Evaluation of Land Use Land Cover Change Impact on Surface Runoff Characteristics of Hawassa City, Sidama Region in Ethiopia

By: Yisak Mancho Gallo

A Thesis Submitted to the Department of Geomatics Engineering,

School of Civil Engineering & Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master of Science in Geo-informatics

Office of Graduate Studies
Adama Science and Technology University

August, 2022 G.C

Adama, Ethiopia

Evaluation of Land Use Land Cover Change Impact on Surface Runoff Characteristics of Hawassa City, Sidama Region in Ethiopia

By: Yisak Mancho Gallo

Advisor: Tilahun Erduno (PhD)

A Thesis Submitted to the Department of Geomatics Engineering,

School of Civil Engineering & Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geo-informatics

Office of Graduate Studies
Adama Science and Technology University

August, 2022 G.C

Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis entitled "Evaluation of Land Use Land Cover Change Impact on Surface Runoff Characteristics of Hawassa City, Sidama Region in Ethiopia" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

____________________	________________	__________
Name of student	Signature	Date

RECOMMENDATION OF ADVISORS/ SUPERVISORS

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Evaluation of Land Use Land Cover Change Impact on Surface Runoff Characteristics of Hawassa City, Sidama Region in Ethiopia" prepared under my guidance by Yisak Mancho submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Geo-informatics. Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Tilahun Erdino (PhD)	______________________	_______________
Major Advisor	Signature	Date
Dereje Birhanu (PhD)	______________________	_______________
Co-Advisor	Signature	Date

APPROVAL PAGE OF M.Sc. THESIS

I/we, the advisors of the thesis entitled "Evaluation of Land Use Land Cover Change Impact on Surface Runoff Characteristics of Hawassa City, Sidama Region in Ethiopia" and developed by Yisak Mancho, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Tilahun Erdino (PhD)	______________________	_______________
Major Advisor	Signature	Date
Dereje Birhanu (PhD)	______________________	_______________
Co-Advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the Board of Examiners of the thesis by Yisak Mancho have read and evaluated the thesis entitled "Evaluation of Land Use Land Cover Change Impact on Surface Runoff Characteristics of Hawassa City, Sidama Region in Ethiopia" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geo-informatics.

____________________	____________	____________
Chairperson	Signature	Date
____________________	____________	____________
Internal Examiner	Signature	Date
____________________	____________	____________
Eternal Examiner	Signature	Date
____________________	____________	____________
Department Head	Signature	Date
____________________	____________	____________
School Dean	Signature	Date
____________________	____________	____________
Office of Postgraduate Students, Dean	Signature	Date

ACKNOWLEDGMENTS

First and foremost, my extraordinary thanks go to my Almighty God; for his priceless help and protection during the whole activity of my work.

I would like to express my deepest gratitude and sincere thanks to my advisor Dr. Tilahun Erdino; for his guidance and support.

I would also like to thank Hawassa University for sponsoring my Masters study at Adama University.

It is also important and right to acknowledge the support and help of various people who had contributed for the successful completion of this study. Hawassa City Metrological Agency and SNNPRS Plan Institute for providing me with different data for this thesis work.

Finally, my heartfelt thanks go to my family for their support and encouragement during my project work and to all others who directly or indirectly contributed to the success of my thesis work.

TABLE OF CONTENTS

LIST OF TABLES

Table Number and Title Page

LIST OF FIGURES

Figure Number and Title page

LIST OF ACRONYMS AND ABBREVIATIONS

A.A	Addis Ababa
ASTU	Adama Science and Technology University
ASCE	American Society of Civil Engineers
ENVI	Environment for Visualizing Images
ERA	Ethiopian Road Authority
GPS	Global Position System
LULC	Land Use Land Cover
LULCC	Land Use Land Cover Change
MCMC	Markov Chain Monte Carlo
NMA	National Meteorological Agency
PIA	Percent of Imperviousness Area
Q	Peak Runoff
SCS-CN	Soil Conservation Service Runoff Curve Number
SWMM	Storm-Water Management Model
SNNPR	Southern Nations, Nationalities and Peoples
SRUDHB	Sidama Region Urban Development and Housing Brue
SWBMP	Stormwater Best Management Practices
WEF	Water Environmental Federation
TC	Time of Concentration
TS	Total Sample
TCS	Total Corrected Sample
USDA	United States Department of Agriculture

ABSTRACT

Due to the rapid growth of Hawassa city, land use and land cover (LULC) change occur in the city and its vicinity. The main objective of this study was to quantify the characteristics of the LULC change and examine the effect of the LULC changes on the surface runoff in the watershed of the study area. Runoff depends upon the surface condition, slope, and land features. Rainy season in the city leads flooding in the several areas. This has been the cause for a problem of overtopping, blockage of drainage facilities and water logging in some of the drainage area that leads a serious impact on both the road access and its strength. This study presented a land use/land cover (LULC) map and investigated the long-term effects of LULC change on surface runoff in Hawassa city. Landsat TM/ETM+ imagery (acquired in 2002, 2007, 2012, 2017 and 2021) were used to prepare the LULC maps using the support vector machine method in EVI 5.3 by supervised classification. Different thematic maps such as slope map, hydrologic soil group (HSG) map and land use/land cover (LULC) map have been created in the GIS environment and processed to generate the curve number (CN) and surface runoff. Based on the soil classification results, the study area was categorized into four HSGs (C, D, C/D and D/D). SCS-CN method was applied to assess the impact of LULC change on surface runoff. Results indicated that the selected study area experienced rapid urbanization from 2002 to 2021. Urban areas increased from 5.2% in 2002 to 20.5% in 2021 in the whole area. The results also indicated that the long-term surface runoff increased by 13.2% in the area from 2002 to 2021, and the runoff increase was found to be highly correlated with urban expansion (R^2 = 0.97). Therefore Understanding how land use land cover change (LULCC) influence on watershed hydrology will contribute for urban planners and urban engineers when planning and designing effective and appropriate land-use plane and drainage structures to minimize the undesirable effects of increasing urban runoff because of future land use land cover change.

Keywords: LULC; Urbanization; SCS-CN; slope; rainfall-runoff; Hawassa city

CHAPTER-I INTRODUCTION

1.1. Background of the Study

Growing populations and economies are driving expansion of urban built-up areas in the form of urbanization across the globe and, by 2050; over 70% of the world's population will expected to live in urban areas. As urbanization progresses, urban land use changes, augmenting the area of impervious surfaces and, as a consequence, reducing infiltration during storm events and increasing direct runoff that eventually alters urban hydrologic processes(Li et al.; 2018).

The increase in urbanization and population leads to the gradual replacement of naturally pervious areas with man-made impervious materials. Urbanization reduces the amount of infiltration and evapotranspiration, and results in an increase of rain water runoff, downstream flooding, erosion, and degradation of receiving water bodies. Urban floods range from localized micro-drainage problems, inundating streets and troubling pedestrians and urban traffic, to major inundation of large portions of the cities, when both micro and macro-drainage fail to accomplish their basic functions; they can lead to damage to urban infrastructure, material losses to buildings and their contents and residential housing in a village. Urban flooding is a common problem in cities around the globe due to the dominance of impervious surfaces and lack of sufficient drainage. Urban floods create hazardous situations by affecting the daily life of people, disrupting utility services, and damaging property (Abedin and Stephen, 2019).

In urban catchments, natural water courses are altered and the amount of impervious surfaces increases significantly due to urban expansion. Impervious surfaces consist of man-made structures such as paved roads, sidewalks, driveways and parking lots. These structures are covered by impenetrable materials such as asphalt, concrete, brick and even soils compacted by urban development. They restrict the ability of storm water to soak into the soil and instead water runs off directly. The combination of mostly non-porous and expansive soils and intense urban infrastructure, resulting in impervious surfaces, creates a serious need for better monitoring technology and methodologies to combat storm water runoff that results in flooding. Procedures for predicting runoff volumes are constantly being designed and tested with more recent models implementing remote sensing and geographic information system technologies (Jennings, 2012).

Impervious surfaces associated with urbanization alter the natural amount of water that takes each route as topography of land changes by urbanization. The consequences of this change are a decrease in the volume of water that percolates into the ground, and a resulting increase in volume and decrease in quality of surface water. These hydrological changes have significant implications for the quantity of fresh, clean water that is available for use by humans, fish and wildlife. As imperviousness increases, less water infiltrates and more and more runoff. In highly urbanized areas, over one-half of all rain becomes surface runoff, and deep infiltration is only a fraction of what it was naturally .The increased surface runoff requires more infrastructure to minimize flooding. Natural waterways end up being used as drainage channels, and are frequently lined with rocks or concrete to move water more quickly and prevent erosion. In addition, as deep infiltration decreases, the water table drops, reducing groundwater for wetlands, riparian vegetation, wells, and other uses. Consequently, as the land cover and land use changes during urbanization so does the water cycle (Werkneh, 2017).

Branger et al. (2013) conducted their research in a peri-urban catchment near Lyon in France, with an increasing level of urbanization when moving downstream. The goal of their research was to perform long-term, continuous simulations. After having those, they compared the effects of the different levels of urbanization on the runoff. The general trend that they found when applying the various land uses, is that with higher levels of urbanization, the mean discharge increases. For example, the catchment with an estimated impervious area of 2-6% has a mean discharge of 0.046 m3/s; while the catchment with an estimated impervious area of 8-29% has a mean discharge of 0.600%.

Li et al. (2018) analyzed trends of direct runoff from 1984 to 2015 at different scales in Shenyang, northeastern China; they ascertained that total direct runoff volume of the study area increased from 6.36×10^7 to 7.23×10^7 m^3 from 1984 to 2015. Large volumes of direct runoff generally increase the frequency and grade of flooding, which increases potential property damage. Because rainfall–runoff is a complex and dynamic process, direct runoff is generally affected by precipitation, evapotranspiration, substrate permeability, soil moisture, and other factors. Under similar rainfall conditions, more than 40% of rainfall can be converted to direct surface runoff in urban landscapes with more than 50% impervious surfaces. However, runoff in woodland areas may be as low as 13%. Increasing direct runoff caused by urbanization is a major challenge for urban ecological security that calls for integrated storm water management solutions in urban planning and development.

Beyene (2016) conducted a research on urbanization and its effect on surface runoff (a case study on great Akaki River, Addis Ababa, Ethiopia); Based on his study, the land use of the study area is changing from time to time. Since Addis Ababa is found at the center of the catchment large portion of the agriculture land was converted in to residential. Especially in recent years the change is dynamic. As shown from his study the percentage of residential area increases from 8.77% in 1989 to 17.96% in 2010 whereas, agricultural land decreases from 37.26% to 31.84% within these years. the Soil Conservation Service Curve Number (SCS CN) method used in his study is found very simple method to estimating runoff. The CN value is the cumulative effect of different soil types and land use/cover of the project area. The Curve Number value of the project area is increased from 1989 to 2010. This result shows hydrological characteristics of the catchment are the major factors which alter the peak discharge of the study area using equal rain fall distribution. When the Curve Number (CN) increase the amount of peak discharge generated from Great Akaki River increases.

The SCS-CN model combines the parameters of the watershed with the climatic factors in a single entity called the curve number (CN). A high CN indicates low infiltration and high runoff, while a low CN implies high infiltration and low runoff. The SCS-CN method is mainly influenced by significant runoff-associated watershed features such as land use/land cover (LULC), hydrologic soil group (HSG), slope, and climate conditions. The usage of LULC can take many forms, including built-up land, water bodies, agricultural land and barren land (Al-Ghobari et al.; 2020). The four standard classes HSG; A, B, C, and D; correspond to soils with low, moderately low, moderately high, and high runoff potential, respectively. Wet soils have high runoff potential (regardless of texture) due to the presence of a groundwater table within 60 cm of the surface. These soils are assigned dual HSGs (A/D, B/D, C/D, and D/D), as a less restrictive class group can be assigned if they can be adequately drained.

As a capital city of Sidama Region and industrial base in southern part of Ethiopia, Hawassa city is experiencing rapid urbanization. The process of urbanization affects the changes in land use and thus further affects the direct runoff. As a result, increasing direct surface runoff has become a serious problem in the study urban area.

1.2. Statement of the Problem

With the growth of towns, storm-water management has become more and more challenging, especially in developing countries. This is characterized by the urban explosion over a short period giving rise to unplanned urban development patterns, and inadequate provision of storm-water infrastructure within the rapidly increasing developments. This constitutes major obstacle to effective urban storm water drainage (Odhiambo, 2015).

Over time there has been an increase in developments in urban areas without much upgrading of the existing drainage systems; this causes a strain on the current systems thus limiting their capacity to handle storm-water. This may be a result of shallow drains that are not able to carry all the storm-water flowing and undersized culverts that restrict the natural storm water, flow causing an overflow of the storm water (Odhiambo, 2015).

A study conducted by Werkneh, (2017) dealt with Investigation of Flooding Problems in Urban Drainage Systems: the case at Zenebe Werk in Addis Abeba, Ethiopia according to him the cause of flooding problems in the study area are construction and/or design problems and drainage poor management. The construction and/or design problems are cross slopes of the asphalt road which do not guide the flow over the asphalt to inlets, the surface runoff from the two sub-catchments have no inlets to join the drainage and the reversed runoff from the neighboring catchment. In addition, blockages of inlets with sediments aggravate the flooding.

A study conducted by Chali, & Zewdie, (2020) Performance Assessment of Urban Drainage Systems of Holeta Town Using Storm-water Management Model (SWMM). Similarly a study conducted by (Birhanu, 2018), on Performance Assessment of Storm Water Drainage Systems; Case study of Debere Berehan Town. According to their findings there was no proper sewage system to collect wastes extracted from each household, as a result, solid and liquid wastes were directly disposed of into the storm drainage system, lack of a well-connected drainage network, which results in decreasing the efficiency of the system, unavailability of drainage systems at the proper place.

However, those studies which dealt with this sensitive issue of our cities and towns in the country focused on the performance and effect of the drainage system but neglected or go little attention regarding the impact of spatiotemporal change of catchment area as it is the major cause of flooding problems in an urban area now days. Understanding urban flood is very challenging and no effective flood remediation measures can be undertaken without an insightful understanding of the spatio-temporal behavior of runoff. Therefore, this study was done to examine runoff characteristics by considering spatio-temporal changes in the watershed because of LULCC in the study area.

The rainy season in Hawassa city leads to flooding in several areas. This has been the main cause problem of overtopping, blockage of drainage facilities, and water logging in some of the drainage areas that leads to a serious impact on both the road access and its strength. The flooding also affect traffic congestion, it delays the movement of pedestrians as the flood flows over the walk-way. The impact is too much on the socio economic activity of the area for it affects their day-to-day activities. The following pictures which are taken on September 08, 2021 show some of the extent of the urban flood problem.

A) Georgis mazoria street

B) Georgis mazoria street

C) Main gate from Bishan Guracha

D) Main gate from Bishan Guracha

Figure 1 A, B, C, and D extent of flooding problem on study areas sample roads, During the rainy season, it is common to see long rows of vehicles along the highway for a long hour based on the duration and intensity of rainfall. Only one car moves at a time when crossing the flood otherwise the following car would get difficulty crossing and this aggravates the traffic congestion.

As surface runoff has an impact on the socio economic activity of urban areas it affects their day-to-day activities; the impact of LULCC on surface runoff is analyzed using integrated GIS and remote sensing methods with the SCS-CN model because rapid urbanization is taking place in Hawassa city.

1.3. Objective of the Study

The general objective of the study is assessment of the impacts of land use land cover change on surface runoff characteristics of Hawassa city.

The specific objectives of the study are to:

- To analyze the spatiotemporal LULC changes in Hawasa City administration from the years 2002 to 2021.
- To determine the variations of runoff depth due to the LULC changes.
- To evaluate the relation between LULCC and spatio-temporal change of the runoff in the study area.

1.4. Research Questions

This study investigates the following questions related to the effects of storm-water flooding:

- What is the extent of spatiotemporal LULC change in Hawassa city?
- What is the effect of spatio-temporal change of urbanization on runoff generated from the catchment area?
- How the relationship between spatio-temporal change of urbanization and runoff could be analyzed?

1.5. Significance of the Study

Ethiopia is highly vulnerable to natural hazards in particular to hydro-metrological hazards. The National reports from Ethiopian Disaster Prevention and Preparedness Agency indicate that the frequency and intensity of hydro-metrological hazards are increasing at alarming rate. Scholars systematically categorized hydro-metrological hazards in different categories. Of these flash flood is one of the prominent hazards. The problem is visible in developing countries in general and in Ethiopia in particular. The effect of such kinds of hazards becomes harsh in urban areas (Tilahun, 2018). The limited availability of measured surface runoff restricts various activities of water resources development and management. To overcome this limitation, the GIS, RS, and SCS-CN methods were combined to estimate the surface runoff and assess the impact of land use change on surface runoff in the studied region (Al-Ghobari et al.; 2020).

This research has significance in exploring the contemporary theoretical perspectives to fill the knowledge gap and to contribute ideal approaches and models to understand deeply spatiotemporal impacts of urbanization on runoff characteristics, i.e. Specifically to quantify the characteristics of the LULC changes, to estimate runoff generating from the catchment area, to analyze the effect of LULC change on runoff, and finally to evaluate the relationship between LULC and spatio-temporal change of the runoff in the study area.

Furthermore, the research is used as a base for comparing the past and present condition and predicts the future trends of the effect of LULC change on surface runoff depth. The study provides a simple method for urban planners and urban engineers to assess potential hydrological impacts of future planning and development activities in the study catchment.

1.6. Scope of the Study

This study is geographically limited to Hawassa city, Sidama Region, Ethiopia. The content scope of the study is bounded to examining the extent and characteristics of land cover and land use, identification of spatio-temporal change of land use land cover for the past 2 decades, slope, soil class of the catchment area and its effect on runoff characteristics of the study area.

1.7. Organization of the study

The study was organized into five chapters, the first chapter deal with the introduction part, the second chapter deal with the review of related literature, the third chapter deals with methodology, the fourth chapter deal with data analysis and presentation, and the last chapter deal recommendation, and conclusion.

CHAPTER-II: LITERATURE REVIEW

2.1. Introduction

Because of the development in urban areas and the expansion of urbanization, the frequency of urban flooding increases and so do the consequences. This chapter of the research presents the review of related literature on the concept and definition of LULC, LULCC, and the effect of LULC change on runoff, urban runoff, urban flooding, and economic impacts of urban flooding. This literature is reviewed in order to provide the research with a conceptual framework to explain theories underlying the study to further define the problem and thereby identify previous research studies which were done by other scholars on the LULCC, the effect of LULC change on runoff, and application of geospatial technology for analysis of land use land cover change and runoff characteristics.

Land is a delineable area of the Earth’s terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern, and physical results of past and present human activity. Land is the most important and precious natural resource and the basic material condition for the stable development of human society. Land use refers to the arrangements, activities, and inputs by people to produce change, or maintain a certain land cover type which establishes a direct link between land cover and human activities in our environment (Chu, 2020).

