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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

The Impact of Land Use Change on Addis Ababa Drainage System

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A Thesis Submitted to School of Civil & Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering

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Abstract

Urbanization in Ethiopia has increased population densification along with urban infrastructure development. Urban growth is linked with the land use change of the city and plays a major role in changing the Drainage condition. The city is exposed to flash floods. Moreover, extensive land use changes due to housing developments, road and other infrastructure constructions increase the susceptibility to flooding. This study evaluates the effect of land use change on the Drainage System. Starting with Satellite image for 1985, 1995 and 2015 of the study areas, land use analysis was executed using ArcGIS software. Based on the analyzed land use data for different land use scenario, simulation of rainfall-runoff process is done on 50 sample drainage outlet points using the SWAT Model. The result of the model which covers the full extent of Addis Ababa Region, showed considerable increase of discharge and structures designed using older land use data were insufficient for the new land use/land cover condition. The rate of increase has been presented in different charts which can be use by Designers and governmental or non-governmental organizations to consider in future design works. In addition, the result can be a guide for future planning and land use policies and related research on the city drainage system.

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Abbreviations

AACRA	Addis Ababa City Roads Authority
ASF DAAC	Alaska Satellite Facility Distributed Active Archive Data Center
CN	Curve Number
CSA	Central Statistics Agency
DEM	Digital Elevation Model
ERA	Ethiopian Road Authority
FAO	Food and agriculture organization
GEV	General Extreme Value
GIS	Geographic information system
HSG	Hydrological Soil Groups
HWSD	Humanized world soil database
HRU	Hydrological
IA	Initial Abstraction
IDF	Intensity-Duration-Frequency
ISODATA	Iterative Self-Organizing Data Analysis
LULC	Land use Land Cover
NMSA	Meteorological Service Agency of Ethiopia
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Efficiency
P	Rainfall
Q	Flood Discharge
Q_{FLU}	Future land use Discharge
Q_{CULU}	Current land use Discharge
R2	Coefficient of Determination
RGB	Red, Green, Blue
RT	Terrain resolutions
S	Potential Maximum Retention
SCS	Soil Conservation system
SWAT	Soil and water assessment tool
TR55	Technical Release 55
TR22	Technical Release 22
USGS	United States Geological Survey

Chapter One

Introduction

1.1 Background

As per Ethiopian Central Statistics Agency estimates (2013), Addis Ababa is home to about 20% of the urban population in Ethiopia estimated about 3.6 million and is one of the fastest growing cities in Africa. The city is expected to expand quickly with its population to exceed 5 million by 2035. This will put a significant strain on the city's ability to deliver on the goal of being a livable and safe city (World Bank, 2015). Urbanization is accompanied by two major changes. The first change is the urban centers tend to concentrate people, enterprises, infrastructures and public institutions. The second change is the large scale urban spatial expansion as cities and towns swell and grow outward in order to accommodate population increases.

Urban growth is linked with the land use change of the city and plays a major role in changing the Drainage condition. The city is exposed to both riverine and flash floods. Moreover, extensive land use changes due to housing developments, road and other infrastructure constructions increase the vulnerability to flooding.

Changes in land use have occurred at all times in the past, present, and are continue in the future. Rapid development and population increase of an area require more land and space. Thus, land cover change is unavoidable. Land cover is a combination of various factors created by natural and human beings, including vegetation, soil, and a variety of buildings.

Informal and unplanned settlements are areas not designated for residential use or often lack basic infrastructure services including storm water drains, proper roads, and decent sanitation services etc. (World Bank, 2002). Due to increased flooding, drainage problem has become one of the major issues that need sustainable solution. Due to flooding Loss of life, destruction of houses and damage to Road Infrastructure has occurred every year. The intensity of the problems increases from time to time.

Land use decisions have significant impacts on water and other natural resources. As the intensity of land use increases, the potential negative impacts to water and natural resources also increase. More intensively developed areas have a greater level of impervious surfaces, such as roads, parking lots, sidewalks, and rooftops. Impervious surfaces prevent natural infiltration of water and increase storm water runoff.

The dynamics of human land use and land cover (LULC) changes have implications for land use impact assessment.

To evaluate the present and envisage the future effects of land use change on the drainage system, it is important to have an understanding of the effects of land use changes have on urban drainage system in the past using recorded data. Moreover, detecting and simulating the effects of the change and management on drainage system requires a new and improved procedure to understand the impact and provide a feasible recommendation.

Therefore, this research intends to evaluate the impacts of the land use on the drainage systems of urban area and it tries to provide factors, approach or methods to accommodate the future land use change effects on the time of design and construction of drainage structures, particularly in urban area, while taking the case of Addis Ababa as sample urban area.

Analysis was done to relate the land use and estimated discharge which will be an input for new drainage system design or to evaluate an existing drainage performance. The results of the analysis are summarized to produce a defined design parameter that can consider for impacts of future land use change. In addition, the study will provide the peak floods at selected locations that can be used to evaluate sufficiency of the sample structures.

1.2 Statement of the Problem

Addis Ababa has troubled with storm water leading into floods especially during the rainy season due to the land use change and inadequate installation of desired infrastructure. The pattern of urbanization and modernization has meant increased densification along with urban infrastructure development. This has led to deforestation, use of corrugated roofs and paved surfaces. The combined effect of this results in lesser rainfall infiltration and consequently accelerated and concentrated runoff. This increase runoff is affected the drainage system in Addis Ababa and flooding has become common problem in many locations. Erosion and damage of asphalt roads, disruption of pedestrian and vehicular transportation, and faller of houses and loss of life of people who live along the river channel has happened due to the increased flooding.

Although, the road network in the city provide with drainage system, the design and the construction of these drainages are not accommodating the flood coming due to the land use changes. As exemplary, one of the common roads in Addis, Churchill Road was constructed before more than 30 years, its drainages were designed for the pick floods computed based on the land use, before 30 years. The land use of the city for the last 30 years changed rapidly from tree covers to concrete and roof covers, which increase the floods pass on the drainage systems, and affect the traffic. The effect of these challenges is observed at the lower sections of the road, particularly around National theater.

The drainage structures design and construction with consideration of the future land use change in the area is to be one of the potential mitigations for such challenges, which was not addressed with our previous drainage issues research and design manuals. Therefore, this thesis investigates the impact of the land use change on Addis Ababa drainage system and tries to provide potential methodology to accommodate future land use change factors on the discharge computation of our drainage structures design methodology.

1.3 Objectives

1.3.1 General objective

The general objective of this thesis is to evaluate dynamic impact of land use change on Addis Ababa drainage system and to have approach/methodology to accommodate the future land use change effects on our drainage structures design and construction procedures.

1.3.2 Specific objectives

- Analyze how land use has changed in Addis Ababa over a period of last 4 Decades.
- Evaluate the amount of runoff quantity for varying land use scenarios
- Evaluate the performance of drainage Structures
- Develop the runoff land use change relationship that accommodate future land use change on the drainage design methodology

1.4 Research Questions

This research will answer the following questions:

1. How do associate land use changes with hydrologic changes?
2. What is the impact of land use change on the drainage system?
3. What is the relationship between the land use and the runoff estimation?

1.5 Significance of the study

The knowledge how land use change influence watershed hydrology will enable local governments and policy makers to formulate and implement effective and appropriate response strategies to minimize the undesirable effects of future land use change or modifications.

This study has been Evaluates how different land use change Will affect the Drainage System of Addis Ababa and use to provide relevant information for government and non – government organizations which helps them for taking appropriate decision making and designing appropriate intervention to minimize the effect of the Dynamics of Land use change impact on Drainage system. It will also significant especially for the road designers to consider the land use change of the future when designing the drainage system.

Chapter two

Literature Review

General

This chapter discusses about theories and concepts of land use change and drainage structures and tries to review literatures that have been done previously on the topics related to this research. The first section starts with the theory of land use change which includes its definition, concept and classification. The second section shows the land use/ land cover (LULC) change conditions and effects around Addis Ababa. The relationship between LULC change and drainage structures is discussed in the third section. The Forth section discusses briefly the problems noticed in Addis Ababa Drainage structures and its effects. In the fifth section reviews of hydrological process and Hydrological modeling factors are presented. Finally, the last section reviews the literatures about Drainage structures design and its application related to hydrological studies.

2.1. Land Use/ Land Cover (LULC) change Definition, Concept and Classification

Land cover changes considered as one of the important global phenomena exerting perhaps one of the most significant effects on the environment than any other factor. It is, therefore, vital that accurate data on land cover changes are made available to facilitate the understanding of the link between land cover changes and environmental changes to allow planners to make effective decisions.

2.1.1.Land Use/Land Cover Definition:

FAO (2000) defines land cover as “the observed bio-physical cover on the Earth’s surface”. As such, land cover reflects the real (de facto) land cover, in other words what grows on the examined plot, what can be “seen”. Land cover is usually examined by means of field mapping or remote sensing.

The term “land use” may be understood as the use of “land cover” by humans plus the social, economic, political or cultural “function” of land cover. As a result, land use is seen either as a human activity as such (physical use of an area) or as an existing situation that reflects human activities in the landscape. FAO (1998) defines that land use “is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it”. In other words, Land use refers to the intended use or management of the land cover type by human beings such as building construction, agriculture and forestry.

LULC Change:

Land use/land cover change is the human modification of Earth's terrestrial surface. Though humans have been modifying land to obtain food and other essentials for thousands of years, the change has accelerated significantly in recent time.

An understanding of processes that cause the shifting mosaic of land cover in regions should be based on fundamental knowledge of the physical environment's influence on vegetative communities as well as human impact on the landscape. The incorporation of physical and human factors is especially important for environmental or ecosystem analysis in urbanizing and urban landscapes. Human impact has become a major determinant for land cover through the various modifying activities associated with land use.

Classification Methods

Classification is an abstract representation of a situation or an object using well-defined criteria. Sokal (1974) defined it as: "the ordering or arrangement of objects into groups or sets on the basis of their relationships". A classification describes the systematic framework with the names of the classes and the criteria used to distinguish them, and the relationship between classes. Classification thus requires the definition of class boundaries, which should be clear, precise, possibly quantitative, and based upon objective criteria.

2.1.2.Geographic information System GIS

In recent years, the significance of spatial data technologies, especially the application of remotely sensed data and geographic information systems (GIS) has greatly increased. An analysis of natural resources and rates of environmental change over time is essential for a proper understanding of why present environmental problems have arisen. Information on the existing land use/land cover patterns regarding the spatial distribution and changes in the land use pattern is a prerequisite for environmental planning. Incorporating these data in models will help in the utilization and formulation of policies and programs for making any developmental decisions.

Some of the application of remote sensing technology in mapping and studying of the land use and land cover changes are; map and classify the land use and land cover, assess the spatial arrangement of land use and land cover, allow analysis of time-series images used to analyze landscape history, report and analyze results of inventories and to provide a basis for model building.

Geographic Positioning System (GPS) provides a reliable source of data for assessing and monitoring spatial and temporal land use and land cover changes. Land use and land cover maps can be a powerful tool to compare the changes of an area over time and with them possible to analyze a large area of land in short period of time (Billah and Rahman, 2004).

2.1.2.1. Image Classification and pre-processing

In order to examine and asses environmental and socioeconomic applications such as: urban change detection and socioeconomic variables, image classification results with better accuracy are mandatory.

Image classification refers to the extraction of differentiated classes or themes, usually land cover and land use categories, from raw remotely sensed digital satellite data. There are two primary types of pixel-based classification algorithms applied to remotely sensed data: unsupervised and supervised.

The unsupervised classification approach uses the Iterative Self-Organizing Data Analysis (ISODATA) algorithm to group pixels in the image according to their reflectance values. Pixels with spectral similarities are grouped into clusters by the algorithm with a high degree of objectivity since the process is done with little analyst input initially. Once the clusters are defined, the analyst must assign information class labels (land cover classes) to each cluster. Unsupervised classification methods represent the best choice when extensive fieldwork is not possible as the algorithm insures all spectrally similar pixels are clustered together Whereas in the case of supervised image classification the analyst has previous knowledge about pixels to generate representative parameters for each land cover class of interest.

Supervised image classification is a method in which the analyst defines small training sites on the image, which are representative of each desired land cover category. The delineation of training areas representative of a cover type is most effective when an image analyst has knowledge of the geography of a region and experience with the spectral properties of the cover classes. The image analyst then trains the software to recognize spectral values or signatures associated with the training sites. After the signatures for each land cover category have been defined, the software then uses those signatures to classify the remaining pixels

The Maximum Likelihood classification, under the category of supervised classification, is the most widely used per-pixel method by taking in to account spectral information of land cover classes

2.1.2.2. Land use/Land cover Change Detection

Change detection in GIS is a method of understanding how a given area has changed between two or more time periods. Change detection is helpful for understanding the change in forest coverage and land use. Change detection involves comparing changes between aerial photographs taken over different time periods that cover the exact same geographic area.

Change detection can be used to measure four different types of change:

- Detecting the changes that have occurred
- Identifying the nature of the change
- ensuring the area extent of the change
- Assessing the spatial pattern of the change

2.2. Land Use change in Addis Ababa

Urbanization refers to a growth in the proportion of a population living in urban areas and the further physical expansion of already existing urban centers (Samson, 2009; Alaci, 2010). Urbanization in the developing world in general is progressing much faster than in developed countries. There are more than 900 urban centers in Ethiopia. Addis Ababa, its capital city, consisted of about 25% of the total urban population in the country estimated about 3.4 million (based on 2007 census). To accommodate the ever-increasing population, industry concentration, and commercial expansion, Addis Ababa city has been expanding horizontally towards its peri-urban areas. Addis Ababa is one of the fastest growing cities in Africa.

One study which was done to qualitatively measure the land use/ land cover change in Addis Ababa was the study by M.mulugeta et al, published under the title “Data on spatiotemporal land use land cover changes in peri-urban Addis Ababa, Ethiopia: Empirical evidences from Koye-Feche and Qilinto peri-urban areas”. The study analyzes LULC changes by taking the Information on the spatiotemporal data in Koye-Feche and Qilinto urban expansion areas around Addis Ababa City between 1986 and 2016. The study identified that the built-up areas have increased by 1,017.85ha (10.178km2) with in the total study area of 3,140 ha which is about 32.4%. This increase in built up area is the result of 89.1%, 58.4%, 47% and 13% decline of plantation (mostly eucalyptus woodlots), grasslands, river in vegetation (forestland) and cropland, respectively, between 1986 and 2016.

In other study by Deribew & Dalacho Environ Syt Res (2019), the recent urban expansions and infrastructure developments along per-urban areas of Addis Ababa have exerted additional pressure on LULC change. There has been a surge in population growth in the satellite towns surrounding Addis Ababa as a result of both rural–urban and urban–urban migrations. Particularly, movement of the urban poor from Addis Ababa in search of employment opportunities due to investment on industries and real estate developments in the urban fringes have brought about significant changes on LULC. In this regard a substantial loss of forest land mainly due to expansion of built-up areas and croplands in the peri-urban areas of Addis Ababa. This phenomenon has also been observed in the vicinity of Nairobi, Kenya, where forests were cleared for urban settlements. This suggested that urban expansion and settlement were driving massive scales of deforestation along major urban centers. Thus, rapid urbanization and expansion of settlements were identified as one of the ‘hotspots’ of deforestation especially in many developing countries.

The study focused on detecting long term dynamics of land use/land cover (LULC) change since the 1950s and current state of forest susceptibility to degradation in North-eastern Addis Ababa, Ethiopia.

