

**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**



**Urbanization Impact Assessment on Stormwater Drainage  
Performance of Sebeta Town**

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**A Thesis in Water Supply and Environmental Engineering**

By  
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January ,2020  
Addis Ababa

A Thesis  
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

Urbanization Impact Assessment on Stormwater Drainage Performance of Sebeta Town

The undersigned have examined the thesis entitled ‘Urbanization Impact Assessment on Stormwater Drainage Performance of Sebeta Town’ presented by Ejigayehu Endrias, a candidate for the degree of Master of Science and hereby certify that it is worthy of acceptance.

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**DECLARATION**

I certify that research work titled “**Urbanization Impact Assessment on Stormwater Drainage Performance of Sebeta Town**” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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### ABSTRACT

Sebeta town is one of the rapidly expanding and selected as factories center now a days in Ethiopia. Unfortunately, street flooding and over topping drainage system problems are occurring at the rainy season in a town. The runoff generation in the study area is increasing due to a combination of larger rainfall intensity and more impervious areas. As a consequence several properties have been affected by flooding during heavy rainfall events. The objective of the study is to assess urbanization impact on stormwater drainage performance of sebeta town. To achieve the objectives SWMM model used as method and the total average flow  $0.468 \text{ m}^3/\text{s}$  and total volume to outfalls  $15.840 \times 10^3 \text{ m}^3$  were occurred from all 10 sub catchments. Model calibration and validation were done. The performance of SWMM model was carried out using coefficient of determination ( $R^2$ ), the nash-sutcliffe coefficient ( $R_{NS}$ ) and relative error (RE) the value obtained are 0.95, 0.91 and 12.95% respectively. In order to manage the stormwater LID control method is applied, after LID control provided the discharge values were lesser than that before LID provided. Finally, after the critical locations of overflow are identified, feasibility of suggested LID and their effectiveness in urban flood management are considered. The results of the study shows the urbanization have impact on drainage system. Generally it can be concluded that the drainage system of the study area found to be inadequate due to Inadequate size of the drainage system, improper construction of drainage canal and improper functioning of drainage network due to poor management this leads resulting damages to road surfacing material and flooding problems in the area. For proper disposal of storm water the existing drainage system must be properly managed and clean.

Key words: - Stormwater, Low Impact Development, Urban drainage

## **ACKNOWLEDGMENTS**

First, I would like to thank the almighty God for his unspeakable gift, help and protecting during my work.

Secondly, I would like to express my deepest gratitude and thanks to my advisor Dr. Fisha Behulu for his advice, willingness to consult me at any point of time, encouragement, guidance and support me from the initial to the final level of this thesis.

My thanks also go to my family Endrias Mengesha and Zewditu Tesfaye and to my friends for their endless support.

Finally I, would like to thank National Meteorological Agency and Sebeta town municipality, for their help in providing me with the necessary research data.

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**LIST OF ABBREVIATION**

CSA	Central statistical agency
EPA	Environmental protection agency
GIS	Geographical information system
LID	Low impact development
NMSA	National meteorological service agency
OUPI	Oromia urban planning institute
SUDS	Sustainable urban drainage system
USWD	Urban stormwater drainage
MAMSL	Meter above mean sea level

## CHAPTER 1 INTRODUCTION

### 1.1 General Background

Urbanization is a process whereby populations move from rural to urban area, enabling cities and towns to grow. It can also be termed as the progressive increase of the number of people living in towns and cities. It is highly influenced by the notion that cities and towns have achieved better economic, political, and social actions compared to the rural areas. Moreover, urbanization is a process in which population shift from rural to urban areas, "the gradual increase in the proportion of people living in urban areas", and the ways in which each society adapts to the change (Pawan 2016).

In context to developing countries, most of the urban growth is unplanned and associated with construction of buildings resulting in dramatic increase in impermeable areas. As population grows, demand for housing and commercial facilities naturally follows. The urbanization adds roads, rooftops, parking lots, sidewalks, and other imperviousness to the landscape. Land surface is covered by buildings and pavement; do not allow rain and snowmelt to soak into the ground. Instead, most developed areas rely on storm drains to carry large amounts of runoff from roofs and paved areas to nearby waterways (Bajracary et.al, 2016).

Stormwater (surface runoff) is the major urban flow of concern to the drainage engineer. Safe and efficient drainage of stormwater is particularly important to maintain public health and safety (i.e. attributed to the potential impact of flooding on life and property) and to protect the receiving water environment. Reliable data on the quantity and quality of existing and projected stormwater flows is a pre-requisite for cost-effective urban drainage design and analysis. Stormwater is generated by rainfall, and consists of that proportion of rainfall that runs off from urban surfaces. Hence, the properties of stormwater, in terms of quantity and quality, are essentially linked to the nature and characteristics of both the rainfall and the catchment (Butler & Davies, 2004).

## 1.2 Statements of the Problem

Cities of Ethiopia at large, are troubled with stormwater leading into floods especially during the rainy season due to rapid growth of the urbanization and inadequate installation of desired infrastructure. Storm drainage systems of a city are ideally aimed to handle peak flow resulting from rainfall of return period equal or greater to their design year. Drainage system is expected to function smoothly in handling flow along or across its alignment. Such challenges are also the main issues in Sebeta town especially after the rapid expansion of the urban settlements in the corner of the town.

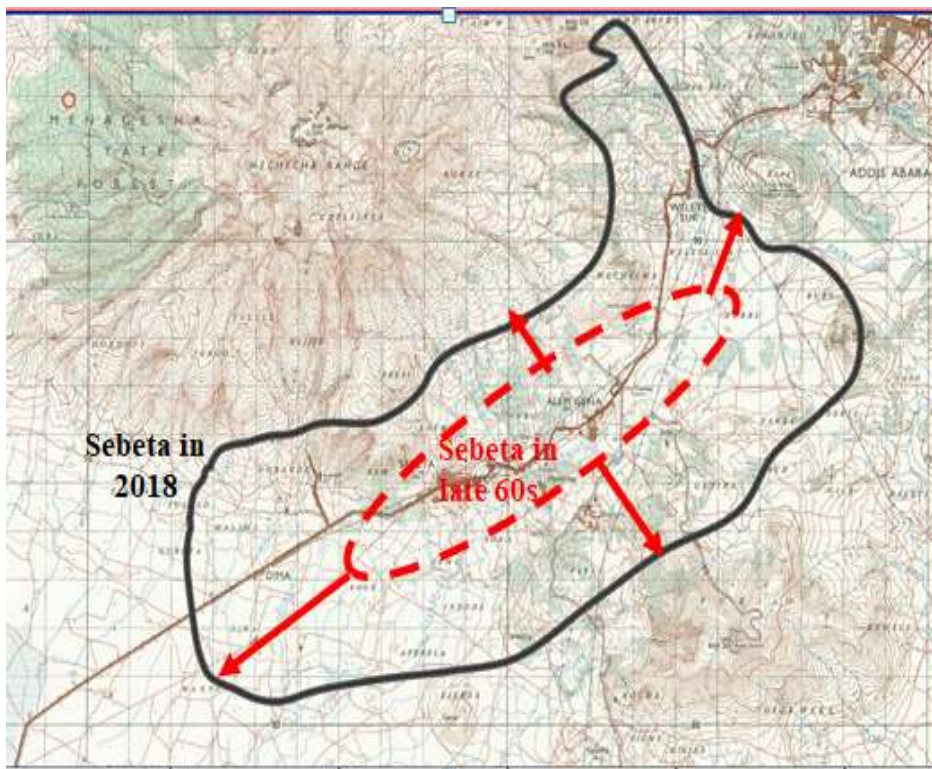


Figure 1-1: Expansion of sebeta town (red dotted color shows old urban boundary and bold black line shows the current boundary)

(Source: Sebeta city municipality,2018)

The risk to the town residents especially in the lower flat terrain was found to be significant. The issue is reflected in frequent damage of infrastructure which in turn resulted in economic impact. Conventionally this problem is being addressed by designing and building drainage infrastructure of larger dimensions to convey flood downstream, if it is being addressed at all. The conventional philosophy of designing large drainage systems is problematic in two regards. First the parameters involved in the design are subject to

continuous change because of the rapid urbanization the city is going through. The second parameters involved in conveying large amount of flow by large drainage infrastructure possess greater exposure at downstream population, even if it protects the immediate infrastructure it is built to protect.

Using a wider range of methods instead of just building a barrier or a conveyance would assure a stronger and dependable flood control solution. This study was aims to identify flood prone area based on impacts of urbanization on stormwater drainage performance of Sebeta town. The modeled area is located on the foot of the Wechecha mountain which is problematic area due to runoff generated from the mountain and increased paved area and this study show how urbanization affect the drainage system by using hydrodynamic models to address appropriate solution.

### **1.3 Objectives of the study**

#### **1.3.1 General Objective**

The general objective of this study is the assessment of urban development on stormwater drainage performance of Sebeta town.

#### **1.3.2 Specific Objectives**

Under the umbrella of the general objective, the study was conducted in view of the following key specific objectives:

- To examine the performance of existing stormwater drainage system of Sebeta.
- To assess the impact of urbanization on the performance of stormwater drainage system of sebeta town.( for different period land development )
- To identify the flood prone area of sebeta using SWMM models.

## **1.4 Research Question**

This research was conducted in line with the following question to be answered:

- What is the performance of existing urban stormwater drainage system of Sebeta?
- What is the impact of urbanization on stormwater drainage system of Sebeta?
- How the urbanization has affected the urban stormwater drainage system?
- What are the appropriate solutions for the encountered problems?

## **1.5 Scope and limitation of the study**

As the impact of urbanization is reflected through both municipal and stormwater waste the effect were more pronounced in low laying areas. Hence, this thesis was only limited to the stormwater effect and does not consider the municipal waste water and solid wastes. Moreover, the stormwater quality may not be considered in this case study. And also the model area covers 64.44 (ha).