Land-use and land-cover changes may have four major direct impacts on the hydrological cycle and water quality: they can cause floods, droughts, and changes in river and groundwater regimes, and they can affect water quality. As land development increases, runoff discharges to surface water bodies more quickly and for a longer period. Because of this change in volume, rate and duration, surface water bodies may be unable to convey the increased flow downstream, which may lead to flooding of nearby areas. In addition, increased flow rates and velocities in water bodies may lead to erosion of stream channels and increased pollution entering water bodies (Blick et al.; 2004).

When a LULC change occurs due to urbanization (the building up and paving over of undeveloped areas) and is along a city boundary, it increases the size of the city. Its process has a considerable environmental impact such as a hydrological impact, in terms of influencing the nature of runoff and other hydrological characteristics, stream flow response, delivering pollutants to rivers, and controlling rates of erosion. Surface runoff from storm events is part of the natural hydrologic process. It can arise from overland surface flow, flow within drainage pipes and sewers, or flow from the top, saturated layers of soil near the stream. (Ongsomwang and Pimjai, 2014)

2.2. The concept and Definition of LULC and LULC change

2.2.1 Land Use/ Land Cover

The terms "land cover" and "land use" are sometimes used interchangeably, they are actually different. Simply put, land cover is what covers the surface of the earth and land use describes how the land is used. Examples of land cover classes include water, snow, grassland, deciduous forest, and bare soil. Land use examples include wildlife management areas, agricultural land, urban, and recreation area. Some classified maps include a mix of land cover and land use. Some maps include both land cover and land use information. One way to do this is to represent land cover using different colors while using different patterns or symbols overlaid on the map to represent land use. (Horning, 2004). As can be seen from the definitions and examples, the term now includes not only the vegetation that covers the land but also human structures, such as roads, built-up areas, and immediate subsurface features such as groundwater. Land use is defined as the way or manner in which the land is used or occupied by humans. In a nutshell, the land cover represents the visible evidence of land use. A land covered by vegetation can be a forest as seen from the ground or through remote-sensing observations; however, the same tract of forest can be used for production, recreation, conservation, and religious purposes. In other words, land cover is the observed physical cover, whereas land use is based on function or the socioeconomic purpose for which the land is being used. A piece of land can have only one land cover (e.g., forests), but can have more than one land use (e.g., recreational, educational, and conservational) (Giri, 2012).

Land-use and land-cover change (LULCC), or more succinctly land change, is an integral component of global environmental change. Land cover refers to the physical characteristics of the Earth’s surface such as water, grass, trees, or concrete. Land use, on the other hand, refers to how the land is utilized by humans for various social and economic purposes. The same land cover may be used for different purposes. Land-use change refers to a change in the management of land by humans, which may or may not lead to a land cover change (Wang, 2020).

A modern nation, as a modern business, must have adequate information on many complex interrelated aspects of its activities in order to make decisions. Land use is only one such aspect, but knowledge about land use and land cover has become increasingly important as the Nation plans to overcome the problems of haphazard, uncontrolled development, deteriorating environmental quality, loss of prime agricultural lands, destruction of important wetlands, and loss of fish and wildlife habitat. Land use data are needed in the analysis of environmental processes and problems that must be understood if living conditions and standards are to be improved or maintained at current levels (Anderson et al.; 1983).

2.2.2 Land-Use and Land-Cover Change

Land-cover change can be characterized as land-cover conversion and modification. Land-cover conversion is a change from one land-cover category to another, and modification is a change in condition within a land-cover category. An example of the former is the change from cropland to urban land, and an example of the latter is the degradation of forests. Forest degradation may be due to changes in phenology, biomass, forest density, canopy closure, insect infestation, flooding, and storm damage. Conversion is generally easier to measure and monitor than modification using remotely sensed data. Modification is usually a long-term process and may require multiyear and multi-seasonal data for accurate quantification. Land-use change is a change in the use or management of land by humans. Land-use change may change without land-cover conversion or modification. For example, a production forest can be declared a protected area, and the number of visitors to a recreational forest may change without land-cover modification. On the contrary, land cover may change even if the land use remains unchanged; however, land-use change is likely to cause land-cover change (Giri, 2012).

Landsats have operated continuously since 1972 and have been central to many land-cover mapping initiatives. Landsats 1–5 and 7 have acquired millions of images of the earth, which have been used in a wide range of scientific and operational applications. However, land-cover studies are a key driver of the Landsat mission. Landsats provide global, synoptic, and repetitive multispectral imagery coverage of the earth’s land surfaces at a scale in which natural and human-induced changes can be detected, differentiated, characterized, and monitored over time (Giri, 2012).

Knowledge of the present distribution and area of such agricultural, recreational, and urban lands, as well as information on their changing proportions, is needed by legislators, planners, and State and local governmental officials to determine better land use policy, to project transportation and utility demand, to identify future development pressure points and areas, and to implement effective plans for regional development (James et al.; 1983).

Growing populations and migration towards built areas is driving land use change in the form of urbanization across the globe and by 2050 some 70% of the world's population is expected to live in urban areas (UN, 2008). For the cities, one of the main factors of LUCC is urbanization. Urbanization is a common worldwide trend that is caused by population growth and economic development. In the urbanization process, social conflicts result in the mass movement of people, which undermines the operational systems of land access (Liu et al.; 2015).

2.2.3 Driving Forces for Land Use and Land Cover Change

According to Allan et al.; (2022), Gessesse and Bewket (2014) the driving forces for land use land cover change are studied in a three-level interaction on this basis. In the center, direct, place-based urban development initiatives (i.e., building transportation infrastructure, industries, housing, and services) create LULCC in urban areas. The second tier drives urban processes through the creation of policies, regulations, and financing of urban development projects, which is facilitated via various agents, entities and operational processes. Finally, the outer tier, contextual, is perceived as a set of effective factors (i.e., demographic, socio-economic, environment) through which the process of LULCC of an urban area is developed. *Urban Growth Factors:*-These factors explore the driving forces of urban growth that contribute to changing the spatial structure and LULC of urban areas. This theme includes physical factors and growth of transportation infrastructure, industry, accessibility to services, and residential development. *Policy and Regulation Factors:*-These factors refer to a series of policies, rules, regulation and operational efforts on general urban issues (such as land use) and processes by which urban growth requirements are facilitated. In this way, the physical and spatial structure of cities including land use/land cover is formulated. *Economic and Financial Factors:*-Along with policy and regulation factors, these factors drive urban growth through rendering developmental projects feasible. On this basis, it is important to study the economic structure of cities as well as financial system. *Demographic Factors:* **-** Increasing urban population is the major demographic factor that many articles take into account as the effective factors in the formation and changes of land use and land cover and population density. Demographic changes are the result of the improvement in the state of health and well-being of families and individuals, housing affordability, and the growth of communication technology in many regions. As a result, there has been an increasing trend of an intensification of population density in some cities and the emergence of mega cities in recent years. *Environment and Natural Resources:* **-** environment and natural resources have the capability to change urban land use and land cover patterns. They include geographical location, flood prone areas, climate quality, sea shoreline, and distance from water bodies such as rivers, lakes, wetlands, ponds all of which are fundamentally important determinants of the extent, spatial distribution, and spatial expansion of urban lands. Furthermore, it can relate to the efficiency of terrestrial resources such as forestry and ecological resources, oil resources, minerals, and ecosystem services. Slope and elevation also determines the location of physical developments within a city since the developers generally prioritise development in flatter areas.

2.3. Impacts of Urbanization on Runoff Characteristics

The development of land to construct industrial facilities, businesses, and homes involves land-use change that transforms pervious surfaces of woods, pasture, and meadow into impervious surfaces of stone, pavement, and roofing. The addition of an impervious area to a site changes the hydrology of that site and the surrounding watershed. The topography of a site is almost always disturbed to accommodate the construction of an impervious structure. Changing topography usually removes natural surface depressions in the landscape that capture, hold, and slowly infiltrate water into the subsurface. Grading of a site usually transforms an undulating vegetated surface into a plane impervious surface or grass lawn. In either case, surface depressions are removed and water that was once captured and infiltrated now accumulates and travels across the landscape to a downstream point. Natural flow paths that twist and wind across the landscape are usually altered into linear, constant-slope paths that are changed in length and roughness. The change in these flow-path characteristics affects the time required for surface runoff to move across and through the landscape. This change in timing directly affects runoff rates, usually increasing their magnitude and causing an increase in the frequency of flooding. The addition of impervious areas requires a reduction in pervious area that reduces the capacity of a site to infiltrate rainfall. When infiltration capacity is reduced, runoff potential increases, and groundwater recharge potential decreases (Seybert, 2006).

Urbanization impacts the rainfall-runoff process in a variety of ways. Infiltration is reduced due to the addition of impervious surfaces, resulting in increasing quantities of runoff. Tree removal, surface leveling, soil flipping, and surface compaction are also likely to boost the quantity of runoff. In addition, the rate of storm water runoff is intensified due to the extensive network of pipes and channels that are designed into the urban environment. The long surface travel times from undeveloped land are shortened, and gutters and pipes quickly convey storm water to receiving streams. Unfortunately, the increase in runoff quantities and rates can produce downstream flooding and accelerate channel erosion (Akan and Houghtalen, 2003).

The changes in land use associated with urban development affect flooding in many ways. Removing vegetation and soil, grading the land surface, and constructing drainage networks increase runoff to streams from rainfall and snowmelt. As a result, the peak discharge, volume, and frequency of floods increase in nearby streams. Changes to stream channels during urban development can limit their capacity to convey floodwaters. Roads and buildings constructed in flood-prone areas are exposed to increased flood hazards, including inundation and erosion, as new development continues. Information about stream flow and how it is affected by land use can help communities reduce their current and future vulnerability to floods (Christopher, 2003).

From a hydrologic perspective, there are two important physical changes to a catchment resulting from urbanization. The first is the increased percentage of impervious surfaces such as roofs, roads, parking lots, and sidewalks. Second is the conversion of the natural drainage system to an artificial conveyance system with the introduction of uniform slopes and pipe and channel systems with relatively reduced roughness. These changes in combination lead to an increase in runoff volume and runoff peak and a decrease in the time to peak. The urban area characteristics that cause an increase in the runoff volume are also responsible for an increase in the runoff peak. Uniform ground slopes, reduced roughness of surfaces, and the presence of an improved drainage system result in a relatively more rapid flow of storm-water runoff. This reduces the time of concentration, which refers to the time required for runoff to flow from the most remote part of the catchment to its outlet. This results in an increase in the runoff peak. The time to peak flow decreases with urbanization. Firstly, more streamlined drainage pathways introduced by urbanization decrease the hydrograph duration. This phenomenon is essentially characterized by the “flashy” nature of an urban catchment in relation to storm water runoff (Liu et al.; 2015).

2.4. Urban Runoff Characteristics

2.4.1 Hydrologic Description of Rainfall

Rainfall is the amount of liquid precipitating in the form of rain. A rainfall event takes place over a period of time during which measurable rainfall occurs. The length of this period, which is preceded and followed by periods of no measurable rainfall, is called rainfall duration. The total depth or depth of rainfall is the depth to which the rainwater would accumulate if it stayed where it fell on the ground. The rainfall intensity refers to the time rate of rainfall. The average intensity is equal to the total depth of rainfall divided by the storm duration (Akan and Houghtalen, 2003).

Rainfall has many destinations. Part of the rainfall is intercepted by vegetation. Some will end up in surface puddles. Some will infiltrate into the soil. Small amounts may evaporate before reaching the ground. What remains will produce surface runoff. Abstractions or losses from rainfall refer collectively to that part of the rainfall that does not show up as runoff. In general, the abstractions include interception, surface depression storage, evaporation, transpiration, and infiltration. Under design-storm conditions, evaporation and transpiration are negligible in an urban area (Akan and Houghtalen, 2003).

Rainfall excess or effective rainfall is calculated as the total rainfall minus abstractions. The rate of rainfall excess or rate of effective rainfall is defined as the depth of rainfall excess produced per unit time. It can be calculated as the rate of rainfall minus the rate of loss. We usually assume that the rainfall excess is solely responsible for storm runoff in urban watersheds. Therefore, the total volume of rainfall excess is equal to the total volume of runoff produced (Akan and Houghtalen, 2003).

Rainfall is one of the most important inputs in hydrologic runoff models. Stormwater design deals with rainfall events that can be classified as rainfall intensities and rainfall depths. Rainfall intensities are flow rates. Rainfall depths are volumes. Rainfall can be described according to four key characteristics: *Volume*: The volume of rainfall is commonly provided in a length dimension, usually as depth in inches or centimeters. The volume of rainfall is implied in the depth dimension by associating the magnitude of the drainage area with the rainfall depth; *Intensity*: Rainfall intensity has the units of velocity. It is the rate at which rainfall falls from the sky. Like rainfall volume, intensity is associated with the magnitude of the surface runoff area. Intensity is expressed in dimensions of length per time (L/T), typically in the units of inches/hour or cm/hour. However, rainfall intensity can also be used to determine a volume flow rate because the rainfall is associated with the drainage area; *Duration*: Duration is the time span over which rainfall occurs for a particular storm event. Duration is often associated with standard storm lengths specified in a particular hydrologic method. In some methods, design storm durations are dictated by the time of concentration of the drainage area. Longer-duration storms typically contain more rainfall volume. Shorter-duration storms typically have larger rainfall intensities; *Temporal Variation*: Rainfall varies with time. For any given rainfall event of finite duration, the rainfall intensity varies with time. There could be periods of very light rainfall (low intensity) and other periods of very heavy rainfall (high intensity). There may even be short periods of no intensity. Sometimes the rainfall comes relatively uniform over the entire storm duration; *Spatial Variation*: Rainfall varies with space. For watersheds of significant size, at any given time during a storm event, rainfall may be falling in a spatially non-uniform manner (Seybert, 2006).

2.4.2 Runoff Depth and Peak Flow

Before any type of stormwater management design can begin, estimates of surface runoff are necessary. Runoff occurs during a storm event after certain initial losses are satisfied. Rainfall initially wets the surface of the Earth, including trees, grass, rooftops, and pavement. After surface and vegetation wetting, the soil absorbs and infiltrates rainfall as long as the soil infiltration capacity is not exceeded by the rainfall intensity. As the soil saturates, the soil infiltration capacity reduces, and rainfall that cannot infiltrate transforms into surface water. The water gathers on the watershed surface, collecting in small depressions and surface undulations. As the water accumulates on the surface it eventually finds a flow path, following linear depressions, concentrating in small swales and creating overland runoff flow. The surface runoff eventually travels downslope and collects in the major drainage way in the watershed. In the urban watershed, the drainage way may be a natural stream, a man-made storm sewer, a concrete-lined channel, or some combination of these (Seybert, 2006). Rainfall excess, also called runoff depth, is the amount of precipitation that survives the hydrologic losses and produces overland runoff toward streams, creeks, rivers, lakes, and oceans (Guo, 2017).

Runoff estimates are made for specific design purposes. Peak runoff rates are required when sizing stormwater conveyance structures, and runoff volumes are required when designing stormwater storage facilities. The methods available for estimating surface runoff commonly applied methods are: *Runoff curve number method:* The Natural Resources Conservation Service (NRCS), previously known as the Soil Conservation Service (SCS), developed the curve number (CN) methodology for estimating runoff. The method was originally developed for agricultural watersheds, but later adapted to developing watersheds. The method is based on a hydrologic soil-cover classification system for the selection of curve numbers, a watershed abstraction and infiltration relationship, and a simplified form of the conservation of mass equation (Seybert, 2006); *Rational Method*: The Rational Method is used to compute the peak runoff, Qp, following a rainfall event. It makes no attempt to estimate runoff before or after the peak but simply estimates the one quantity of flow that is greatest. The primary application of the Rational Method is in estimating peak runoff for small drainage basins; those that are tributary to minor drainage structures such as storm sewers and small drainage swales. The usual basin size is less than 15 acres, and the Rational Method should not be used for drainage areas larger than 100–200 acres (Gribbin, 2014).

2.4.3 Watershed's Hydrologic Response to Land cover Change

In calculating the rate of runoff in a stream resulting from a rainfall event, we must first determine the size of the area over which the rain falls. For every stream, a well-defined area of land intercepts the rainfall and transports it to the stream. The area of land is called the catchment area, watershed, or drainage basin. These three terms generally are used interchangeably (Gribbin, 2014).

Surface runoff modeling depends on the designation of a region or area as the study focus. The concept of a watershed is used to establish an area of water study. A watershed is an area bounded peripherally by a divide, with all the area eventually draining to a point, usually a location in a swale, stream, or river. This point is often called the point-of-interest, or, watershed outlet, and is the low point in the watershed. Most hydrologic analyses for stormwater design deals with watersheds that range from a few thousand square feet to several square miles (Seybert, 2006).

According to Guo (2017) hydrologic characteristics of watershed are: The amount of runoff generated from a watershed is directly proportional to the watershed area upstream of the design point; the longest waterway from the most upstream boundary to the design point is selected as the representative length of the watershed; Waterway slope is an important factor in determining the water flow velocity; *Hydrologic types of soils*: An infiltration rate reflects the ability of the soil medium to absorb water. This parameter is usually given in inch per hour or millimeter per hour. The Natural Resources Conservation Service (NRCSSCS, 1964) has developed a set of Soil Conservation Service (SCS) classifications on soils. In general, all soils are categorized into four hydrologic types; based on their infiltrating nature as follows:-*Type A soil*: soils having high infiltration rates between 0.30 and 0.45 in. /h if thoroughly wetted and consisting mainly of moderately deep, well to excessively drained sand and gravel; *Type B soil*: soils having moderate infiltration rates between 0.15 and 0.30 in. /h if thoroughly wetted and consisting mainly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures such as loamy soils; *Type C soil*: soils having slow infiltration rates between 0.05 and 0.15 in./h if thoroughly wetted and consisting mainly of soils with a layer that impedes the downward movement of water or soils with moderately fine to fine textures; *Type D soil*: soils having very slow infiltration rates between 0.01 and 0.05 in./h if thoroughly wetted and consisting mainly of clay soils with a swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious materials; Based on the surface textures, a watershed is divided into impervious and pervious areas. Land use land cover change; one of the factors that influence the hydrological characteristics of watershed area.

2.5. Flooding and its Impact

Flooding in urban areas caused by intense and/or prolonged rainfall which overwhelms the capacity of the drainage system is one of the principal hazards in modern towns and cities. This type of flooding often leads to major economic losses and devastating social and environmental impacts. Unlike other types of flooding, pluvial flooding is a direct, quick and localized consequence of rainfall. It often happens with little warning and in areas not obviously prone to flooding, making it hard to manage and predict. Whilst intense and/or prolonged rainfall events can also take place in rural areas, pluvial flooding is a predominantly urban phenomenon, as it is in urban areas that its effects are most pronounced and damaging (Rodriguez et al.; 2006).