From the result of the research (Deribew & Dalacho Environ Syt Res (2019)), over the course of 60 years (1957–2017) the extent and direction of LULC have become more dynamic. Agricultural land and forest land showed a comparably equal extent of net change (+36.7% and −37.8%, respectively) but to opposite directions. Forest lost 25.1% and 18.7% of its cover to barren land and agricultural land, respectively. The net change for forest was negative except for the period 1975–1995, with varying rates of deforestation during the four distinct study periods. However, a heightened level of deforestation occurred after the mid-1990s due to rapid urban growth and a change in government economic policy. A 6.2% net change of urban/settlement served as a catalyst for LULC transformations in the last two decades. The findings also revealed that 97.2% of forests were located at a radius of 1 km distance from urban centers and settlements whereas 92% of them were accessible by road networks of a km radius.

2.3. Urbanization/ Land Use Change/ impact on the drainage System

As humans develop cities, they alter the hydrologic cycle by extracting water for urban uses, and by modifying biophysical structures or substituting built infrastructure in order to transfer and control the water flow. The extraction of water to meet the needs of urban residents and activities affects flow regimes in urbanizing watersheds. Urban surfaces alter the microclimate and the rate of precipitation, reduce infiltration, and encourage runoff. Compared to water in undeveloped areas, water in cities primarily moves over impermeable surfaces, traveling much faster and collecting a variety of human-made organic and inorganic pollutants before it reaches a treatment plant or body of water. A complex network of culverts, gutters, drains, pipes, sewers and channels extracts, redistributes, and moves the water between the natural hydrological process and the artificial hydrological system that supports human settlements and activities.

However, the realization of interactions via inefficient infrastructure has resulted in a revisionist approach, increasingly treating urban hydrology as an integrative area of research, encompassing both natural and engineered water dynamics. Traditionally, assessing the impacts of urban characteristics on hydrological dynamics has occurred at the catchment scale, seeking to assess the wider impacts of substantial development on both quantity and quality dynamics of freshwater systems. However, there is an emerging recognition that small, local developments including individual buildings or neighbor hoods with contrasting materials, topography and infrastructure impact on the rate of transformation and flow pathways of water during its transition from atmosphere to the ground.

The main issues in developing countries is urban development without planned drainage. Developing counties experience accelerated urbanization without adequate investment in infrastructure, and against a background of deficient public services for water treatment, collection and treatment of foul sewage, garbage collection, urban drainage, transport and health.

The main impacts of urbanization on drainage systems can summarized as

- Increase run-off quantity
- Flooding problems due to insufficiency of existing structures

2.4. Major Problems of Addis Ababa Drainage System

Many studies were done on problems that exist in Addis Ababa city drainage system which indicate the extent of the problems in different parts of the city. The result of most of the studies shows a significant problem related to the capacity of drainage structures, integration of road and urban storm drainage and maintenance of available drainage system.

In Addis Ababa or even 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 is highly essential.

Assessment of the integration of road and urban storm water drainage infrastructure with the help of topographic map and also the condition, pavement type and hierarchy of every road and drain in Addis Ketema Sub-city (Dagnachew, 2011) has shown inadequate integration between road and urban storm water drainage infrastructure and poor management of available structures. In some locations, storm water drains are connected to sewerage lines which undermines the functionality of the drainage system. While the other poor practice is dumping of solid waste it to the drains. This has resulted in negative impacts on urban storm water drainage provision including blockage of drains by solid wastes and flooding. To safely discharge the flood generated within the study area, the urban storm water drainage facilities should be revised and designed in addition to implementation of strict drainage system maintenance practices.

On other study done to evaluate the existing storm water drainage system in Addis Ababa by selecting 3 sample Woredas (Woreda 6, 7 and 8) around Kebena Stream catchment, found that they have been facing overflowing and flooding which was mainly caused by the increment of built up area. (Eskedar, 2015). Storm water drainage was studied with the help of check list, base map for the roads, tap meter and different software to analyze the quantitative data. From the study, capacities of most of the existing drainage system can't handle the current runoff that flows over the area. Of all the drains only, 44%, 40%, and 34 % of the drainages are capable of conveying safely the runoff in to the water ways in Woreda 6, Woreda 7 and Woreda 8 respectively.

From the findings of the above studies and observations on the functionality the drainage system in Addis Ababa, it is not difficult to understand the huge drainage problem in the city. The main challenge in this regard remains Addis Ababa's poorly developed drainage system. Only 615 kilometers, or only about 29 percent of the city's road mileage, are equipped with drainage lines, with non-asphalted roads the main victims (Uli, 2008).

In other research, of the city's 395 kilometers of asphalted roads only 193 kilometers had storm drainage lines, and out of 960 kilometers of no asphalted roads only about 143 kilometers had drainage channels. More often than not, unlined channels are to be found in areas where ground profiles are steep, which exposes those areas to erosion through high velocities of flow.

Most of housing units are not connected to drainage lines by proper ditches or canals. Only about 33 percent of the houses studied in 1996 were found to have sufficient connection with the drainage system. The case may be worse in recent years considering illegal construction practices and blockage or damage of existing system.

Various efforts are underway to improve the situation including construction of coble stone roads with proper drainage, ditch and pipe clearing activities and construction of new drainage and sewer lines along different parts of the city. However, the difference made by these actions is lessened by the sheer size of the problem. Moreover, the hydraulic insufficiency of some of the drainage structures intensifies the drainage problem to a considerable scale. Apparently, the drainage system of Addis Ababa is sadly underdeveloped by any standard.

2.5. Hydrological Processes

The water cycle, also known as the hydrological cycle, is the continuous exchange of water between land, waterbodies, and the atmosphere. Approximately 97% of the earth's water is stored in the oceans, and only a fraction of the remaining portion is usable freshwater. 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. Impervious surfaces associated with urbanization alter the natural amount of water that takes each route. The consequences of this change are a decrease in the volume of water that percolates into the ground, and a resulting increase in volume of surface water. The urbanization will also decrease the quality of the surface water as pollutants collected on impervious surface are washed and mixed with the surface water.

Urbanization Affects the Water Cycle. According to California Water and Land Use Partnership Publication, with natural groundcover, 25% of rain infiltrates into the aquifer and only 10% ends up as runoff. As imperviousness increases, less water infiltrates and more and more runs off is created. 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.

Storm drain systems in urban areas have two separate drainage systems. One of the systems is the minor system to handle the frequently recurring storms. The minor system consists of underground piping, natural waterways and required appurtenances to protect against the average storms. The second system is the major system to handle the large infrequent flows. The major system includes street flow and other overflow provisions to pass the infrequent, large flows and protect against excessive property damage and ponding depth.

The urban water cycle is often differentiated from the "natural" hydrological cycle on simple geographical boundaries. The presence of engineered water systems, which include the import and export of water via piped networks and artificial routing of water into subsurface drainage networks have traditionally resulted in a separation of the two cycles

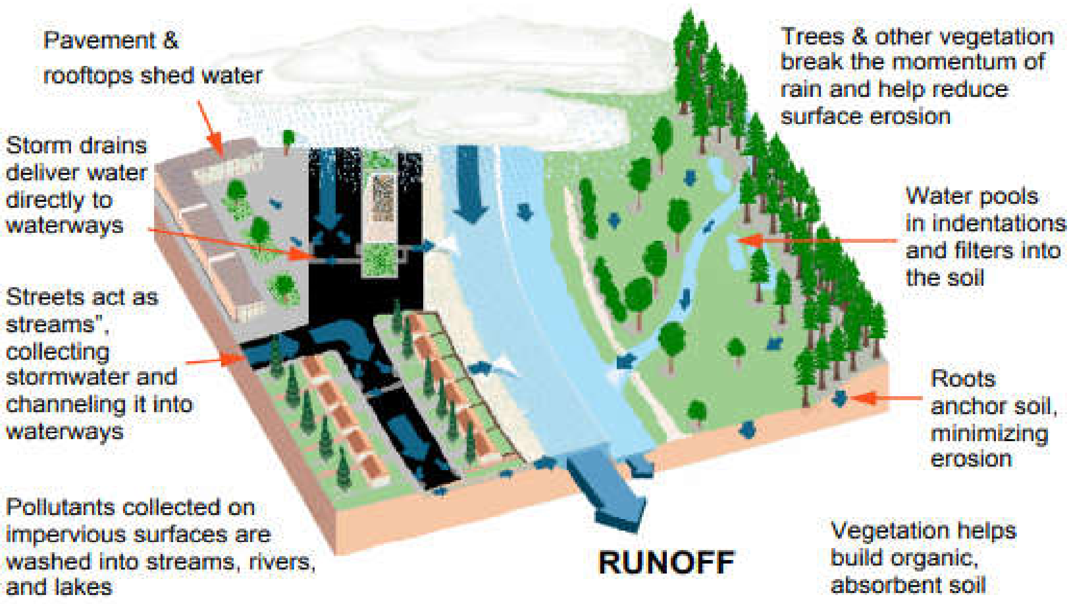


Figure 2.5-1 Impervious cover and urban drainage systems VS Natural Hydrological System

A catchment is a basic unit of landscape particularly for investigations of hydrologic processes. Typically, the topographic boundary of a catchment coincides with the hydrologic boundary causing any precipitation falling on to the catchment to be routed to a stream where it is transported out of the catchment. Fundamental components of the hydrologic cycle, such as precipitation, runoff and evapotranspiration (computed by difference between precipitation and runoff over long periods), have been documented from water balance studies on small catchments. Observations and time series data collected from small catchments provide a basis for the development of hydrologic models, and many such models have been used for flood forecasting.

One of the most accurate measurements made in small catchments is streamflow or discharge. Streamflow is the integrated result of all meteorological and hydrologic processes in the catchment. Considerable effort has been expended over the past several decades to evaluate the information contained in the surface water hydrograph, i.e. the factors producing it, and to try to relate these factors quantitatively to the discharge.

2.6. Hydrologic Modelling and Factors

Flood prediction and modeling refer to the processes of transformation of rainfall into a flood hydrograph and to the translation of that hydrograph throughout a watershed or any other hydrologic system. Flood prediction and modeling generally involve approximate descriptions of the rainfall-runoff transformation processes. These descriptions are based on either empirical, or physically-based, or combined conceptual physically - based descriptions of the physical processes involved.

The following methods and sources can be used in determining peak flood magnitudes for design of road drainage structures in Ethiopia as per the recommendation given in Ethiopian Roads Authority Drainage Manual.

- Rational Method
- NRCS Runoff Curve Number Methods;
- Statistical analysis of stream data; and
- Regional regression equations

2.6.1.Rational Method:

The Rational Method provides estimates of peak runoff rates for small urban and rural watersheds of less than 50 hectares (0.5 square km) and in which natural or man-made storage is small. It is best suited to the design of urban storm drain systems, small side ditches and median ditches, and driveway pipes. It shall be used with caution if the time of concentration exceeds 30 minutes. Rainfall is a necessary input for this method of flow estimation.

2.6.2.NRCS Runoff Curve Number Methods:

The Natural Resources Conservation Service (formerly Soil Conservation Service) developed the runoff curve number method as a means of estimating the amount of rainfall appearing as runoff. Technical Release 20 (TR20) employs the Runoff Curve Number Method and a dimensionless unit hydrograph to provide estimation of peak discharges and runoff hydrographs from complex watersheds. The procedure allows the designer to estimate the effect of urbanization, channel storage, flood control storage, and multiple tributaries. TR 20 can be applied to the design of culverts, bridges, detention ponds, channel modification, and analysis of flood control reservoirs. Technical Release 55 (TR 55) is a simplified form of TR 20 for use in estimating peak discharges for small watersheds (urban and rural) whose time of concentration does not exceed 10 hours. TR 55 includes a hydrograph development procedure; however, where hydrograph determination is necessary, use TR 20 or another hydrograph procedure.

The unit hydrograph used by the SCS method is based upon an analysis of a large number of natural unit hydrographs from a broad cross section of geographic locations and hydrologic regions in USA. However, the SCS Curve Number method is applicable to small catchments (maximum
area 6,500 ha) with a time of concentration for any sub-area of 0.1 – 10 hours.

The SCS method should be used on watersheds that are homogeneous in CN; where parts of the watershed have CNs that differ by 5, the watershed should be subdivided and analyzed using a hydrograph method, such as TR-20(SCS,1984). The SCS method should be used only when the CN is 50 or greater and the Tc is greater than 0.1 hour and less than 10 hours. The computed value of Ia/P should be between 0.1 and 0.5.

The method should be used only when the watershed has one main channel or when there are two main channels that have nearly equal times of concentration; otherwise, a hydrograph method should be used. Other methods should also be used when channel or reservoir routing is required, or where watershed storage is either greater than 5 percent or located on the flow path used to compute the discharge.

2.6.3.Statistical Analysis of Stream Gauge Data:

Where stream gauge data are available, stream gauge data can be used to develop peak discharges. The Ministry of Water Resources keeps annual stream gauge data. The method commonly used for estimating the peak discharges is usually Log-Pearson Type III distribution. However, as the record length is increased, a Log-Normal distribution or General Extreme Value (GEV) distribution could also be used. The recent data analysis demonstrated that GEV can be used to estimate the peak flow in Ethiopia.

It is recommended that the distribution method, which gives a best fit to the record data, should be used.

2.6.4.Regional Regression Equations:

Regional regression equations provide estimates of peak discharge for watersheds in specific geographic regions.

Of these possible hydrologic methods based on the available data, it should be noted that, at the present time, only the Rational and SCS methods are applicable to the whole country in Highway drainage design. Regression equations and derivations from stream gauging (Gumbel, Log Pearson, General Extreme Value) are often preferred but rely on data not available. For this reason, only the Rational Method and the SCS method are commonly used in Highway drainage designs

2.7. Drainage Structures Design

General

The opening size of the drainage structures are determined to pass safely the design flood by hydraulic calculation. The design flood is the flood that adopted for the design of drainage structures after consideration of economic and environmental factors.

The hydraulic design is carried out for newly proposed drainage structures and also for existing drainage structures. The size of the vent is determined based on the peak design discharge, bed slope of the crossing. In deciding the type and size of structure, hydraulic efficiency and economy are taken besides local hydrologic and geomorphologic characteristics.

In order to determine the type of structures whether it's minor or major shall be decided based on the following criteria as per Ethiopian Roads Authority Design Drainage Manual (ERA DDM).

- Minor structures are those structures with clear span of < 4.0 meters.
- Major structures are those structures with clear span of > 4.0 meters.

2.7.1.Determinations of Capacity of Drainage Structures

The main objective of this task is to determine the opening sizes of the drainage structures at a particular location.

The hydraulic opening size analysis and design deploys the hydraulic characteristics of the stream influencing the maximum discharge, such as velocity of flow, slope of the stream, cross sectional area of the stream and shape and roughness of the stream and finally on the amount of transported materials in the channel as well as coming from the catchment. This method will be used for major streams to compute the design flood levels at crossing sites after the design discharges have been estimated by the hydrological methods and compared with the observed flood marks. Cross-Sections of the crossing sites are determined from topographic survey.

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The type of flow or the location of the control is dependent on the quantity of flow, roughness of the culvert barrel, type of inlet, flow pattern in the approach channel, and other factors. In some instances, the flow control changes with varying discharges, and occasionally the control fluctuates from inlet control to outlet control and vice versa for the same discharge. Thus, the design of culverts should consider both types of flow and should be based on the more adverse flow condition anticipated.

