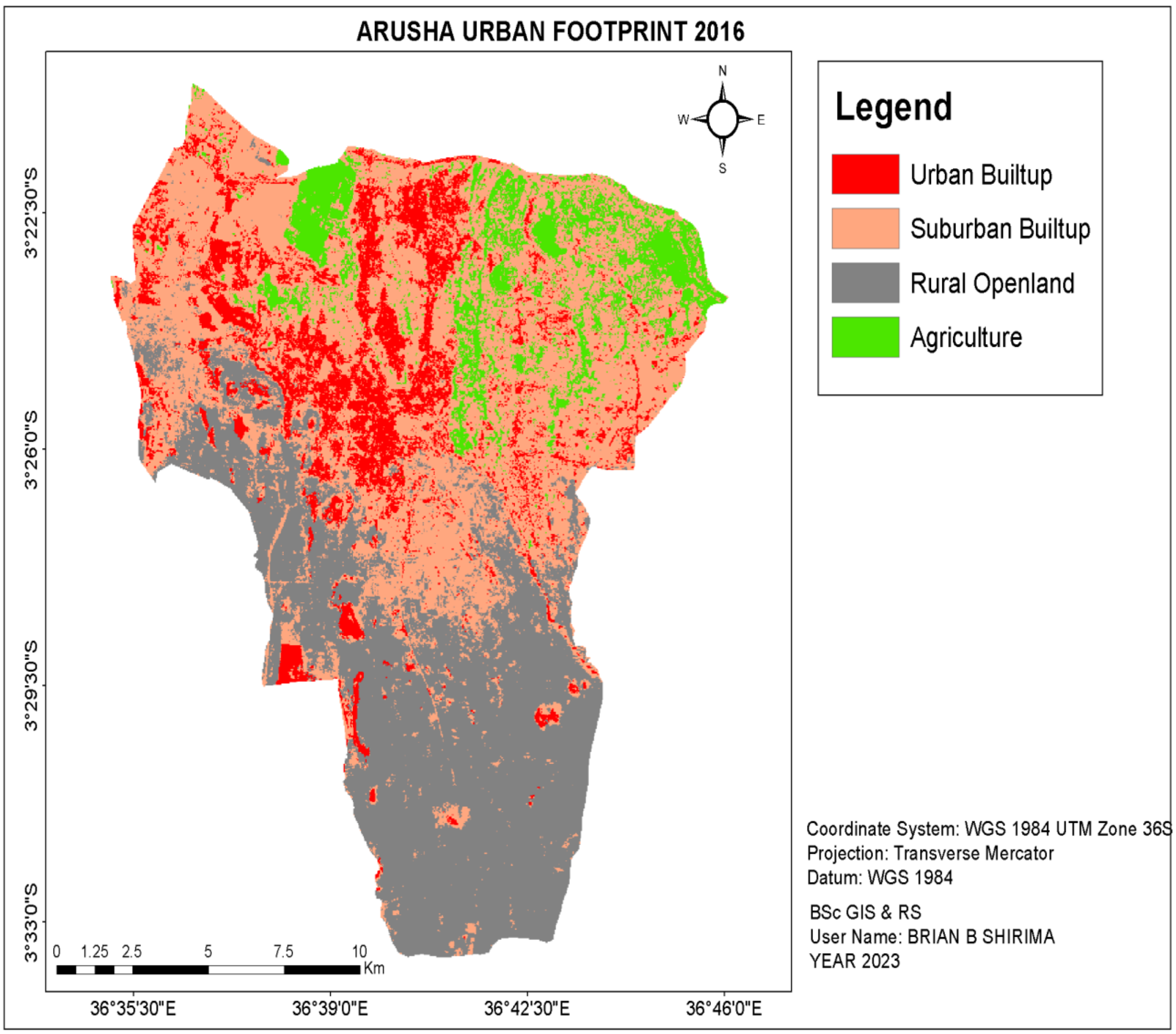

Figure 4.6 Urban Footprints 2016

4.3.2 Urban Footprints of 2019

In this class of 2019, the classes under the classification scheme of NLCD it show that the suburban built-up class has increased compared to the previous year of 2019 where the suburban built-up indicates the areas in urban but not fully constructed or populated. The distribution from the map show that the urban built up is less compares to the suburban built-up, and less or equal to the agriculture class. In the class of urban built-up, represents developed and highly urbanized zones within Arusha urban, suburban built-up serves the areas typically of medium-density residential areas, mixed-use developments and commercial center. From the map, the suburban class shows to expand indicating the growth of the city and the population growth.