The hazard of surface water flooding occurring is higher in urban areas due to the high proportion of tarmacked and paved surfaces, which limit water infiltration and increase the amount of water running off the ground surface as well as its speed. This is exacerbated by the fact that natural drainage routes are often altered in cities, which results in reduced capacity for excess water. Further, the growing urban population and degree of urbanisation puts great pressure on the existing drainage systems, increasing the likelihood of them being overwhelmed. Moreover, the potential impacts of flooding are significantly greater in urban areas: a consequence of cities' high density of population, properties and vital infrastructure (Rodriguez et al.; 2006).

2.5.1 Economic Impact of Flooding

Because of urban storm-water flooding, considerable damage to; Public buildings, Public utility works, housing, and household assets is a common phenomenon. Loss of earnings in industry and trade, loss of employment to daily earners, and loss of revenue due to road and transportation interruption are among those urban flooding economic impacts (Bansal et al.; 2015).

The Economic impacts of urban storm water runoff are often with damaged cause physical impacts. On the whole, the developing nations have insurance coverage, lower than 25% of total losses. To evaluating of the economic impact of rainstorm flooding there are two main effects can be occurred in anywhere: That economic losses, which attempts to measure the impact on society of the actual damage, city infrastructure deterioration, and that financial, or insured losses, which covers payment of the maintenance of damaged social properties and maintain damaged infrastructure and associated expenditure (Bansal et al.; 2015).

2.5.2 Physical Impacts of flooding

Physical impacts of storm-water runoff are including to property damage, infrastructures, and contents of buildings. Flooded waters can cause failure to piping situations and damage water supply system, resulting is loss of drinking water as well as other forms of infrastructure and urban services such as electricity supply and waste disposal systems (Parkinson, 2003).

2.5.3 Social Impacts of Flooding

According to Jha et al.; (2011), the most difficult and disastrous heavy rainstorm floods on society is loss of life have tended to occur in developing nations. Social mortality rates and deaths are caused by water-born disease, disruption of food supplies, ill-health, or shock after the event and are also related to flood and development characteristics. Another problem is a shortage of freshness consumption water and spoiled sanitation systems by rainstorm flood-affected populations. The occurrence of severe including, diarrhea, malaria, respiratory infections, and skin diseases is high due to on-street stores and pollution into the waters of a rainstorm. Flooding does not only result in destroyed infrastructure and damaged property, but also has an adverse social impact on citizens affected by the natural disaster. Impacts on physical and mental health can be both short-term and long-term and can result in changes to the livelihoods of affected citizens. While more personal, the social repercussions of flooding have impacts on individuals and families that can be felt in other areas of work and life (Alberta Water Portal Society, 2014).

2.5.4 Environmental Impact of flooding

During urban development, several human settlements could produce environmental impacts because of increasing storm-water runoff through the construction of the building, clearing of vegetated land for new housing developments, construction of streets, avenues, highways, and installation of other infrastructure leading to seriously degraded areas. In addition, because of the difficulties related to impermeable surfaces, drainage systems, solid waste, movable assets, and the sites of buildings, the predictability of rainstorm flood flows were much lower once the affected urban environment was reached (Parkinson, 2003). stormwater runoff flows over man-made structures in communities these structures may contain or host many harmful substances. These substances may include: oil, metals, pesticides, bacteria, soil, soap, fertilizers, chemicals, or any other material you can imagine might fall on the ground. As these materials are picked up by stormwater runoff and carried through storm drains, they are deposited into lakes, oceans, rivers, and other bodies of water. If there is too much runoff, the water that drains into nearby bodies of water can be overfilled. As a result, surrounding communities may experience floods. On the other hand, because man-made structures prevent stormwater from being absorbed by the soil and plants in an area, there can be a water shortage within the community as groundwater is not replenished (American Oceans Campaign, 2022).

2.6. Causes of flooding

The urban area is paved with roads, houses etc and the discharge of heavy rain can't absorbed into the ground due to drainage constraints leads to flooding of streets, underpasses, low lying areas and storm drains .Causes of urban flooding are either natural or human. The natural causes are heavy rainfall or flash floods, lack of lakes and silting. On the other hand, human causes are: *Urbanization:* leads to paving of surfaces which decreases ground absorption and increases the speed and amount of surface flow. The water rushes down suddenly into the streams from their catchment areas leading to a sudden rise in water level and flash floods. Unplanned urbanization is the key cause of urban flooding. Various kinds of depression and low lying areas near or around the cities which were act as cushions and flood absorbers are gradually filled up and built upon due to urbanization pressure. This results in inadequate channel capacity causing urban flooding; *Population pressure:* Because of large amount of people, more materials are needed, like wood, land, food, etc. This aggravates overgrazing, over cultivation and soil erosion which increases the risk of flooding; *Deforestation:* Large areas of forests near the rivers/catchment of cities are used to make rooms for settlements, roads and farmlands and is being cleared due to which soil is quickly lost to drains. This raises the drain bed causing overflow and in turn urban flooding; *Poor Water and Sewerage Management:* A lot of the sewerage and drainage network would be old and its condition may be unknown. They cannot cope with the volume of water or are blocked by rubbish and by non-biodegradable plastic bags. Sewers overflow because of illegal connections and the sewer system cannot cope with the increased volumes. As new development cover previously permeable ground, the amount of rainwater running off the surface into drains and sewers increases dramatically (Werkneh, 2017).

According to ERA Drainage Design Manual (2001) in the hydrologic analysis of a drainage structure, it must be recognized that there are many variable factors that affect runoff. Some of the factors that need to be recognized and considered on an individual site by-site basis are rainfall amount and storm distribution; catchment area size, shape and orientation; ground cover; type of soil; slopes of terrain and stream(s); antecedent moisture condition; storage potential (overbank, ponds, wetlands, reservoirs, channel, etc.); and catchment area development potential.

The rainfall-runoff process is extremely complex, making it difficult to model accurately. In undeveloped areas, the quantity and rate of storm water runoff are affected by natural surface detention, soil infiltration characteristics, and the drainage pattern formed by natural flow paths. The soil type, vegetative cover, and topography play key roles (Akan and Osman, 2003).

According to Christopher (2003) Streams are fed by runoff from rainfall and snowmelt moving as overland or subsurface flow. Floods occur when large volumes of runoff flow quickly into streams and rivers. The peak discharge of a flood is influenced by many factors, including the intensity and duration of storms and snowmelt, the topography and geology of stream basins, vegetation, and the hydrologic conditions preceding storm and snowmelt events. Land use and other human activities also influence the peak discharge of floods by modifying how rainfall and snowmelt are stored on and run off the land surface into streams. In undeveloped areas such as forests and grasslands, rainfall and snowmelt collect and are stored on vegetation, in the soil column, or in surface depressions. When this storage capacity is filled, runoff flows slowly through the soil as subsurface flows. In contrast, urban areas, where much of the land surface is covered by roads and buildings, have less capacity to store rainfall and snowmelt. Construction of roads and buildings often involves removing vegetation, soil, and depressions from the land surface. The permeable soil is replaced by impermeable surfaces such as roads, roofs, parking lots, and sidewalks that store little water, reduce infiltration of water into the ground, and accelerate runoff to ditches and streams.

2.7. Urban Flood Management

There are many approaches for reducing flood hazards in basins under development. Areas identified as flood-prone have been used for parks and playgrounds that can tolerate occasional flooding. Buildings and bridges have been elevated, protected with floodwalls and levees, or designed to withstand temporary inundation. Drainage systems have been expanded to increase their capacity for detaining and conveying high stream flows; for example, by using rooftops and parking lots to store water. Techniques that promote infiltration and storage of water in the soil column, such as infiltration trenches, permeable pavements, soil amendments, and reducing impermeable surfaces have also been incorporated into new and existing residential and commercial developments to reduce runoff from these areas (Christopher, 2003).

Urbanization generally increases the size and frequency of floods and may expose communities to increasing flood hazards. Current stream flow information provides a scientific foundation for flood planning and management in urban areas. Because flood hazard maps based on stream-flow data from a few decades ago may no longer be accurate today, floodplain managers need new peak stream flow data to update flood frequency analyses and flood maps in areas with recent urbanization. Stream flow-gaging stations provide a continuous record of stream flow that can be used in the design of new urban infrastructure including roads, bridges, culverts, channels, and detention structures. Storm water managers can use stream flow information in combination with rainfall records to evaluate innovative solutions for reducing runoff from urban areas (Christopher, 2003).

Urban flood management is wide-ranging. It addresses flood forecasting and warning, flood evacuation, flood protection, mitigation and recovery from floods. *Flood Forecasting and Warning*: The accurate and timely forecasting and warning of likable floods are extremely important for flood protection and mitigation. The reliability of forecasting greatly depends on the understanding of the hydrological process, the data collection, and processing, as well as telecommunication systems. As the use of radar technology, satellite imagery, and GIS increase, the accuracy of flood forecasting and warning improves; *Flood Control and Mitigation:* Reducing the risk of floods, minimizing the magnitude of floods and alleviating the consequences of floods are the objectives of flood control. In engineering practice, flood defense mainly relied on capital works and control structures in a direct physical attempt to protect vulnerable objects in floodplains and to reduce the greatest damage from floods; *Urban Flood Management Issues*: the risk of urban flooding is also increasing due to rapid urbanization. Unlike river floods, urban flooding happens more frequently and causes a large amount of accumulated damage, though the damage per event is relatively smaller compared with the severe consequences caused by river flooding. In addition, urban flooding has brutal impacts on the municipality's activities when it happens. Therefore, more attention should be paid to it (Nie, 2003).

2.8. Application of Geospatial Technology for Analysis of Land Use Land Cover Change and Runoff Characteristics

Surveying and mapping have recently undergone a transition from discipline- oriented technologies, such as geodesy, surveying, photogrammetry, and cartography, into the methodology-oriented integrated discipline of geoinformatics. This is based on GPS positioning, remote sensing, digital photography for data acquisition, and GIS for data manipulation and data output. Data integration is made possible by geocoding, in which the GPS satellite positioning system plays an increasing role (Weng, 2010). From geospatial technologies which are applied for analysis of LULCC detection and storm runoff characteristics; the most common are remote sensing technology and GIS.

The integration of remote sensing and geographic information systems (GIS) has been applied widely and has been recognized as a powerful and effective tool for detecting urban growth. Remote sensing collects multispectral, multi-resolution, and multi-temporal data and turns them into information that is valuable for understanding and monitoring urban land processes and for building urban land-cover data sets. GIS technology provides a flexible environment for entering, analyzing, and displaying digital data from various sources necessary for urban feature identification, change detection, and database development. In hydrologic and watershed modeling, remotely sensed data are found to be valuable for providing cost-effective data input and for estimating model parameters (Weng, 2010).

According to Weng, (2010) integration of GIS and remote sensing in runoff modeling involves two processes: (1) hydrologic parameter determination using GIS and (2) hydrologic modeling within GIS. Hydrologic parameter determination using GIS entails preparing land-cover, soil, and precipitation data that go into the SCS model, whereas hydrologic modeling within GIS automates the SCS modeling process using generic GIS functions. Remote sensing is used for obtaining land-cover data each year and for obtaining information about the nature, rate, and location of LULC changes. Urban growth analysis then is carried out by superimposing administrative boundaries on the LULC change map. After a surface runoff image is obtained from the hydrologic modeling, the technique of image differencing is applied to evaluate the changes in surface runoff over time. The urban-expansion map is overlaid with the runoff-change map to analyze the impact of LULC change on the environment.

The combined use of remote sensing and GIS proves to be an effective tool for urban growth analysis. The technique of LULC change detection can be refined to find out the nature, rate, and location of urban growth. GIS allows for determining the magnitude of satellite-derived urban growth rates within administrative units. The integration of GIS and remote sensing has been applied successfully to surface runoff modeling. Effects of urban growth on surface runoff can be modeled at local levels using an integrated approach of remote sensing and GIS. This linkage is based on the fact that LULC data are the main input parameter to both urban growth analysis and surface runoff modeling and that remote sensing and GIS are able techniques for spatial data acquisition and handling (Weng, 2010).

2.9. Hydrological Response to LULC change in Ethiopia

The hydrological cycle is the continuous exchange of water between land, water bodies, and the atmosphere. When precipitation falls over the land, it follows various routes. Some of it evaporates, returning to the atmosphere, some seeps into the ground, and the remainder becomes surface water, traveling to oceans and lakes by way of rivers and streams. Construction of roads and buildings often involves removing vegetation, soil, and depressions from the land surface. The permeable soil is replaced by impermeable surfaces such as roads, roofs, parking lots, and sidewalks that store little water, reduce infiltration of water into the ground, and accelerate runoff to ditches and streams. Impervious surfaces associated with urbanization alter the natural amount of water that takes each route as topography of land changes by urbanization. The consequences of this change are a decrease in the volume of water that percolates into the ground, and a resulting increase in volume and decrease in quality of surface water. These hydrological changes have significant implications for the quantity of fresh, clean water that is available for use by humans, fish and wildlife (Raghunath, 2008).

As imperviousness increases, less water infiltrates and more and more runs off. In highly urbanized areas, over one-half of all rain becomes surface runoff, and deep infiltration is only a fraction of what it was naturally .The increased surface runoff requires more infrastructure to minimize flooding. Natural waterways end up being used as drainage channels, and are frequently lined with rocks or concrete to move water more quickly and prevent erosion. In addition, as deep infiltration decreases, the water table drops, reducing groundwater for wetlands, riparian vegetation, wells, and other uses. Consequently, as the land cover and land use changes during urbanization so does the water cycle. Scientific measures need to be considered in order to sustain the water cycle while urbanization is taking place (Raghunath, 2008).

In Ethiopian context, where watersheds of many urban centers receive significant amount of annual rainfall and where rainfall intensity is generally high, control of runoff at the source, flood protection, and safe disposal of the excess water/runoff through proper drainage facilities become essential (Tafete, 2013). Drainage problems in Ethiopian urban centers include flooding, deterioration of roads, land degradation, sedimentation, water logging, blockage of drainage facilities and the like. With urbanization, impermeability increases with the increase in impervious surfaces (i.e. residential houses, commercial buildings, paved roads, parking lots, etc.), drainage pattern changes, overland flow gets faster, flooding and environmental problems such as land degradation increases. It is a crucial problem facing the existing and future environmental conditions of urban centers (ERA, 2013).

According to Adane (2019) the existing stormwater drainage of Hawassa city has been evaluated with the help of Base map for the roads, structural map, contour map, tap meter and including Bentley CivilStorm software to analyze the quantitative data. Drainage lines around Wanza square have been evaluated and it is concluded that they have been facing overflowing and flooding which was mainly caused by the growth of built up area. The results from this study show that the drainage system has been hindered to function well because of the challenges that have been faced over years. After analyzing the results, he concluded as: the performance of stormwater drainages was not satisfactory. Therefore, it is recognized that its capacity has shown lower results which needs some adjustment or improvement to give the best service, and needs a serious of regular maintenance and also provide drainage networking for the areas without drainage systems for its complete service.

Therefore, cities in different urbanization stages will have different trends in runoff changes. As a result, increasing direct surface runoff has become a serious problem in Hawassa city urban area. This study used Hawassa city as a case study to explore the impact of urbanization on direct runoff. In doing so, this study had several goals: (1) to develop an effective and efficient method to simulate direct runoff in the Hawassa city urban area; (2) to explore trends of direct runoff from 2002 to 2021; and (3) to analyze potential factors behind direct runoff changes.

CHAPTER-III: MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

Hawassa city is found in Sidama Regional State. The city is a regional administrative capital as well as an important business center for the region and is also used as an administrative station for Southern Nations, Nationalities, and Peoples (SNNPR's). Moreover, it is also an important tourist destination site in the south whereby a several foreign and domestic tourists visited the city. The city is located at a distance of 273 km south of Addis Ababa, the capital city of Ethiopia (Adane, 2019). Geographically the city lies approximately between $7^{0}55'$ to $7^{0}6'$ latitude North and $38^{0}25'$ to $38^{o}34'$ longitudes East.

Hawassa city is bounded by Lake Hawassa in the West, Oromia region in the North, Wondogenet woreda in the East and Shebedino woreda in the South. The city administration has 8 sub-cities and 32 kebeles. These Eight sub-cities are Hayek Dare, Menehariya, Tabore, Misrak, Bahile-Adarash, Addis Ketema, Hawela Tula, and Mehal-ketema sub city. The average elevation at the town is 1700m and that of the lake surface is 1680m above sea level. The drainage of the city is towards Lake Hawassa (Abebe, 2017).