There are two procedures for designing culverts: manual use of inlet and outlet control nomographs, and the use computer programs such as HY8. The use of culvert design nomographs requires a trial and error solution. The steps to be carried out are as follows. Allowable Headwater is the depth of water that can be pounded at the upstream end of the culvert that will be limited by one or more of the following:

- Non-damaging to upstream property;
- No higher than the shoulder or 0.3 m below the edge of shoulder;
- Equal to Head-Water (HW) /D not greater than 1.5;
- Not higher than the low point in the road grade; and/or
- Equal to the elevation where flow diverts around the culvert.

The Headwater is the flood depth that does not exceed 0.5 cm increase over the existing 100-year in the vicinity of buildings or dwellings, and has a level of inundation that is tolerable to upstream property and roadway for the review discharge.

For inlet control, the following equation has been used:

$$\mathbf{Q = C\ A\ N\ [2g\ (H - 0.5D)]^{1/2}}$$

Where

Q design discharge (m3/s)

H maximum design headwater level (m)

D diameter of a pipe culvert or height of a box culvert (m)

g the acceleration of gravity ($9.81 m/s^2$)

A cross-sectional area of the culvert, $\pi D^2/4$ for pipe culverts and D -width for box culverts (m^2)

N - Is the number of pipe or box culverts of equal size

C- a dimensionless discharge coefficient varying with H/D.

Box culverts: 1.0 < H/D < 1.5: C varies linearly from 0.55 to 0.60

Pipe culverts: < H/D < 1.5: C varies linearly from 0.55 to 0.61

Estimation of the outflow velocities is based on balancing the energy equation between culvert inlet and outlet, assuming non-submerged conditions at the culvert outlet, and expressed by the following formula:

$$\mathbf{H_1 + z_1 = y_2 + v_2^2/2g + h_f + h_l}$$

Where H_1 depth of flow at point 1 upstream of inlet (m)

z_1 bed level at outflow point 2 (m)

y_2 depth of flow at point 2 (m)

v_2 flow velocity at point 2 (m/s)

g is the acceleration of gravity (9.81m/s2)

h_f friction losses between point 1 and 2 (m)

$h_f = [(n*v)/r^{0.667}]^2 *L$

n = Manning's roughness coefficient (0.015 for smooth concrete)

v = average velocity between 1 and 2 (m/s)

r = average hydraulic radius between 1 and 2 (m)

L = culvert length (m)

h_l losses at inlet (m)

$h_l = k*v22/2g$

Where the recommended 'k' values are:

Wing walls between 30° and 75° - 0.25

Wing walls 15° and 90° - 0.5

Culvert face shaped to fill slope - 0.7

Wing walls at 0° (extension of culvert sides)- 0.9

Inlets and outlets of culverts will have paved waterways, as per ERA standard, for protecting scour of foundation materials. The end walls will be determined in consideration of type and direction of flow among the possible alternatives of ERA standard. Furthermore, a check for exit velocities and scour-ability of the streambed will be undertaken.

Chapter Three

Study Area and Data Collection

3.1. Description of the study area

This section started with the General Overview of the Study Area which is Addis Ababa. Addis Ababa lies at an elevation of 2,300 meters, located at 9°1′48″N 38°44′24″E Coordinates: The city lies at the foot of Mount Entoto and forms part of the watershed for the Awash. The city Addis Ababa is located at the center of the Akaki River catchment and this catchment geographically bounded between 8°46′–9°14′N and 38°34′–39°04′E with an area of about 1500 km2 (Misganaw 2016). Akaki River is one of the tributaries of the Awash River The Awash rises south of Mount Warqe, west of Addis Ababa and entering the bottom of the Great Rift Valley, the Awash flows south to loop around Mount Zuqualla in an easterly then northeasterly direction, before entering Koka Reservoir. The Awash River Basin is the fourth largest catchment in Ethiopia in terms of area.

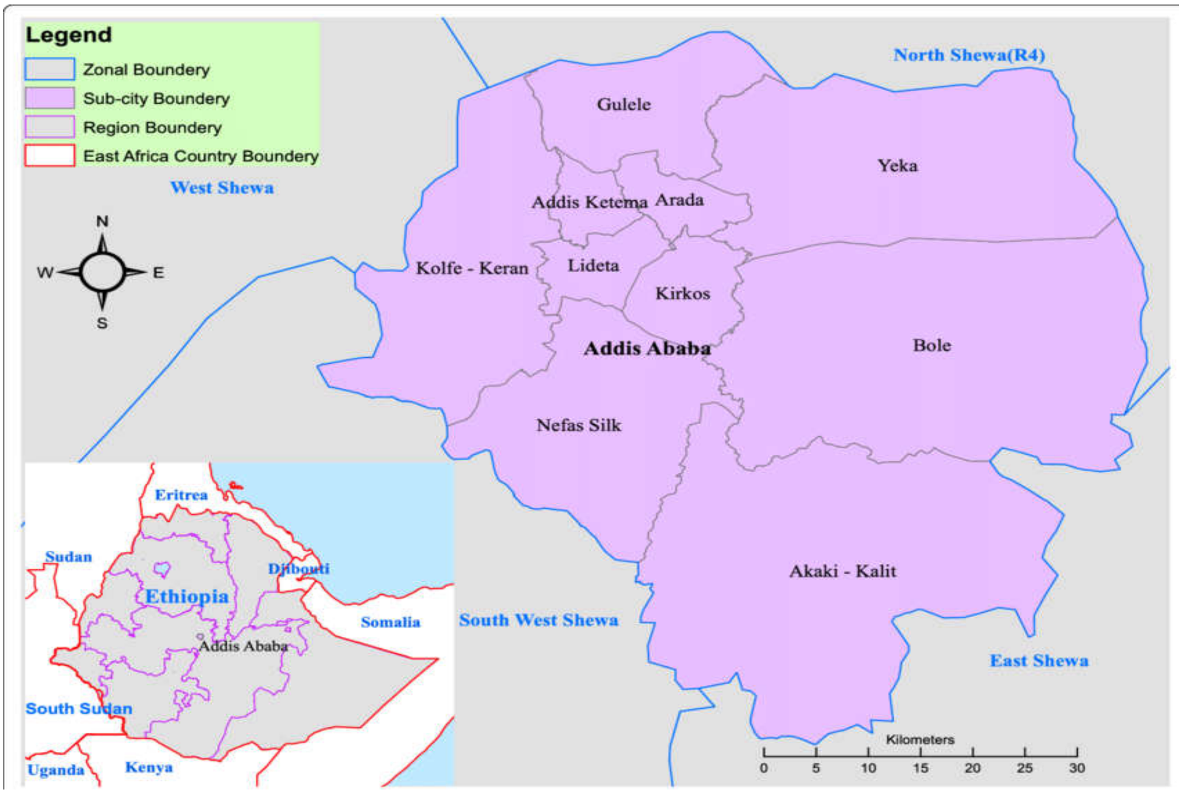


Figure 3.1-1 Location of Study Area

3.1.1. Topography

Addis Ababa, Ethiopia, which displays range of elevation with From its lowest point, around Bole International Airport, at 2,326 meters above sea level in the southern periphery, the city rises to over 3,000 meters in the Entoto Mountains to the north. The elevation map of Addis Ababa, is generated using elevation data from ALASKA's 12.5m resolution SRTM data.

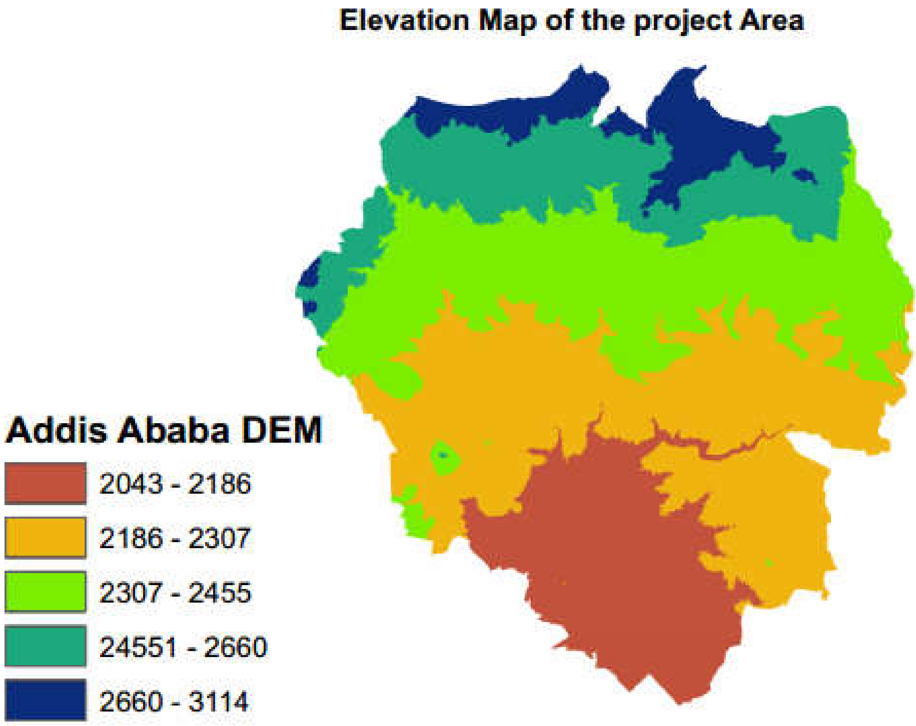


Figure 3.1-2 Elevation of the Project area

3.1.2. Climate

Temperature

Addis Ababa has a subtropical highland climate. The high elevation moderate's temperatures year-round, and the city's position near the equator means that temperatures are very constant from month to month.

Mid-November to January is a season for occasional rain. The highland climate regions are characterized by dry winters, and this is the dry season in Addis Ababa. During this season the daily maximum temperatures are usually not more than 23 °C, and the night-time minimum temperatures can drop to freezing. The short rainy season is from February to May. During this period, the difference between the daytime maximum temperatures and the night-time minimum temperatures is not as great as during other times of the year, with minimum temperatures in the range of 10–15 °C At this time of the year, the city experiences warm temperatures and a pleasant rainfall. The long-wet season is from June to mid-

September; it is the major winter season of the country. This period coincides with summer, but the temperatures are much lower than at other times of year because of the frequent rain and hail and the abundance of cloud cover and fewer hours of sunshine. This time of the year is characterized by dark, chilly and wet days and nights.

Rainfall

Addis Ababa is provided with on balance 1089 mm (42.9 in) of rainfall per year, or 90.8 mm (3.6 in) per month. On average there are 148 days per year with more than 0.1 mm (0.004 in) of rainfall (precipitation) or 12.3 days with a quantity of rain, sleet, snow etc. per month. The driest weather is in November when an average of 9 mm (0.4 in) of rainfall (precipitation) occurs. The wettest weather is in August when an average of 269 mm (10.6 in) of rainfall (precipitation)

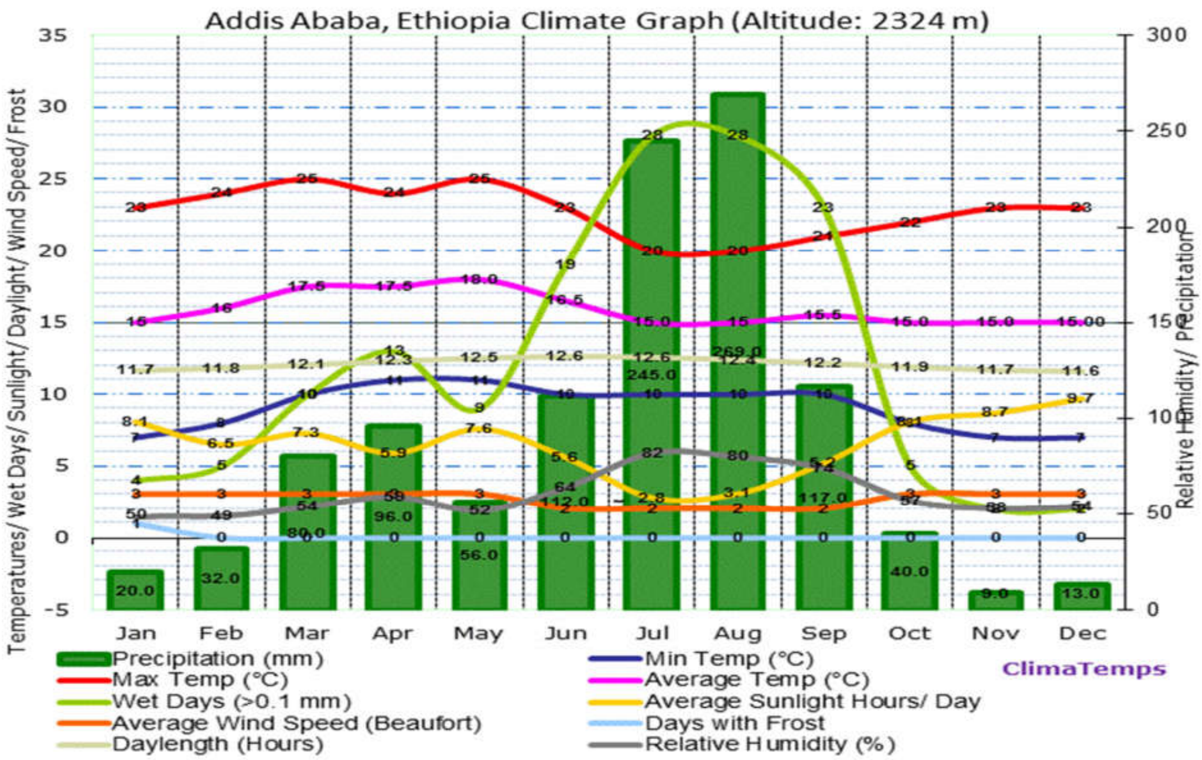


Figure 3.1-3 Climate Addis Ababa

3.1.3. Soil cover of the Study Area

Hydrological soil type classification of the study area considers the physical properties of soils including texture, infiltration capacity, and particle size and soil structure. HWSD is a global soil database framed within a Geographic Information System (GIS) and contains up-to-date information on world soil resources This database was established in July 2008. The HWSD constitutes significant improvements for about 60% of the land area in comparison with the FAO/UNESCO Soil Map of the World. These properties dictate the portion of rainfall that is infiltrated and hence affects the catchment hydrology.

hydrological zoning of Ethiopia is determined by using spatially distributed raster layers of rainfall, soils, topography, and potential evapotranspiration. A weighting overlay approach, with different scale and influence factors of the layers within ArcGIS, is selected as the basic tool for the development of qualitative hydrological zone classification of the country.

The land mass of Ethiopia is classified into 60 soil types with an area coverage ranging from 1.4 to 208,882 km2 and organized as spatial soil database with 19,865 records of GIS polygons. But the FAO soil data base, which classified the country's land mass into only 45 soil types. Lithic Leptosols, Humic Nitisols and Eutric Vertisols as the major three soil types with large area coverage. Which is Lithic Leptosols is 18.46% followed by Humic Nitisols (11.90%), and Eutric Vertisols (10.18%) (B. Birhanu et al).

the soil hydrological group of the country indicate that the HSG-A dominates with 48.2% areal coverage followed by HSG-B (30%) and HSG-D with areal coverage of 21.6%. when thoroughly wet, the soils in HSG-A and HSG-B have low and moderately low runoff potential, respectively.

Hydrological Soil Group (HSG) coverage of the study area found in the area categorized on two. which is C and D.