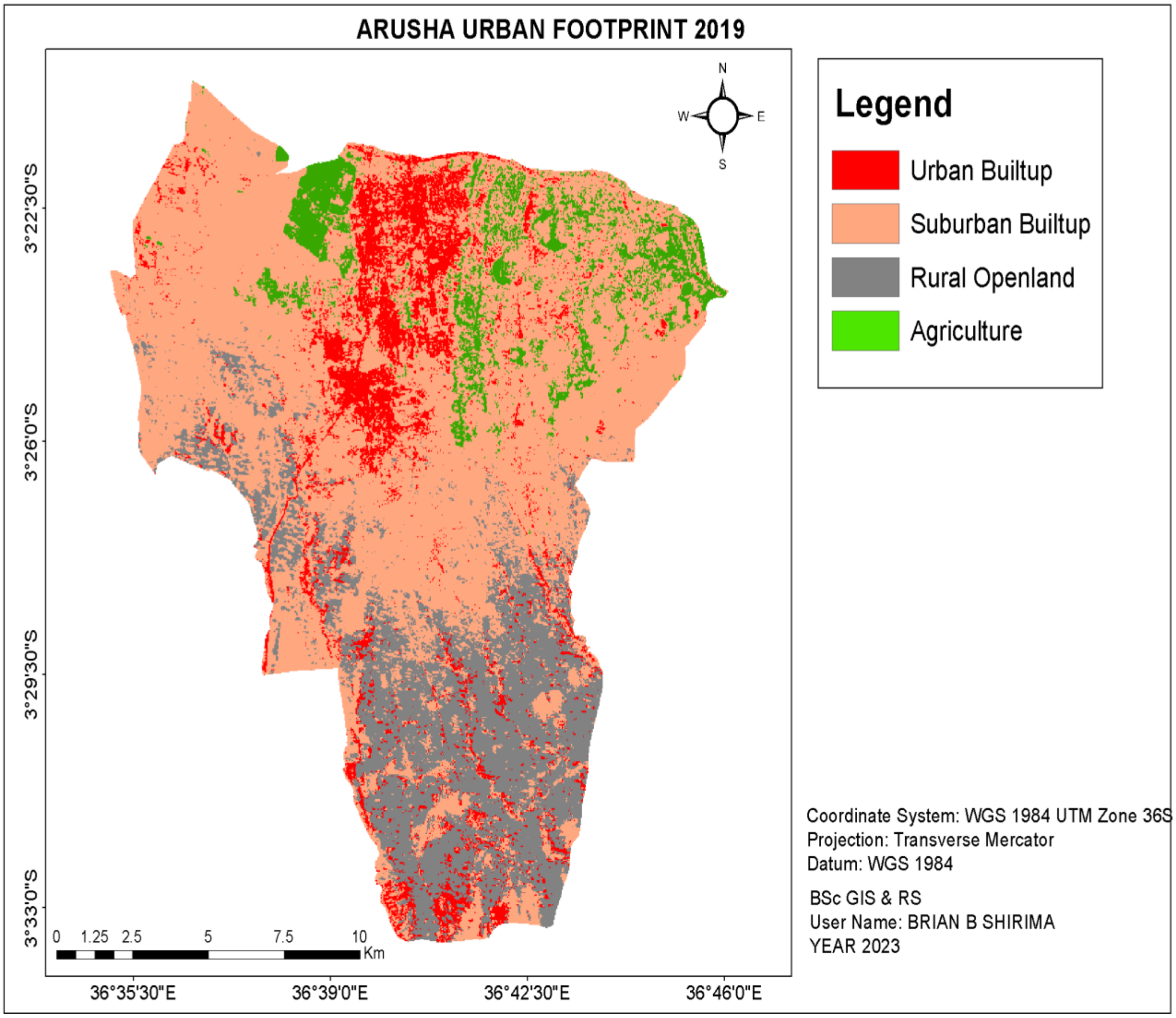

Figure 4.7 Urban Footprint 2019

4.3.4 Urban Footprints of 2022

In this class of 2016, the classes under the classification schyme of NLCD it show that the suburban builtup class has increased compared to the previous year of 2016 and 2022 where the suburban builtup indicates the areas in urban but not fully constructed or populated. The distribution from the map show that the urban built up is less compares to the suburban builtup, and less or equal to the agriculture class.

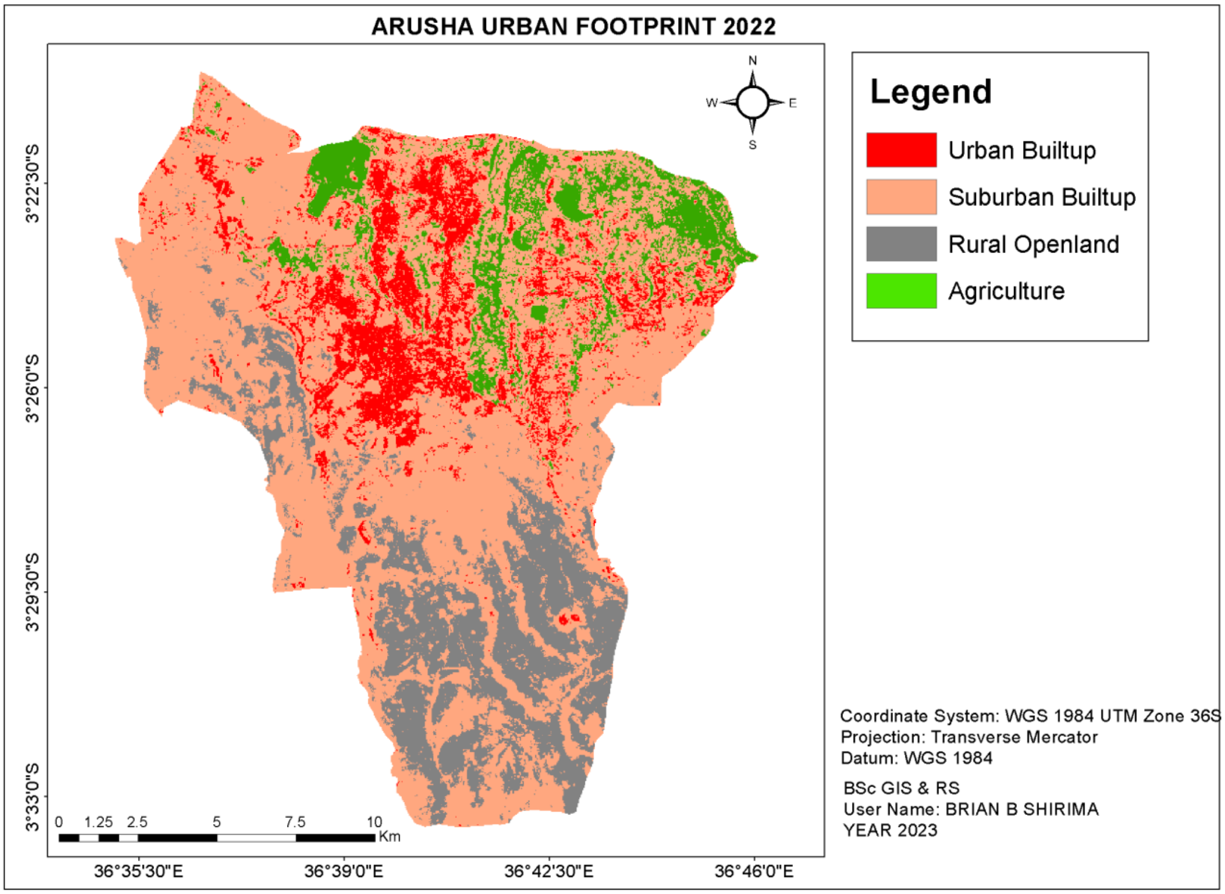

Figure 4.8 urban Footprint 2022

4.4 Hydrological analysis results

4.4.1 Slope

A slope map is a visual representation of the gradient or steepness of the terrain in a particular area. Slope maps are created by analyzing elevation data, such as digital elevation models (DEMs), using mathematical algorithms. The resulting map displays different slope categories, typically represented by color or shading variations, to indicate the varying degrees of steepness across the area.