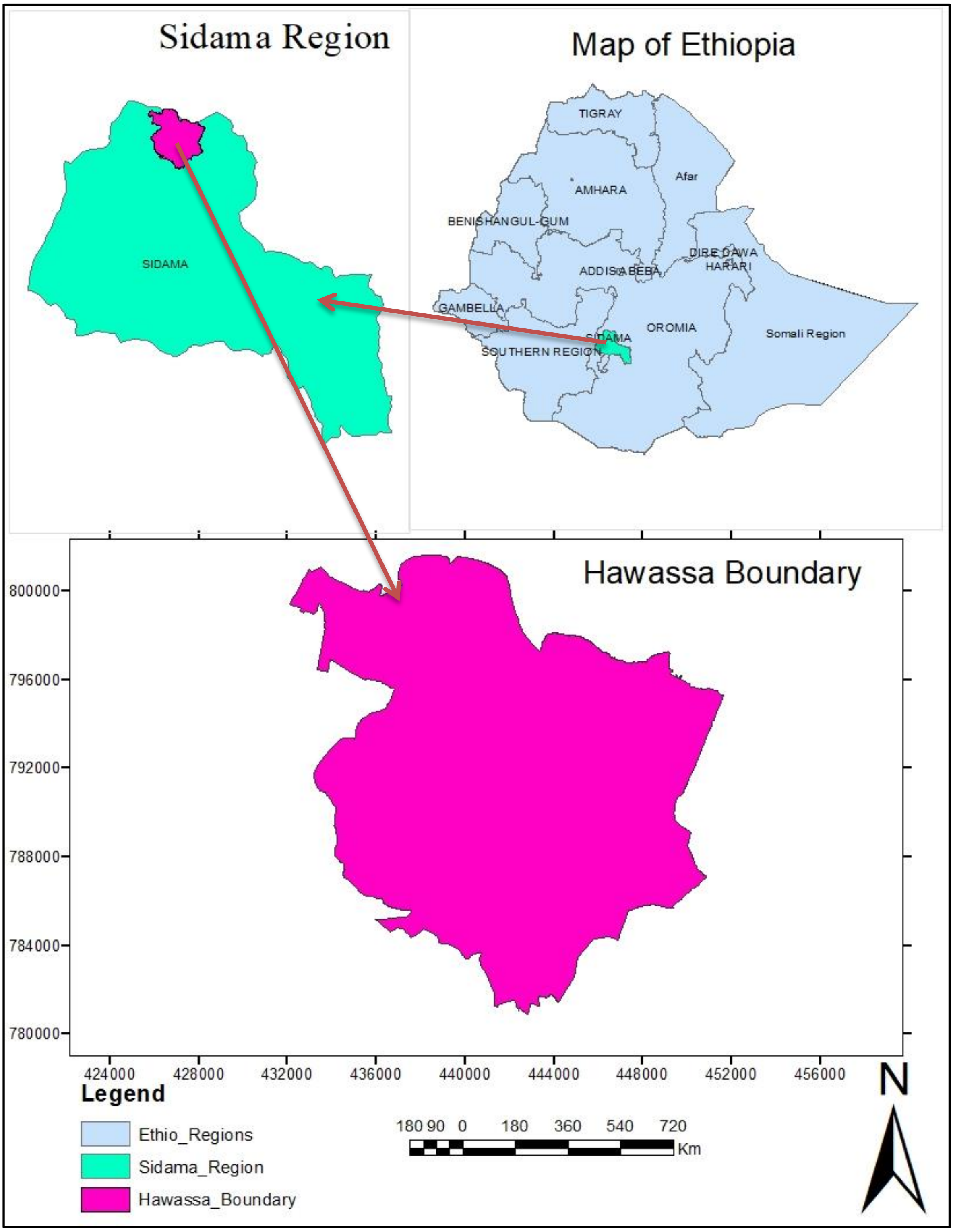

Figure 3-1 Administrative boundary of the study area

3.1.2 Climate and Demography

The mean annual precipitation is 933.4 mm. Temperatures vary between 5^0C in winter and 34^0C in summer. The city experiences sub-humid-called 'Woyina-Dega' type of climate. It has the highest and lowest temperature of 34^0c and 3^oc respectively. The average annual temperature is 20.3^{o}c. Hawassa gets rainfall twice a year. It falls during 'Belg' and 'Kiremt' (winter rainy season). The first rainfall falls from 'Megabit' to the mid of 'Ginbot' (May) and the next comes from 'Sene' (June) to the mid of 'Meskerem'(September). Due to the city's location in the Great Rift Valley on the shore of rift valley Lake Hawassa, its weather condition changes dramatically from day to night. (Adane, 2019).

3.1.3 Rainfall Data

Time series rainfall records (2002-2021) based on Hawassa meteorological station was analyzed to investigate the urban hydrological runoff of the study area. The data were checked for missing values, and a few gaps 4.2 % identified in the data which is less than 10% were filled using XLSTAT-2015 add-ins plugin in Microsoft excel using multiple imputation estimation methods (MCMC). Daily precipitation values were aggregated to give annual rainfall as shown in figure 3.2. The maximum annual rainfall was observed in the year 2020 with an amount of 1,277.50 mm and the minimum value was observed in the year 2015 with a value of 670.90 mm.

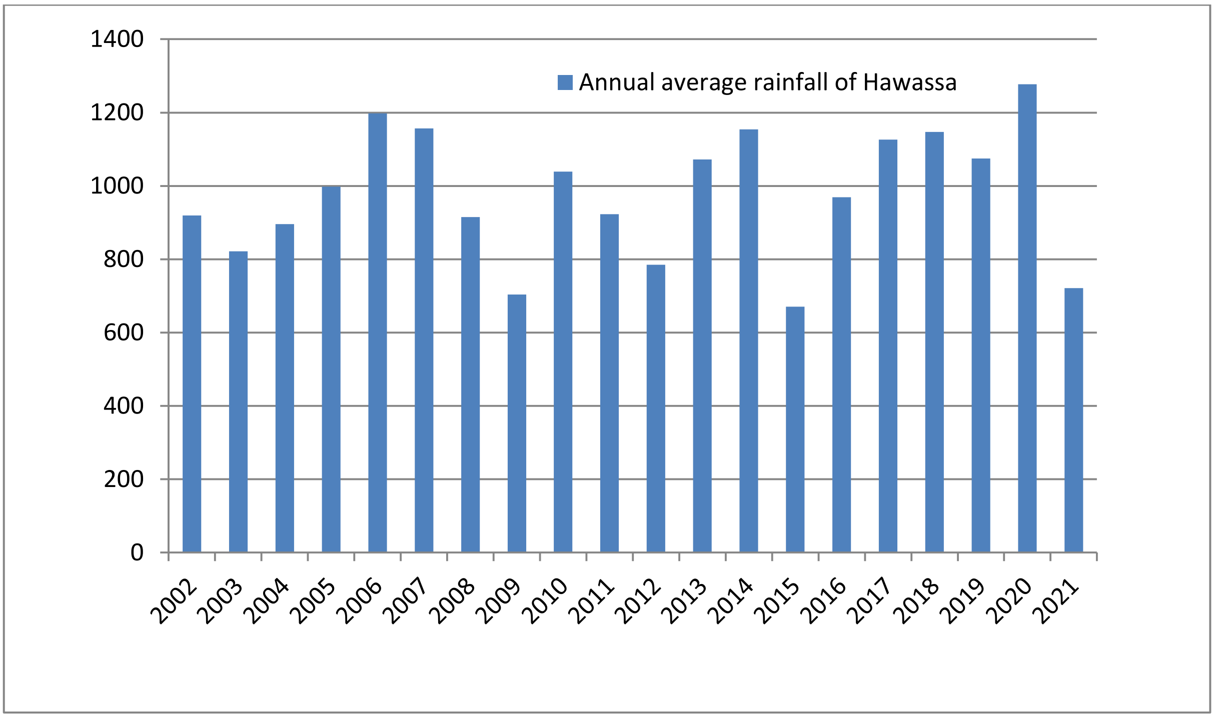

Figure 3.2 Annual average rainfall of the study area from 2002-2021

In Hawassa the main rainy season generally extends from June to September and was selected for runoff computation for analyzing the impacts of LULCC on runoff response in the city's administration watershed. The maximum daily precipitation in the rainy season was selected for runoff computation for analyzing the impacts of urbanization on runoff response in the city administration area. It is found to be 71.5 mm precipitation record corresponding to Sep 20, 2007. It is used for the study, and helped to analyze the impacts of LULC on the surface runoff depth of the study area, by considering the other factors as constant.

3.1.4 Hydrologic Soil Group

Hydrologic soil groups (HSGs) are a fundamental component of the USDA curve number (CN) method for estimation of rainfall-runoff; which was developed a globally consistent gridded dataset defining HSGs resulting data product (HYSOGs 250m) that represents rainfall runoff potential at 250-m spatial resolution. The four standard classes; A, B, C, and D; are correspond to soils with low, moderately low, moderately high, and high runoff potential, respectively. Wet soils have high runoff potential (regardless of texture) due to the presence of a groundwater table within 60 cm of the surface. These soils are assigned dual HSGs (A/D, B/D, C/D, and D/D), as a less restrictive class group can be assigned if they can be adequately drained (Ross et al.; 2018).

Table 3.1: the relationship of pixel values and HSGs for Curve Number-Based Runoff Modeling

Pixel values	**Description**
1	HSG-A: low runoff potential (>90% sand and <10% clay)
2	HSG-B: moderately low runoff potential (50-90% sand and 10-20% clay)
3	HSG-C: moderately high runoff potential (<50% sand and 20-40% clay)
4	HSG-D: high runoff potential (<50% sand and >40% clay)
11	HSG-A/D: high runoff potential unless drained (>90% sand and <10% clay)
12	HSG-B/D: high runoff potential unless drained (50-90% sand and 10-20% clay)
13	HSG-C/D: high runoff potential unless drained (<50% sand and 20-40% clay)
14	HSG-D/D: high runoff potential unless drained (<50% sand and >40% clay)

Using table 3.1 as a reference; the Soil of Hawassa watershed is classified into four HSGs: C, D, C/D, and D/D. According to four hydrologic soil groups defined by US Soil Conservation Service, the soil type classification data was reclassified to output the soil hydrological map using ArcGIS software (Fig. 3.3). Soil properties influence the relationship between rainfall and runoff by affecting the rate of infiltration.

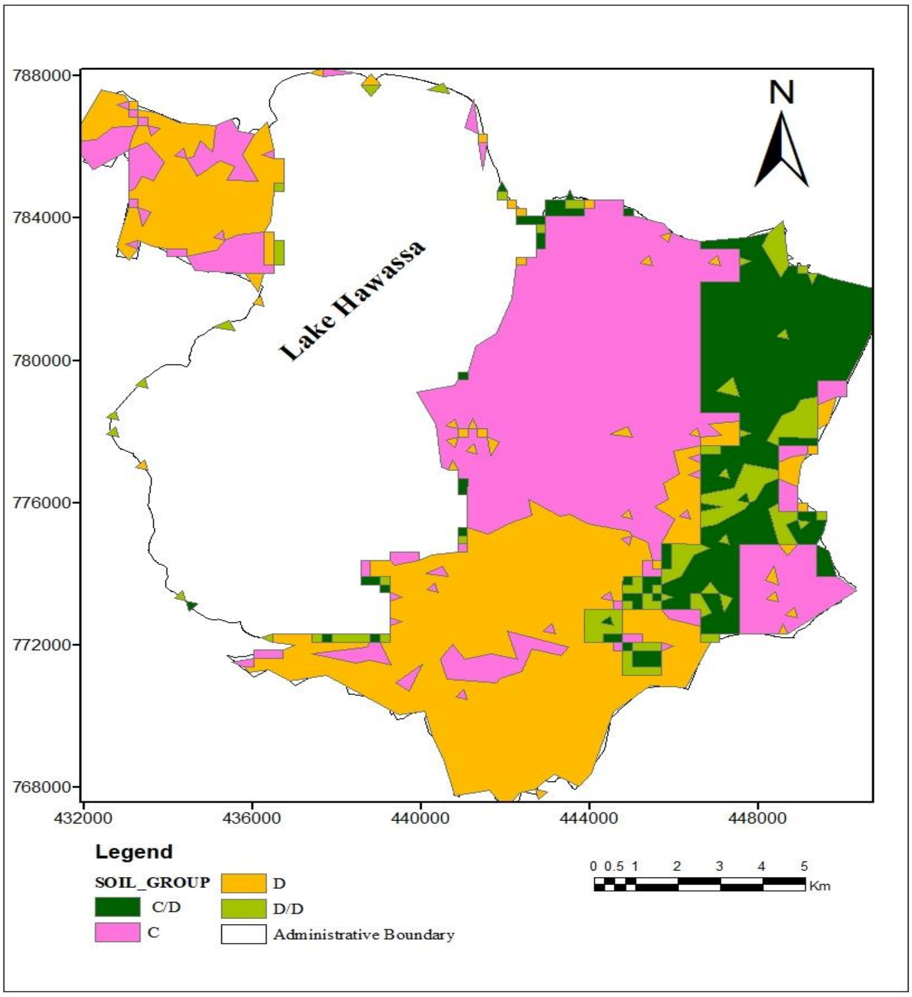

Figure 3.3 Hydrologic soil group (HSG) map of the study area

3.1.5 Urban watershed Delineation

Figure 3.4 shows a Watershed map for the storm drain of the study area which is generated in the GIS platform using DEM. The DEM is made error free to prepare data for watershed creation. To make error free to the DEM; the gap filling process was done using the Fill tool in the Arc toolbox.

The filling process includes removing small sinks or depression areas in the DEM, and then elevates their elevations to the adjacent lowest cell. The reconditioned DEM is further processed to determine the direction of flow in each cell. The flow direction of a cell is obtained by finding out its adjacent lowest elevation cell, and the flow from the cell is toward the lowest cell. Flow Direction tool is used to do this task. This is followed by creating a Flow Accumulation map. The flow accumulation technique assigns to each cell, the number of upstream cells that contribute their flows to the cell. The flow accumulation grid was used to generate the stream network. In this process, first, the cells exceeding a threshold accumulation are identified and considered to form streams. Then using the flow direction grid and the pour point watershed of the study area was analyzed.

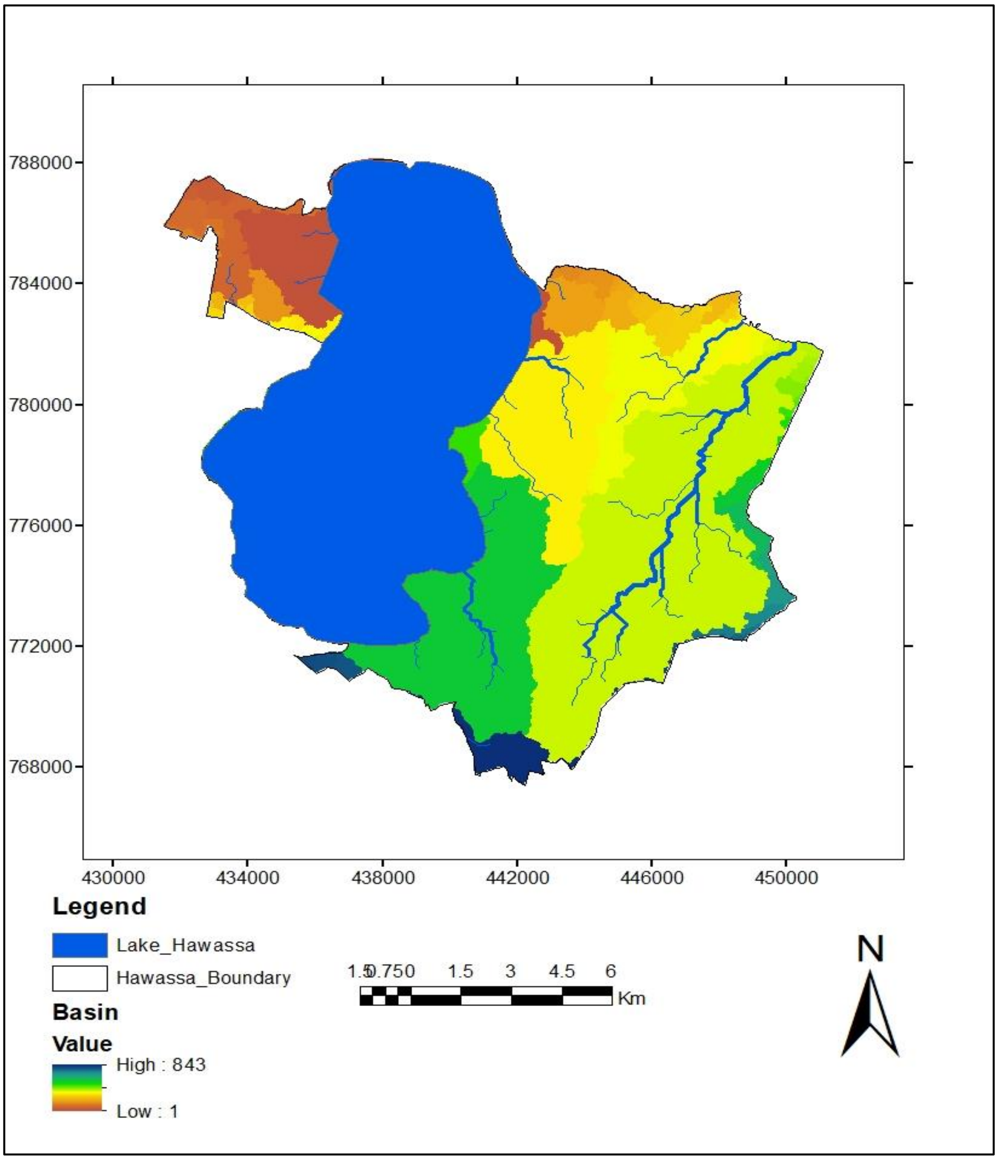

Figure 3.4 watershed map of study area

3.2. Data types and Software used

Both spatial and attribute data types are used in this study. Geographic information system (GIS) and remotely sensed datasets had been collected and prepared for analysis; One image of Landsat satellite imagery from each year of (2002, 2007, 2012, 2017, and 2021) with free cloud contamination was accessed from the USGS (https: //espa.cr.usgs.gov/) was used to develop the LULC map of the study area. It is freely accessible for multiple dates and considered suitable for time-series analysis (Bulti and Abebe, 2020).

Specifications of the satellite data acquired for LULC analysis are given in Table 3.2 the rainfall data of the study region was obtained from Ethiopian Meteorological Agency Hawassa branch and used to calculate runoff of the catchment area. A digital elevation model (DEM) with a resolution of 30 m was downloaded from the USGS that is a representation of the bare ground topographic surface of the earth excluding trees, buildings, and any other surface objects and used to derive the elevation, slope, stream network and extents of the basin for the study area. ArcGIS 10.8, ENVI 5.3, and IBM SPSS –V26 software were used to build, manage, and generate various layers and maps for the research.

Table 3.2 Dataset and equipment

Dataset	Date	Resolution/Scale	Source
The Landsat-7 Thematic Mapper (TM)	2002, 2007 and 2012	30m(path-168/ Row-055)	USGS
The Landsat-8 Thematic Mapper (TM)	2017, and 2021	30m(path-168/ Row-055)	USGS
DEM data		30m	USGS
Administrative boundary data			SRUDHB
Rainfall data	2002- 2021	NA	NMA, Hawassa branch.
Soils series data		250 m	FAO,
Softwares			
Esri ArcGIS		Version 10.8	ASTU Geomatic Eng. Dep.
ENVI		Version - 5.3	ASTU Geomatic Eng. Dep.
IBM SPSS		Version - 26	ASTU Geomatic Eng. Dep.

3.3 Land use/land cover mapping

The land use map for the study area was made ready by clipping the area of interest from Landsat-7 and 8 images that were accessed from the USGS and the images were first re-projected into the Universal Transverse Mercator (UTM) zone 37N coordinate system. Taking into account the importance of short-term changes in urban areas due to rapid urbanization and climate changes (Bulti, and Abebe, 2020), LULC maps of the study area were prepared at about 5 years intervals (2002, 2007, 2012, 2017, and 2021) using Landsat images through supervised classification method. It involves defining a classification scheme, selection of training samples, running an algorithm to assign each pixel into a class, and accuracy assessment.

3.3.1 Defining classification scheme

The study area was classified into five types of land use: built-up area, agriculture, vegetation, barren land, and water body. Detailed descriptions of these land use classes are provided in table 3.3. The spectral resolution satellite image was used for the analysis because the spectral dimension is the most important source of cover type information in coarse resolution images.

Table3.3 LULC classes and description used in the study

LULC Classes	Description
Built-up Area	Developed areas covered by constructed materials or areas with a mixture of constructed materials and vegetation.
Agriculture	Areas used for the production of annual crops, such as corn, vegetables and tobacco.
Vegetation	Areas dominated by trees and shrubs.
Barren	Areas of bedrock, gravel, sand, and other accumulations of earthen material.
Water	Areas of open water, including river and reservoir.