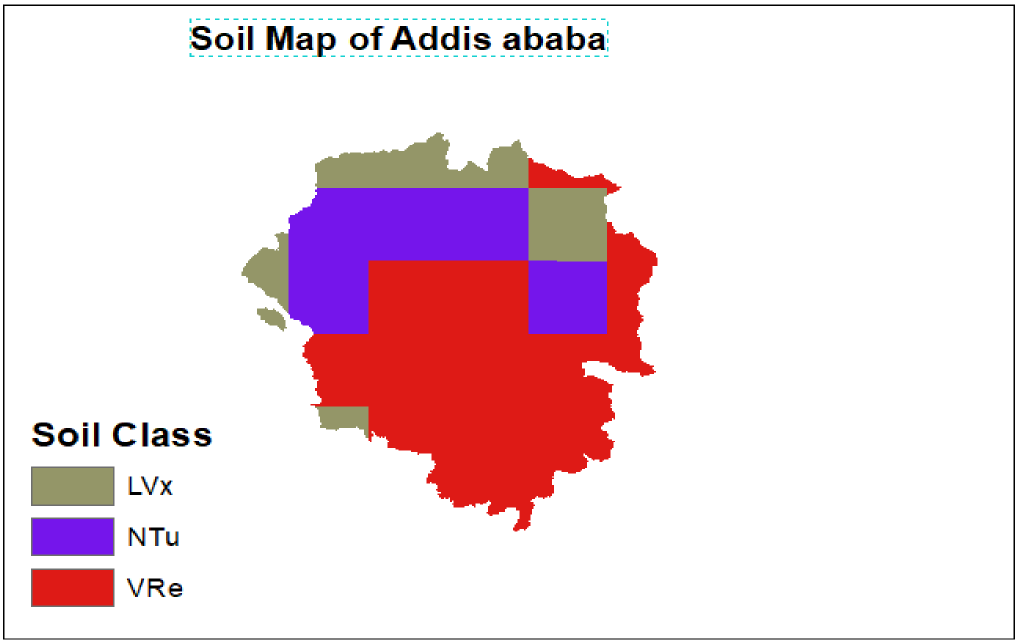


Figure 3.1-4 soil classification of the study area

3.1.4. Land Use Land Cover

Addis Ababa is urbanizing and growing at a rapid pace. Consequently, the city land use land cover types classified in to eight major classes these are residential, industry Asphalt, Cultivation, grass land waterbody, forest and barren land.

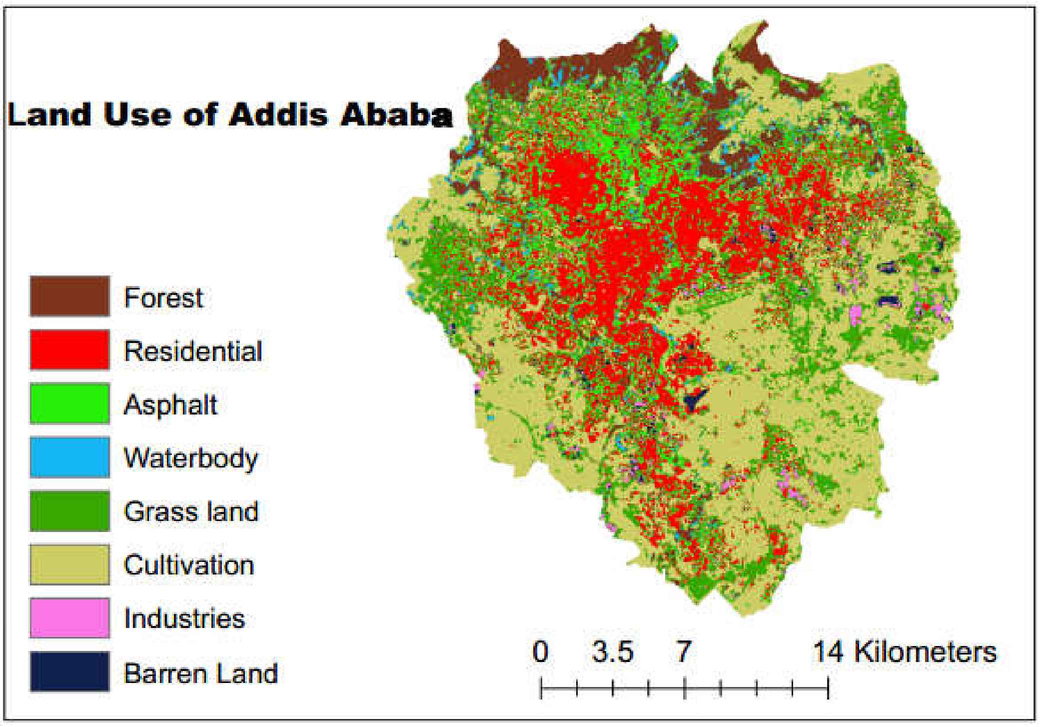


Figure 3.1-5 Land use of the study area

3.2. Data Collection

3.2.1. Data Types and Sources

In order to achieve the objective of the study A good understanding of the topographical, hydrological and climatic condition of the study area and proper set of data defining them are very important for analyzing and replicating the actual hydrologic and hydraulic situation. both primary and secondary sources of data was used.

3.2.1.1 Satellite images

The Landsat data used is downloaded from the official website of United States Geological Survey (USGS) and it is freely accessible by using the following link: http://earthexplorer.usgs.gov/. The dataset with the resolution of 30mx30m collected from the USGS were divided in to decadal land use years. Which is 1985, 1995, 2002 and 2015.

3.2.1.2 DEM of 12.5m resolution

A digital elevation model (DEM) is the digital representation of the land surface elevation with respect to any reference datum. DEM is frequently used to refer to any digital representation of a topographic surface and is the simplest form of digital representation of topography. DEMs are used to determine terrain attributes such as elevation at any point, slope and aspect. For Addis Ababa a 12.5mx12.5m spatial resolution DEM was downloaded from Alaska Satellite Facility Distributed Active Archive Data Center (ASF DAAC). The Radiometric Terrain Correction Products are distributed at two resolutions. RT1 Products with a pixel size 12.5m are generated from high-resolution and Mid- Resolution Digital Elevation Model (DEMs). RT2 Products are generated at 30m level at all available DEMs.

3.2.1.3 Metrological data (Climate Data)

Meteorological data (rain fall, humidity, temperature, solar radiation and wind) collected from National Meteorological Service Agency of Ethiopia (NMSA). this daily metrological data is for 7 stations (AA bole, AA Observatory, Akaki mission, Entoto, Debrezeit, Sendafa, and kotebe met for the year of 1983 – 2016 were found

3.2.1.4 Hydrological *data (stream Flow Data)*

Daily flow data for Akaki River for a period of 1983-2008 recorded at Akaki bridge gauging station was collected from Ministry of Water Resources (MoWR). the stream flow data used for calibration and validation of the model.

Table 3.2.1-1 Stream Flow data

Scenario No	**Data Period**		**Land use year**
1	1983 – 1990	1983 – 1988 Calibration	1985
		1989 – 1990 Validation	
2	1991 – 2000	1991 – 1997 Calibration	1995
		1998– 2000 Validation	
3	2001 – 2008	2001 – 2006 Calibration	2002
		2007 – 2008 Validation	
4	2009 – 2015	2009 – 2013 Calibration	2015
		2014 – 2015 Validation	

3.2.2. Drainage Location selection

The objective of this study is to determine the impact of land use on drainage system. The study tries to see the road minor drainage structures and bridges which drains to downstream side of Addis Ababa. The size and the type of the drainage point was found from AACRA that was done for 2009 inventory. There are 433 numbers of minor drainage structure 294 Major Drainage Structures in Addis Ababa.

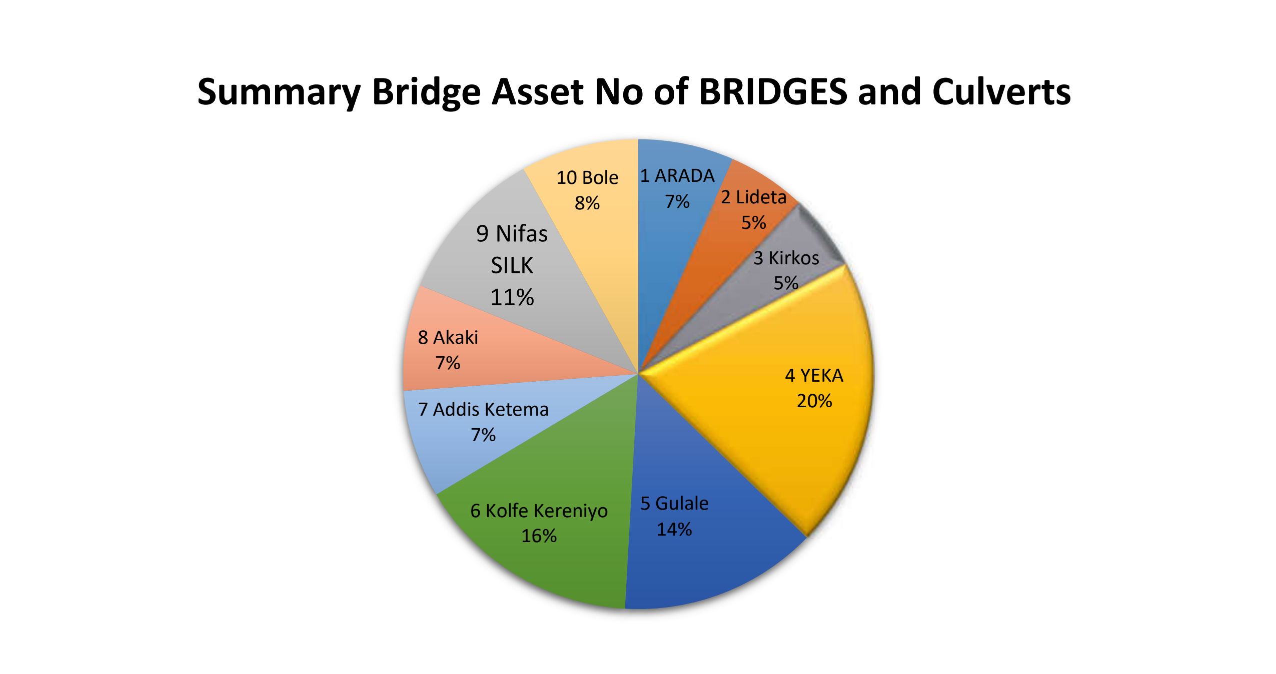


Figure 3.2.2-1 Summary Drainage Asset no of bridges and Culverts from AACRA

Therefore, from the total drainage system try to study some drainage structures selected using the sampling method.

3.2.2.1. Sampling method

A sample is "a smaller (but hopefully representative) collection of units from a population used to determine truths about that population. (Field, 2005). Due to the scope of this study it is not possible to assess all the drainage structures. Thus, it is important to select the few structures Using Random Sampling Method that are manageable in the allocated time and resource.

3.2.2.2. Random Sampling Method

Every member and set of members have an equal chance of being included in the sample. To Get the number of samples needs some sort of chance process sample. By Drawing grid of 2kmx2km in arch GIS and import the Grid to google earth. Next taking select one drainage point in one cell of the grid.

Table 3.2.2.2-1The Selected Drainage structures

No.	Elevation	X	Y	Kifle Ketema	Bridge Name	Bridge No	Width (m)	(Span length) Length (m)	No of Span	Type	Side Walk width	No o lane	type of Surface	Crossing type
1	2565	466562	1E+06	kk	Asko	x5		5	1	DC	2	3	Under Cons	
2	2527	468862	1E+06	KK	Derea	x1	7	6	1	Arch	1	2	Asp	R/C
3	2570	469383	1E+06	GU	beyene bridge	1	6	6		DC	no	2	gravel	RIC
4	2467	486164	1E+06	YK		1	15	5	1	DC	4	4	Conc	R/C
5	2426	466593	999718	KK		x1	7	6	1	DC	1	2	ASP	R/C
6	2520	467921	1E+06	KK		2	35	3	1	DC				
7	2454	467929	999547	KK		6	2	5	1	wood	ped	1	wood	R/C
8	2454	468959	999740	AD	Taiwan	1	20	16	1	DC	2.5	3	conc	RIC
9	2500	471234	1E+06	AR	enkulal fabrika Bridge	1	11	10	1	DC	2	3	Asphalt	RIC
10	2463	471299	999371	AD	Addisu Michael	1	9	3	1	DC	-	2	Asphalt	River
11	2451	473019	999874	AR	Afencho ber	NEW	18	36	3	DC	2X2		Asphalt	River
12	2484	473284	1E+06	GU		2	7	1	2	DC	no		asp	RIC
13	2456	474738	1E+06	GU	Hamle 19	2	4	5.3	1	DC	-	1	Asphalt	River
14	2473	476086	1E+06	YK	Abo Dildiy 12/Kebele 17	3	9	12	1	DC	1.4	1	Concrete	River
15	2401	467975	998543	kk	lukanda	1	8	52	1	GC	2	2	Asphalt	RIC
16	2463	470505	999202	AD	Haleluya T/bet	4	14	3	1	DC	2	3	Asphalt	River
17	2379	473490	997843	AR	Extreme	1	9	8	1	DC	-	2	Asphalt	GS
18	2419	475872	999084	YK	Germen Embassy	New 3'	9	5	1	DC	-	2	AC	RIC
19	2482	483780	999155	YK	college ITC	1	7	4		arch	no	2	asp	RIC
20	2483	484355	998938	YK		1	20	21	1	DC	4	3	Asphalt	R/C
21	2328	468009	997022	KK	Keraniyo	1	21	10	1	ARCH		4	Asphalt	River
22	2394	471118	997554	AD	Around abenet area	3	3	3.5	1	DC	-	-	con	R/C
23	2343	473136	996777	AR		2	2	5	1	DC	-	-	con	R/C
24	2371	475775	997445	YK		1	27	16	1	DC	3X3	6	AC	RIC
25	2360	477746	996891	YK	Blunile Clinic	New 3[1]	26	5	1	DC	6	GS	RIC	wing wall
26	2394	479849	997401	YK		xx	20	12	1	DC	4	3	asp	RIC
27	2357	480762	996797	BO	Egzyaberabe	1	8	6	1	DC	1	2	Conc	R/C

No.	Elevation	X	Y	Kifle Ketema	Bridge Name	Bridge No	Width (m)	(Span length) Length (m)	No of Span	Type	Side Walk width	No o lane	type of Surface	Crossing type
28	2348	481293	996619	BO		x1	19	11	1	DC	3	3	Asp	R/C
29	2374	482821	997235	BO		x2	40	7	2	DC	4	4	Asphalt	R/C
30	2415	464582	994622	KK		1	5	5.6						
31	2322	467887	994846	KK		2	1.5	6		pipe	no	2	Gravel	R/C
32	2314	470728	995571	LD	lideta	NEW	30	10	1	DC	4	6	asphalt	R/C
33	2329	474371	996048	KR	Bambis NoC	New 4	30,20	14, 22	1	ARCH	2.8X2.2	6	Asphalt	River
34	2339	477091	996147	BO	Ezana Pensions	2		4	9	DC	-	1	Asphalt	River
35	2329	477281	995455	BO		1	8	15	2	DC	-	2	-	Asphalt
36	2347	479101	996099	BO		x2	9	6	1	DC	1	2	Gravel	R/C
37	2281	481826	994638	BO	yerer Goro	x2	7	145	4	Girder	4	2	Asp	R/C
39	2278	471147	993711	NL	Vatican	2	22	6	1	DC	4	6	asp	RIC
40	2295	475536	994076	BO	Bole Ruanda	1	34	20	1	DC	3.5	6	asphalt	gr
41	2281	480635	994494	BO		new E	30	10	2	dc	5.5	6	AC	R/C
42	2312	466218	992888	kk		x2	8	6	1	Arch	1	2	Asp	R/C
43	2213	470628	992060	NL	mekannisa	2	135	15	1	DC	2.5	3	asphalt	RIC
43	2213	470628	992060	NL	mekannisa	2	135	15	1	DC	2.5	3	asphalt	RIC
44	2245	474252	992129	NL	Bole Michale	1	35	157	4	DC	2.5	6	AC	RIC
45	2250	482675	992673	BO		1	8	15	2	DC	-	2	-	Asphalt
46	2198	472424	990202		Lafto		7	15						
47	2208	470605	989736	NL		1	13	10	1	DC	2	3	asphalt	RIC
48	2149	475146	988642	AK	bulbula bridge	1	20	107	5	DC	2	2	asphalt	ROC
49	2081	472078	984356	AK	KADISKO	1		60	1	GC	10	3	concrete	RIC
50	2051	476478	981340	AK	Beseka T/bet	NEW 7	7	3	1	DC	-	2	AC	RIC

Chapter Four

Methodology and Analysis

The method to evaluate the impacts due to land use changes can be achieved through integrating Geographical Information System (GIS), Arch SWAT for delineating the catchment for Different point and calculating the Runoff which will be used to get the discharge at selected points in the drainage system. (Kassa Tadele, et al. 2007)

The research was carried out by Different steps. First, a database was established and land use

Images for different years (1985, 1995, 2002 and 2015) were produced to analyze the land use land cover dynamics. Hydrological components were simulated within the SWAT model based on the water balance equation. Then the efficiency of the model was assessed by comparing simulated and observed annual and monthly Stream flow.