## **1.6 Outline of the thesis**

This thesis was compiled in five Chapters. Chapter one contains the introduction, statement of the problem and objective of the Research, and scope and limitation of the study. Chapter two contains Literature review information regarding to urbanization and flooding and description of different models. Chapter three presents a general description of the study area, data collection and materials used, Existing Drainage system, Meteorological data analysis and IDF curve development, Data analysis and Modeling rainfall using SWMM model. In Chapter four the obtained results from the simulations are presented and discussed finally chapter 5 presents, the conclusion and recommendation about the obtained results.

## CHAPTER 2 LITERATURE REVIEW

### 2.1 Historical perspective of urbanization in Ethiopia

While known for its ancient civilization; urbanization in Ethiopia is a recent phenomenon. It is conditioned by historical factors. There is establishments of many medium-sized towns in Ethiopia as a result of socio-political and military reasons (Markakish, 1984) and some due to the establishment of roads connecting Addis Ababa to different parts of the country and in some cases the construction of Ethio-Djibouti railway; whereby towns like Akaki, DebreZeit (Bishoftu), Modjo and Adama (Nazreth) were formed as urban-industrial complex.

Rapid urbanization in East Africa (Ethiopia) poses several serious challenges for planning, city development, living conditions and a great challenge for urban ecosystem sustainability. To sustain their life a number of peoples try to solve their housing needs by getting land informally at the urban fringe. This result has become a problematic consequence for proper land use and planned urban development (Bjørn, 2007). In Africa the rapid rate of urbanization has created several challenges and problems similar to situations in other parts of the world and most of the city are characterized by substandard and inadequate housing and lack of infrastructure, transportation problems, low productivity, poverty and crime (Mabogunje, 2002).

### 2.2 Stormwater

The idea of stormwater is related to urban areas, stormwater also it is interesting regarding the urban water balance. The change of impervious land-cover implies both larger stormwater runoff volumes and peak flows and consequently reduces other components of the hydrologic cycle, e.g. infiltration and evapotranspiration (Adams.J.W, 1980).

Stormwater becomes more important when it comes to flooding since the quantity of water is much higher. The stormwater results from all kind of precipitation (snow melt, rainfall, etc...) and comprises the water flowing in the surface (Butler and Davies 2004). Therefore, the characteristics of both the rainfall and the catchment area represent important factors in the stormwater properties. Indeed, part of the water of the rainfall goes to initial losses as interception, depression storage, infiltration and evapotranspiration. The remaining water is

then run. (Durrans & Haestad Methods, 2003). An important social aspect is to maintain public health and safety, hence an efficient drainage of stormwater and wastewater it is essential to avoid impact of flooding on life and property.

According to Surya Dev Parkash et al., 2016 the global runoff damage and the increasing risk of runoff both in river basins and in urban areas are more. Then, the objectives of runoff management are discovered, where emphasis is given to urban runoff control. Stormwater runoff occurs when precipitation from rain or snowmelt flows over the land surface. The addition of roads, driveways, parking lots, rooftops and other surfaces that prevent water from soaking into the ground to our landscape greatly increases the runoff volume created during storms. This runoff is swiftly carried to local streams, lakes, wetlands and rivers and can cause flooding and erosion, and wash away important habitat for critters that live in the stream. Stormwater runoff also picks up and carries with it many different pollutants that are found on paved surfaces such as sediment, nitrogen, phosphorus, bacteria, oil and grease, trash, pesticides and metals. It comes as no surprise then that stormwater runoff is the number one cause of stream damage in urban areas.

#### ➤ **Historical Perspective of Urban drainage**

Historically, urban drainage systems have been viewed with various perspectives. During different periods and in different locations, urban drainage has been considered a vital natural resource, a convenient cleansing mechanism, an efficient waste transport medium, a flooding concern, a nuisance wastewater, and a transmitter of disease. In general, climate, topography, geology, scientific knowledge, engineering and construction capabilities, societal values, religious beliefs, and other factors have influenced the local perspective of urban drainage. For as long as humans have been constructing cities these factors have guided and constrained the development of urban drainage solutions. Historical accounts provide sights of many interesting and unique urban drainage techniques. (Burian, S. and Edwards, F. 2002)

Urban drainage was firmly established as a vital public works system in the early parts of the twentieth century. Engineers continued to improve design concepts and methods. During the second half of the twentieth century regulatory elements were spread in the United States, Europe, and other locations addressing urban drainage issues. Computer modeling tools advanced the methods used to design and analyze urban drainage systems.

Regulations, monitoring, computer modeling, and environmental concerns have altered the perspective of urban drainage from a public health and nuisance flooding concern during the first half of the twentieth century into a public health and nuisance flooding with additional concerns for ecosystem protection and urban sustainability (Garg, 2005)

Communities worldwide are yet searching for innovative techniques to capture, keep, and use rainwater within the watershed instead of constructing massive drainage structures. Many communities are developing watershed wide stormwater quality management plans to meet the dual objectives of flood prevention and water quality control. Urban drainage has indeed expanded significantly during the past few decades beyond a technical challenge to drain the urban area rapidly to include the consideration of social, economic, political, environmental, and regulatory factors (David Butler and John W. Davies, 2004).

### ➤ **Urban Stormwater Drainage Systems**

The main purpose of an urban stormwater drainage system is to collect stormwater from its catchment and convey it to the receiving waters, with minimum trouble, damage or danger to its operating environment. Traditionally, these systems provide man-made impervious pathways for guiding storm flow over the land surface and underground. Main components of a stormwater drainage system are property drainage, street drainage, trunk drainage, retention basins, detention basins and receiving waters, which are described briefly below (Siriwardene, 2003).

**a. Property drainage:** - The property drainage system collects stormwater from both impervious and pervious surfaces of the properties. Impervious areas consist of surfaces such as house roofs, backyard sheds, garages, driveways, access roads, parking places, tennis courts etc. Pervious areas in urban catchments consist of areas such as residential backyards, parks, playgrounds etc. The stormwater from both impervious and pervious surfaces is connected to the drainage system. The roof is the main impervious portion of a property. The roof drainage system consists of gutters, down pipes, receiver boxes and runoff inlets. Roof gutters have different shapes such as rectangular and trapezoidal gutters. The gutters generally discharge freely into a receiver box, the depth of which can be selected so as to match the use of a downpipe of convenient size. The receiver box is then connected by down pipes. It should be noted that the receiver boxes are used only for large

buildings such as office buildings, schools, factories etc. And not for small houses (Siriwardene, 2003).

**b. Street drainage:** -Streets are normally drained by a network of gutters, pits and pipes. The street drainage system collects runoff from road surfaces as well as land adjoining streets, and discharged to trunk drains. In addition, in some cases runoff from properties is also disposed to the street drainage system (Dayaratne, 2000). The stormwater from the street gutter system enters the underground drainage system through inlets located in street gutters. There are three types of inlets in use, namely curb inlets, gutter inlets and combined inlets. The curb inlet has a vertical opening to catch the gutter flow. Although the gutter may be depressed slightly in front of the curb inlet, it offers no obstruction to traffic. The gutter inlet is an opening covered by a horizontal grate through which stormwater enters. The disadvantage of the gutter inlet is that debris collecting on the grate may block the inlet. Combined inlets, composed of both curb and gutter openings, are also common in urban drainage system. (Dyaratne, 2000)

**c. Trunk drainage:** - The trunk drainage system generally consists of large open channels to convey the runoff from street drainage to receiving waters. Trunk drains serve several sub-areas, which are physically large, and therefore, the overflows are likely to cause direct damage and prolonged inconvenience (Dayaratne, 2000).

**d. Retention basin:** -The retention basin is a small lake located in or off stream along the urban waterways. Retention basins, often known as water quality control ponds at least in recent times, are small lakes located in-stream or off-stream along urban waterways. They can be extremely effective in removing pollutants, since they allow a range of physical, chemical and/or biological processes to take place, which improve water quality. Retention basins hold stormwater for considerable periods, which cause stormwater to be in the hydrologic cycle via infiltration, percolation and evapotranspiration (Siriwardene, 2003).

**e. Detention basin:** - Detention basins are commonly known as retarding and compensating basins. The detention basins hold runoff for short time periods to reduce peak flow rates and later release into natural or artificial watercourses. Therefore, the volume of stormwater runoff is relatively unchanged from the original volume (Siriwardene, 2003).

**f. Receiving water Bodies:** - The major receiving water bodies that are considered in urban drainage include rivers, lakes, bays, and the sea and ground water storages (Dayaratne, 2000).

➤ **Urban Stormwater runoff**

The development of urban areas has a significant impact on urban stormwater runoff and generation due to the replacement of natural green infiltration surfaces (i.e. natural soil cover) with impervious surfaces (such as concrete roads, rooftops and buildings) within cities (EPA, 2009). Due to this, stormwater is transported downstream at a much faster rate (since water moves faster over hard surfaces in comparison to natural surfaces). The result will be that urban areas experience a faster moving runoff flow (with a higher peak flow) that will enter the urban drainage system at a faster rate. But the urban runoff flow will also die away much faster (compared to natural green areas) which will result in a higher peak flow (Butler and Davies, 2004).