3.3.2 Training sample selection

The training samples were selected from the Landsat image of 2002 for each land-use class as a first step and these samples were treated as training samples for the initial image and used as a base for the next 2007 image; to check if the change in class occurred or not; the base samples were overlaid with the second image. The sampling biases were reduced by consistency in sample selection that was kept by selecting pixels that remained unchanged at different times to train the classifier. If changes were observed, a new sample with more confidence was substituted from the image. Similarly, the same procedures were followed by the selection of training samples for the rest of the images.

3.3.3 Classification algorithm

A supervised classification with the Support Vector Machine (SVM) algorithm in ENVI-5.3 was used to classify the area of study into different classes of LULC from the Landsat images. SVM is a non-parametric classifier. Non-parametric classifiers do not base classification on a normality assumption or statistical parameters. Non-parametric classifiers provide better results as compared to parametric classifiers in complex landscapes (Bulti and Abebe, 2020).

3.3.4 Accuracy assessment

One of the most important final steps in the classification process is accuracy assessment (Sophia S. and Rwanga, 2017). The accuracy is essentially a measure of how many ground truth pixels were classified correctly. When looking at the land cover map, it is important to remember that no map is a perfect representation of reality. There are always errors in maps and we need to keep in mind how accurate they are, and whether that level of accuracy is sufficient for the ways we want to use the map information. The accuracy of the classification was verified by field checking or comparing with existing land-use and land-cover maps that had been field checked.

In this study, LULC classification accuracy was assessed quantitatively using error matrix which is the commonly used method in LULC classification accuracy assessment (Bulti and Abebe, 2020). From each of the classified images, sample pixels were selected through a stratified random sampling scheme in ENVI software. This enables to undertake unbiased sample selection, as it includes each LULC class in the sample.

The selected samples were overlaid with Google Earth (for 2002, 2007, 2012 and 2021) and digital ortho-photo (for 2017) to visually interpret and determine their respective classes. Based on the error matrix generated for each classified map; overall accuracy, user's accuracy, producer's accuracy and kappa variance were calculated. Users Accuracy is when the total number of correct pixels in a category is divided by the total number of pixels that were classified in that category (row total), the result is a measure of Commission error. The overall accuracy is calculated by summing the number of pixels classified correctly dividing by the total number of pixels. The enough number of samples that represent the thematic classes and ensure good distribution across the map is important to test the attribute accuracy.

Using the Accuracy assessment formula (Stehman, 2020):

$$\text{Users Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total no.of classified pixels in that category (the raw total)}}\ x\ 100 \qquad (1)$$

$$\text{Producer accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total no. of reference pixels in that category (the column total)}}\ x\ 100 \qquad (2)$$

$$\text{Overall accuracy} = \frac{\text{Total number of correctly classified pixels (Diagonal)}}{\text{Total number of Reference pixels}}\ x\ 100 \qquad (3)$$

$$\text{Kappa Coefficient(T)} = \frac{(\text{TS}*\text{TCS}) - \sum(\text{Column total x Raw total})}{\text{TS2} - \sum(\text{Column total x Raw total})}\ x\ 100 \qquad (4)$$

As mentioned by Rwanga and Ndambuki, (2017) A Kappa coefficient equal to 1 means perfect agreement whereas a value close to zero means that the agreement is no better than would be expected by chance. Categorization of Kappa statistic is widely referenced which is reproduced in Table 3.4.

Table 3.4 Kappa statistic Categorization

S.No	Kappa statistics	Strength of agreement
1	<0.00	Poor
2	0.00 - 0.20	Slight
3	0.21 - 0.40	Fair
4	0.41 - 0.60	Moderate
5	0.61 - 0.80	Substantial
6	0.81 - 1.00	Almost perfect

For a reliable land cover classification, Kappa is used to measure the agreement or accuracy between the remote sensing derived Classification map and the reference data as indicated by the major diagonals and the chance Agreement, which is indicated by the total row and column (Rwanga and Ndambuki, 2017).

3.4 Research Methods

ENVI –software was used as a tool to classify LULC of the project area and the GIS-based data-base was used for the analysis of LULC change; integration of LULC and hydrological soil group (HSG) shapefiles; HSG and LULC shapefiles were intersected in a GIS environment to produce new and smaller polygons associated with names of HSG and LULC. Based on the intersected LULC-HSG layer and its associated attribute table, the curve number (CN) was constructed. A further correction was made to the created CN using slope data to derive slope-corrected CN. Finally, the surface runoff depth from the slope-corrected CN and rainfall data was calculated.

A. Investigation of land use land cover change

Using the analyzed LULC maps of the study areas spatio-temporal change of LULC was identified by the following equation:

$$\Delta_{LULC} = \frac{A2-A1}{A1} x100 \quad (5)$$

Where; Percentage change LULC (Δ_{LULC})

A1 *and* A2 are areas of a LULC class in consecutive years.

B. Analysis of change in impervious area

Features that are categorized under urban land use are considered as impervious surfaces and the PIA of each water shade was calculated using the ratio of impervious surface area at different years to the area of the respective analysis boundaries. To compute the change in imperviousness with respect to the first year of the analysis the following equation was used:

$$\Delta PIA_i = \frac{PIA_i - PIA_{2002}}{PIA_{2002}} \text{ x } 100 \quad (6)$$

where ΔPIA_i : percentage change of imperviousness; PIA_i: imperviousness in respective years; PIA_{2002}: imperviousness in the baseline year (2002).

C. Calculating Surface Runoff Depth

Analysis of the temporal variations of the runoff depth due to the impacts of LULC changes in the study area involves computation of runoff and percentage change with respect to a baseline/ reference year. The model used for estimating surface runoff in this research was developed by the United States Soil Conservation Service (SCS). SCS method has been commonly used to estimate storm runoff depth for every patch within a watershed based on soil conservation service runoff curve number (SCS-CN).

This model is chosen for use in this data analysis because it is based on a study area's hydrologic soil group, land use/cover and hydrologic conditions and also is a simple method.

SCS-CN has been adapted over the years within the urban hydrology community and become the most recognized method for computing peak runoff rates and volumes. The SCS uses a combination of soil conditions and land-use (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher the CN indicates the higher the runoff potential. The CN for each LULC class was determined by considering the effects of urbanization on the natural hydrologic soil group and the variation range of CN is $0 \leq CN \leq 100$.

To determine a single curve number for respective analysis boundaries for runoff estimation using the SCS-CN method, the catchments were spatially intersected with LULC maps and the area of each class in each catchment was computed. Then, the weighted CN for respective watersheds was computed.

According to ERA Drainage Design Manual (2002); The SCS method is based on a 24-hour storm event which is applicable for the interior rather than the coastal regions and should be appropriate for Ethiopia.

i) Antecedent Moisture Condition (AMC)

Calculating CN value for each land use type is for average conditions (Antecedent Moisture Condition Class-II). The CN values for AMC-II can be converted into CN values for AMC-I and AMC-III by using the SCS standard tables 3.5 below. To determine which AMC class is the most appropriate relative to the study area, the use of rainfall data is necessary.

The formula of API is:

$$\text{API} = \sum_{i=1}^{5} Pi \tag{7}$$

Where API is Antecedent Precipitation Index and Pi is the rainfall amount.

The 5 day rainfall magnitude (Antecedent Precipitation Index) is found to be 105.8 mm from (Sept 16-20, 2007). To convert the average antecedent moisture condition into the wet condition and for computing the potential maximum soil retention; equation 8 and 9 was applied.

Table 3.5 Types of antecedent Moisture Condition (AMC) in the SCS-CN method

AMC	Conditions Description	Total Rain in Previous 5 days	
		Dormant Season	Growing Season
I	An optimum Condition of catchment area soils, where soils are dry but not to the wilting point, and when satisfactory plowing or cultivation takes place	Less than 13 mm	Less than 36 mm
II	The average case of annual floods	13 to 28 mm	36 to 53mm
III	When heavy rainfall, or light rainfall and low temperatures, have occurred during the five days previous to a given storm	More than 28mm	More than 53mm

Source: ERA, Drainage Design Manual – 2002

To determine CN values for the study the following formula was used:

$$CN_{II} = \frac{\sum_{i=1}^{n} CNai}{\sum_{i=1}^{n} ai} \quad (8)$$

$$CN_{III} = \frac{CN_{II}}{0.427+0.00573CN_{II}} \quad (9)$$

ii) Slope Corrected Curve Number for AMC-III

Slope is an important factor that can influence runoff. As the slope increased, the initial abstraction, infiltration, and recession time of overland flow decreased, which resulted in less of an opportunity for infiltration and more surface runoff as compared with a horizontal surface. In the original SCS-CN method the effect of the slope has not been taken into account while calculating CN. In addition to LULCC and AMC; the land slope parameter has been considered an important factor in determining runoff (Ajmal et al.; 2020). The average CN values of AMC-II were slope corrected by the equation (10) and converted to equivalent antecedent moisture condition (AMC-III), for the wet condition of the study area by using equation (9). To determine the Slope Corrected Curve Number value for AMC-III the land class is categorized using slope intervals of 0%, 0-2%, 2-6%, 6-15%, 15-30%, and > 30% for analysis of urban surface runoff in the study area.

$CN_{II\alpha} = CN_{II} \times K$, and (10)

$$K = \frac{322.79+15.63(\alpha)}{\alpha+323.52} \quad (11)$$

Where $CN_{II\alpha}$ is the value of CN_{II} for a given slope, CN_{II} is the NRCS-CN for soil moisture condition II (average), K is CN constant, and α (m/m) is soil slope.

The major steps of the surface runoff estimation, which was processed in this thesis, are as follows:

i) Analysis of the hydrologic soil group-land cover complex. Soil and LULC data are used to create the hydrologic soil group-land cover complex for the runoff curve number (CN) extraction based on the standard SCS-CN value table. It shows the relationship between LULC types and hydrologic soil groups, which are the infiltration rates of soils by classifying soils into 4 groups: A - low runoff potential, B - moderately low runoff potential, C - moderately high runoff potential, and D - high runoff potential, depending on their minimum infiltration rates for surface runoff estimation(U.S. Department of Agriculture, 1986)
ii) Calculation of slope corrected CN_{III} from equations (9 and 10)
iii) Calculation of potential maximum storage. Potential maximum storage (S) is computed for each location (pixel) as:

$$S = \frac{25{,}400}{CNIII} - 254 \quad (12)$$

where S is the potential maximum storage in mm and depends on the soil hydrological group and the land cover class., and CN is the runoff curve number of the hydrologic soil group land cover complex.

iv) The maximum rainfall data from 20 years of climatological data of Hawassa city from the years 2002 to 2021 was used.
v) Surface runoff estimation: The surface runoff depth (Q) is here generated using the SCS equation for storm runoff depth as:

$$Q = \begin{cases} \frac{(P-0.2S)^2}{(P+0.8\,S)} & P > 0.2\,S \\ 0 & P \leq 0.2\,S \end{cases} \tag{13}$$

where Q: accumulated direct runoff depth (mm); P: accumulated rainfall (mm); S: potential maximum retention after runoff begins (mm) and 0.2S is an initial abstraction.

Thus, equation (12) is used to estimate S at each grid cell, and equation (13) to estimate cell runoff for a given rainfall which is considered to be uniform throughout the watersheds.

D. Analyzing Surface Runoff Changes

Spatio-temporal impact of urban land use change on surface runoff was assessed by evaluating the runoff discrepancies under different land use conditions. The surface runoff of the study area was simulated by inputting the land use maps of 2002, 2007, 2012, 2017, and 2021 individually to drive the SCS-CN model under different rainfall events. The impact assessment was conducted by comparing the difference of runoff variables between the initial land use condition and final land use condition.

Temporal variations of the runoff depth due to the impacts of LULC change were determined using the runoff depth change ratio. To determine the temporal variations in storm runoff depth attributable to the changes in LULC of the study area with respect to that of the baseline year, equation 14 was used.

$$\Delta Qi = \frac{Qi-Qj}{Qj} x\ 100 \tag{14}$$

where ΔQi Percentage change of runoff depth; Qi is runoff depth in respective years, *Q*j is runoff depth in the reference year (j).

E. Analyzing the impact of LULC Change on Surface Runoff Change

The spatiotemporal surface runoff depth using LULCC from 2002 to 2021 was first estimated using the SCS-CN method, and the impact of the LULC changes on the surface runoff depth was then examined using spatial and linear regression analyses.

The process of estimation of the dependent variable from the other independent variable is often referred to as regression analysis. Regression analysis is the common method to investigate the relationship between a quantitative outcome (dependent variable) and a quantitative explanatory variable (independent variable). The most common form of regression analysis is linear regression, in which one finds the line (more complex linear combination) that most closely fits the data according to a specific mathematical criterion. To analyze the impact of spatiotemporal changes of PIA on runoff in the catchment area and to relate the change in a runoff with the flooding problem in the area regression analysis was used. A Correlation was used to denote the association between the spatiotemporal changes of PIA and runoff variables. The degree of association between these dependent and independent variables was measured by correlation coefficient(r) using SPSS software. Null Hypothesis (H0) and Alternative Hypothesis (HA) was done using significance value. Null Hypothesis (H_0) refers No effect exists on surface runoff change because of LULCC and Alternative Hypothesis (H_A) refers the effect exists in the surface runoff change because of LULCC. P-value was calculated from correlation coefficient(r) and the null hypothesis was rejected according to the result (Bewick et al.; 2003).

3.5 Technological Scheme of the Research Work

Figure 3.5 shows the overall flowchart of the methodology used for the research work employed by the geographic information system (GIS) and soil conservation service-curve number (SCS-CN) method in estimating the surface runoff within the studied region.

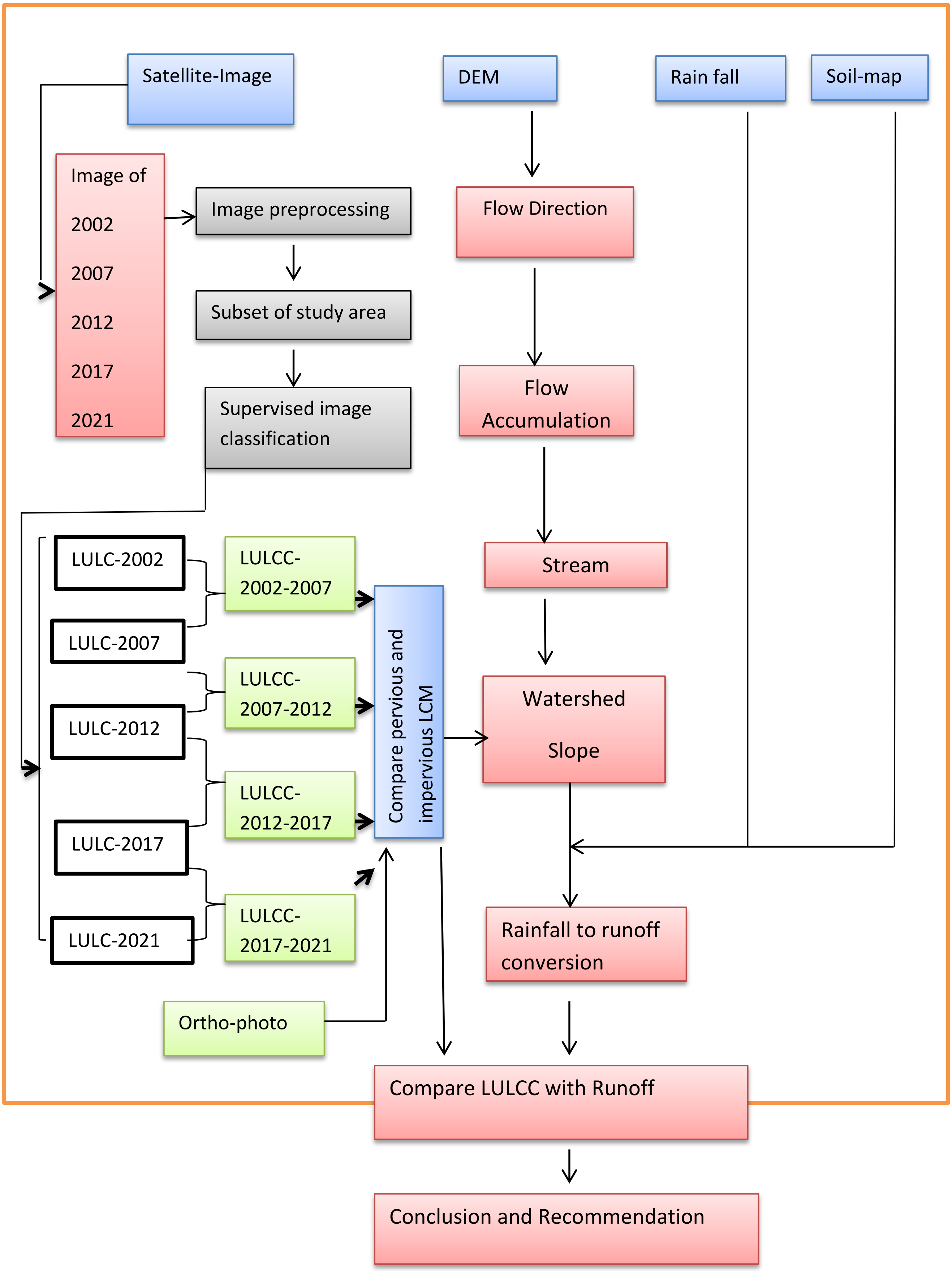

Figure 3.5 Technological scheme of the research work

CHAPTER-IV: RESULTS AND DISCUSSIONS

4.1 Land Use/Land Cover Change Map

LULC maps of Hawassa city for the years 2002, 2007, 2012, 2017, and 2021 were prepared and the LULC types were classified into five categories: (1) urban area, (2) agricultural land, (3) vegetation, (4) water body and (5) barren land. Fig 4.1 a - f illustrates the spatial distributions of LULC classes in Hawassa city for 2002, 2007, 2012, 2017, and 2021.

LULC of the year 2002 showed that 5.2% area was covered by built-up area, 21.2% by agriculture, 33.9% by vegetation, 0.8% by barren and 38.9% by water body; LULC of the year 2007 was 6.5% for built-up area, 27.4% for agriculture, 26.9% for vegetation, 0.5% for barren and 38.7% for water body; LULC of the year 2012 was 8.3% for built-up area, 22.7% for agriculture, 30.4% for vegetation, 0.2% for barren and 38.3% for water body; LULC of the year 2017 was 13% for built-up area, 15.7% for agriculture, 32.9% for vegetation, 0.2% for barren and 38.1% for water body; while LULC of the last sample year 2021 was 20.5% for built-up area, 8.5% for agriculture, 31.6% for vegetation, 0.3% for barren and 39.1% for water body (Table 4.1).