This chapter gives a detailed overview on data employed to address the research objectives which is evaluating the Land Use Change impact on Addis Ababa Drainage System and on Model Development and stepwise procedures for the simulation and modelling. The methodology used for carrying out Rainfall Runoff Modelling can be described by categorizing them into four sections, which are as follows:

I. Land Use Analysis
II. Hydrological Modelling with SWAT Model
III. Evaluate the performance of drainage Structures
IV. Developing relationship between runoff computation and the Land use change.

4.1. Land Use Analysis

Land use from large areas can be detected easily in a short time with low cost compared to the traditional methods. The Landsat data used is downloaded from the official website of United States Geological Survey (USGS). For this study the Landsat data of the catchment for 1985, 1995, 2002 and 2015 with a resolution of 30mX30m is selected and used. Image Processing functions involve those operations that are normally required prior to the main data analysis and extraction of information. Selecting appropriate satellite imagery is the first task in image data processing.

The Landsat data downloaded from the Landsat archive in the form of Geo tiff with different bands. In order to view and discriminate the surface features clearly, all the input satellite images were composed using the True Color RGB (Red Green Blue) color composition. After changing the Image to RGB color Composite it was Extracted by The Project Area Shape File.

4.1.1.Image Classification

The Image classification method used in this paper is supervised image classification. Supervised image classification is a method in which the analyst defines small training sites on the image, which are representative of each desired land cover category. In this case by taking the training data from google earth and Create training sample data in GIS. Then the training sample data was changed to signature file to import the file in Maximum Likelihood Classification method.

The Diagram below shows the Image Classification process in GIS.

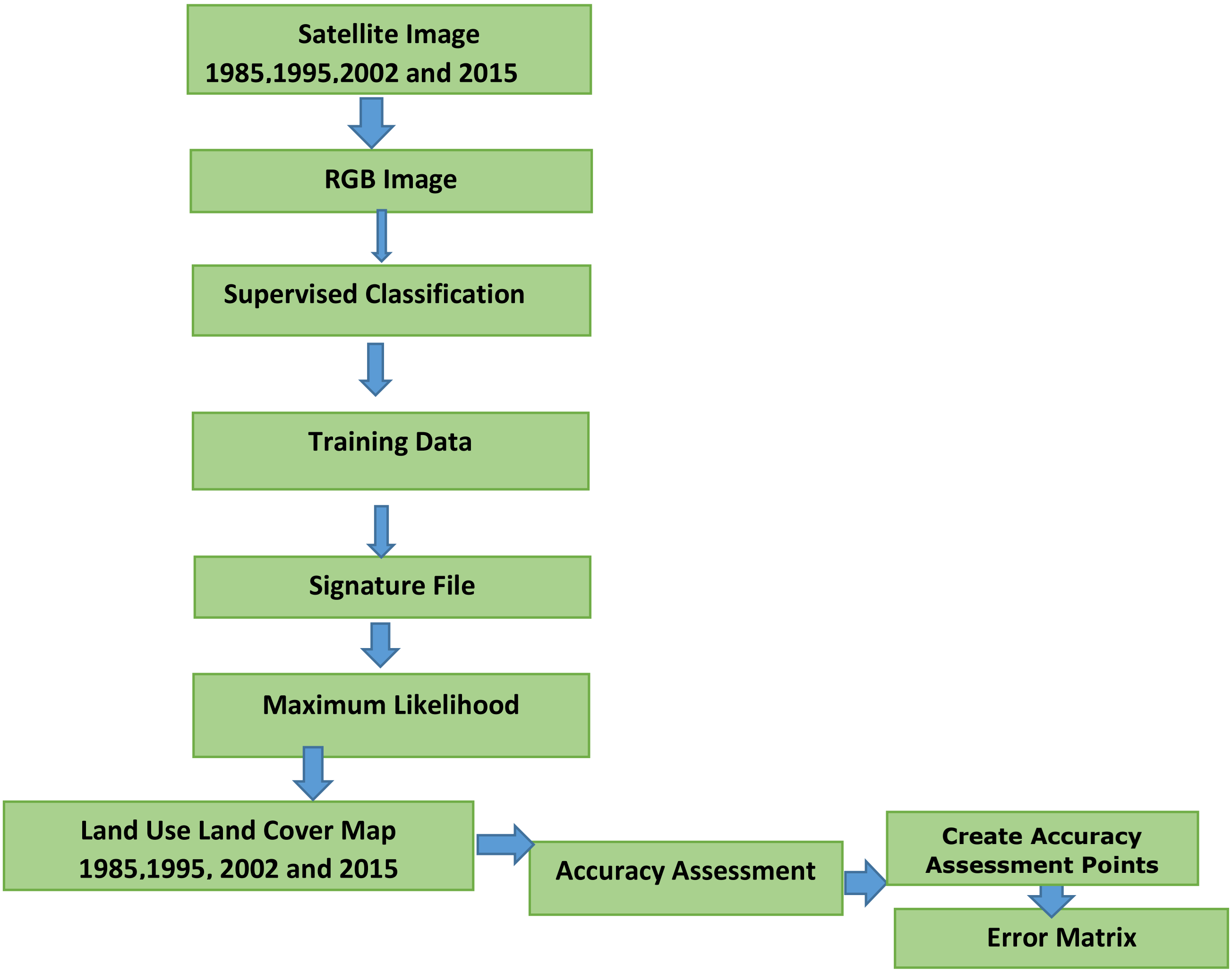


Figure 4-4.1-1 Model processing for change detection analysis

Land use/cover class is carried out by assigning a grid code for each class. Accordingly, seven types Land use for year 1985 to 2002 were identified in the Study Area. namely

1. Forest,
2. Residential,

3. Asphalt,
4. water body,
5. grass land,
6. Cultivation,
7. Industries and
8. Barren

Barren land was identified only for year 2015 in the study area.

4.1.2.Accuracy assessment:

Accuracy assessment was critical for a map generated from any remote sensing data. Error matrix is the most common way to present the accuracy of the classification results.

The error matrix is a cross-tabulation of the class labels allocated by map and reference data. It is derived as a q x q matrix with q being the number of classes assessed. The elements show the number of data points which represent a map class i and reference class j (nij). Usually the map classes are represented in rows and the reference classes in columns. The diagonal of the matrix contains the correctly classified data points, whereas the cells off the diagonal show commission and omission errors. Commission error is the complimentary measure to user's accuracy, calculated by subtracting 100% from the user's accuracy for each class. Commission error, calculated for each of the map classes, is the probability that the spatial unit classified into a given category on the map represents that category in the reference data. Omission error is the complimentary measure to producer's accuracy, calculated by subtracting 100% from the producer's accuracy for each class. Omission error, calculated for each of the map classes, is the probability that the spatial unit classified into a given category in the reference data represents that category in the map data.

The accuracy measures are derived from the error matrix and reported with their respective confidence intervals. They include overall accuracy, user's accuracy and producer's accuracy. The overall accuracy is the proportion of area classified correctly, and thus refers to the probability that a randomly selected location on the map is classified correctly. User's accuracy is the proportion of the area classified as class i that is also class i in the reference data. It provides users with the probability that a particular area of the map of class i is also that class on the ground. Producer's accuracy is the proportion of area that is reference class j and is also class j in the map. It is the probability that class j on the ground is mapped as the same class.

The Kappa statistic incorporates the off-diagonal elements of the error matrices and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance

4.2. Hydrological Modelling with SWAT Model

Basin Processing was Executed in Different steps using Arc SWAT version 5.21 and SWAT version 2012 on ArcGIS 10.5 platform. These steps are delineation, HRU definition, data base editing, weather stations definition, inputs parameterization and editing, model running, and calibration of simulation results. SWAT model can simulate runoff, sediment, nutrients, pesticide and bacteria transport from agricultural watersheds. It simulates the hydrological cycle parameters based on the water balance

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

The SWAT model is a continuous, long-term, physically based distributed model considered one of the most suitable models for the simulation of land use impacts on water, agricultural pollutants and sediment in large complex watersheds. Hydrological components simulated within the model include surface runoff, evapotranspiration, percolation, lateral flow, return flow, transmission losses and ponds. (Arnold et al.)

The hydrology model is based on the water balance equation. SWAT uses two phases for the simulation of hydrology, land phase and routing phase. The land phase simulation calculates the amount of Runoff, sediment, water pesticide and nutrient loading in to the main channel in each basin. The routing phase of define the movement of water, sediment, etc. in to the outlet through channel network of the watershed.

The model reflects difference in evapotranspiration for various land use and soil type in the subdivision of watersheds. The runoff was predicted separated from each HRU and routed to obtain the total yield for the watershed. Hence, increase the accuracy and gives a better physical description of water balance. (Tewodros 2012)

4.2.1. Surface runoff

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. SWAT provides two methods for estimating surface runoff: the SCS curve number procedure (SCS, 1972) and the Green & Ampt infiltration method. relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous hydrologic and vegetative cover conditions. Data for land-treatment measures, such as contouring and terracing, from experimental catchment areas were included. The equation was developed mainly for small catchment areas for which daily rainfall and catchment area data are ordinarily available. It was developed from recorded storm data that included total amount of rainfall in a calendar day but not its distribution with respect to time. The SCS runoff equation is therefore a method of estimating direct runoff from 24-hour or 1-day storm rainfall.

The SCS runoff equation is used for estimating direct runoff from 24-hour or 1-day storm rainfall by the equation given below.

The equation is:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S}$$

Where Q = accumulated direct runoff, mm

P = accumulated rainfall (potential maximum runoff), mm

Ia= initial abstraction including surface storage, interception, and infiltration prior to runoff, mm

S = potential maximum retention, mm.

The relationship between Ia and S was developed from experimental catchment area data. It removes the necessity for estimating Ia for common usage. The empirical relationship used in the SCS runoff equation is:

$$Ia = 0.2S$$

Substituting 0.2S for Ia in the above equation, the SCS rainfall-runoff equation becomes:

$$Q = (P - 0.2S)^2/(P + 0.8S)$$

S is related to the soil and cover conditions of the catchment area through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = 25400/(CN - 254)$$

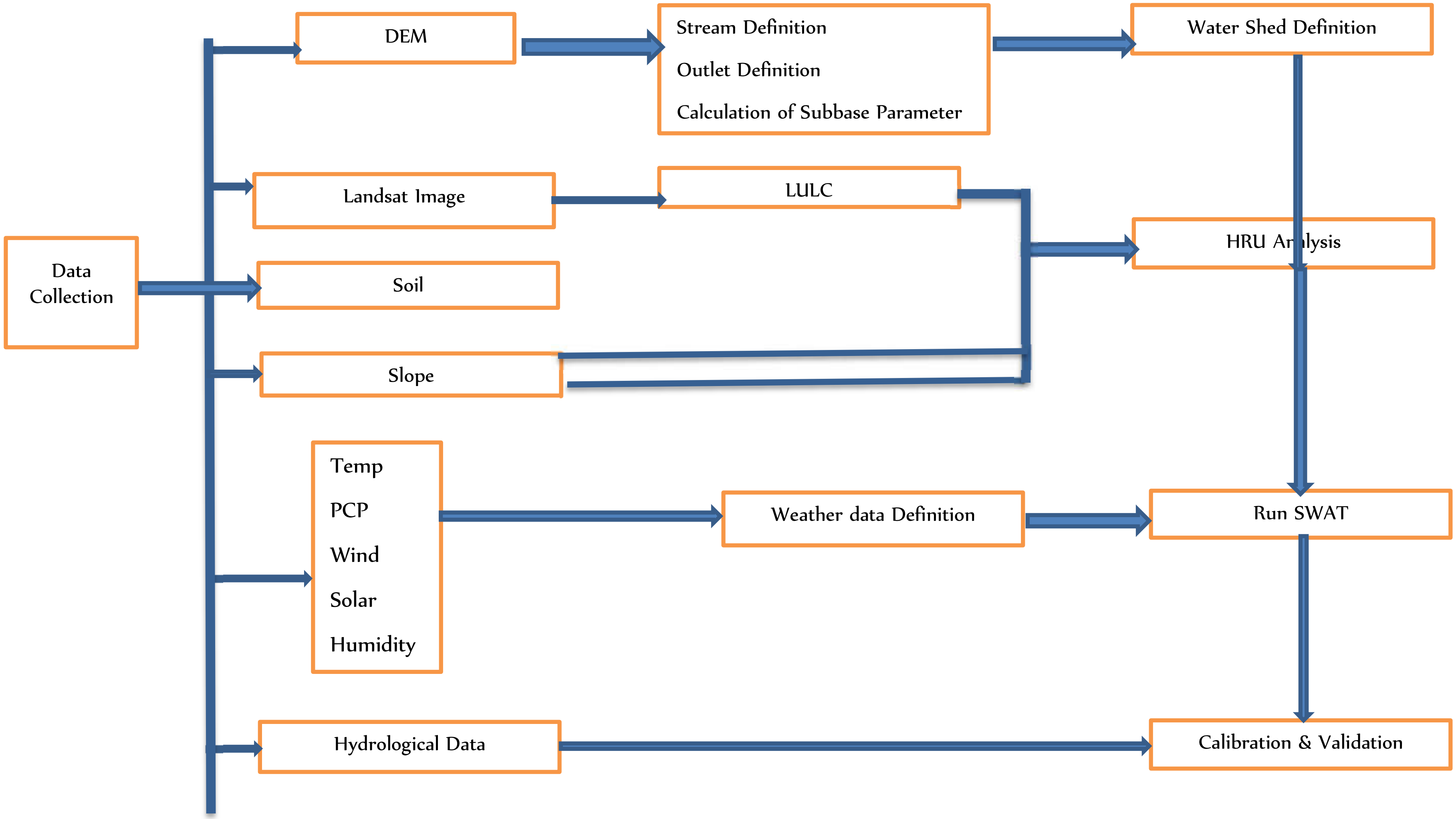
4.2.2.Routing

The routing phase is the second division of hydrological cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet. Water is routed through the channel network using the variable storage routing method or the Muskingum River routing method. The concept of Continuity equation is used for storage routing

$$`\Delta V_{\text{stored}} = V_{\text{in}} - V_{\text{out}}$$

Where: V_{in} is the volume of inflow during the time step
V_{out} is the volume of outflow during the time step
ΔV_{stored} is the change in volume of storage during the time step.