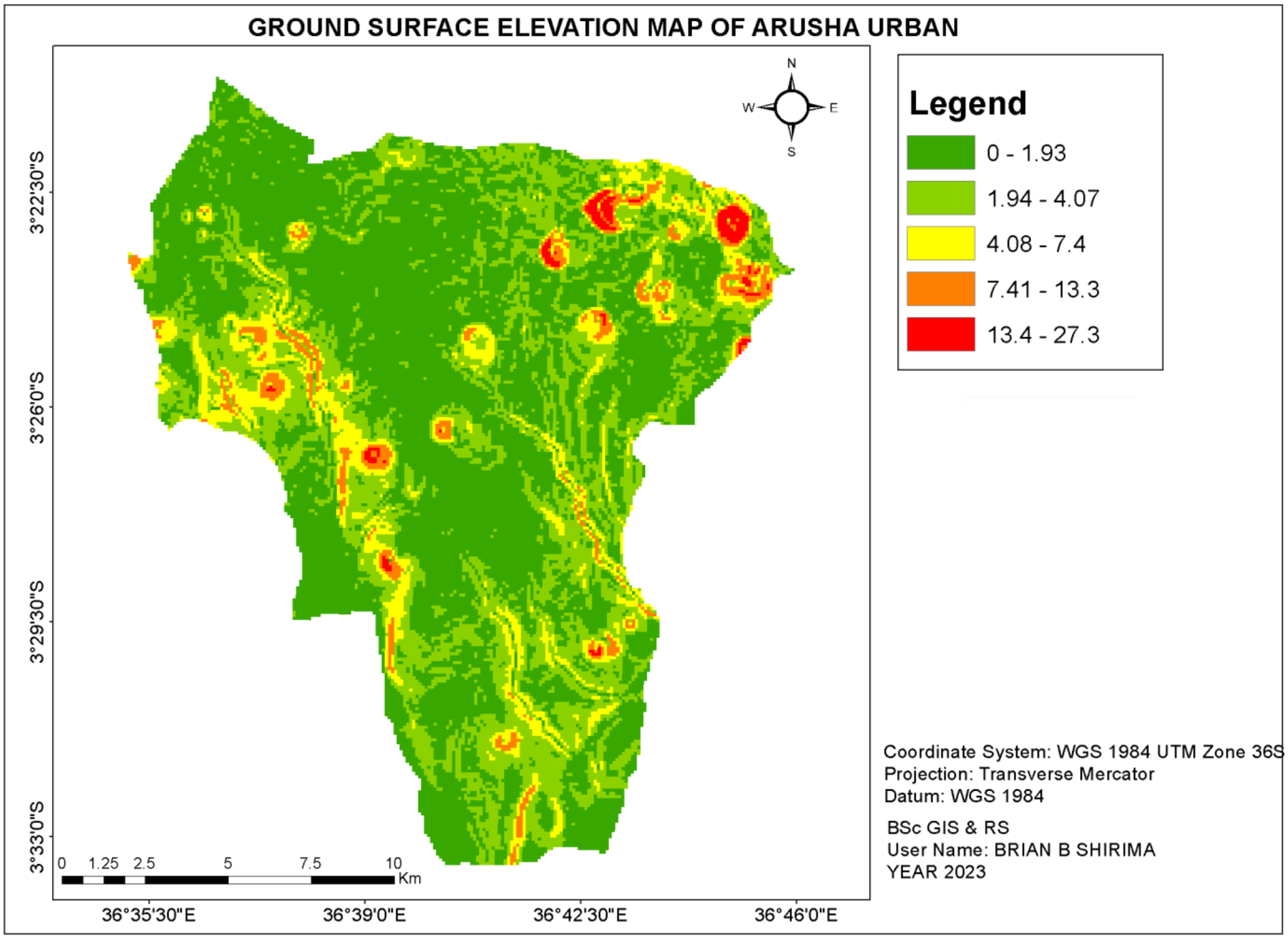

Table 4.9 Elevation map

4.4.2 Curvature

By using SRTM image of 2016 then formed the elevation where the aspect was calculated by the raster surface tool in 3D analyst tool which analyzed terrain features such as, hills, valleys, ridges and depressions. They provide valuable insights into the shape and form of the land surface, highlights areas with high and low reliefs.