The distribution of percentage change of LULC for the years 2002-2007 was for built-up area 25.7%, for agriculture 29.3%, vegetation (-20.8%), barren (-38.1%) and water body (-0.5); for the years 2007-2012 was for built-up area 27.3%, for agriculture (-17.2%), vegetation 13.2%, barren (-50.6%) and water body (-0.9); for the years 2012-2017 was for built-up area 55.9%, for agriculture (-30.7%), vegetation 8.3%, barren (-7.8%) and water body (-0.5); for the years 2017-2021 was for built-up area 58.2%, for agriculture (-46%), vegetation (-4.1%), barren 21.2% and water body 2.6% (Table 4.1).

Initially, in 2002 Agriculture and vegetation lands dominated the whole area but decreased with the continuous increase of urban areas at the end sample study year (2021). The proportion of urbanized area to the total land area was increased by 5.2%, 6.5%, 8.3%, 13.0% and 20.5% in 2002, 2007, 2012, 2017 and 2021 respectively. Urban areas increased from 5.2% in 2002 to 20.5% in 2021 while agricultural land areas decreased from 21.2% in 2002 to 8.5% in 2021 and vegetation area decreased from 33.9% in 2002 to 31.6% in 2021. While Water bodies increased from 38.9 % in 2002 to 39.1 % in 2021 and barren land also decreased from 0.8% in 2002 to 0.3% in 2021 (Figure 4.1 and Table 4.1).

Built-up land has expanded by 25.7 % from 2002-2007, 27.3% from 2007-2012, 55.9% from 2012-2017 and 58.2% from 2017-2021 respective years. Table 4.1 shows the spatial extent, area in percent and percentage changes over time of the five classes of LULC (Built-up, agriculture, vegetation, barren land and water-body) in Hawassa city from 2002 to 2021.

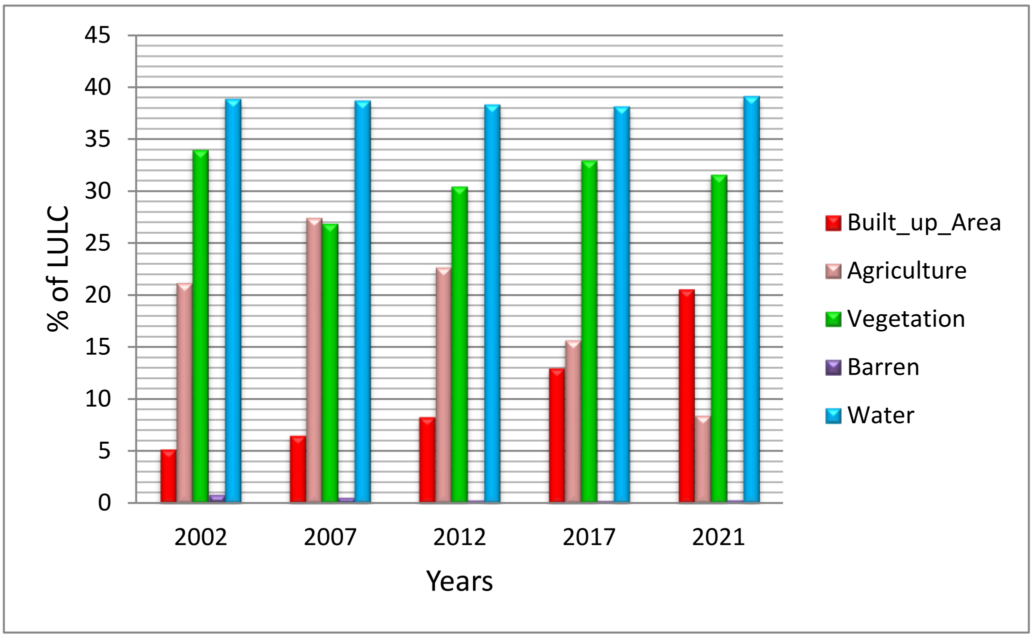

Figure 4.1 Percent area of LULC from 2002 to 2021

The output of this analysis clearly shows from figures 4.1 and 4.2 that; from the LULC map of 2002 and 2007 agricultural and vegetation lands were dominated in most study area, and there was little change in urban areas. The LULC map in 2012 indicated that urban areas started to expand around the city. In the LULC map of 2017 urban areas dominated the city and a large area of the agricultural part was converted into urban areas. In the LULC map of 2021 urban areas continuously increased, becoming the dominant LULC type and continuously extending around the city. The city experienced rapid LULC change of urbanization especially starting from 2012 – 2017(that shows 55.9%) and 2017 – 2021 (that shows 58.2%) respectively.

Table 4.1 Change in LULC maps of Hawassa city from 2002 to 2021.

LULC	Area(ha)					Area in %					Percent Change (ΔLULC)			
	Year					Year								
	2002	2007	2012	2017	2021	2002	2007	2012	2017	2021	2002-2007	2007-2012	2012-2017	2017-2021
Built_up_Area	1260.7	1584.8	2016.8	3144.3	4973.7	5.2	6.5	8.3	13.0	20.5	25.7	27.3	55.9	58.2
Agriculture	5129.1	6633.6	5490.9	3805.4	2055.3	21.2	27.4	22.7	15.7	8.5	29.3	-17.2	-30.7	-46.0
Vegetation	8212.9	6505.2	7361.3	7972.1	7643.0	33.9	26.9	30.4	32.9	31.6	-20.8	13.2	8.3	-4.1
Barren	187.7	116.2	57.4	52.9	64.1	0.8	0.5	0.2	0.2	0.3	-38.1	-50.6	-7.8	21.2
Water	9411.4	9371.2	9282.3	9235.7	9474.5	38.9	38.7	38.3	38.1	39.1	-0.5	-0.9	-0.5	2.6
Total	24201.7	24211.1	24208.8	24210.4	24210.6	100	100	100	100	100				

The (-) sign describes the decreasing of the spatial area of the LULC types

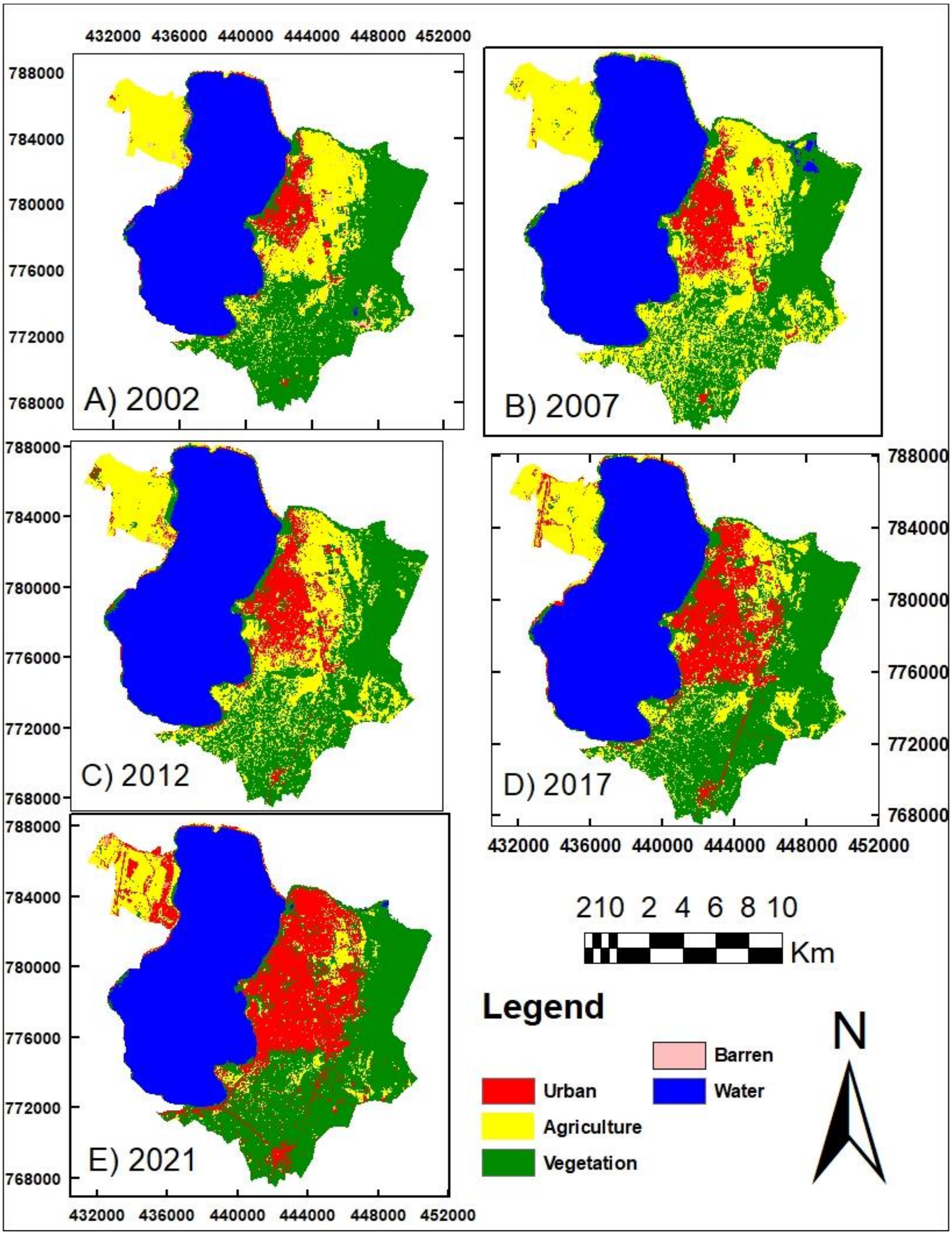

Figure 4.2 LULC Map of the study area in 2002, 2007, 2012, 2017 and 2021

4.2 Accuracy Assessment

For classified LULC map of the watershed area the overall accuracy (OA) was (87.5%, 87.5%, 90 %, 92.5 %, and 95.12 %) and the Kappa value was (83.25 %, 83.5 %, 86.6 %, 90 %and 93.4 %) for the years 2002, 2007, 2012, 2017 and 2021 respectively. As shown in table 4.2; the accuracy requirements for change detection analysis were determined based on the suggestion of Rwanga and Ndambuki, (2017) and the value of Kappa statistics is greater than 0.8, which indicates strong agreement between the class label on the map and the reference data.

Table 4.2 Summary of accuracy assessment

Year	Accuracy	Built-up area	Agriculture	Vegetation	Barren	Water
2002	PA	85.71%	80 %	90%	100%	100%
	UA	100%	85.7%	90%	75%	83.3%
	OA	87.5 %				
	Kappa	83.25 %				
2007	PA	100%	77 %	77%	75%	100%
	UA	75%	90.9%	83.3%	75%	100%
	OA	87.5 %				
	Kappa	83.5 %				
2012	PA	100%	92.3%	100%	25%	100%
	UA	75%	85.7%	100%	100%	100%
	OA	90 %				
	Kappa	86.63 %				
2017	PA	100%	83.3%	100%	50%	100%
	UA	92.3%	71.4%	100%	100%	100%
	OA	92.5 %				
	Kappa	90 %				
2021	PA	100%	100%	100%	66.66%	80%
	UA	92.8%	87.5%	92.8%	100%	100%
	OA	95.1 %				
	Kappa	93.38				

4.3 Slope Map of the Study Area

The slope of the watershed was determined using DEM of 30m resolution. The average CN values of AMC-II were slope corrected by the equation (10) and converted to equivalent antecedent moisture condition (AMC-III), for the wet condition of the study area by using equation (9). To determine the Slope Corrected Curve Number value for AMC-III the land class is categorized using slope intervals of 0%, 0-2%, 2-6%, 6-15%, 15-30%, and > 30% for analysis of urban surface runoff in the study area. The slope map derived using ARCGIS showed that out of 24,197.02 ha total areas of the watershed, 39.1% area has a slope of 0% that is covered by lake Hawassa; 30.01% of the area is covered by a 0-2% slope, 18.20% of the area is covered by 2-6% slope; 4.16% of the area is covered by 6-15% slope; 45.58% of the area is covered by15-30% slope and 2.05% of the area is covered by > 30% slope. Figure 4.3 shows the classified slope map of the study area.

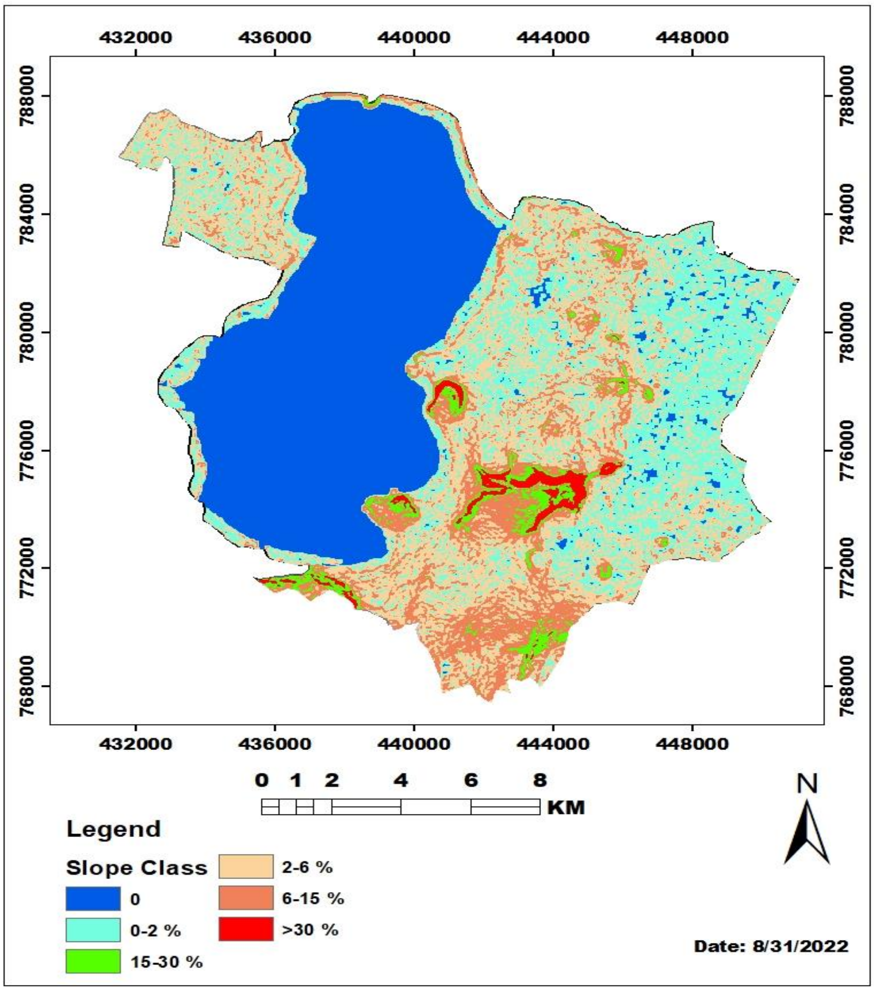

Figure 4.3 map of Study area based on percentage slope

4.4 Change in Impervious Area

With the urban expansion, urban land use land cover was changed and large amounts of agricultural land and non-construction land were converted to urban land. This increased the area of impervious surfaces, which resulted increasing in surface runoff. The percent of LULC imperviousness was computed based on output maps of the analysis shown in (figure 4.2: a-e). Initially in the base year (2002) built-up area was 1260.7 hectares (5.2% of the total area) and after twenty years it reached 4973.7 hectares (20.6% of the total area).

Table 4.3 showed an increase of percentage impervious areas over time was 25.71% from 2002-2007, 27.26% from 2007-2012, 55.91% from 2012-2017, and 58.18% from 2017-2021 respectively. The percentage of impervious area to a base year for LULC of the city as shown in table 4.4 was 25.7%, 60%, 149.4%, and 294.5% for the years 2007, 2012, 2017, and 2021 respectively. It shows Spatiotemporal change of urbanization was increased continuously within the study period.

Table-4.3 Areal extents and percentage change over 5-year intervals of Built-up area class in Hawassa city from 2002 to2021

LULC	Area(ha)					% Change (ΔLULC) of impervious area			
	Year								
	2002	2007	2012	2017	2021	2002-2007	2007-2012	2012-2017	2017-2021
Built Up_Area	1260.7	1584.8	2016.8	3144.3	4973.7	25.7	27.3	55.9	58.2

Table 4.4 Percent of imperviousness of LULCC to the baseline year (2002)

LULC	Area(ha)					% Change (ΔPIA_i) of impervious area to the base year			
	Year								
	2002	2007	2012	2017	2021	2007-2002	2012-2002	2017-2002	2021-2002
Built-up Area	1260.7	1584.8	2016.8	3144.3	4973.7	25.7	60.0	149.4	294.5

4.5 Variations in Surface Runoff Due to Watershed Slope Variation

The maximum daily precipitation of 71.5mm recorded on Sep 20, 2007, was selected for runoff computation for analyzing the impacts of urbanization on runoff response in the city administration area using the SCS-CN method. In calculating the quantity of runoff from the watershed of the basin, the curve number is used to determine the amount of excess precipitation that results from a storm event over the basin. Estimation of the curve number requires mapping of HSG (Figure 3.3) and LULC (Figure 4.2) information within the basin boundaries. LULC classes, namely built-up, agriculture, vegetation, and barren water bodies were taken into consideration to determine the curve number values.

The weighted curve number determined for average antecedent moisture condition before slope correction was computed by equation-9 using the thematic maps of soil groups and LULC types and converted to wet moisture condition is summarized in Table 4.5. Slope corrected weighted curve number values for average antecedent moisture conditions were calculated using the thematic maps of soil groups, LULC types, slope of the terrain, DEM data, and the output CN-III value (table 4.6).

The calculated weighted CN-III values before slope correction are 86.61, 87.205, 87.271, 87.914, and 89.272 for the year 2002, 2007, 2012, 2017, and 2021 respectively (Table 4.5); slope corrected weighted CN-III values are 86.9153, 87.511, 87.576, 88.22 and 89.5789 for year 2002, 2007, 2012, 2017 and 2021 respectively (Table 4.6).

Table 4.5 weighted curve number for average antecedent moisture condition

Year	2002	2007	2012	2017	2021
CN-III	86.6	87.2	87.3	87.9	89.3

Table 4.6 Summary of the result of slope corrected weighted curve number for average antecedent moisture condition

Year	2002	2007	2012	2017	2021
CN-III	86.9	87.5	87.6	88.2	89.6

The runoff depth (in mm and m^3) of each watershed at a different time is computed before slope consideration (table 4.7) and after taking into account the impact of slope (table 4.8). The total runoff depth (mm) of the city's watershed without slope consideration was 157.5mm, 161.9mm, 162.5mm, 167.5mm, and 178.4mm for the years 2002, 2007, 2012, 2017, and 2021 respectively (table 4.7). Slope corrected runoff depth was 199.70mm, 205.4mm, 206.03mm, 212.4mm, and 226.2mm for the years 2002, 2007, 2012, 2017, and 2021 respectively (table 4.8). *Detailed calculation of runoff is attached in Annex-2.*

In terms of volume, the calculated runoff depth before slope correction was 5821684.29m^3, 6005688.2m^3, 6059778.01m^3, 6265279.2m^3 and 6566837.3m^3 for the year 2002, 2007, 2012, 2017 and 2021 respectively; and the result of slope corrected surface runoff volume was 5887573.4m^3, 6072895.5m^3, 6127035.7m^3, 6333992.1m^3 and 6639123.2m^3 for the year of 2002, 2007, 2012, 2017 and 2021 respectively.