The figure below illustrates the difference in runoff volume before urbanization and after urbanization has taken place

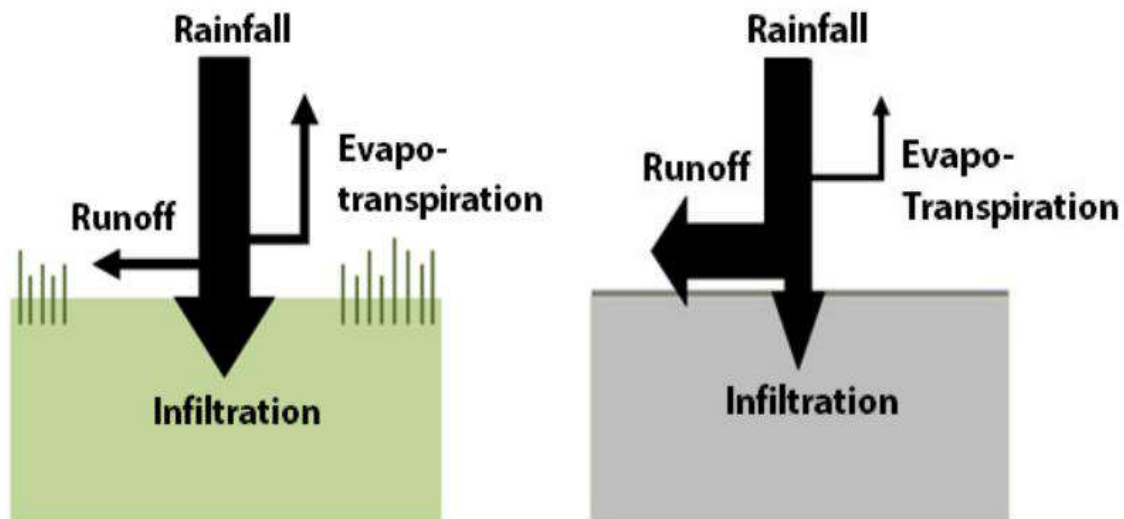


Figure 2-1: Water transport as a result of precipitation before urbanization and after urbanization.

Rainfall is normally measured as intensity (mm/hour) and is representative on a specific location and often recorded together with duration and frequency. Rainfall duration refers to the specific time period for which the rainfall lasts. Rainfall frequency is an expression

of the return period of a similar rainfall event with the same magnitude rate and is normally expressed in years. As an example, if a specific rainfall occurs 25 times during a 100 year period then it has a return period of 4 years (Butler and Davis, 2004). During a rainfall event the intensity is typically the largest at the beginning (i.e. the first hour) and then diminishes with every hour after that (i.e. the intensity reduces with duration). This could be illustrated in an IDF graph (i.e. how rare or frequent a certain rainfall event is) (Butler and Davis, 2004).

### **2.3 Causes and effects of flooding**

Floods generally develop over a period of days, when there is too much rainwater to fit in the rivers and water spreads over the land next to it (the “floodplain”). However, they can happen very quickly when lots of heavy rain falls over a short period of time. These flashfloods occur with little or no warning and cause the biggest loss of human life than any other type of flooding (Vente chow, 1988).

Flooding is described as a condition where wastewater and/or surface water escapes from or cannot enter a drain or sewer system and either remains on the surface or enters buildings. Flooding is often thought of as a result of heavy rainfall, but floods can arise in a number of ways that are not directly related to ongoing weather events. Thus, a complete description of flooding must include processes that may have little or nothing to do with meteorological events. Flooding, by its very nature, is usually a result of both meteorological and hydrologic processes; the character of a flood is determined both by the detailed behavior of the precipitation and by the nature of situation in which the event is likely to occur (soil conditions, amount of antecedent rainfall, and so on). It is not likely that precisely detailed forecasts of flooding events will ever be possible, although it is certainly well within our capability to anticipate the possibility of most flood events. ( Deswell ,1993)

Floodwater can seriously disrupt public and personal transport by cutting off roads and railway lines, as well as communication links when telephone lines are damaged. Floods disrupt normal drainage systems in cities, and sewage spills are common, which represents a serious health hazard, along with standing water and wet materials in the home. Bacteria and viruses cause disease, trigger allergic reactions, and continue to damage materials long after a flood. Floods can distribute large amounts of water and suspended sediment over vast areas, restocking valuable soil nutrients to agricultural lands. In contrast, soil can be

eroded by large amounts of fast flowing water, ruining crops, destroying agricultural land, buildings and drowning farm animals. (Deswell, 1993)

➤ **Effects of urbanization in flooding events**

The evolution of the land use is much related with urban development and the increment of floods derived from it. In the undeveloped areas the water coming from precipitation infiltrate in the soil filling the holes between particles until the storage capacity (saturation) is fulfill. After that, the runoff generation starts on the surface. However, within urbanized areas the paved and other impervious surfaces hinder the capacity of the soil to absorb water. Consequently, the velocity of the runoff is increased leading to sharp peak discharges and greater amount of water in the surface (EPA, 2003).The Figure below show the influence of urbanization in the runoff generation. As can be seen, the water cycle balance is modified since the groundwater table level decreases and the runoff is raised instead.

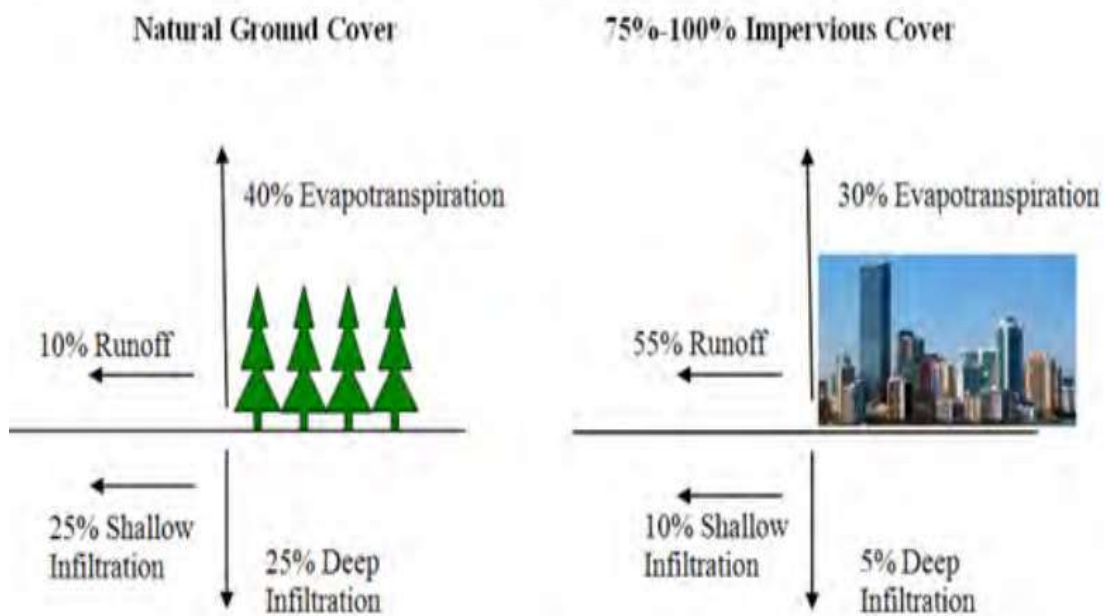


Figure 2-2: Influence of urbanization in runoff generation

(Source: Modified from EPA, 2003)

➤ **Flood Issues of Sebeta town**

Stormwater becomes a hazard when they cause damage to property and death to human beings and livestock. In Sebeta town, floods are frequent phenomena and exerting complicated negative impacts on the residents. Usually flood hazard can have far reaching financial and psychological impacts on the victims. Those who had their houses heavily flooded had to think of resources and time to maintain the damages.

There were also damages occurred to public property such as access roads and schools disrupting inter-town mobility and service delivery in the town. The following Table presents a summary of life loses and property damages cause by flooding in Sebeta.

Table 2-1: Damages caused by flooding in Sebeta town

No	Types of damages	Brief descriptions
1	Loss of human life and injuries	-in 2002, 3 women were taken by flood, 2 risked 1dead -3 years from now a young girl was taken by flood near Gojeb hotel -in 2007 one man was taken by flood
2	Destruction of houses	-More than 1000 homes have experienced different levels of damaged in 2009
3	Loss of household property	-This commonly occurs as thousands of homes are inundated every year in all parts of the town.
4	Damages to business institutions	-Several shops were destroyed in 2008 along which supplies worth thousands

(Sources: - Sebeta city Administration, 2018 G.C)



Figure 2-3: Residential home affected by heavily flood (photo taken in summer 2017)

## 2.4 Urban stormwater drainage models

Combined sewers were constructed in many cities of the United States before 1900 without recognizing the need for segregation and treatment of domestic and industrial wastes from storm runoff (Hall, 1984). Although these systems still exist in older municipalities in the U.S., separate sewers have dominated the construction during the 20th century. Separate systems for stormwater drainage and sewerage are almost universal in Australia. The main purpose of urban drainage systems is to collect stormwater and convey it to receiving waters, with minimal nuisance, danger or damage, at least in the conventional drainage systems. However, in recent times emphasis has been shifted from disposal of stormwater to total management of stormwater, considering stormwater as a resource (CEPA, 1993). In addition to collection and disposal of stormwater, several other objectives are considered in total management of stormwater. These objectives include: limiting pollutants entering receiving waters through water quality control measures such as wetlands; minimizing other adverse impacts of urbanization (e.g. erosion and sedimentation); water conservation in semi-arid and arid areas; integration of large-scale drainage works into overall town planning schemes with multipurpose land-use (such as drainage, recreation or

transportation), and reuse of stormwater. The design methods for urban drainage systems include a wide range from rule-of-thumb methods to computer models. The Statistical Rational method has been commonly used in Australia for computing flows for urban drainage design. However, there is an increased tendency in recent times to use computer models to analyze complex drainage systems (CEPA, 1993).

These models generally consider the major hydrological and hydraulic processes of urban drainage systems such as interception, infiltration (from pervious surfaces), depression storage, overland flow, gutter flow and pipe flow. These computer models can be used for both storm event modeling and continuous simulation. Storm event modeling which considers the generation of flood hydrographs due to a storm is important in urban drainage design. The continuous modeling, which deals with modeling of the drainage system over a long period, is important in estimating stormwater yield, which can be reused. (CEPA, 1993)

➤ **Use of models in urban development**

Computer models are important tools for engineers because they can help perform engineering tasks with speed and accuracy. Numerous computer models exist for urban drainage system analysis and design. Hydraulic models are used to calculate hydraulic processes in the network and describe water flow and pressures in pipes and channels in the network. This is also called the routing. Computer-based hydraulic models are used for accurate design, sizing and analysis of sewer. This is done by dividing the catchment into sub-catchments and connecting the sub-catchments to the nodes in the network.