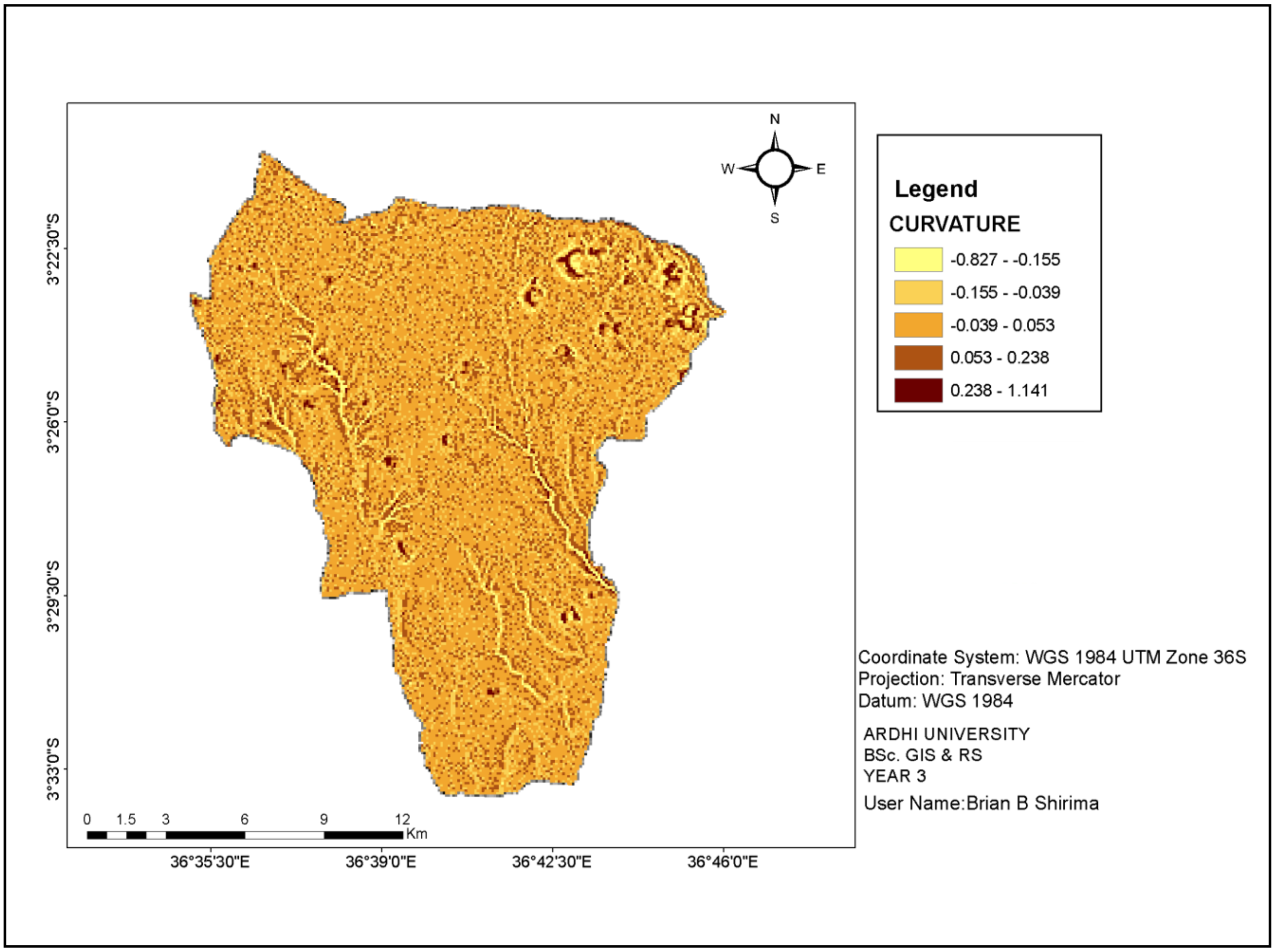

Figure 4.10 Curvature of Arusha Urban 14.10

Drainage density is a measure of how far the stream channels are separated from one another. Drainage density Figure below is calculated from drainage network layer using line density analysistool in Arc GIS software. The drainage density of the study area was classified into five classes, namely, ‘very high’ and ‘high’ drainage densities were observed over the central parts and along the other parts of the study area