From table 4.7 and table 4.8; because of consideration of terrain slope; the runoff was increased by 42.3mm, 43.5mm, 43.6mm, 44.9mm, and 47.7mm for 2002, 2007, 2012, 2017, and 2021 years respectively. This shows Slope of the terrain influences the runoff depth potential of the watershed. The increase in the slope of the watershed resulted in an increase of a more runoff depth. This shows in addition to LULCC the slope of the watershed has its own influence on the change in runoff depth of the analysis.

Table 4.7 Daily accumulated runoff depth of the city's watersheds before slope correction

LULC	2002		2007		2012		2017		2021		Change of Q (2002-2021)
	Q(mm)	Q(m^3)	Q(mm)	Q(m^3)	Q(mm)	Q(m^3)	Q(mm)	Q(m^3)	Q(mm)	Q(m^3)	
Built_up_Area	39.4	496220.9	40.5	641688.5	40.6	819098.5	41.8	1316300.0	44.6	2217712.1	Q(mm)
Agriculture	39.4	2018899.6	40.5	2685918.2	40.6	2227712.7	41.8	1591600.2	44.6	914818.1	20.9
Vegetation	39.4	3232702.3	40.5	2631046.2	40.6	2989664.6	41.8	3335243.6	44.6	3405723.3	
Barren	39.4	73861.6	40.5	47035.3	40.6	23302.2	41.8	22135.3	44.6	28583.8	
Total	157.4	5821684.3	161.9	6005688.2	162.4	6059778.0	167.4	6265279.2	178.3	6566837.3	

Table 4.8 Daily accumulated runoff depth of the city's watersheds from 2002 to 2021 after slope correction

LULC Based on Slope	Slope (α=m/m)	2002		2007		2012		2017		2021	
		Q(mm)	Q(m^3)	Q(mm)	Q(m^3)	Q(mm)	Q(m^3)	Q(mm)	Q(m^3)	Q(mm)	Q(m^3)
0 - 2	0.02	39.2	1742338.5	40.4	1809431.6	40.5	1850591.4	41.7	1926595.9	44.5	1945969.8
2 - 6	0.06	39.4	1060483.4	40.5	1090865.7	40.6	1094201.5	41.9	1127853.7	44.6	1201289.3
6 - 15	0.15	39.7	244253.7	40.9	251235.3	40.9	252001.8	42.2	259734.6	44.9	276609.2
15 - 30	0.3	40.3	2716048.5	41.4	2793387.4	41.5	2801878.5	42.8	2887539.6	45.6	3074464.3
> 30	0.5	41.0	124449.3	42.2	127975.4	42.3	128362.6	43.6	132268.1	46.4	140790.5
Total		199.7	5887573.4	205.4	6072895.5	206.0	6127035.7	212.3	6333992.0	226.1	6639123.2

4.6 Temporal Variations of Runoff Depth

The spatiotemporal surface runoff depth for 2002, 2007, 2012, 2017, and 2021 was first estimated using the SCS-CN method and impacts of LULC change on surface runoff was then assessed for consecutive years. Using runoff for 2002 as a reference, a runoff change ratio for the years 2007, 2012, 2017, and 2021 can be calculated using the runoff analyzed for that year divided by the runoff of a base year. This runoff change ratio can be used to assess the spatial distribution of runoff variations due to the LULC change.

The result of the analysis indicates that the runoff depth of the study area watershed continuously increased during all of the selected years for the analysis (figure 4.4). Slope corrected runoff depth was 199.7mm, 205.4mm, 206mm, 212.3mm, and 226.1mm for 2002,2007, 2012, 2017, and 2021 years respectively. As table 4.9 indicates the percentage of change in runoff depth to the base year (2002) was increased by 2.9%, 3.2%, 6.3%, and 13.2% for 2007, 2012, 2017 and the final year of 2021.

Table 4.9 Percentage change over time of runoff depth in Hawassa city from 2002 to2021

LULC	Runoff Depth(mm)					% Change runoff depth				% Change runoff depth to the base year(2002)			
	Year												
Runoff depth	2002	2007	2012	2017	2021	2002 - 2007	2007 - 2012	2012 - 2017	2017 - 2021	2007 - 2002	2012 - 2002	2017 - 2002	2021 - 2002
	199.7	205.4	206.0	212.3	226.1	2.8	0.31	3.06	6.5	2.9	3.2	6.3	13.2

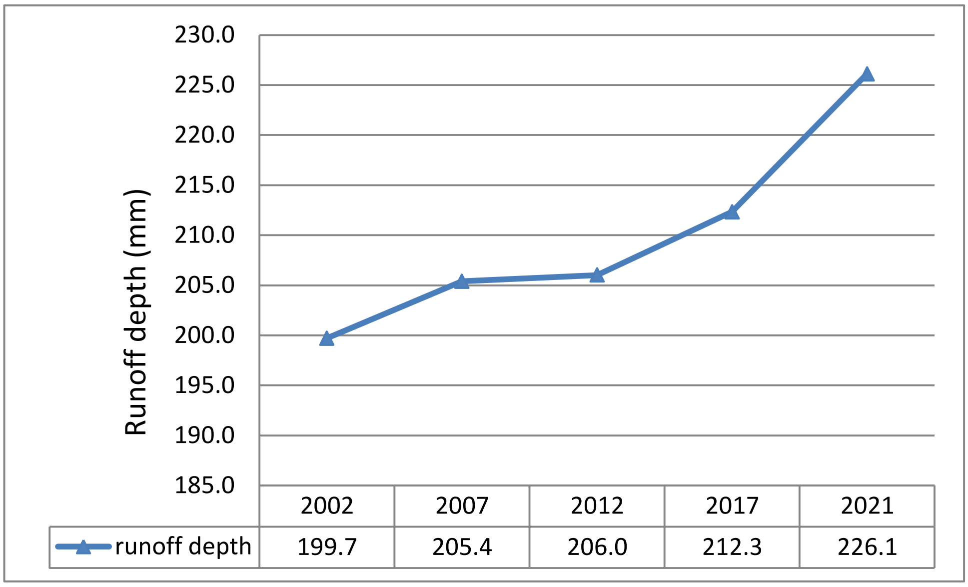

Figure 4.4 Slope corrected runoff increase depth

4.7 Analyzing the impact of LULC Change on Surface Runoff Change

Urbanization leads to increased impervious surfaces, resulting in surface runoff increases. Table 4.10 shows the relationship between surface runoff depth increment (ΔQ) and ΔPIA from 2002 to 2021 both variables computed using equations 6 and 14. As shown in the table 4.9 the change in surface runoff has increased as the change in percent of the impervious area has increased with respect to the baseline year. In 2007 when a change in PIA is 25.7% the change in runoff became 2.8%, in 2012 when the change in PIA is 59.9% the change in runoff became 3.2%, and in 2017 when the change in PIA is 149.4% the change in runoff became 6.3% and in 2021 when the change in PIA is 294.5% the change in runoff became 13.2%. This result is greater than the result of the study conducted by Bulti and Abebe, (2020) reported on the impacts of LULC change in Adama city over the period of 25 years. This disparity could be because of local conditions, which can be associated with socioeconomic, level of urbanization, level of spatial planning, and environmental variability, and also the impact of slope of the terrain was considered in this analysis.

Regression analysis was used to show the extent to which the temporal variations in runoff depth can be affected by the changes in PIA. Percent changes for both ΔQ and ΔPIA in respective years are calculated with respect to the base year (2002). The scatter plots overlaid with the best-fit line depicted in Fig.4.5 illustrate the relationship between the percentage changes of runoff depth and that of PIA from the year 2002 to 2021.

These results show that the percent in surface runoff depth change was positively correlated to the change in percent of impervious land. Pearson correlation analysis was used to examine the relationships between two variables.

Figure 4.5 showed the relationship between runoff increase and the percentage of urban areas increase. Positive and Strong relationships were observed between the variables in the whole watershed. To quantify the strength of the relationship between surface runoff depth change and Percentage change in imperviousness area; the calculated correlation coefficient was (R^2=0.972). The value of r always lies between –1 and +1(Bewick et al.; 2003). Hence the value of the correlation coefficient from table 4.11 was close to +1 indicates a strong positive linear relationship (i.e. variable ΔQ increases with the increase of ΔPIA; Figure 4.5).The results indicated that the runoff increase was highly correlated with urban expansion.

From the output conducted using SPSS; p-value (Sig.) was 0.009 (table 4.11) which was lower than significance level (p-value) of 0.05 (Bewick et al.; 2003) was the evidence to reject a null hypothesis. Therefore the null hypothesis was rejected because there was statistically significant increase of change in runoff which was significantly influenced by spatiotemporal change in percent of impervious area.

Table 4.10 Percentage change in imperviousness area (ΔPIA) and runoff depth in Hawassa city from 2002 to2021 with respect to the baseline year (2002)

Study Areas	2007	2012	2017	2021
ΔPIA	25.7	59.9	149.4	294.5
% ΔQ	2.8	3.2	6.3	13.2

Table 4.11 Regression analysis summary

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.99	0.98	0.97	0.81	0.98	104.0	1	2	0.009
a. Predictors: (Constant), ΔPIA									
b. Dependent Variable: ΔQ									

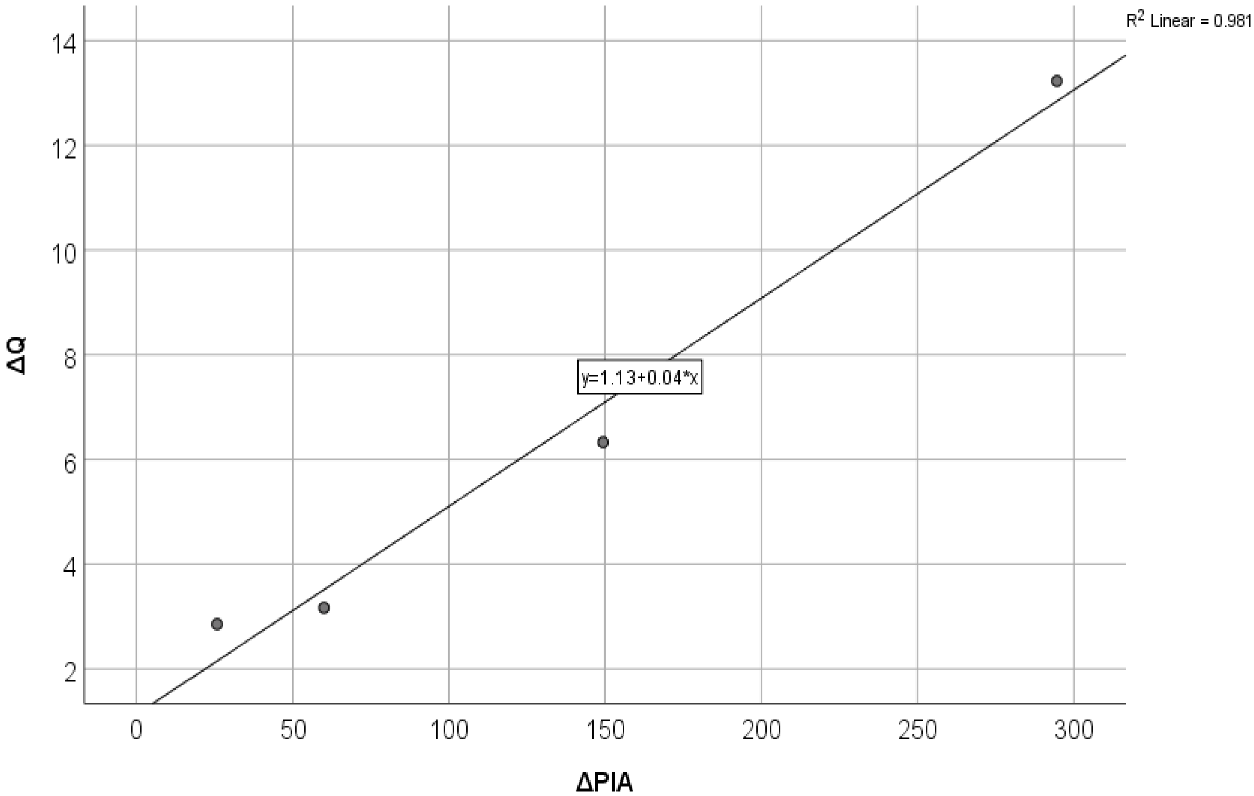

Figure 4.5 Relationship between runoff increase and the percentage of urban areas increase

CHAPTER-V: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This paper presented a case study to investigate the spatiotemporal impacts of LULC change on surface runoff in Hawassa city. An integrated approach of GIS and remote sensing are excellent tools for the processing of DEM, land use and land cover map, HSG classification, slope classification and displaying model results. These techniques were applied to enable and asses the land cover dynamic effects on the hydrology of the watershed.

From Landsat TM/ETM+ imagery acquired the land use and land cover classes of the year 2002, 2007, 2012, 2017 and 2021 were produced using a supervised classification with the Support Vector Machine (SVM) algorithm in ENVI-5.3 and the accuracy assessments of the maps were checked using the Confusion Matrix. The LULC types were classified into five categories: urban area, agricultural land, vegetation, water body and barren land.

The impact of the land use land cover change on surface runoff was analyzed using SCS-CN method. To do this analysis, first land use and land cover change during the past 20 years (2002-2021) was analyzed; then SCS-CN method was used in order to examining the hydrological response of the watershed to changes in land use and land cover change and evaluation of the relationship between LULCC and spatio-temporal change of the surface runoff in the study area was analyzed.

The study results indicated that from the LULC map of 2002 and 2007 agricultural and vegetation lands were dominated in most study area, and there was little change in urban areas. The LULC map in 2012 indicated that urban areas started to expand around the city. In the LULC map of 2017 urban areas dominated the city and a large area of the agricultural part was converted into urban areas. In the LULC map of 2021 urban areas continuously increased, becoming the dominant LULC type and continuously extending around the city. The city experienced rapid LULC change of urbanization especially starting from 2012 – 2017(that shows 55.9%) and 2017 – 2021 (that shows 58.2%) respectively. This urbanization has clearly shown a strong effect on the hydrological regime of the study area and has contributed to a considerable increase in surface runoff. According to the analysis, urban areas increased from 5.2% in 2002 to 20.5% in 2021 while agricultural land areas decreased from 21.2% in 2002 to 8.5% in 2021.

In addition to LULC change, the effect of the slope was considered with slope intervals of 0%, 0-2%, 2-6%, 6-15%, 15-30%, and > 30% for analysis of urban surface runoff in the study area. Regression analysis was used to show the extent to which the temporal variations in runoff depth can be affected by the changes in PIA. Percent changes for both ΔQ and ΔPIA in respective years are calculated with respect to the base year (2002).

The research output information is vital for comparing the past and present conditions and predicts the future trends of the effect of LULC change on surface runoff depth as the urban flood is very challenging and no effective flood remediation measures can be undertaken without an insightful understanding about the spatio-temporal behavior of runoff. Understanding how land use land cover changes (LULCC) influence on watershed hydrology will enable local governments and policymakers to formulate and implement effective and appropriate response strategies to minimize the undesirable effects of future land use land cover change or modification and sustain the local socio-economic situation.

5.2 Recommendations

Based on the present study, some recommendations can be provided;

- According to natural hydrological phenomena, due to increased impervious area precipitation responds quickly reducing the time to peak and producing higher peak flows in the drainage channels. Therefore, the design and construction (road as well as drainage) need to be revised as urbanization is highly growing in the city.
- Elevation, rainfall, soil and land cover data should be of high resolution as much as possible since these are the four most important parameters of the GIS-framework flood model. Therefore, before utilizing the GIS-framework for another study site or another rainfall event it should be made sure that these data are of high resolution and error free as much as possible.
- This research can provide a simple method for urban planners, urban engineers and scholars to assess potential hydrological impacts of land use land cover change on future planning and development activities in the study of the catchment area.

Reference

Abebe, A. (2017). Land use and land cover change detection analysis using remote sensing techniques : The case of Hawassa Town, Southern Ethiopia. *AAU*. http://etd.aau.edu.et/handle/123456789/4937

Abedin, S., & Stephen, H. (2019). GIS Framework for spatiotemporal mapping of urban flooding. *Geosciences*, *9*(2), 77. MDPI AG. http://dx.doi.org/10.3390/geosciences9020077

Adane, Y. (2019). Performance evaluation of storm water drainage system: The case of Hawassa City. *AAU*. http://etd.aau.edu.et/bitstream/handle/123456789/20886

Alberta Water Portal Society (2014). Social impacts of flooding. *Alberta water portal society*. https://albertawater.com/what-are-the-consequences-of-flooding/social/

Allan et al.; (2022). Driving Forces behind Land Use and Land Cover Change: A Systematic and Bibliometric Review. *Land*, *11*(8), 1222. MDPI AG. http://dx.doi.org/10.3390/land11081222

Al-Ghobari et al.; (2020). Estimation of Surface Water Runoff for a Semi-Arid Area Using RS and GIS-Based SCS-CN Method. *Water*, *12*(7), 1924. MDPI AG. http://dx.doi.org/10.3390/w12071924

Ajmal et al.; (2020). A Pragmatic Slope-Adjusted Curve Number Model to Reduce Uncertainty in Predicting Flood Runoff from Steep Watersheds. *Water 12*(5), 1469. MDPI AG. http://dx.doi.org/10.3390/w12051469

Akan, A.O & Houghtalen, R. J. (2003). Urban hydrology, hydraulics, and stormwater quality: Engineering Applications and Computer Modeling. *John Wiley & Sons, Inc*. New Jersey. https://www.wiley.com/enus/Urban+Hydrology%2C+Hydraulics%2C+and+Stormwater+Quality%3A+Engineering+Applications+and+Computer+Modeling-p-9780471431589

American Oceans Campaign (2022). Stormwater Runoff: Effects and Impact on the Environment. *American oceans campaign*. https://www.americanoceans.org/blog/how-stormwater-runoff-affects-environment/

Anderson et al.; (1983). A Land Use and Land Cover Classification System for Use with Remote Sensor Data. *United States Government Printing Office*.