Simulation modeling of urban drainage systems is aimed at understanding and predicting the behavior of the systems so that effective solutions to structural and operational problems can be tried out and evaluated. Modeling is part of a much larger process of handling the information associated with a water-based asset. (Shamsi, 2005)

Urban drainage modeling approaches contribute to an improved process understanding of the Sustainable urban drainage system practices in flow mechanism, sources of pollutants reduction, cause of flooding, water quality measuring and facilitate the application of integrated urban drainage system in the field with respect to water quantity and quality simulations, sustainable drainage device modeling and spatial planning. (Shamsi, 2005)

Urban drainage models contain functions on hydrological and hydraulic simulation in terms of rainfall generation and runoff routing and capable of simulating the drainage network hydraulics. Regarding the ability to incorporate sustainable devices, most models can be used to investigate reduced imperviousness, ponds and wetlands, infiltration trenches and swales.

➤ **Model selection**

When choosing a suitable model, it should first be considered if it is possible to use the model in respect of investments in time and money. It should then be considered whether the model gives the desired output data required for the study and if the input data required is possible to obtain within a reasonable amount of time and price (Beven, 2003).

A complex model often requires more input data than a simple model, while a simple model with fewer input data instead may not be specific enough for the study. It is therefore important to select a good combination of model complexity and available input data (Shamsi, 2005). Finally, it should be considered whether there are limitations in the model that will affect the results (Beven, 2003).

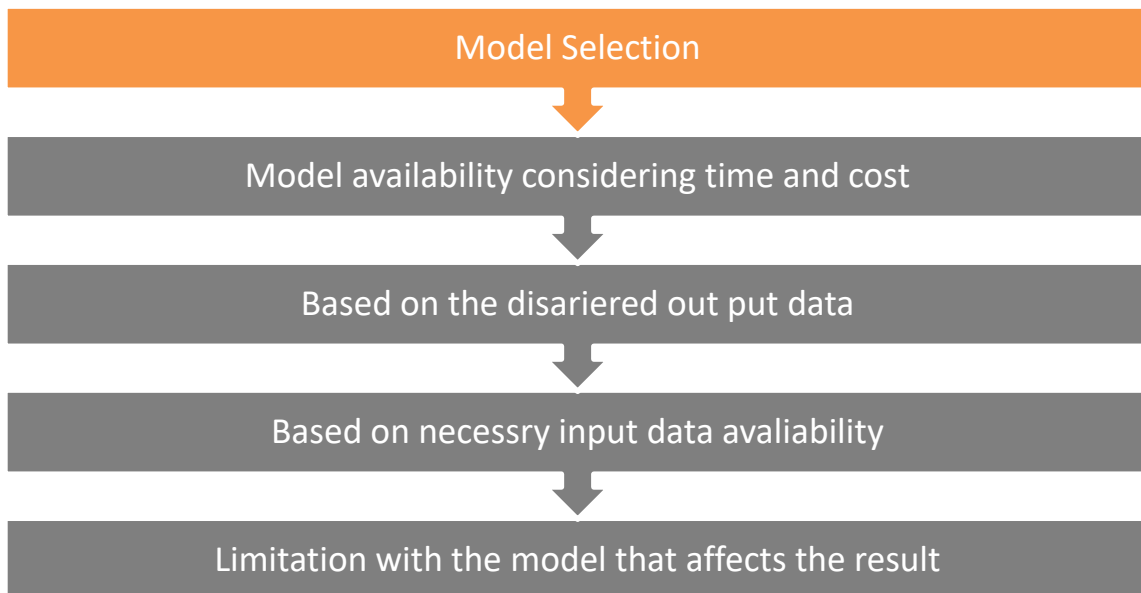


Figure 2-4: Steps to choose a proper model

For Simulation of runoff there are more models to simulate. Like SWMM5.1, ARC SWAT and HEC–HMS models. From those models based on the above mentioned criteria for this Study I select SWMM5.1 (stormwater management model) because this software is more

comfortable for flood modeling and analyses to fix the drainage size by considering the pervious and impervious areas. The model is readily available, relatively less time consuming and no need of money to gain this model. But Arch SWAT Software is used to model and analyze flood especially for rural areas with a large catchments and HEC-HMS is used to simulate the discharge of a river.

## **2.5 Stormwater management systems**

Stormwater management system is a tool for managing stormwater runoff from rainfall. Naturally, this water flows from fields to stream from stream to rivers and so on. However, development has changed some of these natural flows and has led to overflowing concerns. As a result, stormwater management system is required in order to deal with the overflows. Therefore, a sustainable stormwater management on the street has a potential to bring street comfort through shading and reducing peak stormwater runoff volumes (Gebrewahed, 2016). Archaeological evidence reveals that drainage was provided to the buildings of many ancient civilizations such as the Mesopotamians, the Minoans (Crete) and the Greeks (Athens). Historical accounts show that the objectives of the drainage systems were to collect rainwater, prevent flooding, and convey wastes. Urban drainage was firmly established as a vital public works system in the early parts of the twentieth century. Engineers continued to improve design concepts and methods.

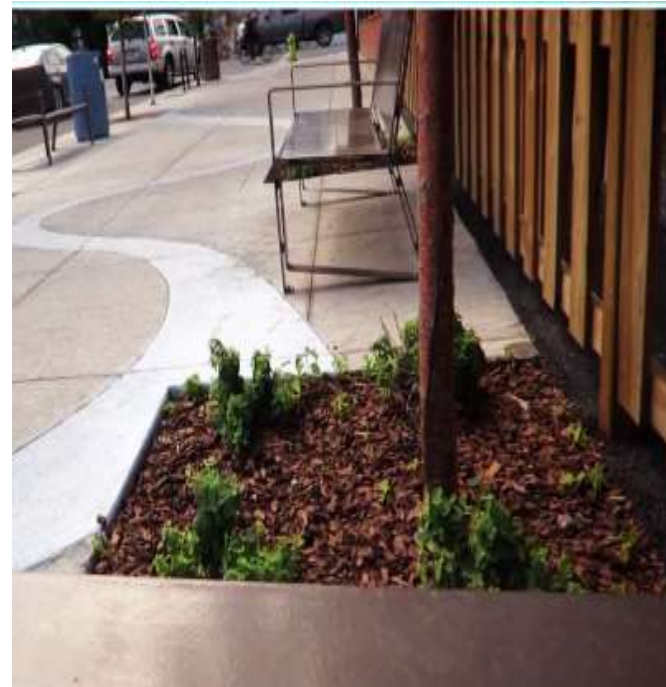
During the second half of the twentieth century regulatory elements were spread in the United States, Europe, and other locations addressing urban drainage issues (Alemu, 2017). First stormwater management systems were found in Greece or even in the Mesopotamian Empire. Stormwater runoff systems experienced various changes until sewer network system were established in the 19th century. Their concept was to collect waste and stormwater in urban areas and dispose it outside as fast and as fully as possible.

Depending on in which country you are looking to, the ways of stormwater management system have different name such as Sustainable Urban Drainage Systems (SuDS) in United Kingdom, Low Impact Development – (LID) in United States, Best Management Practice – (BMP) Canada and United States as well, and Water Sensitive Urban Design (WSUD) in Australia. But this technique basically plays an equally important role of integrated way of taking care of storm water

## Urbanization Impact Assessment On Stormwater Drainage Performance of Sebeta Town

There are 7 typical LID controls that can be modeled in SWMM model. The LID practices that are included in SWMM are bio-retention, permeable pavement, rain garden, rain barrel, infiltration trench, rooftop disconnection, vegetative swale, and green roofs. Each LID in SWMM model has a variety of process layers such as: surface, soil, storage, and drain. (USEPA,2000). This study explains the modeling techniques of bio-retention cell, permeable pavement and infiltration trench.

- Bio-retention cell is the most widely applied LID practice throughout the U.S., which restores the natural system function by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source (Davis et al., 2009). Bio-retention cell consists of a grass buffer strip, a sand bed, a pond area, an organic layer of mulch, planting soil, and plants. Runoff water passes across the length of the pond area which consists of organic substance. Later, water infiltrates into planting soil and sand beds



(USEPA, 2000).

Figure 2-5: Bio-retention

- Infiltration trenches are excavated trenches that are filled with rock, or other relatively large granular material, or commercial void forming products. A geotextile is used to provide separation between the trench media and the surrounding soil. They normally have a rectangular vertical cross-section and are usually designed to receive stormwater runoff from adjacent properties and transportation links such as asphalt roads and footpaths (Debo & Reese, 2003, Stormwater permeates through the voids in the trench and is temporarily stored. Over a period of time this water infiltrates into the underlying soil and replenishes the groundwater (Hobart City Council, 2006).



Figure 2-6: Infiltration trenches

- Permeable pavements refer to pavements that are constructed in such a manner that they promote the infiltration of stormwater runoff through the surface into the sub-layers and/or underlying strata. There are many alternatives for the load-bearing surface material including: permeable concrete block pavers (PCBP), brick pavers, stone chip, gravel, porous concrete and porous asphalt. The latter two are also referred to as porous pavements. In places with suitable climates and low traffic loading even grass can be used with or without reinforcement as the situation demands. Patented open celled concrete grass pavers or cellular plastic grids are often used for the reinforcement of the grass surface layer. Permeable paving surfaces are suitable for pedestrian and vehicular use, and can be modified to carry heavier loadings (Taylor, 2003).

Permeable paving is generally constructed on a coarse gravel sub-base which creates temporary storage facilities and allows stormwater runoff to infiltrate into the underlying stratum, promoting the recharge of the groundwater table (Stahre, 2006). Stored rainwater can be reused for several domestic purposes typically gardens and lawns (Hobart City Council, 2006). Sub-drains can be utilized to improve collection. Permeable pavements generally do not remove litter and other debris from stormwater runoff as this is left on the surface; however this provides an opportunity for it to be collected through street-sweeping.