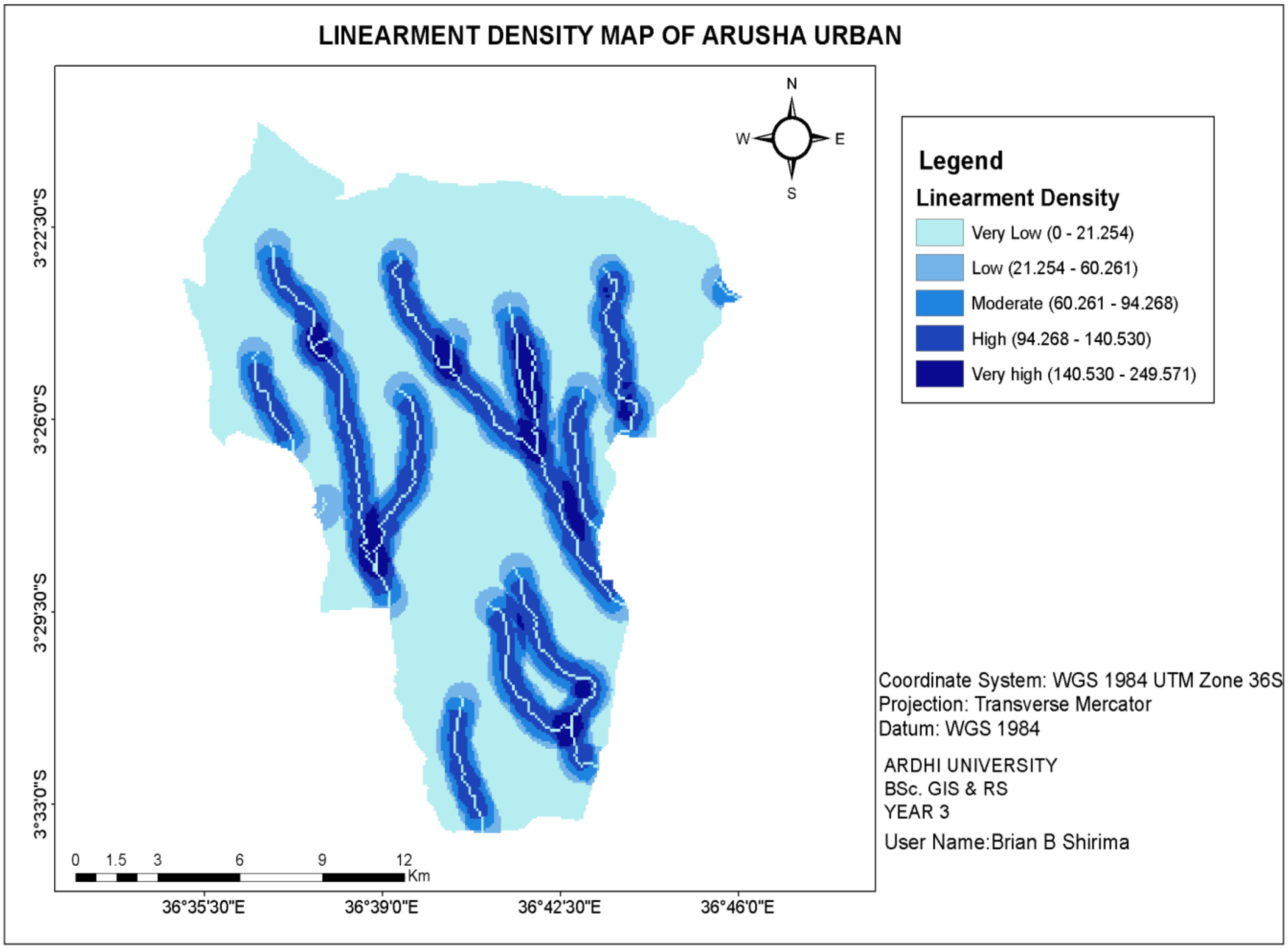

Figure 4.11 Lineament Density Of Arusha Urban

4.4.4 Topographic Wetness Index (TWI)

Topographic Wetness Index (TWI) plays a significant role in the ground water modelling system. TWI can explain the effect of topographic conditions on the size and location of saturated sources ofsurface runoff generation. It shows the representation of the potential wetness or soil moisture conditions of a landscape based on its topographic characteristics. It identify areas prone to water accumulations, or valleys, as well as areas with better drainage and lower moisture content, such as hilltops or slopes.

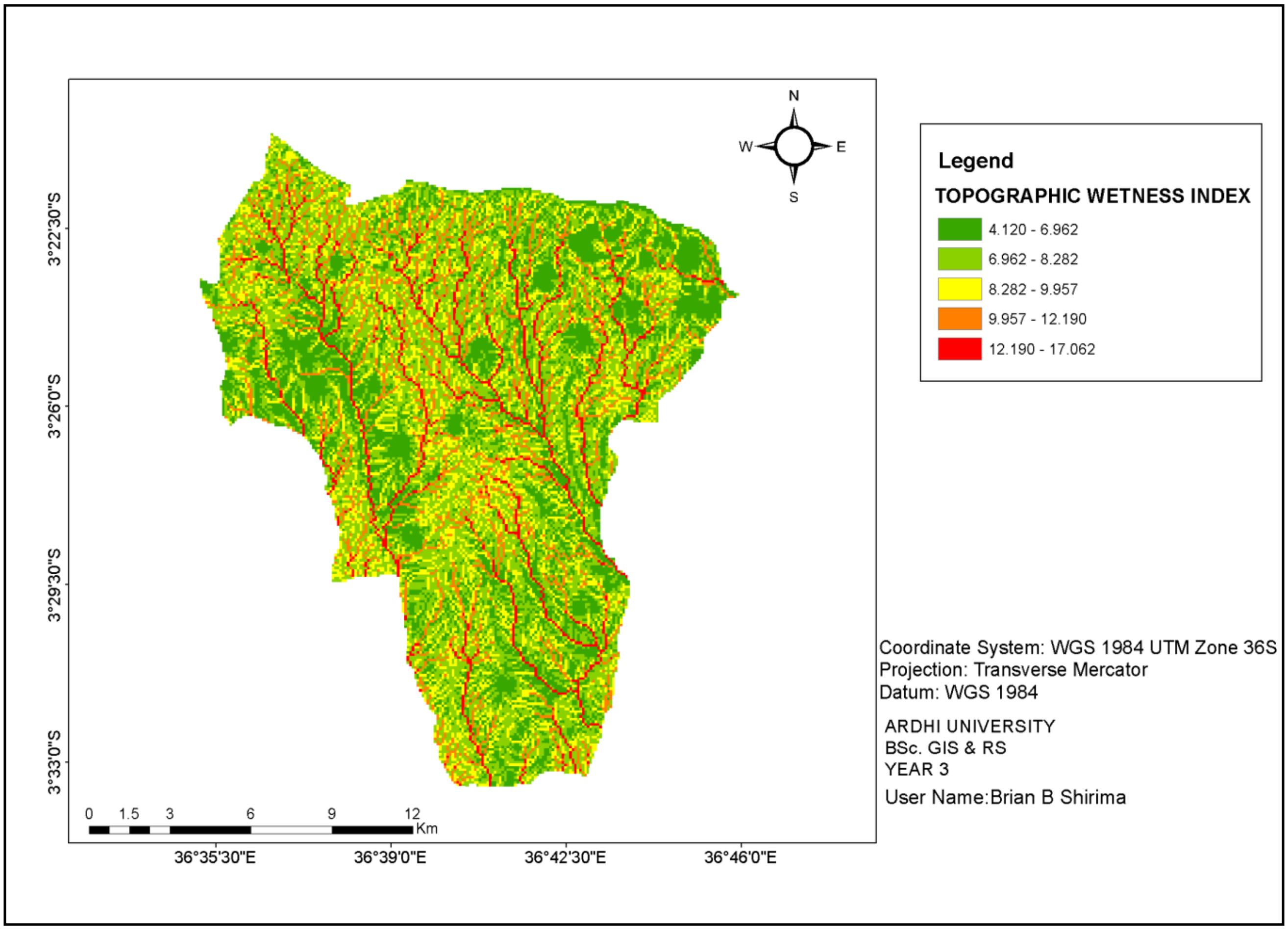

Figure 4.12 Topographic Wetness index of Arusha Urban

4.4.5 Watershed Areas

A watershed, also known as a catchment or drainage basin, refers to a geographic area of land where all the water within it drains into a common outlet, such as a river, lake, or ocean. It is defined by the topography of the land, with the boundaries of a watershed typically delineated by the highest points or ridges, known as watershed divides or drainage divides.

Water in a watershed flows over the land surface as runoff or seeps into the soil to become groundwater. As precipitation falls onto the land, it follows various pathways within the watershed, eventually converging into streams, rivers, and other water bodies. Watersheds encompass all the land, vegetation, water bodies, and ecosystems within their boundaries.