Figure 4-4.2-1 SWAT Modeling Process



4.2.1. Watershed Delineation

This is The First Step in SWAT hydrological Model. The watershed and sub watershed delineation were carried out using 12.5 m DEM. The study area was extended up to some level of Akaki watershed. It's used to get realistic result in calibration of the model in Akaki gage station and runoff generation. the watershed delineation process consists of five major stages such as DEM setup, stream definition, outlet and inlet definitions, watershed outlets selection, definition and calculation of sub-basin parameters.

4.2.2. Land use, soil and Slope Definition

After delineating the watershed next step was Land use, soil and Slope Definition (HRU). HRU definition helps to load land use map, soil map and also incorporate classification of HRU in to different slope classes. When we load the land use map as well as soil map should overlapped 100 % with the delineated watershed. After loading the land use and soil maps we need develop the lookup tables to convert from the numeric values found in the land use and soil maps to SWAT land use codes and soil names respectively.

Weather Generator Data Preparation

The climate data defined in the user weather generator for metrological stations is loaded. SWAT requires long-term daily records of meteorological data.7 stations data were collected from National Meteorological Service Agency (NMSA) which includes precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. These data records were prepared according to the SWAT model table format. In this study, weather generator parameters were estimated using more than 33 years of measured records.

Table 4.2-1 Station List and Location

Station Code	Station Name	Latitude	Longitude	Elevation
1	AABole	8.98	38.75	2354
2	AAObs	9.02	38.45	2408
3	Akmis	8.52	38.48	2120
4	Debrezeit	8.44	38.57	1900
5	Intoto	9.11	38.44	2610
6	Sendafa	9.09	39.01	2560
7	Sululta	9.11	38.44	2610

4.2.3.Calibration and Validation

After the model setup has been completed, the next step is to run the model and analyze the simulation result. The applicability of the model for intended purpose should be evaluated through the process of calibration and validation

Calibration is tuning of model to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. In this process, model parameters varied until recorded flow patterns are accurately simulated.

The calibration steps followed based on swat calibration user manual. Thus, first calibration of the water balance followed by that of temporal flow was done. Water balance calibration takes care of the overall flow volume and its distribution among hydrologic components. this was done for all year of different land use scenario. whereas temporal flow calibration takes care of the flow time lag and the hydrograph shape. Calibration was commenced by the yearly average of surface runoff volume.

There were 7 - 8 parameters that affect the model result were adjusted in order for simulated output to meet the actual values as a result the objective functions $E_{NS} > 0.5$ and $R^2 > 0.6$ are improved. The calibration step started from 10 – 50 iterations by simulation until the objective function was reached. The objective function was defined by the Nash Sutcliffe efficiency coefficient developed by Nash & Sutcliffe (1970).

Table 4.2-2 Parameters used for calibration of the models.

Parameter	Meaning
CN2	Number of the initial curve for the moisture condition AMCII (dimensionless)
ALPHA_BF	Baseline flow recession constant (days)
GW_DELAY	Time interval for recharge of the aquifer (days)
GWQMN	Water limit level in the shallow aquifer for the occurrence of base flow (mm)
SOL_K	Saturated soil hydraulic conductivity (mm h-1)
ESCO	Soil water evaporation compensation factor (dimensionless)
GW_REVAP	Coefficient of water rise to saturation zone (dimensionless)

4.3. Design and checking of selected drainage points for different land use

In this section the Runoff generated for different land use scenarios were analyzed for the selected sample drainage structures. Design of the drainage structures were done taking the 1985 land use scenario as a base and design the structures for 10-year return period. The sizes sufficient for the peak discharges were calculated using culvert design guidelines in ERA manual. Then, the discharge at those locations for 1995, 2002 and 2015 land use conditions were estimated for the same return period.

4.4. Computation of the peak discharge of the drainage points for different land use

The estimation of peak discharge for the sample drainage structures Based on the above ERA classification. Addis Ababa found in meteorological region of A2 on according to ERA classification and rainfall depth for 10, 25, 50, and 100 return periods is obtained from rainfall intensity-duration curves.

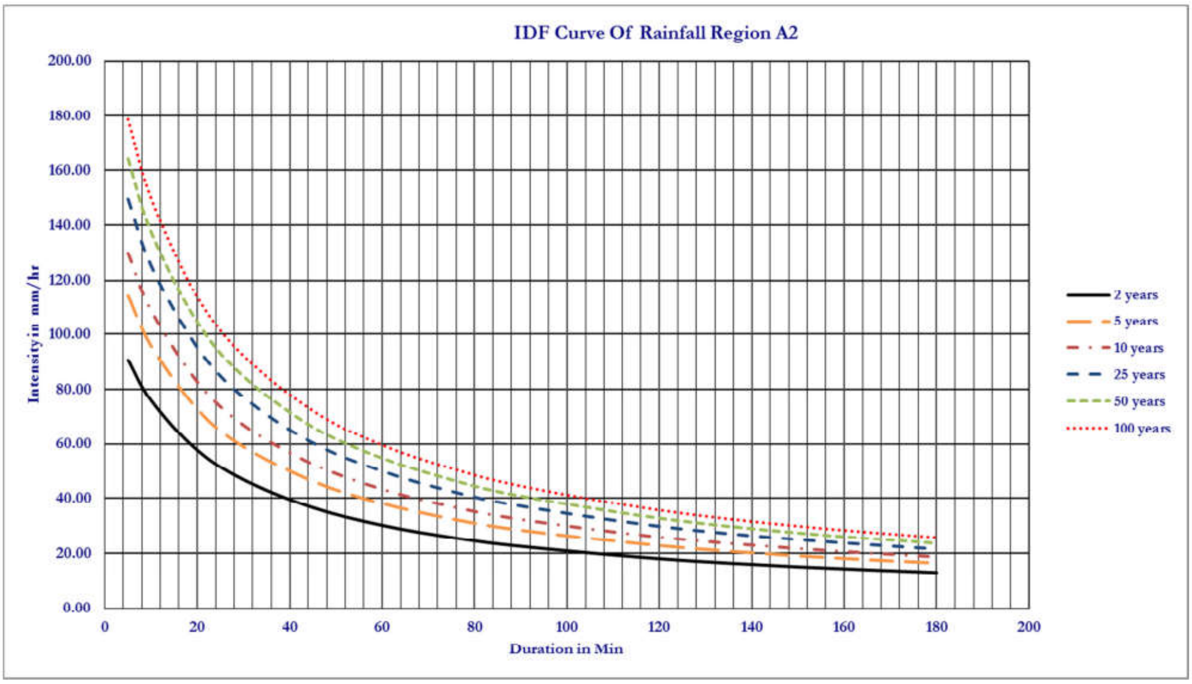


Figure 4.4-1ERA IDF curve for A2

The surface runoff generated from the catchment is estimated based on the rainfall intensity and major characteristics of the catchment area which are the major factors for designing urban storm water drainage facilities and structures.

4.5. Developing relationship between runoff computation and the Land use change.

Relation between the Runoff and the land use developed using graphical method. It starts with computing the discharge for selected sample points. Then by calculating the mean standard deviation and the coefficient of variation for those selected drainage points and graphing the values with land use.

Chapter Five

Results and Discussion

5.1. land use changes of Addis Ababa

The results of the land use/cover (LULC) change analysis over the last four decades indicated that Addis Ababa is one of the cities in the world living with has dynamic Land use change. Urbanization, investment on industries and real estate developments in the cities have brought such significant changes on LULC. As indicated in figures below., the Residential, Asphalt and the industries land use class grows from 7.3%, 5.3%, and 0.04% cover in 1985 to 17.6%, 11% and 2.3% in 2015 respectively. On the other hand, forest, Grass land and Cultivation cover reduced from 19.95%, 26.29% and 38.47% to in 1985 to 7.37% 21.25% and 35.26% respectively in 2015.

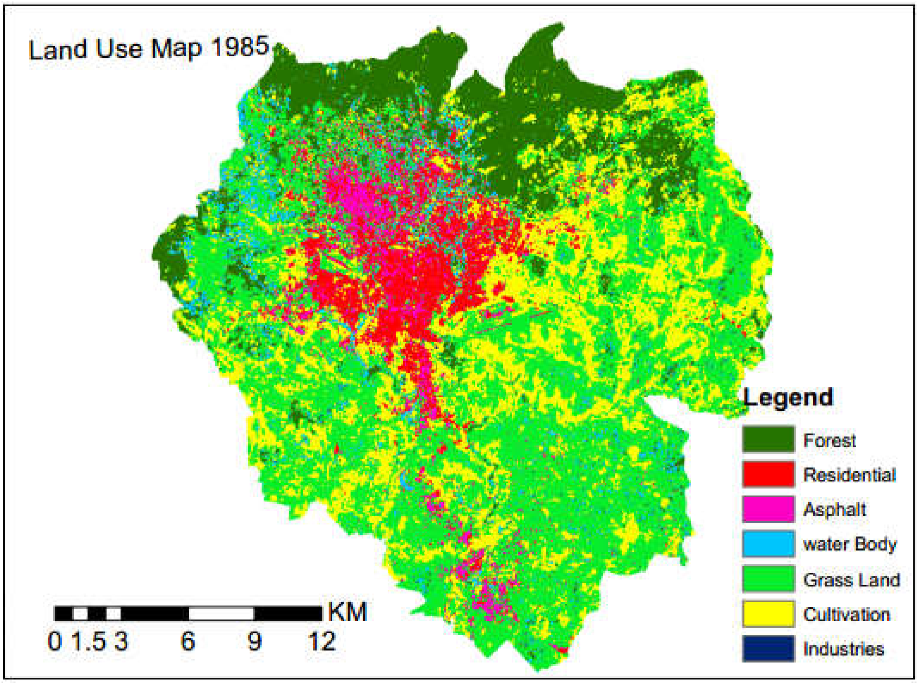


Figure 5.1-1 Land use/Landcover Class of 1985

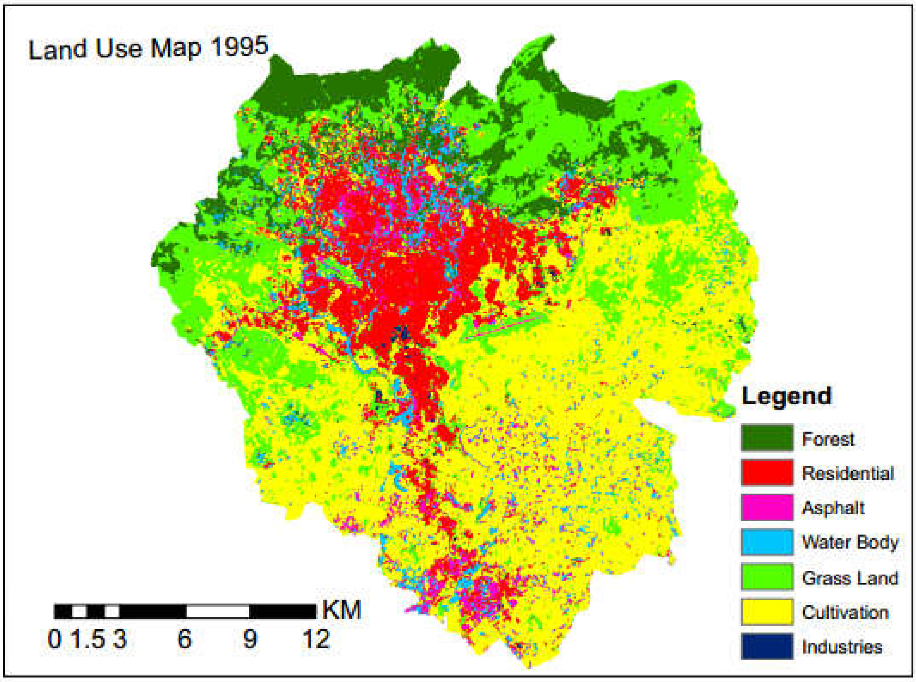


Figure 5.1-2 Land use/Landcover Class of 1995

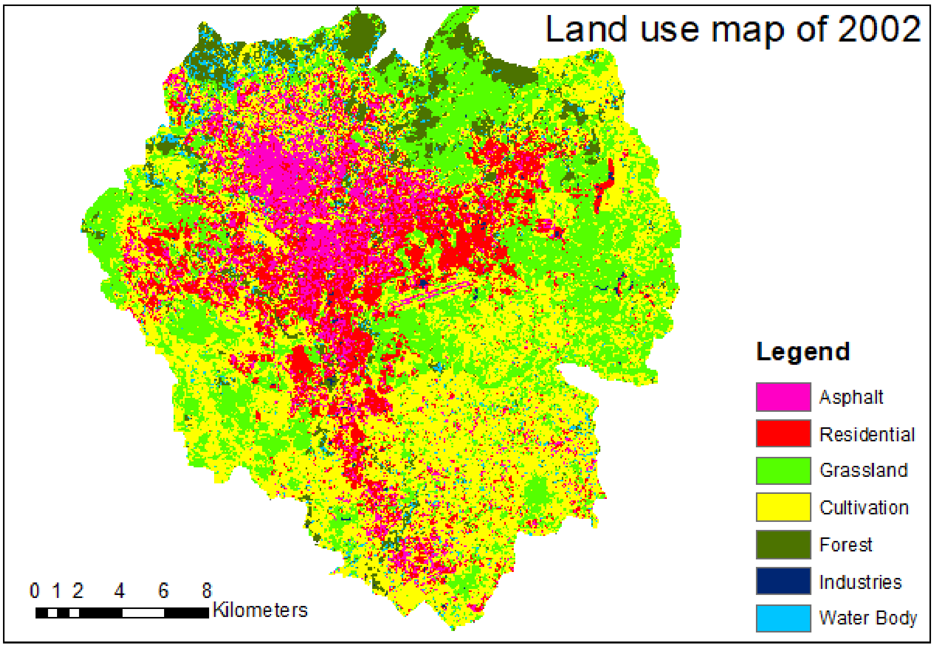


Figure 5.1-3 Land use/Landcover Class of 2002

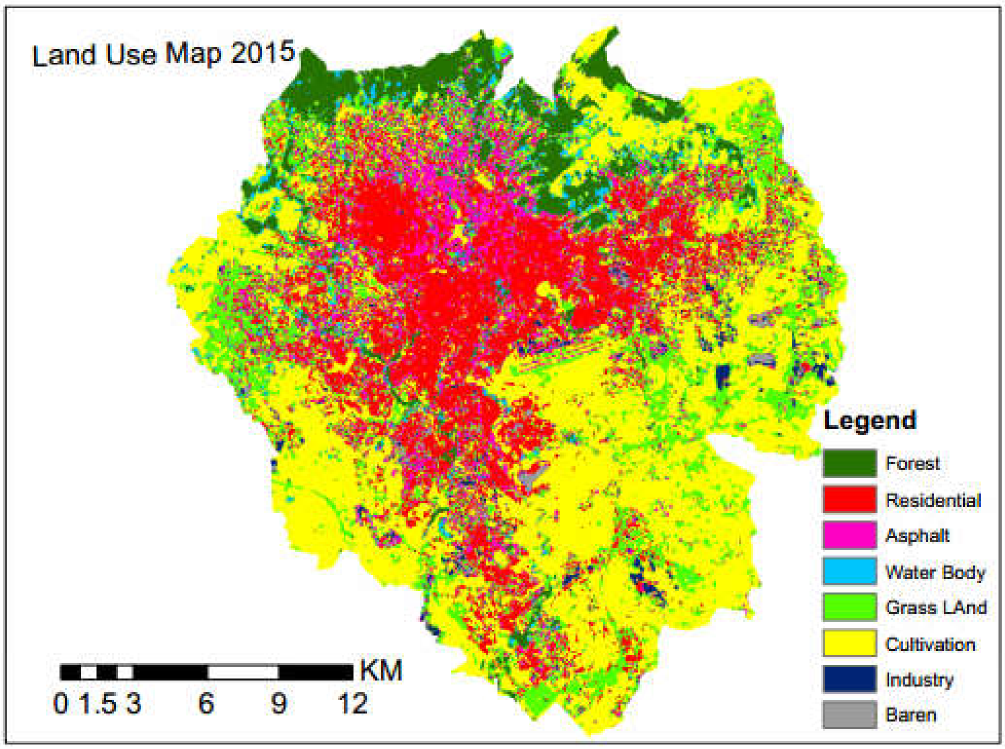


Figure 5.1-4 Land use/Landcover Class of 2015

The land use changes over the last four decade further indicated that, the city gain new land use/cover; Barren land (bad land), which possibly express unwise land management practices of the city (Table5.15.1)