Bansal et al.; (2015). Causes and impact of urban flooding in Dehradun. *International Journal of Current Research. 7*(02). https://www.researchgate.net/publication/332330521

Bewick et al.; (2003). Statistics review 7: Correlation and regression. *BioMed Central Ltd*. http://ccforum.com/content/7/6/451

Beyene, M.N. (2016). Urbanization and Its Effect on Surface Runoff (A Case Study on Great Akaki River, Addis Ababa, Ethiopia). http://etd.aau.edu.et/bitstream/handle/123456789/9852/Misganaw%20Nega.pdf?sequence=1&isAllowed=y

Birhanu, E. (2018). Performance assessment of storm water drainage systems ;(Case study of Debere Berehan Town). *AAU-ETD*. http://etd.aau.edu.et/handle/123456789/15840.

Blick et al. (2004). New Jersey storm water best management practices manual. *New Jersey department of environmental protection*. https://rucore.libraries.rutgers.edu/rutgers-lib/44586/PDF/1/play/

Branger et al.; (2013). Assessment of the influence of land use data on the water balance components of a peri-urban catchment using a distributed modelling approach. *Journal of Hydrology*. *505*. https://doi: 10.1016/j.jhydrol.2013.09.055

Bulti, D.T. & Abebe, B.G.(2020). Analyzing the impacts of urbanization on runoff characteristics in Adama city, Ethiopia. *SN Appl. Sci. 2*, 1151. https://doi.org/10.1007/s42452-020-2961-3

Christopher, P. K. (2003). Effects of Urban Development on Flood. *USGS Science for a changing world*. https://pubs.usgs.gov/fs/fs07603/pdf/fs07603.pdf

Chu, D. (2020). Remote Sensing of Land Use and Land Cover in Mountain Region: A comprehensive study at the central Tibetan Plateau. *Springer Nature Singapore Pte Ltd*. Singapore; pp-41

ERA, (2013). Drainage design manual. *Ethiopian Roads Authority*.

ERA, (2002). Drainage design manual; Hydraulic design of open channels. *Ethiopian Roads Authority*.

ERA, (2001). Drainage Design Manual; storm drainage facilities. *Ethiopian Roads Authority*.

Gessesse B. & Bewket W. (2014). Drivers and implications of land use and land cover change in the central highlands of Ethiopia: Evidence from Remote Sensing and

Socio-demographic Data Integration. *Ethiopian Journal of the Social Sciences and Humanities. 10*(2). https://www.ajol.info/index.php/ejossah/article/view/119354

Giri, C. P. (2012). Remote Sensing of Land Use and Land Cover: Principles and Applications. Taylor & Francis Group.

Guo, J. C.Y. (2017). Urban flood mitigation and stormwater management. Taylor & Francis Group.

Gribbin, J. E. (2014). Introduction to Hydraulics and Hydrology with Applications for Stormwater Management; 4th edition; Delmar, Cengage Learning.

Horning, N. (2004). Land cover classification methods,. *American Museum of Natural History, Center for Biodiversity and Conservation*. http://biodiversityinformatics.amnh.org

Jennings, L. (2012). A storm water runoff investigation using GIS and Remote Sensing. *UNT Digital Library*. https://digital.library.unt.edu/ark:/67531/metadc149613/

Jha, et al.; (2011). Five feet high and rising cities and flooding in the 21st century. Policy research working paper. East Asia and Pacific region. *Policy Research Working Paper*. https://doi.org/10.1596/1813-9450-5648

Li et al. (2018). Assessing the Impact of Urbanization on Direct Runoff Using Improved Composite CN Method in a Large Urban Area. *International Journal of Environmental Research and Public Health. 15*(4) doi: 10.3390/ijerph15040775

Liu et al.; (2015). Role of rainfall and catchment characteristics on urban stormwater quality. *Springer*.

Nie, L. (2003). Flooding analysis of urban drainage systems. *Norwegian University of Science and Technology*. http://hdl.handle.net/11250/231206

Odhiambo, L.P. (2015). Using GIS in urban storm water management: A case study of South C Estate, Nairobi. *University of Nairobi*. http://erepository.uonbi.ac.ke/bitstream/handle/11295/90716/Odhiambo_Using%20GIS%20in%20urban%20storm%20water%20management.pdf?sequence=1&isAllowed=y

Ongsomwang S. & Pimjai M. (2014). Land use and land cover prediction and its impact on surface runoff. *Suranaree University of Technology, Thailand*. *22*(2). https://www.thaiscience.info/journals/Article/SJST/10973252.pdf

Parkinson, J. (2003). Drainage and stormwater management strategies for low-income urban Communities. *Environment & Urbanization.15*(2). https://doi.org/10.1177/095624780301500203

Raghunath, H.M. (2008). Hydrolohy: priniciples, analysis and design. *New Age International*.

Rodriguez et al.; (2006). Urban flooding: Urban pluvial flooding and climate change: London (UK), Rafina (Greece) and Coimbra (Portugal). *Imperial College London.* https://www.imperial.ac.uk/grantham/research/resources-and-pollution/water-security-and-flood-risk/urban-flooding/

Ross et al.; (2018). Global hydrologic soil groups (HYSOGs250m) for curve number-based runoff modeling. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1566

Rwanga, S. & Ndambuki, J. (2017). Accuracy assessment of Land Use/Land Cover Classification using Remote Sensing and GIS. *International Journal of Geosciences. 8*(4). https://doi: 10.4236/ijg.2017.84033

Seybert, T. A. (2006). Stormwater Management for Land Development: Methods and Calculations for Quantity Control. *John Wiley & Sons, Inc., Hoboken, New Jersey*.

Stehman, S. (2020). Ground Verification and Accuracy Assessment. *The Geographic Information Science & Technology Body of Knowledge*. http://doi: 10.22224/gistbok/2020.1.14(link is external)

Tafete, E. (2013). Evaluation of Drainage system in Kebena stream catchment, Addis Ababa. *AAU*. http://etd.aau.edu.et/handle/123456789/10223

Tilahun B. (2018). Analysis of the causes and consequences of flash flood and design for flood resilient neighborhood in Kebelle 02 of Bishoftu Town. *Ethiopian Institute of Architecture*. http://etd.aau.edu.et/handle/123456789/17638

United Nations, (2008). United Nations expert group meeting on population distribution, urbanization, internal migration and development. *United Nations population division*. http://sustainabledevelopment.un.org/content/documents/2529P01_UNPopDiv.pdf.

U.S. Department of Agriculture. (1986). Urban hydrology for small watersheds: TR-55. Natural Resources Conservation Service, Conservation Engineering Division. ftp://ftp.wcc.nrcs. usda.gov/downloads/hydrology_hydraulics/tr55/ tr55.pdf.

Chali, W., & Zewdie, M. (2020). Performance Assessment of Urban Drainage Systems of Holeta Town Using Stormwater Management Model (Swmm). *International Journal of Scientific & Engineering. 11*(4). https://www.citefactor.org/journal/pdf.

Wang, Y. (2020). Landscape and Land Capacity. Taylor & Francis Group.

Weng, Q.(2010). Remote Sensing and GIS Integration; Theories, Methods, and Applications. *McGraw-Hill Companies, Inc*., New York.

Werkneh, H.A. (2017). Investigation of Flooding Problems in Urban Drainage System: the case at Zenebe Werk in Addis Abeba, Ethiopia. *AAU*. http://localhost:80/xmlui/handle/123456789/9741

Annex 1

Accuracy assessment table

a) for 2002

LULC Types	Built-up area	Agriculture	Vegetation	Barren	Water	Total (User)
Built-up area	6	0	0	0	0	6
Agriculture	1	12	1	0	0	14
Vegetation	0	1	9	0	0	10
Barren	0	1	0	3	0	4
Water	0	1	0	0	5	6
Total(Producer)	7	15	10	3	5	40

b) for 2007

LULC Types	Built-up area	Agriculture	Vegetation	Barren	Water	Total(User)
Built-up area	6	1	1	0	0	8
Agriculture	0	10	1	0	0	11
Vegetation	0	1	10	1	0	12
Barren	0	1	0	3	0	4
Water	0	0	0	0	5	5
Total(Producer)	6	13	13	4	5	40

c) for 2012

LULC Types	Built-up area	Agriculture	Vegetation	Barren	Water	Total(User)
Built-up area	6	1	0	1	0	8
Agriculture	0	12	0	2	0	14
Vegetation	0	0	12	0	0	12
Barren	0	0	0	1	0	1
Water	0	0	0	0	5	5
Total(Producer)	6	13	12	4	5	40

d) for 2017

LULC Types	Built-up area	Agriculture	Vegetation	Barren	Water	Total(User)
Built-up area	12	1	0	0	0	13
Agriculture	0	5	0	2	0	7
Vegetation	0	0	13	0	0	13
Barren	0	0	0	2	0	2
Water	0	0	0	0	5	5
Total(Producer)	12	6	13	4	5	40

e) for 2021

LULC Types	Built-up area	Agriculture	Vegetation	Barren	Water	Total(User)
Built-up area	13	0	0	1	0	14
Agriculture	0	7	0	0	0	8
Vegetation	0	0	13	0	1	14
Barren	0	0	0	2	0	1
Water	0	0	0	0	4	4
Total(Producer)	13	7	13	3	5	41

Annex 2

Daily accumulated Runoff Depth 2002-2021

LULC (2002)	Area(ha)	%Area	CN-II	CN(weighted)	CN-III	Rainfall(P)	S	0.2*S	0.8*S	Q(mm)	Qm3(Volume)
Built_up_Area	1260.68	8.52	93.00	792.70	86.61	71.50	39.27	7.85	31.41	39.36	496220.90
Agriculture	5129.14	34.68	75.00	2600.92	86.61	71.50	39.27	7.85	31.41	39.36	2018899.57
Vegetation	8212.89	55.53	69.00	3831.48	86.61	71.50	39.27	7.85	31.41	39.36	3232702.25
Barren	187.65	1.27	92.00	116.72	86.61	71.50	39.27	7.85	31.41	39.36	73861.58
Total	14790.36	100.00		7341.82						157.45	5821684.29
Lake Hawassa	9406.66			100.00	100.00	71.50	0.00	0.00	0.00	71.50	6725761.91

LULC (2007)	Area(ha)	%Area	CN-II	CN(weighted)	CN-III	Rainfall(P)	S	0.2*S	0.8*S	Q(mm)	Qm3(Volume)
Built_up_Area	1584.83	10.68	93.00	993.68	87.21	71.50	37.26	7.45	29.81	40.49	641688.51
Agriculture	6633.65	44.72	75.00	3354.22	87.21	71.50	37.26	7.45	29.81	40.49	2685918.24
Vegetation	6498.12	43.81	69.00	3022.84	87.21	71.50	37.26	7.45	29.81	40.49	2631046.18
Barren	116.17	0.78	92.00	72.05	87.21	71.50	37.26	7.45	29.81	40.49	47035.29
Total	14832.77	100.00		7442.78						161.96	6005688.22
Lake Hawassa	9364.25			100.00	100.00	71.50	0.00	0.00	0.00	71.50	6695437.94

LULC (2012)	Area(ha)	%Area	CN-II	CN(weighted)	CN-III	Rainfall(P)	S	0.2*S	0.8*S	Q(mm)	Qm3(Volume)
Built_up_Area	2016.83	13.52	93.00	1257.08	87.27	71.50	37.05	7.41	29.64	40.61	819098.46
Agriculture	5485.20	36.76	75.00	2757.17	87.27	71.50	37.05	7.41	29.64	40.61	2227712.76
Vegetation	7361.32	49.34	69.00	3404.20	87.27	71.50	37.05	7.41	29.64	40.61	2989664.64
Barren	57.38	0.38	92.00	35.38	87.27	71.50	37.05	7.41	29.64	40.61	23302.15
Total	14920.72	100.00		7453.83						162.45	6059778.01
Lake Hawassa	9276.30			100.00	100.00	71.50	0.00	0.00	0.00	71.50	6632551.41
LULC (2017)	**Area(ha)**	**%Area**	**CN-II**	**CN(weighted)**	**CN-III**	**Rainfall(P)**	**S**	**0.2*S**	**0.8*S**	**Q(mm)**	**Qm3(Volume)**
Built_up_Area	3144.34	21.01	93.00	1953.88	87.92	71.50	34.91	6.98	27.93	41.86	1316300.08
Agriculture	3801.97	25.40	75.00	1905.26	87.92	71.50	34.91	6.98	27.93	41.86	1591600.19
Vegetation	7967.13	53.23	69.00	3673.13	87.92	71.50	34.91	6.98	27.93	41.86	3335243.64
Barren	52.88	0.35	92.00	32.50	87.92	71.50	34.91	6.98	27.93	41.86	22135.28
Total	14966.31	100.00		7564.77						167.45	6265279.18
Lake Hawassa	9230.71			100.00	100.00	71.50	0.00	0.00	0.00	71.50	6599955.53
LULC (2021)	**Area(ha)**	**%Area**	**CN-II**	**CN(weighted)**	**CN-III**	**Rainfall(P)**	**S**	**0.2*S**	**0.8*S**	**Q(mm)**	**Qm3(Volume)**
Built_up_Area	4973.68	33.77	93.00	3140.74	89.27	71.50	30.52	6.10	24.41	44.59	2217712.10
Agriculture	2051.67	13.93	75.00	1044.82	89.27	71.50	30.52	6.10	24.41	44.59	914818.11
Vegetation	7638.05	51.86	69.00	3578.51	89.27	71.50	30.52	6.10	24.41	44.59	3405723.30
Barren	64.11	0.44	92.00	40.05	89.27	71.50	30.52	6.10	24.41	44.59	28583.83
Total	14727.51	100.00		7804.11						178.36	6566837.33
Lake Hawassa	9469.51			100.00	100.00	71.50	0.00	0.00	0.00	71.50	6770702.01

Annex 3

Daily accumulated runoff depth of the city's watersheds from 2002 to 2021 after slope correction

LULC (2002)Based on Slope	**Slope (α=m/m)**	**Area(ha)**	**%Area**	**CN-II (weighted)**	**K**	**CNIIα**	**CN-III**	**Rainfall (P)**	**S**	**0.2*S**	**0.8*S**	**Q(mm)**	**Qm^3 (Volume)**
0 - 2	0.02	4438.98	30.01	73.42	1.00	73.32	86.55	71.50	39.47	7.89	31.57	39.25	1742338.46
2 - 6	0.06	2691.67	18.20	73.42	1.00	73.45	86.63	71.50	39.20	7.84	31.36	39.40	1060483.45
6 - 15	0.15	614.76	4.16	73.42	1.00	73.75	86.81	71.50	38.60	7.72	30.88	39.73	244253.71
15 - 30	0.30	6741.64	45.58	73.42	1.01	74.25	87.10	71.50	37.62	7.52	30.09	40.29	2716048.52
> 30	0.50	303.30	2.05	73.42	1.02	74.91	87.49	71.50	36.33	7.27	29.06	41.03	124449.27
Total		14790.36	100									199.70	5887573.40
LULC (2007)Based on Slope	**Slope (α=m/m)**	**Area(ha)**	**%Area**	**CN-II (weighted)**	**K**	**CNIIα**	**CN-III**	**Rainfall(P)**	**S**	**0.2*S**	**0.8*S**	**Q(mm)**	**Qm3 (Volume)**
0 - 2	0.02	4481.39	30.21	74.43	1.00	74.33	87.15	71.50	37.46	7.49	29.97	40.38	1809431.59
2 - 6	0.06	2691.67	18.15	74.43	1.00	74.46	87.23	71.50	37.20	7.44	29.76	40.53	1090865.76
6 - 15	0.15	614.76	4.14	74.43	1.00	74.76	87.40	71.50	36.61	7.32	29.29	40.87	251235.26
15 - 30	0.30	6741.64	45.45	74.43	1.01	75.27	87.70	71.50	35.64	7.13	28.51	41.43	2793387.45
> 30	0.50	303.30	2.04	74.43	1.02	75.94	88.08	71.50	34.36	6.87	27.49	42.19	127975.44
Total		14832.77	100									205.40	6072895.51

LULC (2012)Based on Slope	Slope (α=m/m)	Area(ha)	%Area	CN-II (weighted)	K	CNIIα	CN-III	Rainfall (P)	S	0.2*S	0.8*S	Q(mm)	Qm3 (Volume)
0 - 2	0.02	4569.34	30.62	74.54	1.00	74.44	87.21	71.50	37.25	7.45	29.80	40.50	1850591.35
2 - 6	0.06	2691.67	18.04	74.54	1.00	74.57	87.29	71.50	36.98	7.40	29.59	40.65	1094201.47
6 - 15	0.15	614.76	4.12	74.54	1.00	74.88	87.47	71.50	36.39	7.28	29.11	40.99	252001.77
15 - 30	0.30	6741.64	45.18	74.54	1.01	75.38	87.76	71.50	35.42	7.08	28.34	41.56	2801878.50
> 30	0.50	303.30	2.03	74.54	1.02	76.05	88.15	71.50	34.15	6.83	27.32	42.32	128362.58
Total		14920.72	100									206.03	6127035.67
LULC (2017)Based on Slope	Slope(α=m/m)	Area(ha)	%Area	CN-II (weighted)	K	CNIIα	CN-III	Rainfall (P)	S	0.2*S	0.8*S	Q(mm)	Qm3(Volume)
0 - 2	0.02	4614.93	30.84	75.65	1.00	75.55	87.86	71.50	35.11	7.02	28.09	41.75	1926595.90
2 - 6	0.06	2691.67	17.98	75.65	1.00	75.68	87.94	71.50	34.85	6.97	27.88	41.90	1127853.76
6 - 15	0.15	614.76	4.11	75.65	1.00	75.99	88.11	71.50	34.27	6.85	27.41	42.25	259734.67
15 - 30	0.30	6741.64	45.05	75.65	1.01	76.50	88.41	71.50	33.31	6.66	26.65	42.83	2887539.58
> 30	0.50	303.30	2.03	75.65	1.02	77.19	88.79	71.50	32.06	6.41	25.65	43.61	132268.13
Total		14966.31	100									212.34	6333992.05

LULC (2021)Based on Slope	Slope(α= m/m)	Area(ha)	%Area	CN-II (weighted)	K	CNIIα	CN-III	Rainfall (P)	S	0.2*S	0.8*S	Q(mm)	Qm3(Volume)
0 - 2	0.02	4376.13	29.71	78.04	1.00	77.94	89.21	71.50	30.71	6.14	24.56	44.47	1945969.80
2 - 6	0.06	2691.67	18.28	78.04	1.00	78.08	89.29	71.50	30.45	6.09	24.36	44.63	1201289.36
6 - 15	0.15	614.76	4.17	78.04	1.00	78.39	89.47	71.50	29.89	5.98	23.91	44.99	276609.17
15 - 30	0.30	6741.64	45.78	78.04	1.01	78.92	89.76	71.50	28.96	5.79	23.17	45.60	3074464.33
> 30	0.50	303.30	2.06	78.04	1.02	79.63	90.15	71.50	27.75	5.55	22.20	46.42	140790.50
Total		14727.51	100									226.12	6639123.17