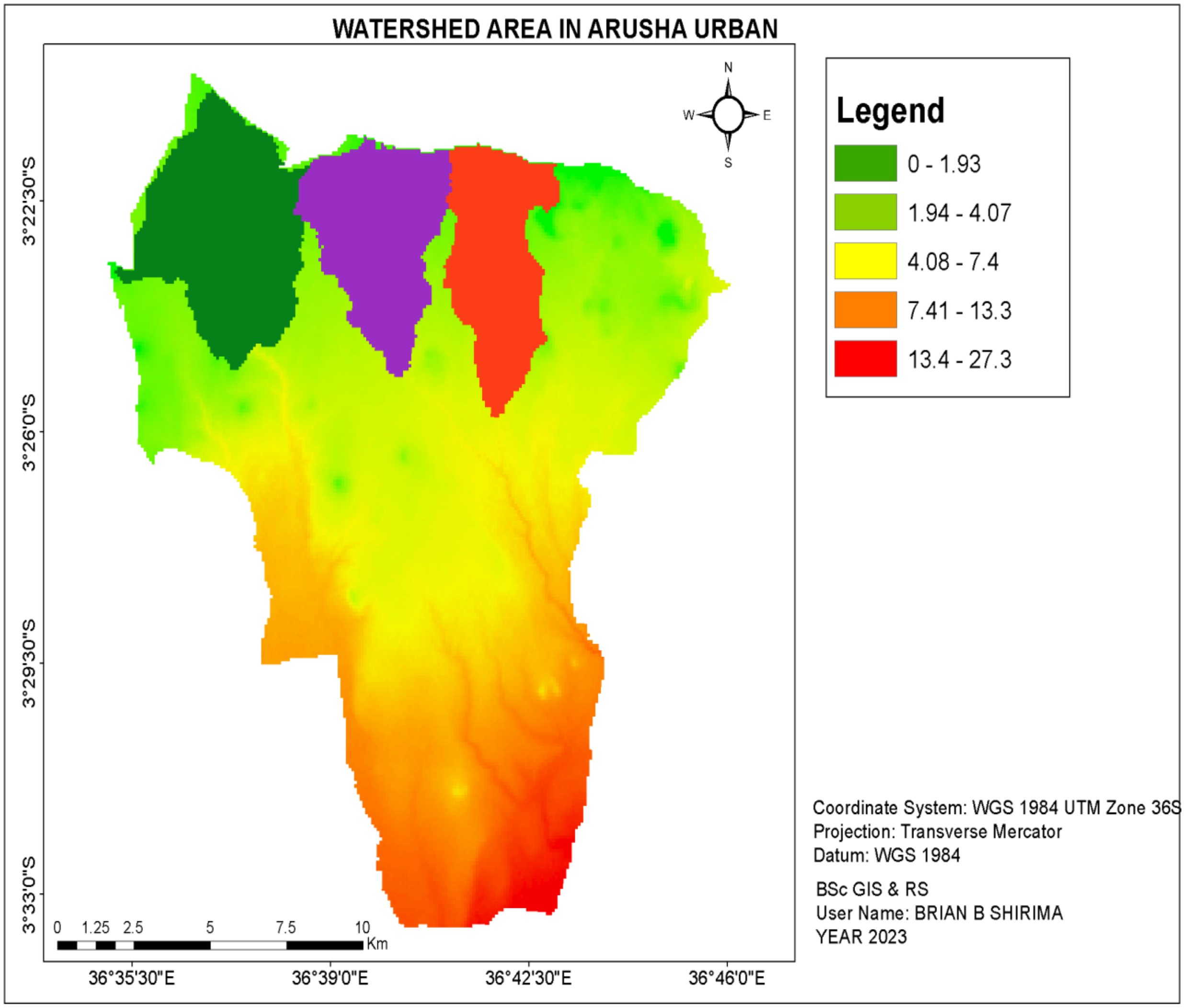

Figure 4.13 Watershed Area In Arusha Urban

A table showing the weights and ranks of the thematic layers:

Layers	Weight	Ranks
Land use	51	1
Slope	26	3
Lineament Density	13	5
Topographic Wetness Index	6	7
Topographic Roughness Index	4	9

Table 4.2 Table Showing Weight and Rank

The pairwise matrix table

Factors	Land use	Slope	Lineament Density	Topographic Wetness Index (TWI)	Topographic Roughness Index (TRI)
Land use	1	3	5	7	9
Slope	1/3	1	3	5	7
Lineament Density	1/5	1/3	1	3	5
Topographic Wetness Index	1/7	1/5	1/3	1	3
Topographic roughness index	1/9	1/7	1/5	1/3	1

Table 4.3 Table showing the pairwise matrix

Reasoning for the assignments of ranks:

Land Use:

Land Use is assigned the highest weight (0.51) and the top rank (1) because it is considered the most influential factor in the analysis. Land use patterns have significant implications for various processes, including urban planning, agriculture, and environmental management. Therefore, it is given the highest rank and weight in this context.

Slope:

Slope is assigned the second-highest weight (0.26) and the second rank (2). The terrain slope plays a crucial role in hydrological processes, erosion potential, and land suitability. While it is an important factor, it is given a lower weight compared to land use since it may have a relatively lesser influence on certain aspects.

Lineament Density:

Lineament Density is assigned a weight of 0.13 and the third rank (3). Lineament density represents the presence of linear geological features, which can have implications for geological structures, hydrological pathways, and potential natural hazards. While it is considered important, it is given a relatively lower weight compared to land use and slope.

Topographic Wetness Index:

The Topographic Wetness Index is assigned a weight of 0.06 and the fourth rank (4). The index represents the wetness conditions of the terrain, which can influence soil moisture, vegetation distribution, and hydrological connectivity. However, it is given a lower weight compared to land use, slope, and lineament density, indicating its relatively lesser influence in this particular analysis.

Topographic Roughness Index:

The Topographic Roughness Index is assigned the lowest weight (0.04) and the fifth rank (5). The index represents the variability and complexity of the terrain surface, which can affect hydrological processes, landforms, and erosion. However, it is given the lowest weight and rank in this analysis, indicating its relatively lesser influence compared to the other thematic layers.