Table 5.1-1: Summary of Land use area coverage of the study area (%) for 1985,1995, 2002, and 2015

	Area coverage (ha)			
Class	**1985**	**1995**	**2002**	**2015**
Grass land	26.59	26.16	27.88	21.25
Residential	7.30	13.39	14.99	17.61
water body	6.31	5.32	3.49	3.11
Cultivation	38.49	37.90	35.66	35.26
Forest	19.95	10.27	7.10	7.37
Industries	0.04	0.52	0.60	2.3
Asphalt	5.30	5.32	10.28	11.25
Barren				1.87

Accuracy Assessment

After classification was done the accuracy assessment was Carried Out to check correctness of the classification result. Accuracy assessment of the classified images was assessed by using the Google Earth images as references,100 randomly sampled points was selected and accuracy assessment was done for each Years 1985, 1995, 2002 and 2015 in Arc GIS.

The Accuracy assessment summarized in table below after Error matrices were developed to be more certain about the land cover classification. analysis of the confusion matrix was done by randomly sampled points then derives a kappa index of agreement between the classified map and data that is considered to be ground truth.

Table 5.1-2 Accuracy Assessment Summery

Land use Period	Accuracy%	Kappa Ǩ %
1985	83.35	80
1995	79.51	75.4
2002	80.8	75.3
2015	75.78	71.2

The table result of accuracy shows that total (overall) accuracy of land use and land cover is which are acceptable for the land use time set.

5.2. Addis Ababa City Hydrological modeling within SWAT

The hydrological system of the city was defined based on the Akaki River basin, which include 1087 HRUs and 62 sub basins based on the overlay results of the three catchment attributes; land use, soil and slope. Such details sub-basins and HRUs delineation were done in the SWAT model to accommodate small drainage systems of the city.

The locations of the river gauging station and the selected 50 drainages locations for watershed delineation were added manually as sub-basin outlets. Once the entire watershed outlets were selected, the sub-basins are delineated and their parameters are calculated.

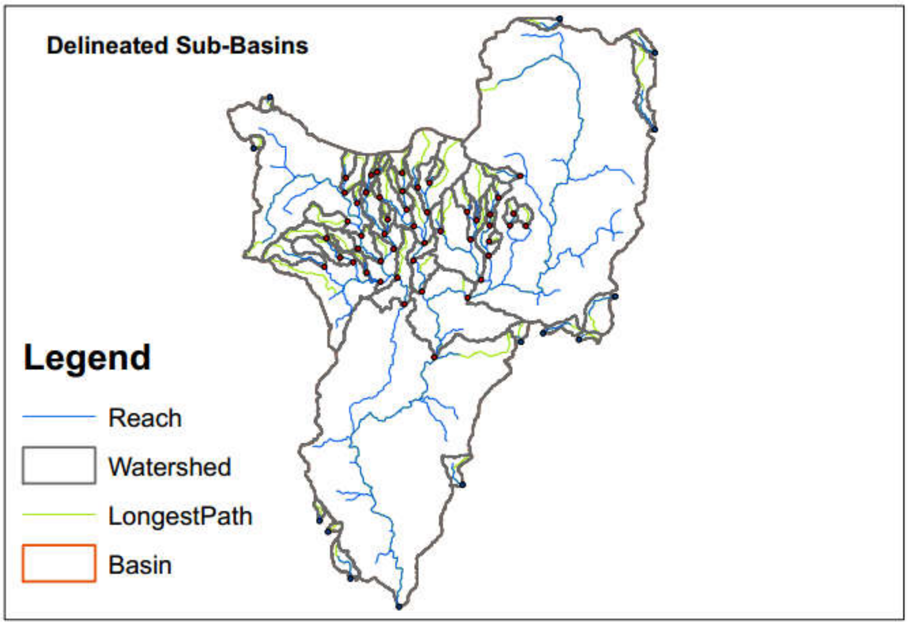


Figure 5.2-1 Map HRUs with their area ranges

5.3. Calibration and validation of SWAT model

In order to capture the actual conditions in the ground the SWAT model was calibrated and validated with different land use conditions and observed flow at Akaki hydrological gauging stations. Both manual calibration and autocalibration tool of SWAT2012 was used to calibrate the model. The calibration results in Table 5.3-1 show that there is a good agreement between simulated and gauged flows.

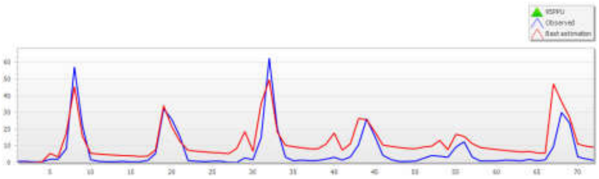
The statistical accuracy indices results (ENS, and R^2) indicate that the model had a good adjustment the table below shows Summery of the calibrated model result the satisfies the minimum criteria.

Table 5.3-1 Calibration and validation statistics of average monthly simulated and gauged flows

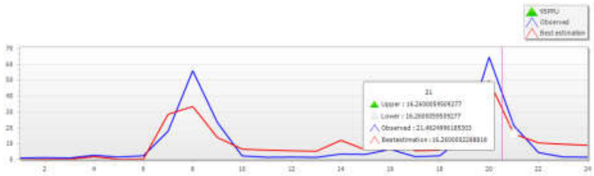
Year	Calibration		Validation	
	R^2	N_{SE}	R^2	N_{SE}
1985	0.71	0.50	0.82	0.78
1995	0.64	0.55	0.80	0.33
2002	0.73	0.71	0.54	0.52

The graphs of the calibration result for different land use time sets. The two model performance indicators Coefficient of determination; R2, Nash & Sutcliff Efficiency; ENS and graphical representations of differences between observed and simulated data were used to check the performance of the model by analysis of Figure 5.3-1. the observed and simulated values were close.

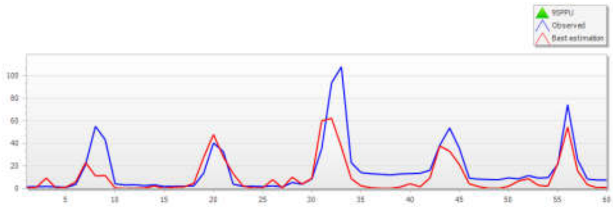
Calibration for the 1985 Land Use



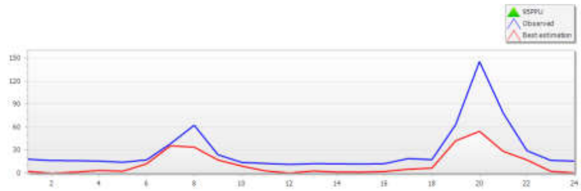
Validation for the 1985 Land Use



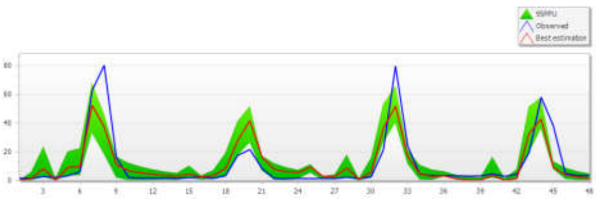
Calibration for the 1995 Land Use



Validation for the 1995 Land Use



Calibration for the 2002 Land Use



Calibration for the 2002 Land Use

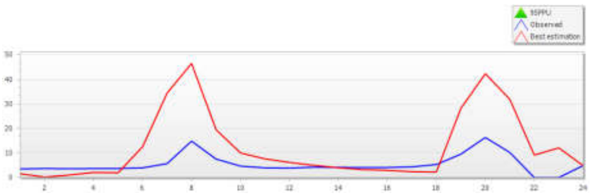
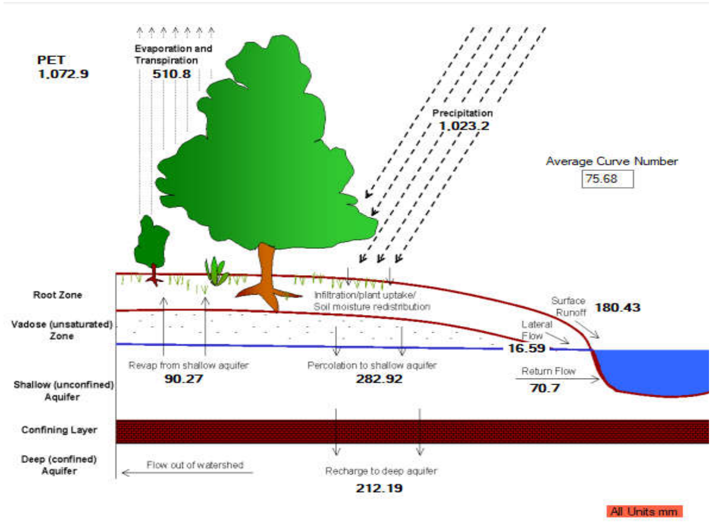


Figure 5.3-1 calibration and validation Graphs

After completing the calibration, the fitted parameter imported to the swat model checked the water balance of the model.

In addition to the confirmation of the statistical calibration and validation of the Model, the model further verified with the hydrological water balance relation with the proportional values of the different hydrological elements using the SWAT water balance checker (Figure 5.3-2).



Water balance 1985

Water Balance Ratios

Streamflow/Precip	0.26
Baseflow/Total Flow	0.33
Surface Runoff/Total Flow	0.67
Perc/Precip	0.28
Deep Recharge/Precip	0.21
ET/Precipitation	0.5

Water balance 1995

Water Balance Ratios

Streamflow/Precip	0.4
Baseflow/Total Flow	0.3
Surface Runoff/Total Flow	0.7
Perc/Precip	0.2
Deep Recharge/Precip	0.01
ET/Precipitation	0.51

Water balance 2002

Water Balance Ratios

Streamflow/Precip	0.2
Baseflow/Total Flow	0.35
Surface Runoff/Total Flow	0.65
Perc/Precip	0.3
Deep Recharge/Precip	0.02
ET/Precipitation	0.55

Water balance 2015

Water Balance Ratios

Streamflow/Precip	0.27
Baseflow/Total Flow	0.36
Surface Runoff/Total Flow	0.64
Perc/Precip	0.28
Deep Recharge/Precip	0.06
ET/Precipitation	0.54

Figure 5.3-2 Water balance for Years of 1985,1995 2002 and 2015

5.4. Estimation of the Peak discharge for Selected Drainage Structures

There were 50 drainage structures was selected from AACRA 2009E.C inventory as sample draining structures to analysis impacts of the drainage due to the land use variability. In this sample drainage structures, 24 culvert and 26 bridge structures identified for the purpose of the undertaking analysis (Figure 5.4-1)

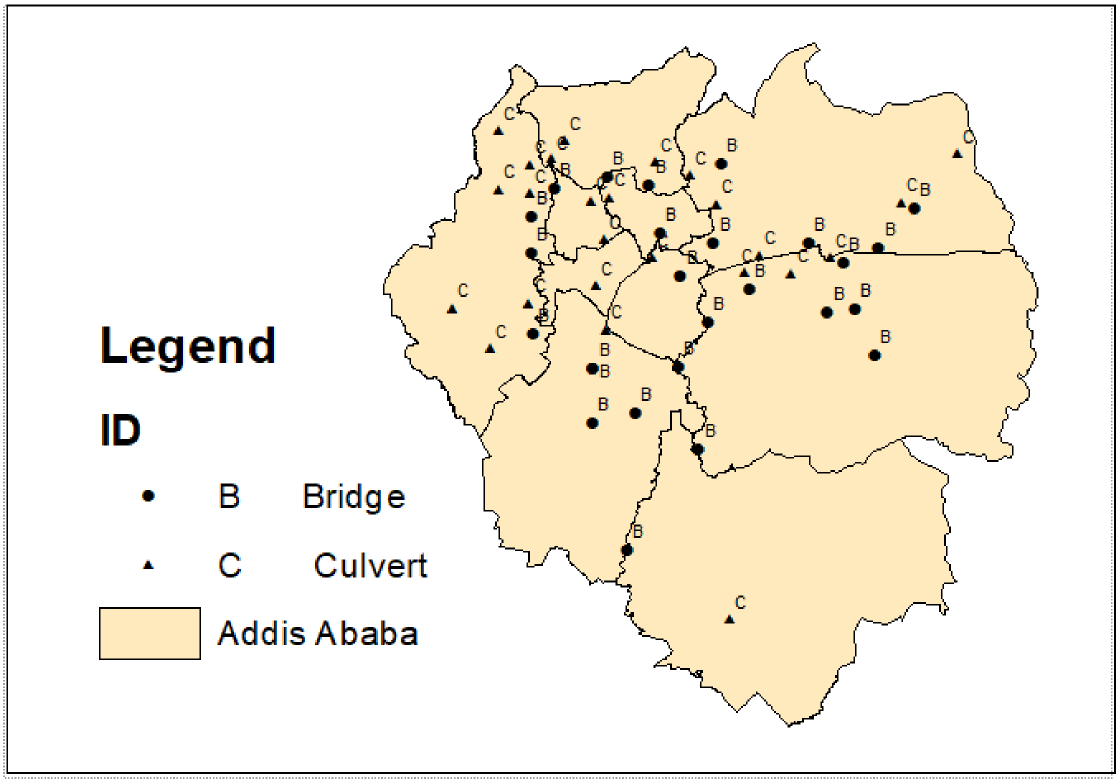


Figure 5.4-1 *Location and type of Sample drainage structures*

The peak discharge of these 50 selected drainage points in Addis Ababa with the four different land use conditions, were computed and presented in the *Table 5.4-1* As it is clearly seen the land use changes changed the magnitude of the peak discharges. Off course at some of the drainage points the peak discharge did not significant change, since land use at the catchment of these catchment haven't done any significant change.