Figure 2-7: Permeable pavement

### **Necessity for managing storm runoffs**

“When rain falls on a natural landscape, it soaks into the ground (infiltration), evaporates, is taken up by plants (evapotranspiration) and some of it eventually finds its way into streams and rivers. These stages of the water cycle can be approached when land is altered by development in urban areas, there tends to be less permeable ground available for infiltration and less vegetation for evapotranspiration. When rain falls on impermeable surface, much more turns into surface water runoff, which can cause flooding, pollution of natural water ways and erosion problems” (Woods, 2015).

According to the results of (WPP, 2015) In July 2015, world population reached 7.3 billion has added one billion people since 2003 and also According to the medium projection variant, it is still expected to reach 8.5 billion in 2030, 9.7 billion in 2050 and 11.2 billion in 2100”. As per the projection, such increases are expected to occur mainly in Africa, which has high fertility, growth of concentration of population towards cities through local migration (rural to urban). In combination of the impacts of rapid population growth (Association, 2002) originally states and (Iwona Wagner, 2008) develop the reasoning of world’s water resources, endangered by the ultimate growth of population, expansion of infrastructures, rooted as consequences while peoples seek for better living standard which initiates migration and potential domination of urban over rural settlements. This makes even harder to the governmental authorities to manage and fulfill the demand of the population residing in cities. As responsible agents failed to do so, Simultaneous constraints enclose the harmony of nature and enforce a complex negative change in environment. Similarly (Damien Tedoldi, 2016) used, the Source of drinking water (surface and ground water) and receiving streams as examples, are facing adverse pollution impacts in which abundant urban-sourced contaminants are transported within Stormwater and soil.

Necessity of stormwater management doesn’t only define or reflect the importance of drainage system, broadly indicates a multiple benefit from well-managed Stormwater to the ecosystem, and withstands poor or choked drainage systems and rapid runoff as such conditions are unable to overcome incidents such as damaging and disruptive flooding result from local heavy rains.

## 2.6 Previous studies on drainage related issues in Ethiopia

The Drainage problems in Ethiopian urban centers include flooding, deterioration of roads, land degradation, sedimentation, and blockage of drainage facilities, water logging and the like. Some studies that had conducted in different parts of Ethiopia shown that there were stormwater drainage problems and some of them are reviewed in this section.

Table 2-2: Stormwater drainage related studies in Ethiopia

No	Topic	Author (year)	Study area	Model used	Finding
1	Hydrologic and Hydraulic Adequacy Assessment of Drainage Structures in Bill Town	Yonas (2019)	Bill Town	SWMM5	There are node flooded, stormwater network system has been not well planned and has not sufficient carrying capacity to satisfy the simulated rainfall event.
2	Performance Assessment of Stormwater Drainage Systems. (Case Study of Deber Berehan Town)	Eyosias (2018)	Deber Berehan	SWMM5	All of the modeled drainage systems are flooded for each event scenario rani.
3	Sustainable Stormwater Management by Implementing low impact development in Jemo, Addis Ababa	Kidist (2018)	Addis Ababa	SWMM5	The drainage system found to be inadequate due to insufficient junction profile.
4	Assessment of Stormwater drainage System in Kemise Town	Biniyam (2016)	Kemise Town	GIS	The stormwater drainage facilities are inadequate to convey the peak discharge for required design period and the drainage system filled by sediment and other rubbish materials.
5	Road and urban stormwater drainage network integration in Addis Ababa (Case Study of Addis Ketema Sub-city)	Dagache w (2011)	Addis Ababa	—	There is lack of adequate integration between road and urban stormwater drain lines followed by blockage of existing channels by solid wastes.

## CHAPTER 3 MATERIALS AND METHODOLOGY

### 3.1 Description of study area

#### 3.1.1 Location

Sebeta is found in Oromia Regional State, south west of Addis Ababa at a distance of about 24 km along Addis Ababa - Jimma tarmac road. The town is the capital of Sebeta-Awas district of Oromia special zone surrounding Addis Ababa. The town is divided into 9 kebeles, namely Sebeta (01), Alemgena (02), Welate (03), Furi (04), Dima (05), Daleti (06), Rogie (07), Kerabu (08) and Furi Gera Bollo (09). From hydro-meteorological setting points of view, Sebeta is found in the Awash River Basin, a basement depression being its sub-drainage. Its proximity to Addis Ababa has made the town a favorable residential site whereby attracting many more inhabitants and enormous capital investment. It is located in the central highlands of Ethiopia within latitude  $8^{\circ} 52'$  to  $8^{\circ} 57'N$  and longitude  $38^{\circ}33'$  to  $38^{\circ} 42'E$  covering total area of 9,827 hectares.

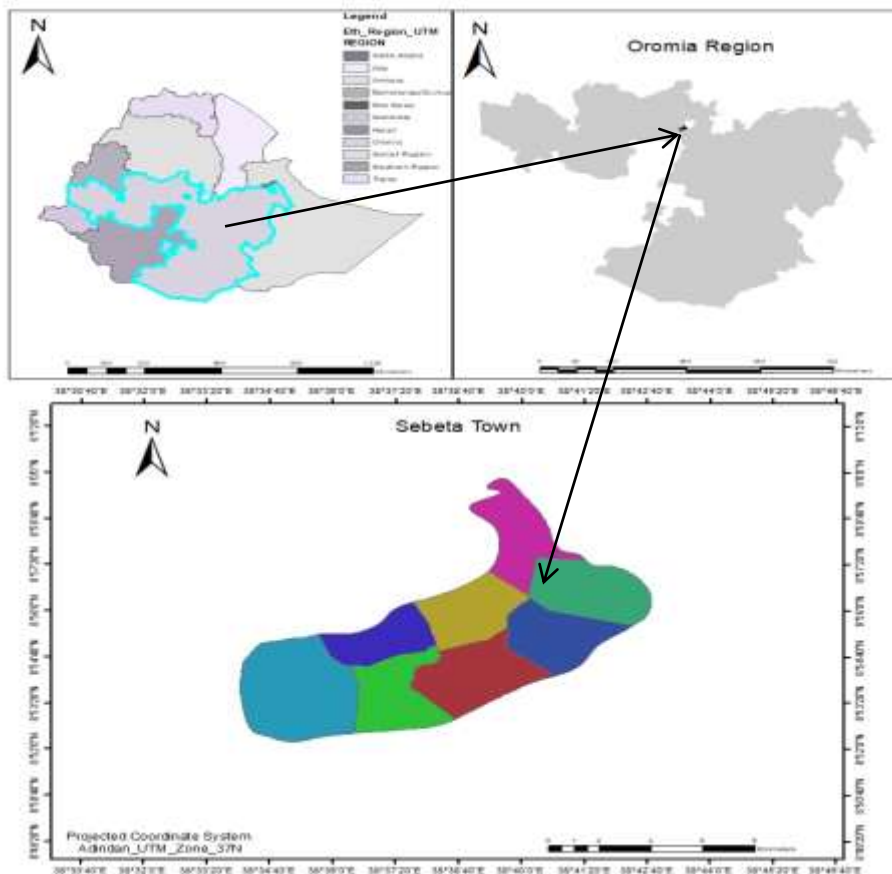


Figure 3-1: Location map of study area

Source: (ARC GIS)

### 3.1.2 Population

The population of Sebeta town based on the 2007 national census data is estimated to be 256,868 from these males are 127,859 and the remaining 129,009 are females. The population of the town becoming increasing from time to time in relation with the town development in investment, trade and other activities (CSA,2007). From 256,868 populations of Sebeta town 38,949 population is found in Furi kebele (Sebeta town administration office).

### 3.1.3 Topography

The topography and landform of Sebeta town is also characterized by natural drainage that comprises both perennial and intermittent streams emanating from the hills near the town. The three hills (i.e. Wechecha, Repi and Furi) are significant land features that forms part of the development of the town on one hand and interrupted the continuity of developments on the other hand through its contribution of high flow.

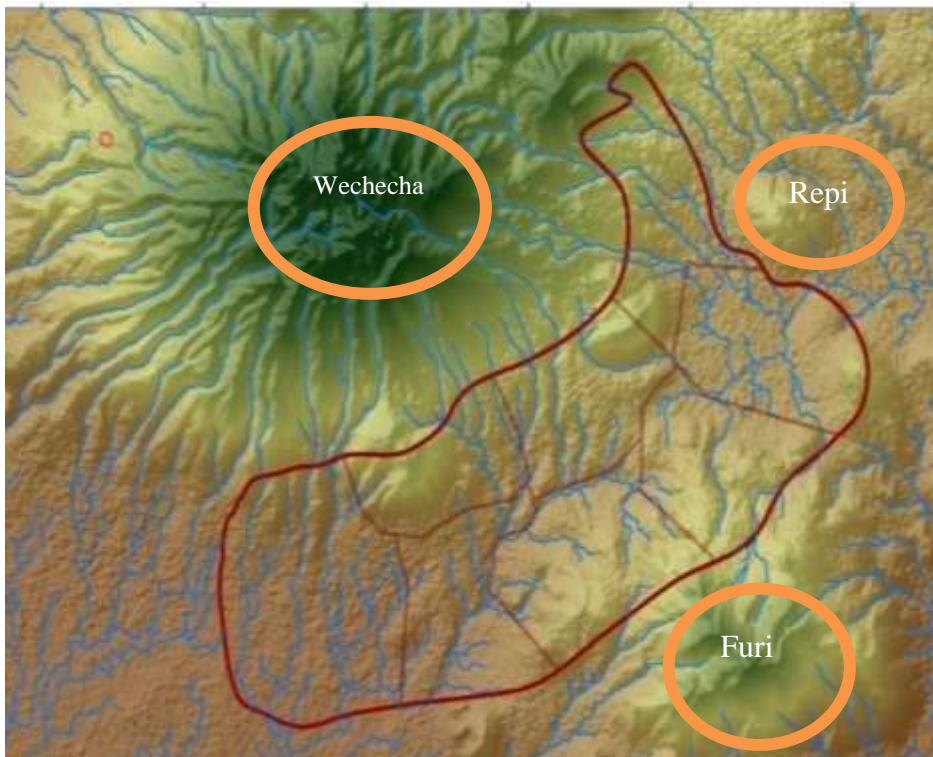


Figure 3-2: The three hills surrounding the town  
(Source: ARC GIS)

### 3.1.4 Land use of the town

Land use planning is one of the most important planning tool for provision of municipal infrastructure and other facilities. It also helps for reducing urban problems and managing built up areas. From the total area of the town that covers 9827 ha, residence receives 43%, green area and industry that covers 29% and 11% respectively. The remaining 17% of land has been allocated for five land use categories for Commerce, Administration, Infrastructure, Service and Urban agriculture.