4.4.6 Groundwater Potential Zone Mapping.

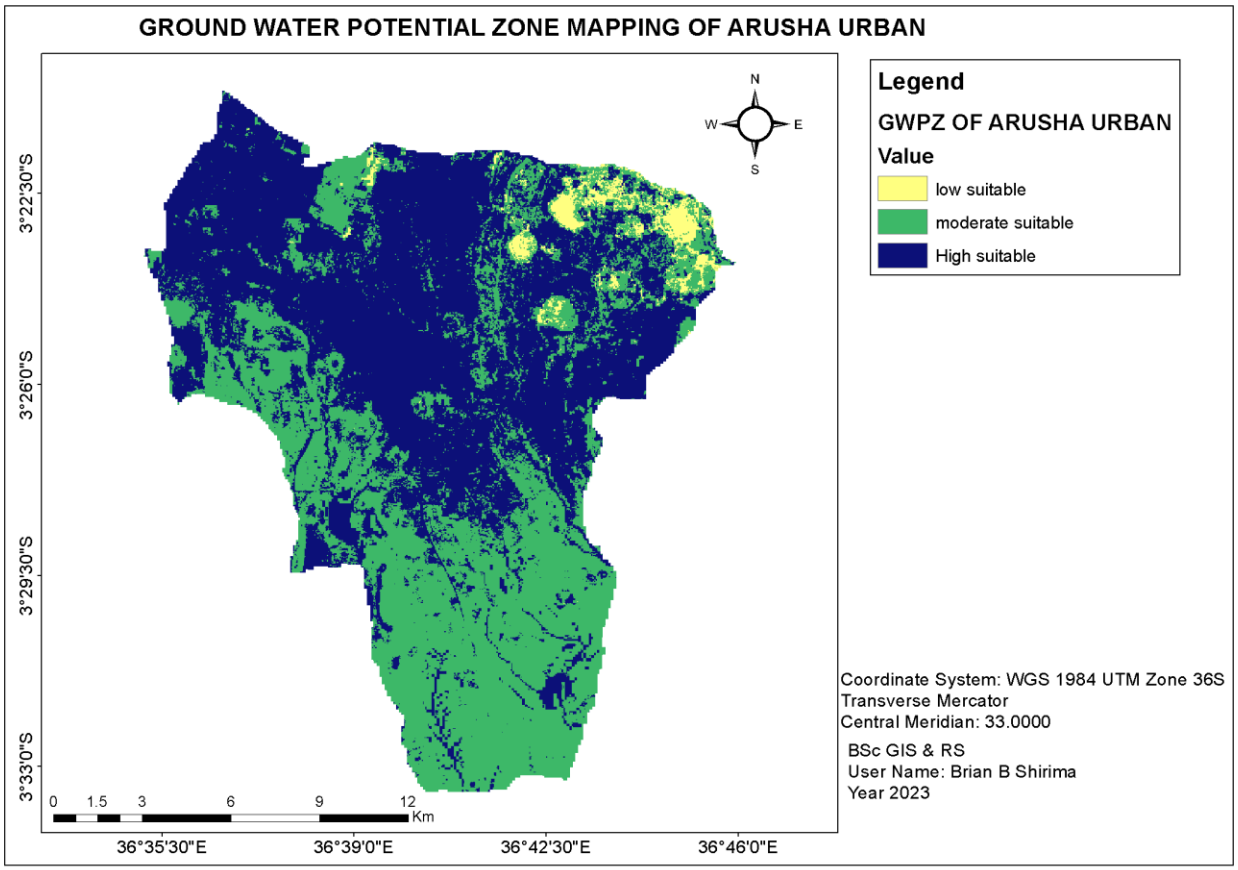

Figure 4.14 Final Ground water Potential Zone Mapping

4.5 Discussion of results

The assessment of the impacts of urbanization on groundwater reveals several key findings and implications. Firstly, urbanization significantly alters land use patterns, resulting in increased impervious surfaces and reduced natural infiltration rates. This disruption of the hydrological cycle has direct consequences for groundwater recharge, leading to decreased groundwater levels and altered flow patterns.

The expansion of urban areas also introduces various sources of contamination, such as industrial discharges, sewage systems, and chemical usage. These anthropogenic activities contribute to groundwater pollution, compromising its quality and potentially posing risks to human health and ecosystem integrity.

The utilization of remote sensing techniques, including satellite imagery and GIS, proves to be instrumental in understanding and monitoring these impacts. These technologies enable the assessment of changes in land use, quantification of impervious surface coverage, and identification of areas at higher risk of groundwater contamination. The spatial analysis approach adopted provides valuable insights into the spatial patterns and dynamics of urbanization impacts on groundwater.

Additionally, the integration of remote sensing data with hydrological models enhances the accuracy of predictions and simulations, aiding in the assessment of future groundwater availability and sustainability under various urbanization scenarios. The assessment of the impacts of urbanization on groundwater using remote sensing techniques yields significant results. The analysis reveals a clear correlation between urbanization and alterations in groundwater dynamics. The expansion of urban areas corresponds to a decrease in groundwater levels and changes in flow patterns. The results also demonstrate the spatial variability of these impacts. Areas with higher urbanization densities exhibit more pronounced declines in groundwater levels and higher levels of contamination. The identification of these hotspots provides valuable information for targeted management and mitigation strategies.

Furthermore, the integration of remote sensing data allows for the identification of specific land use practices that contribute to groundwater contamination. Industrial areas, improperly managed sewage systems, and intensive agricultural activities are found to be key sources of pollutants in urbanized regions.

The results underscore the importance of sustainable urban development practices to mitigate the adverse impacts on groundwater resources. The findings can inform policymakers, urban planners, and water resource managers in implementing effective strategies to safeguard and manage groundwater in the face of urbanization.

Overall, the results of the assessment highlight the need for integrated approaches that combine remote sensing techniques, hydrological modeling, and sustainable urban planning to mitigate the impacts of urbanization on groundwater and ensure the long-term sustainability of water resources in urban areas.

CHAPTER FIVE

CONCLUSION AND RECCOMMENDATION

5.1 Overview

The chapter is based on the findings from the results and analysis chapter in order to respond to the study's research questions, which are summarized in the conclusion. This chapter contains the conclusion as well as recommendation.