Table 5.4-1 The Peak Discharge for 1985, 1995, 2002 and 2015 with different return period

	1985				1995				2002				2015			
Sub basin	Peak Discharge (q_p), m^3/s				Peak Discharge (q_p), m^3/s				Peak Discharge (q_p), m^3/s				Peak Discharge (q_p), m^3/s			
	10 yrs.	25 yrs.	50 yrs.	100yr	10 yrs.	25 yrs.	50 yrs.	100yr	10 yrs.	25 yrs.	50 yrs.	100yr	10yr	25 yrs.	50 yrs.	100yr
6	20.22	26.87	31.88	36.92	21.93	28.64	33.67	38.71	33.0	39.7	44.7	49.7	34.5	41.2	46.2	51.2
7	43.23	60.60	73.79	87.09	47.55	65.15	78.41	91.73	90.6	107.9	120.7	133.5	93.8	111.1	123.8	136.6
8	30.30	42.42	51.73	61.20	33.50	45.87	55.29	64.82	58.6	71.6	81.3	90.9	61.8	74.8	84.4	94.1
9	44.48	60.81	73.35	86.12	49.01	65.70	78.43	91.34	75.3	93.1	106.4	119.7	80.2	98.1	111.4	124.8
10	48.03	62.63	73.63	84.72	51.97	66.72	77.79	88.92	70.5	85.5	96.7	108.0	74.3	89.4	100.6	111.9
11	29.78	39.61	47.02	54.46	32.32	42.24	49.67	57.13	44.4	54.4	61.8	69.3	46.8	56.8	64.2	71.6
12	133.74	183.68	222.15	261.44	147.74	198.89	238.02	277.81	221.2	276.0	317.2	358.6	236.6	291.9	333.3	374.9
13	66.19	92.15	112.20	132.67	73.32	99.92	120.30	141.01	123.0	151.8	173.2	194.8	130.8	159.7	181.2	202.8
14	75.77	102.64	123.17	144.00	83.15	110.52	131.29	152.31	125.7	154.5	176.0	197.5	133.4	162.3	183.8	205.4
15	120.90	159.43	188.59	218.03	131.42	170.44	199.83	229.44	173.1	213.2	243.1	273.1	183.7	223.9	253.9	284.0
16	125.64	158.00	181.84	205.53	132.77	164.91	188.58	212.11	151.1	182.6	205.8	228.9	157.2	188.4	211.4	234.4
17	18.54	24.36	28.68	33.00	19.94	25.76	30.07	34.36	26.6	32.2	36.4	40.6	27.7	33.4	37.5	41.7
18	34.03	46.03	55.13	64.30	37.17	49.32	58.47	67.68	54.1	66.5	75.8	85.0	57.1	69.5	78.7	88.0
19	22.46	29.76	35.25	40.78	24.35	31.71	37.23	42.76	33.2	40.6	46.1	51.6	34.9	42.4	47.9	53.4
20	103.31	144.63	176.63	209.38	114.69	157.11	189.69	222.88	181.0	226.9	261.3	295.9	193.7	239.9	274.4	309.2
21	54.82	74.78	89.98	105.37	60.12	80.40	95.74	111.21	89.8	110.8	126.4	142.1	95.1	116.1	131.7	147.3
22	393.57	533.34	640.64	750.00	433.19	576.11	685.14	795.86	602.9	754.5	868.3	982.9	646.3	799.2	913.8	1029.0
23	62.77	84.88	101.77	118.93	68.89	91.41	108.52	125.84	99.2	122.9	140.6	158.4	105.7	129.4	147.2	165.0
24	19.83	25.56	29.80	34.01	21.15	26.86	31.07	35.26	24.9	30.4	34.6	38.7	26.0	31.5	35.6	39.7
25	106.25	145.21	175.11	205.55	117.06	156.85	187.19	217.96	177.1	219.5	251.1	282.9	188.8	231.3	263.1	295.0
26	104.73	140.51	167.34	194.21	113.59	149.58	176.42	203.25	172.4	207.7	233.9	260.0	179.6	214.8	240.9	266.9
27	75.40	103.66	125.32	147.35	83.07	111.90	133.84	156.07	137.4	167.9	190.6	213.5	145.3	175.9	198.7	221.5
28	38.05	51.00	60.85	70.82	41.59	54.75	64.70	74.75	57.5	71.2	81.4	91.6	61.2	74.9	85.1	95.4
29	55.71	69.60	79.78	89.86	58.58	72.32	82.40	92.40	69.4	82.5	92.2	101.9	71.5	84.5	94.2	103.8
30	216.33	297.62	360.36	424.47	239.20	322.55	386.40	451.39	338.1	427.2	494.1	561.6	363.5	453.4	520.9	588.7
31	33.74	46.10	55.59	65.24	37.17	49.79	59.41	69.18	55.3	68.7	78.8	88.8	59.0	72.5	82.6	92.7
32	49.61	65.05	76.72	88.51	53.86	69.50	81.27	93.13	71.4	87.4	99.4	111.5	75.6	91.8	103.8	115.9
33	1366.48	1875.56	2267.65	2667.79	1509.01	2030.26	2428.87	2834.09	2280.1	2839.2	3258.2	3679.6	2437.2	3000.5	3421.9	3845.2
34	116.52	145.78	167.07	188.05	122.21	151.05	172.05	192.77	148.2	174.9	194.6	214.2	151.6	178.0	197.6	217.1
35	10.95	15.34	18.74	22.23	12.17	16.68	20.15	23.69	18.8	23.7	27.4	31.1	20.2	25.1	28.8	32.5
36	381.57	479.43	550.88	621.43	401.37	498.03	568.63	638.40	481.7	572.7	639.8	706.6	495.1	585.3	651.9	718.2
37	733.93	982.86	1173.38	1367.26	805.19	1059.37	1252.81	1449.02	990.1	1254.4	1453.4	1654.2	1066.6	1333.9	1534.7	1736.9
38	83.20	105.77	122.50	139.17	88.51	111.02	127.68	144.27	105.0	127.1	143.5	159.9	109.6	131.6	148.0	164.3
39	153.85	216.98	266.44	317.46	171.80	237.11	287.81	339.86	284.6	358.3	413.8	469.8	306.6	381.2	437.3	493.8

	1985				1995				2002				2015			
Sub basin	Peak Discharge (q_p), m³/s				Peak Discharge (q_p), m³/s				Peak Discharge (q_p), m³/s				Peak Discharge (q_p), m³/s			
	10 yrs.	25 yrs.	50 yrs.	100yr	10 yrs.	25 yrs.	50 yrs.	100yr	10 yrs.	25 yrs.	50 yrs.	100yr	10yr	25 yrs.	50 yrs.	100yr
40	104.44	146.71	179.69	213.62	116.39	160.00	193.74	228.28	201.9	250.9	287.7	324.7	216.3	265.8	302.8	340.1
41	106.85	145.93	175.99	206.64	117.83	157.81	188.36	219.39	174.8	217.5	249.6	281.8	186.8	229.9	262.1	294.5
42	627.96	886.18	1087.55	1294.55	700.06	966.25	1172.00	1382.46	1191.4	1487.3	1709.4	1932.9	1275.9	1574.4	1797.9	2022.6
43	978.24	1384.49	1703.45	2033.01	1093.86	1514.63	1842.00	2178.48	1746.2	2219.4	2577.2	2938.9	1887.9	2368.3	2730.2	3095.4
44	155.17	208.84	249.83	291.45	170.12	224.80	266.31	308.33	243.1	300.6	343.6	386.7	258.9	316.7	359.9	403.2
45	86.92	118.83	143.43	168.57	95.98	128.69	153.74	179.23	146.3	181.6	208.2	234.8	156.5	192.1	218.9	245.7
46	16.89	23.04	27.75	32.54	18.59	24.86	29.64	34.48	28.8	35.4	40.4	45.4	30.6	37.3	42.3	47.3
47	2275.32	3140.50	3810.04	4495.53	2520.34	3409.02	4091.56	4787.43	3843.7	4809.4	5534.8	6265.5	4123.0	5098.1	5829.0	6564.3
48	330.79	475.16	589.30	707.71	371.59	521.64	639.08	760.22	672.0	846.6	978.3	1111.4	724.7	901.7	1034.9	1169.1
49	467.07	659.88	811.18	967.49	522.05	721.72	877.00	1036.59	836.6	1061.4	1231.2	1402.9	904.1	1132.3	1304.1	1477.5
50	704.65	963.58	1163.75	1368.67	779.16	1045.15	1249.33	1457.52	1181.3	1471.3	1689.3	1908.9	1267.5	1560.7	1780.5	2001.8
51	5765.31	7740.27	9252.77	10792.29	6329.19	8346.36	9882.11	11440.20	8500.9	10626.7	12223.1	13830.6	9114.2	11260.0	12868.0	14485.3
53	78.52	109.18	133.07	157.65	87.32	118.96	143.42	168.46	3685.1	4605.3	5297.7	5995.7	3960.1	4891.1	5589.9	6293.4
57	2067.39	2870.62	3495.68	4138.07	2297.48	3125.56	3764.83	4418.86	5685.8	7175.9	8305.6	9450.4	6162.7	7682.2	8830.0	9990.5

The land use changes over the last four decade the percentage increase of paved surface area and the runoff quantity summarized in *Table 5.4-2* below.

Table 5.4-2 Summary of paved Land use area percentage with increase in runoff quantity

Year	**1985**	**1995**	**2002**	**2015**
Flow for Akaki river	52.78	62.1	76.398	92.54
Land use change (%age area increase of paved surface) ha	12.64	19.23	25.87	31.16

5.5. Design and checking the capacity of selected drainage structures for different land use

In the previous sections, it was shown that the discharge has been affected by the land use change. Unfortunately, this change is not considered in available design manuals including ERA Drainage Manual. To quantitatively illustrate the underestimation that will happen if the land use change is not considered, 9 different culvert locations were selected.

Design of the drainage structures were done taking the 1985 land use scenario as a base and design the structures for 10-year return period. The sizes sufficient for the peak discharges were calculated using culvert design guidelines in ERA manual. Then, the discharge at those locations for 1995, 2002 and 2015 land use conditions were estimated for the same return period. As can see from the table below, from the structures that are designed for 1985 only 4 structures have the ability to dispose the flood that comes from 1995 land use period. None of the structures were found sufficient to accommodate the flood that was calculated for 2002 and 2015 LU with 10-year return period.

This sample evaluation illustrates how structures designed without considering land use changes properly will be insufficient as the land use pattern changes. This may be one of the reasons for frequent flooding and overtopping of drainage structures noticed every rainy season in Addis Ababa.

Table 5.5-1 Evaluations of drainage structures for the 1985,1995,2002and2015

Culvert ID	Design Discharge (1985 LU)	No of Cell	Height	Span Length	Area	DISCHARGE CAPACITY For 1985	DISCHARGE For 1995		DISCHARGE for 2002	DISCHARGE for 2015
6	20.22	1	3	2	6	16.63	21.93	Not ok	33	41.2
8	30.30	1	3.5	3	10.5	31.43	33.5	Not ok	58.6	74.8
11	29.78	1	3	3.5	10.5	29.1	32.32	Not ok	44.4	56.8
17	18.54	1	3.5	2	7	20.95	19.94	ok	26.6	33.4
19	22.46	1	2.5	3.5	8.75	22.14	24.35	Not ok	33.2	42.4
24	19.83	1	2.5	3.5	8.75	22.14	21.15	ok	24.9	31.5
31	33.74	2	3.5	2	7	41.91	37.17	ok	55.3	72.5
35	10.95	1	2	2.5	5	11.31	12.17	Not ok	18.8	25.1
46	16.89	1	2.5	3	7.5	18.97	18.59	ok	28.8	37.3

5.6. Development of land use change factors on the drainage structure design approach

As it is clearly indicating in the above capacity checking analysis and results most of the drainage structures in the city not able accommodate the new flood coming due to the land use change in the urban area. Therefore, it is essential to see options on our drainage structure design to accommodate the land use change factor. In this study, I tried to have a land use change consideration factor using the number of years for future development and the return period for the design schedule.

The following factor question developed to interrelate the computed peak discharge using the available current land use to convert to the magnitude for the future analysis.

For 10 Year Return Period $$Q_{FLU} = T^{0.015n} Q_{CuLU}$$

For 25-year Return Period $$Q_{FLU} = T^{0.092n} Q_{CuLU}$$

For 50-year Return Period $$Q_{FLU} = T^{0.007n} Q_{CuLU}$$

For 100-year Return Period $$Q_{FLU} = T^{0.052n} Q_{CuLU}$$

Where: Q_{FLU} *Future Land Use Discharge*
C_{uLu} *Current Land Use Discharge*
T Return Period
n number of years

These questions further verified using the peak discharge analysis using the four-decade land use change impacts validation data. When the computed peak discharge for different return period at the sample drainage sites were compare with the results of the SWAT models, It confirmed that the questions well capture the land use change peak discharge variation with 0.6 - 0.98 coefficient of determination and 0.74 – 0.95 Nash coefficient (Table 5.6-1)

Table 5.6-1 the Equation verification for Nash and R^2

		Year-1995	Year-2002	Year-2015
For 10 year return period	R^2	0.602	0.920	0.664
	N_{SE}	0.907	0.833	0.748
For 25 year return period	R^2	0.641	0.930	0.638
	N_{SE}	0.930	0.838	0.737
For 50 year return period	R^2	0.658	0.928	0.643
	N_{SE}	0.939	0.840	0.743
For 100 year return period	R^2	0.695	0.981	0.58
	N_{SE}	0.954	0.846	0.69

Chapter Six

Conclusion and Recommendation

6.1 Conclusions

The Land use change is the major and variable entity which shall be considered carefully when designing the Drainage Structures in Urban Areas.

From the results, it can be concluded that Addis Ababa City had experienced a significant change in land use over the past four decades. Particular change noticed is significant increase of the Impervious area and decrease the forest, the grass land and the Cultivation area due to rapid increase in human population. From the modeling done using these changes, there is significant increase of discharge in almost all the 50 drainage points selected and studied.

The rainfall – runoff analysis was performed using SWAT model for the Akaki watershed in four Set of years separately. The peak discharge for the selected drainage location increases from one to next sets of year. which is 27.46 % for 1985 to 1995, 11.76% for 1995 to 2002 and 7.60% for 2002 to 2015. These peak discharge variabilities confirmed that the land use change has significant impacts on the life services of drainage structures, particularly in urban situation. It also justified the need for considering the impacts of the future land use change, when we design and construct drainage structures, particularly in urban area. This study further tried to introduce future discharge estimation question using the return period and the number of years predicted for land use change and development scenario. Capability of the developed questions also evaluated using statistical performance measures, coefficient of determination (R2) and Nash coefficient (NSE) with arrange of 0.6 -0.98 and 0.74 – 0.95 respectively.

Finally, the study concludes that the significant impacts of land use change on the performance and functionality of drainage structures are significant and it has to be accommodate using some estimation factor for the future land use change. In addition, the proposed future land use accommodation question to be a basis for such kind of works.

6.2 Recommendation

From the findings of the study it was observed that the land use change has significant impact on discharge and hence on drainage structures provided. To mitigate impacts such as flooding and damage to road and infrastructures it is recommended to consider the land use dynamics in design of new drainage structures or evaluation of existing structures.

Thus, the following recommendations are forwarded based on the study results

1. Effect of land use change shall be considered assuming at the patterns of land use change identified in this report
2. As the effect of land use change has an adverse effect on the functionality of drainage structures and consumes additional resource of the country, different mechanisms shall be explored to reduce or reverse the land use change pattern. The measures include afforestation, maintaining the greenery of the city, proposing other ways that can reduce run off.
3. A more detailed study on this subject is also recommended so that more locations of Addis Ababa are studied which will provide a better correlation equation to estimate the effect of land use change on drainage structures.
4. Concerned Governmental Organizations are also advised to include such effect in design of drainage structures

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