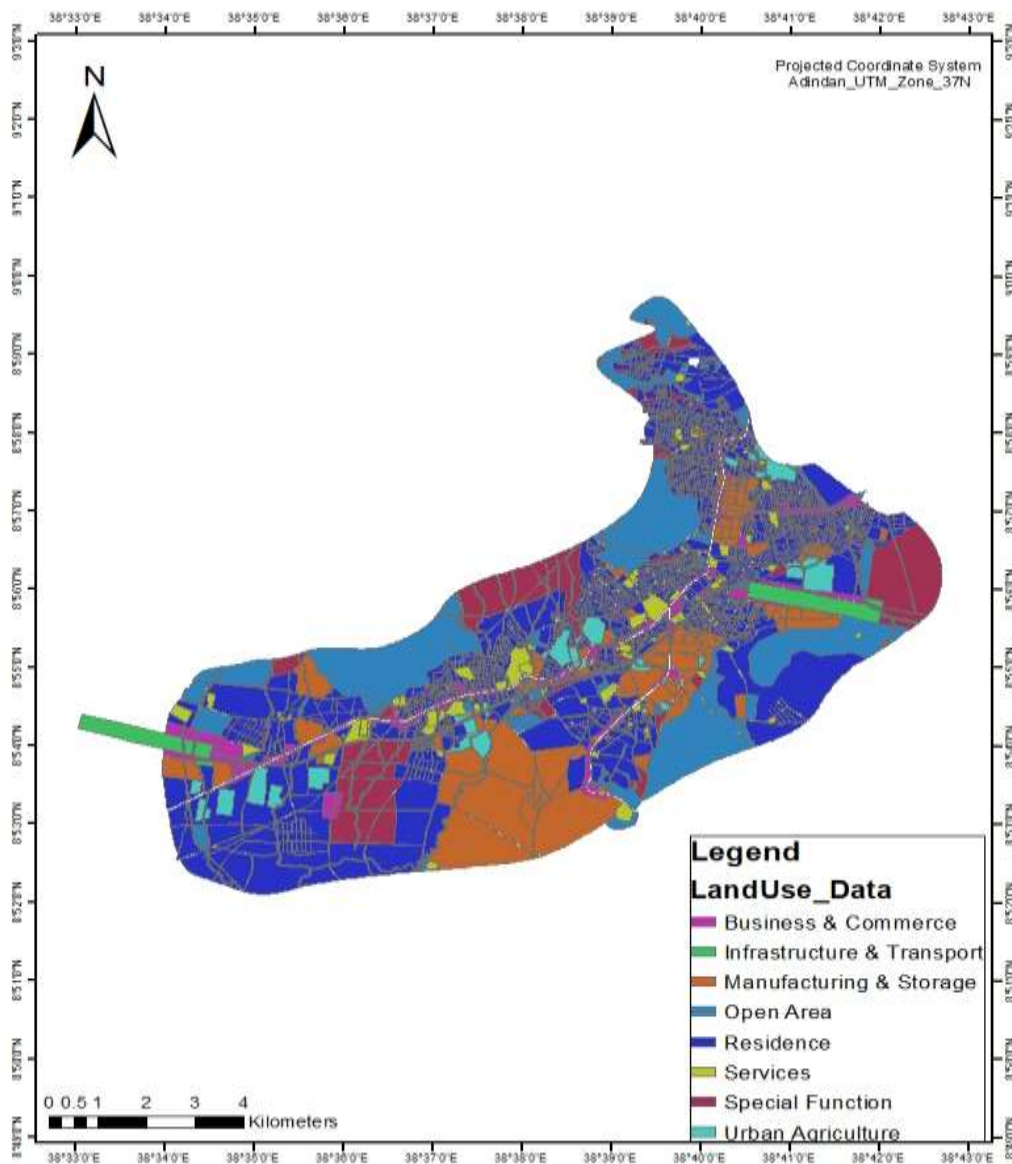


Figure 3-3: Existing land use map of Sebeta  
(Source: Sebeta town municipality, 2018 G.C)

### **3.1.5 Climate**

As per the Ethiopian customary climate classification the town is classified as “Dega” climatic zone with average temperature range of 12.7 °c to 24.4 °c. The town has five rainy months; from March to April and from June to September that make two rainy seasons of spring and summer respectively. Winter is a dry season in Sebeta.

### **3.1.6 Altitude**

Sebeta area has an altitudinal range of 2050 to 2670 MAMSL. The northern part of the town is characterized by mountain ranges lying between 2600-2670 MAMSL. However, the southern part of the town lies between 2060 -2120 MAMSL. Hills and steep slopes are bounding the town in the northwestern, northern and eastern and southern part with moderate and gentle slopes spanning towards the town.

### **3.1.7 Vegetation**

Eucalyptus trees are found in mountain and open spaces and within homesteads, whereas shrub and bush, reverie and other plantation forests are slightly available. Furthermore, community and government protected forests are available. There are nursery sites in Sebeta River mouths owned by Addis Bah project.

### 3.2 Data collection and materials used

#### 3.2.1 Data collection

This research involves collection of both primary and the secondary data and was also including information from respective organization. Primary data was collected from personal field observation/site investigation and Google earth data with the help of a base map. Secondary data was collected through Literature studies and document analysis. Several printed books, journals and manuals were used; in addition to that, internet was the major instrument to access government documents and different journals. The major collected secondary data includes.

Table 3-1: Data collected and their sources

Type of Data	Data source
Metrological data	National Metrological Agency Addis Ababa Ethiopia
Master plan and Road Network	Sebeta town municipality
Digital Elevation Model (30*30 resolution)	Ministry of water, Irrigation and Energy, Addis Ababa Ethiopia
Land use map	Sebeta town municipality
Contour map	Sebeta town municipality

#### 3.2.2 Materials used for field data collection

Data's need for this study collected from different source but those field data collected using different materials as shown in the table below.

Table 3-2: Materials used for field data collection

No.	Material Type	Purpose
1.	Tape measure	To measure the existing urban stormwater drainage facilities and flow depth.
2.	Sebeta map	To investigate the overall conditions of urban stormwater drainage system, natural water ways/rivers and integration of stormwater drains and roads in the study area.
4.	Contour map	To examine the elevation of the catchment areas.

### 3.3 Existing drainage system

The existing drainage infrastructure system in Sebeta town comprises two types: (i) natural streams, (ii) artificial drainage channels.

#### ➤ Existing natural drainage system

The streams that crosses Sebeta town are mainly emanate from Wechecha Mountain which flows to the south west and south east direction. Kebele 03 (Welete), Keble 04 (Furi) and part of Kebele 08 (Kerabu) are drained by the streams that flow towards Akaki sub-system. The remaining five kebeles are drained by streams that contribute to Atebala River before it reaches to Awash River at Melka Kunture.

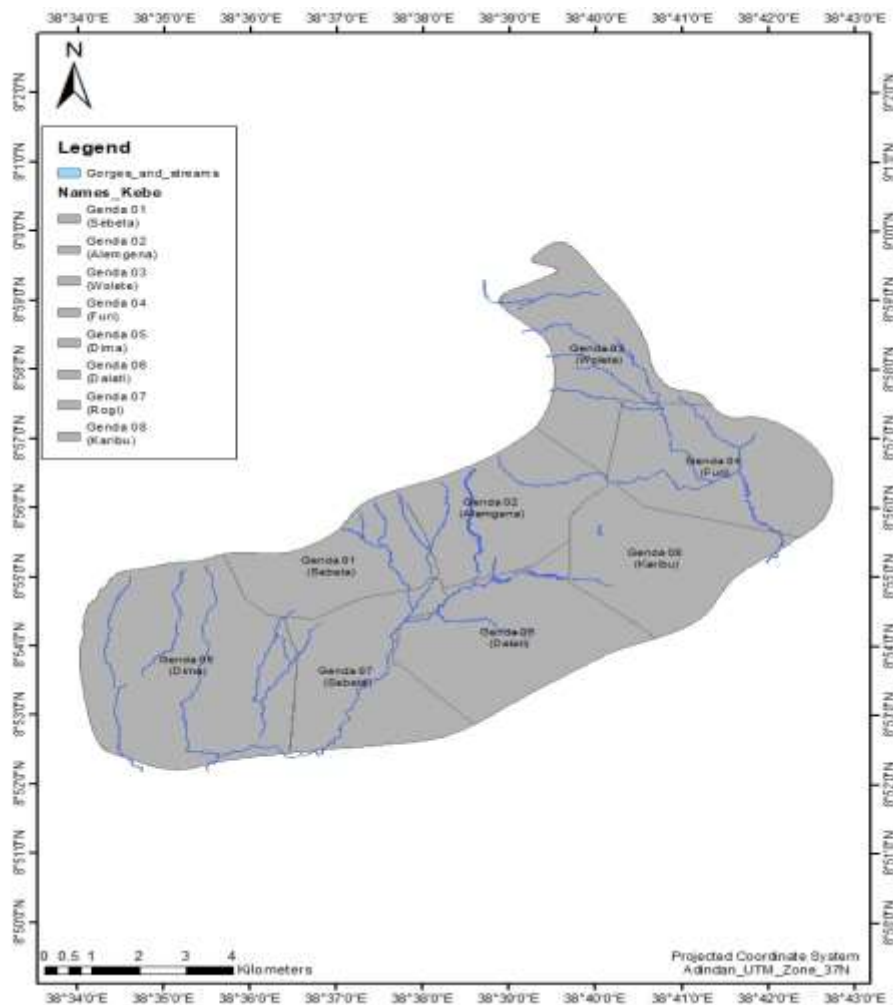


Figure 3-4: Existing Natural drainage networks of Sebeta town

(Source: Sebeta town municipality, 2018 G.C)

➤ Existing Man-Made Drainage System

The existing natural streams in the town are connecting with artificial (man-made) drainage infrastructures for the disposal stormwater from the different land use areas of the town. Sebeta town has got an aggregate of 265.9 km long drainage network over the entire town. From sit investigation, Kebele 04 has got quite long drainage network.