5.2 Conclusion

Although Arusha is stressed, development activities that require water diversions, abstractions and storage are still being carried out at various scales in several parts, within and at its outskirts. This has caused significant change in land use patterns. These changes in turn have significant impacts on the surrounding environment ecosystem. Coupled with climatic variability, these changes may eventually lead to the deterioration of ecosystem. Ecosystem in this context includes biotic (living organisms: human; plants, animals etc) and abiotic (non-living: water) components.

The assessment of the impacts of urbanization on groundwater reveals the significant and complex relationship between urban development and groundwater resources. Through the utilization of remote sensing techniques, such as satellite imagery and GIS, it is possible to gain valuable insights into the spatial patterns and dynamics of these impacts.

Moreover, the expansion of urban areas introduces various sources of pollution, including industrial discharges, sewage systems, and agricultural practices, which degrade groundwater quality. These anthropogenic activities have implications for both human health and ecosystem integrity.

The integration of remote sensing data with hydrological models enhances the accuracy of predictions and simulations, providing valuable information for future groundwater availability and sustainability assessments under different urbanization scenarios.

To mitigate the adverse impacts of urbanization on groundwater, sustainable urban development practices should be implemented. This includes measures to promote green infrastructure, such as permeable surfaces and water-sensitive urban design, which can enhance natural infiltration and recharge processes.

The findings emphasize that urbanization alters land use patterns, resulting in increased impervious surfaces, reduced natural infiltration rates, and disrupted hydrological processes. These changes directly affect groundwater recharge, leading to declining groundwater levels and altered flow patterns in urban areas.

In conclusion, the assessment of the impacts of urbanization on groundwater using remote sensing techniques highlights the importance of understanding and managing the complex interactions between urban development and groundwater resources. By employing integrated approaches and sustainable practices, it is possible to mitigate the negative impacts of urbanization, safeguard groundwater resources, and ensure the long-term sustainability of water supplies in urban areas.

5.3 Recommendation

It is recommended that Arusha Municipality should start thinking of the means of retaining the rainfall instead of just living the runoff to be wasted. Likewise settlement should be away from the recharge and the well field areas. Currently the Municipal needs about 8Mm3 extra to meet only its domestic annual demand.

Enhance monitoring networks: Strengthening and expanding groundwater monitoring networks in urban areas is crucial for assessing the impact of urbanization on groundwater. This includes establishing well-distributed monitoring wells, utilizing modern sensors and technologies for data collection, and regularly updating and analyzing the collected data.

Improve data integration: Foster collaboration and data sharing among various stakeholders, including government agencies, researchers, and water management organizations. Integrating diverse datasets, such as remote sensing data, hydrological models, and socio-economic information, can provide a comprehensive understanding of the impacts of urbanization on groundwater.

Conduct long-term studies: Undertake long-term studies to monitor the temporal variations and trends in groundwater levels, quality, and flow dynamics in urban areas. These studies will provide valuable insights into the cumulative effects of urbanization on groundwater and help identify emerging issues.

Promote sustainable urban planning: Encourage sustainable urban planning practices that consider the preservation and protection of groundwater resources. This includes promoting water-sensitive urban design, green infrastructure, and low-impact development techniques that facilitate natural infiltration and reduce surface runoff.

Implement groundwater protection measures: Develop and enforce regulations and policies to protect groundwater from contamination in urban areas. This includes strict regulations on industrial discharges, proper management of sewage systems, and control of agricultural practices that may contribute to groundwater pollution.

REFERENCE

Anna, J., & Håkan, N. (2003). Water Quality Assessment in the Arusha Wellfield and Surrounding: A Minor Field Study in Tanzania. Department of Geology, Chalmers University of Technology, Göteborg, Sweden.

Akpofure, E., Taigbenu, Ron Chaoka, Brian K. Rawlins, Richard Owen, & Simon Mkhandi. (2002). Introduction to Hydrogeology. Ground Module. Lecture Notes for M.Sc. (IWRM), University of Dar es Salaam – Tanzania.

Aller, L., Bennett, T., Lehr, J. H., & Petty, R. J. (1985). DRASTIC: A Standard System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings. EPA/600/2-85/018, R. S. Kerr Environmental Research Laboratory, U. S. Environmental Protection Agency, Ada, Oklahoma.

Chow, V. T. (1988). Applied Hydrology. McGraw-Hill International Editions.

Chow, V. T. (1964). Handbook of Applied Hydrology. A Compendium of Water Resources Technology. McGraw-Hill International Editions.

Eriksson, E., Gustafsson, Y., & Nilsson, K. (1968). Groundwater Problems. Wener-Gren Centre International Symposium Volume III. Pergamon Press Ltd.

ESRI. (1996). ArcView GIS, The Geographic Information System for everyone. USA Environmental systems Research Institute.

Freeze, R. A., & Cherry, J. A. (1979). Groundwater. Prentice Hall, Inc. Englewood Cliffs, New Jersey 07632.

Gupta, R. P. (1991). Remote sensing Geology. New York: Springer-Verlag Heidelberg.

JBG Consulting Engineers and GKW Consult. (1987). Arusha water Supply Drilling Programme Interim Report. Dar-es-salaam.

Johansson, A., & Nilsson, H. (2003). Water Quality Assessment in Arusha Wellfield and Surroundings. (Examensarbete med MFS-bidrag) Unpublished.

Kahimba, F. C. (2002). Assessment of Groundwater Reserves in Moshi municipality Aquifer using GIS. Unpublished M.Sc. (WRE) Thesis, University of Dar es Salaam.

Khairul, A. M., Juhari, M. A., & Ibrahim, A. (2000). Groundwater Prediction Potential Zone in Langat Basin using the Integration of Remote Sensing and GI. Retrieved from http://www.gisdevelopment.net/aars/acrs/2000/ps3/ps31S.html

Allestro, P. D. (2015). GIS application for NDVI calculation using Landsat 8 OLI images. GeoWorld, 10(21), 42099–42102.