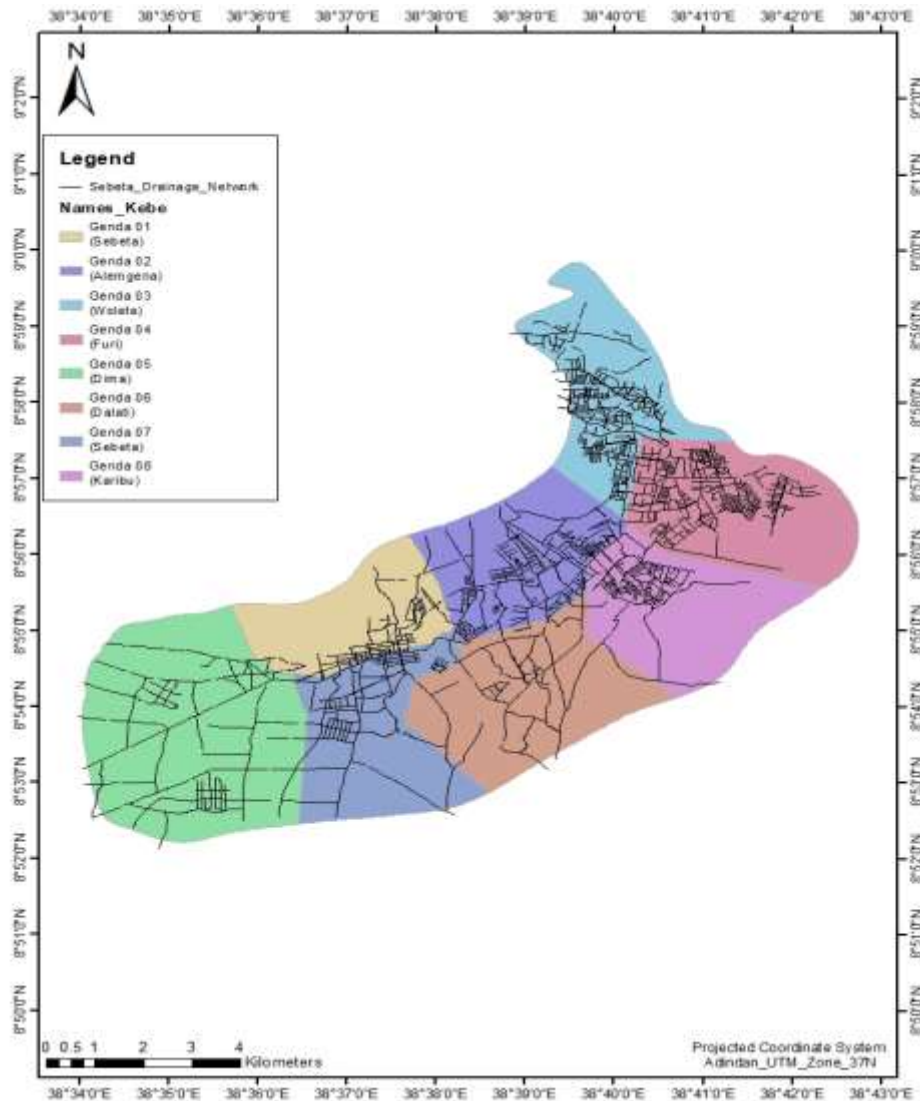


Figure 3-5: Existing artificial drainage networks of Sebeta town in each Kebeles.

(Source: Sebete town municipality, 2018 G.C)

### **3.4 Meteorological data analysis and IDF curve development**

In order to apply flood estimation models for peak discharge computation using available rainfall data, the rainfall depth-duration-frequency relationship is required. Available rainfall data at Sebeta and nearest stations had collected and analyzed using two commonly adopted methods of distribution analysis namely Log Pearson-III and Gumbel's Methods.

#### **3.4.1 Data Quality Control**

##### **A. Estimating missing rainfall data**

Due to the absence of observer or instrumental failure rainfall data record occasionally were incomplete. In such a case one can estimate the missing data by using the nearest station rainfall data. There are different approaches for estimating missing rainfall data varying with and based on the effect of topography on rainfall, distance between the rainfall stations and the variation of rainfall amount recorded on the stations. For this study I was used correlation method by this method I correlate 3 nearest station from those I was selected correlation value nearest to one to fill the missed values.

##### **B) Test for outliers**

An outlier is an observation that deviates significantly from the bulk of the data, which may be due to errors in data collection, or recording, or due to natural causes. Check on outliers has been undertaken on the recoded rainfall data to identify any low or high outliers. The presence of outliers in the data causes difficulties when fitting a distribution to the data. Low and high outliers are both possible and have different effects on the analysis (Rao and Hamed, 2000) The retention or deletion of these outliers can significantly affect the magnitude of statistical parameters computed from the data, especially for small samples.

The annual maximum daily rainfall data of Sebeta from the meteorological station starting from 1998 to 2017 was taken for the design. Hence, 20 years of daily rainfall data is available. These data was also checked for its consistency by higher and lower outlier testes using the equations As it is cited in Rao and Hamed (2000) Grubbs and Beck (G-B) (1972) test is used to detect outliers. In this test the quantities  $X_H$  and  $X_L$  are calculated using the following equations.

- Test for Higher outlier

$$X_H = \exp(\bar{X}) + K_n * S \quad (3.1)$$

- Test for Lower outlier

$$X_L = \exp(\bar{X}) - K_n * S \quad (3.2)$$

Where:  $\bar{X}$  and S are the mean and standard deviations of the natural logarithm of the Annual daily max rainfall respectively and  $K_n$ , is the G-B statistic tabulated for various sample sizes and significant levels by Grubbs and Beck (1972). At 10% significant level, the following approximation proposed by Pilon et al. (1985) is used, where N is the sample size.

$$K_n = -3.62201 + 6.28446N^{1/4} - 2.49835N^{1/2} + 0.49146N - 0.037911N^{3/4} \quad (3.3)$$

Sample values greater than  $X_H$  are considered to be high outliers, while those less than  $X_L$  is considered to be low outliers.

### C) Reliability assessment

Standard error less than 10% the data series could be regarded as reliable or adequate data (Subramanya, 2008).

$$E = \frac{C_v}{\sqrt{N}} * 100 \quad (3.4)$$

Where: E=Standard error

$$C_v = \text{Coefficient of variation } \left( \frac{\sigma}{\bar{X}} \right)$$

N = No of years rainfall recorded

Table 3-3: Data reliability result

Standard error	5.85	< 10%
Test	Adequate data	

### 3.4.2 Analysis of Design Rainfall

#### i. Design Rainfall Computation of Shorter Duration

These rainfall analyses and processing is aimed at determination of appropriate Intensity-Duration Frequency relationship. Extreme rainfall depth at Sebta town station for different return periods was determined using Log Pearson Type III distributions and Gumbel method analysis (Subramanya, 2008).

#### A) Log Pearson Type III distributions

$$X_T = 10^{Y_T} \quad (3.5)$$

$$Y_T = \bar{Y} + K_T * S_y \quad (3.6)$$

$X_T$  = Rainfall depth at return periods T years

$\bar{Y}$  = Mean value of logarithmic Annual daily maximum rainfall [mm]

$K_T$  = frequency factors (From table depend on coefficient of skew (Cs) and return period value (T))

$S_y$  = Standard deviation of logarithmic Annual daily maximum rainfall [mm]

#### B) Gumbel method analysis

$$X_T = \bar{X} + K_T * \sigma_x \quad (3.7)$$

$X_T$  = Rainfall depth at return periods T years

$\bar{X}$  = Mean value of Annual daily maximum rainfall [mm]

$\sigma_x$  = Standard deviation of Annual daily maximum rainfall [mm]

$K_T$  = frequency factors expressed as:-

$$K_T = \frac{-\sqrt{6}}{\pi} \left[ 0.57721 + \ln \left\{ \ln \frac{T}{T-1} \right\} \right] \quad (3.8)$$

**ii. Intensity-Duration-Frequency (IDF) Curves**

The IDF relationships are used when designing drainage works for any engineering project, and allow the engineer to design safe and economical flood control measures. The rainfall depths obtained from gauging station are 24hr duration depth. Design and analysis of drainage structures require rainfall-intensity-duration relationship of shorter duration. Because rainfall data of shorter duration is unavailable, appropriate IDF derivation for shorter duration is required. ERA (2013) suggests the following equation.

$$R_{Rt} = \frac{t}{24} \left[ \frac{(b+24)^n}{(b+t)^n} \right] \quad (3.9)$$

Where:  $R_{Rt}$ = Rainfall ratio ( $R_t$ :  $R_{24}$ )

$R_t$  = Rainfall in a given duration (hr)

$R_{24}$  = Rainfall in 24 hours,

Based on studies of a large number of rainfall gauges in East Africa, the average values of b and n are found to be 0.3 and 0.9 respectively. These values have been adopted for this study IDF development. (M. L. Waikar\* and Undegaonkar Namita U, January, 2015)

$$R_t = \frac{t}{24} \left[ \frac{(b+24)^n}{(b+t)^n} \right] * R_{24} \quad (3.10)$$

Finally Intensity (mm/hr)

$$I_t = \frac{R_t}{t} = \frac{R_{24}}{24} \left[ \frac{(b+24)^n}{(b+t)^n} \right] \quad (3.11)$$

I was used the above equations to develop IDF curve for the shorter duration events. From the frequency analyses Gumbel method analysis is better  $R^2$  value, so for this study Gumbel method analysis was selected. Using the trend line equation obtained from Gumbel method analysis of frequency analysis, i.e.  $y = 6.9089x + 33.229$  where y is 24-hour rainfall depth ( $R_{24}$ ) of a return period x under consideration, 24 hour rainfall depth( $R_{24}$ ) was calculated for 2, 5, 10, 25, 50 and 100 year return period.

### **3.5 Modeling Rainfall Using SWMM model**

SWMM model stands for Stormwater Management Model. All aspects of the urban hydrologic and quality cycles are simulated, including surface runoff, transport through the drainage network, storage and treatment. Like most hydrologic models, SWMM model subdivides the overall catchment into sub catchments, predicting runoff from the sub catchments on the basis of their individual properties, and combining their outflows using a flow routing scheme (EPA, 1992).

The SWMM (stormwater management model) was first developed in 1971 and it continues to be widely used throughout the world for planning, analysis and design of stormwater runoff, combined sewers, sanitary sewers, and other drainage systems. SWMM simulates hydrology, hydraulics and water quality of urbanized and non-urbanized watersheds. The hydrologic processes modeled include precipitation (rainfall or snow fall), evaporation, surface runoff, infiltration, groundwater flow, and snow packs and snow melt. Both single event and long-term (continuous) simulations can be performed accounting for spatial and temporal variability in the climate, soil, land use and topography in the watershed (Rossman 2010).

#### **a) Description of SWMM Model**

SWMM model is a comprehensive computer model for simulation of urban runoff quantity and quality in storm and combined sewer systems. (U.S. Environmental Protection Agency, 1992)

In SWMM model the following objects might be arranged together to represent a stormwater drainage system:-

- i) Sub-catchments: It usually divides into pervious and impervious sub-regions. The following infiltration models such as Horton Infiltration, Green Ampt Infiltration and SCS-curve number Infiltration are described for the analysis of the pervious zone. In SWMM model sub-catchment includes assigned rain-gage, outlet node, assigned land uses, tributary surface area, percent of imperviousness, slope, characteristic width of overland flow, Manning's n for overland flow on both pervious and impervious area, depression storage in both pervious and impervious areas, percent of impervious area with no depression storage.

- ii) Junction nodes: It represents the convergence of natural surface channel, manholes in a series system or pipe fittings. The primary input parameters for a junction are invert elevation and height to ground surface.
- iii) Conduits: They are pipe or channels move water from one node to another node. The common shapes of conduits define in SWMM model are rectangular, trapezoidal, or user-defined irregular cross section shape.
- iv) Outfall Nodes: These are terminal nodes define the final downstream boundaries under dynamic wave flow routing. It behaves as junction for other flow routing. The input parameters for outfall nodes include invert elevation,
- v) Rain-gages: This provides the rainfall data type, recording time interval, source of rainfall data, and name of rainfall data sources. It is essential that rain gages be located within and adjacent to the catchment

In SWMM model subcatchments are represented mathematically as spatially lumped, nonlinear reservoirs and their outflows are routed via the channel/pipe. Sub catchments are subdivided into three subareas, impervious area with and without depression storage and pervious areas with depression storage. Flow from one subarea is not routed over another subarea. Overland flow is generated from each of the three subareas by approximating them as nonlinear reservoirs. This nonlinear reservoir is established by combining the continuity equation with Manning's equation.

Infiltration from pervious areas can be computed by either Horton or Green-Ampt equation. (EPA, 1992). Green-Ampt infiltration method is used for this study. Input parameters required by this method include suction head, conductivity and initial deficit; the values of these parameters depend on soil characteristics.

In SWMM model flow routing within a conduit link is governed by the conservation of mass and momentum equations for gradually varied, unsteady flow (i.e., the Saint Venant flow equations). The model user has different choice used to solve these equations but for this research dynamic wave routing is preferable. The routing portion of the model transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. For good modeling accuracy and successful calibration of the model it is essential that rain gages be located within and adjacent to the catchment.

**b) Governing Equation**

SWMM model conceptualizes a sub catchment as a rectangular surface that has a uniform slope  $S$  and a width  $W$  that drains to a single outlet channel. Overland flow is generated by modeling the sub catchment as a nonlinear reservoir.

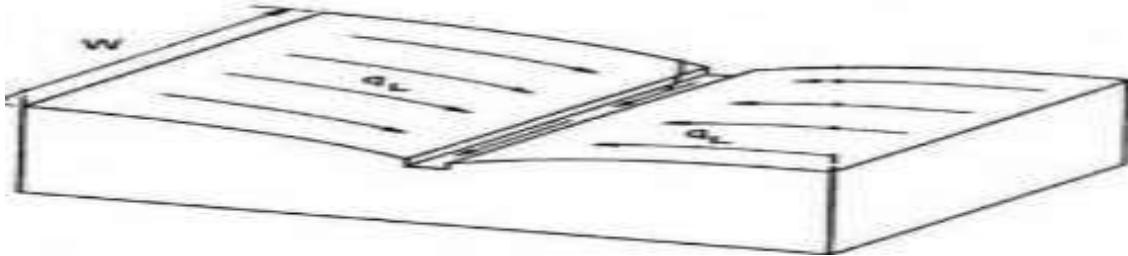


Figure 3-6: Idealized representation of sub catchment

(Source SWMM5.1 user manual)

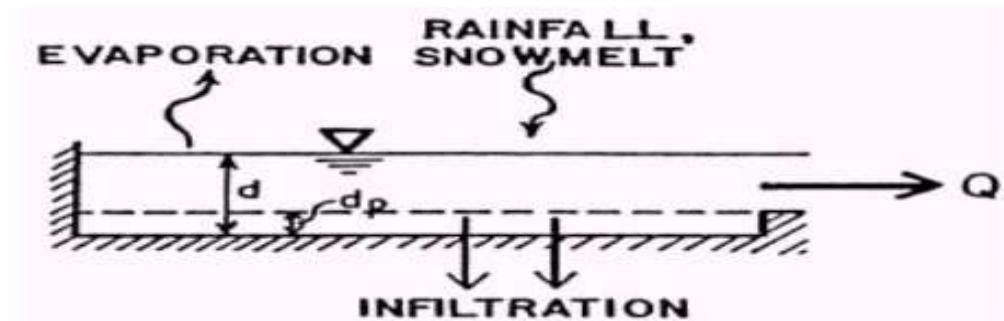


Figure 3-7: Nonlinear reservoir model of sub catchment

(Source SWMM5.1 user manual)

The above figure represents the sub catchment experiences inflow from precipitation (rainfall and snowmelt) and losses from evaporation and infiltration.

The net excess ponds a top the sub catchment surface to a depth  $d$ . Pondered water above the depression storage depth  $d_s$  can become runoff outflow  $q$ . Depression storage accounts for initial rainfall abstractions such as surface ponding, interception by flat roofs and vegetation, and surface wetting.

SWMM5.1 model uses the Manning equation to express the relationship between flow rate ( $Q$ ), cross sectional area ( $A$ ), hydraulic radius ( $R$ ), and slope ( $S$ ) in all conduits. For standard U.S. units,

$$Q = \frac{1.49}{n} AR^{0.66} S^{0.5} \quad (3.12)$$

Where  $n$  is the Manning roughness coefficient. The slope  $S$  is interpreted as either the conduit slope or the friction slope (i.e., head loss per unit length), depending on the flow routing method used.

For pipes with Circular Force Main cross-sections either the Hazen-Williams or Darcy-Weisbach formula is used in place of the Manning equation for fully pressurized flow. For U.S. units the Hazen-Williams formula is:

$$Q = 1.318 C A R^{0.63} S^{0.54} \quad (3.13)$$

Where:

$C$  is the Hazen-Williams C-factor which varies inversely with surface roughness and is supplied as one of the cross-section's parameters.

The Darcy-Weisbach formula is:

$$\sqrt{8g/f} A R^{0.5} S^{0.5} \quad (3.14)$$

Where:  $g$  is the acceleration of gravity and  $f$  is the Darcy-Weisbach friction factor.

For turbulent flow, the latter is determined from the height of the roughness elements on the walls of the pipe (supplied as an input parameter) and the flow's Reynolds Number using the Colebrook-White equation. The choice of which equation to use is a user-supplied option.

A conduit does not have to be assigned a Force Main shape for it to pressurize. Any of the closed cross-section shapes can potentially pressurize and thus function as force mains that use the Manning equation to compute friction losses.

### **Procedure to be followed for model set up**

- a) Set the coordinates of area map/image
- b) Draw network representative and describe sub catchments
- c) Edit the properties of the object that make up the system
- d) Describe how the system is operated
- e) Select a set of analysis options
- f) Run Simulation

#### **3.5.1 Preparation of modeled area**

From the site investigation of Sebeta town the area I have choose for the modeling was faced a problem due to its closeness to the hill (receiving high overland flow), low lying flat area, unplanned settlement toward the hill and improper solid waste management. Therefore, the modeled area covers 64.44 ha from Total to Furi Kuwas Meda and the catchments were divided into 10 different regions called as sub-catchments (S). Each sub-catchment is designed with stormwater lines by providing proper slope at intermediate junctions by connecting with conduits.

The overall runoff which was delivered from all the sub-catchments is discharging to outfalls through conduits with required slope. The present simulated model S1 to S10 denotes 10 sub-catchments, J-indicates junctions between the conduits and C- stands for conduits which connects the flow between successive junctions. The modeled area drainage network consists of 15 nodes means 15 Junctions, 16 links and 1 outfall.

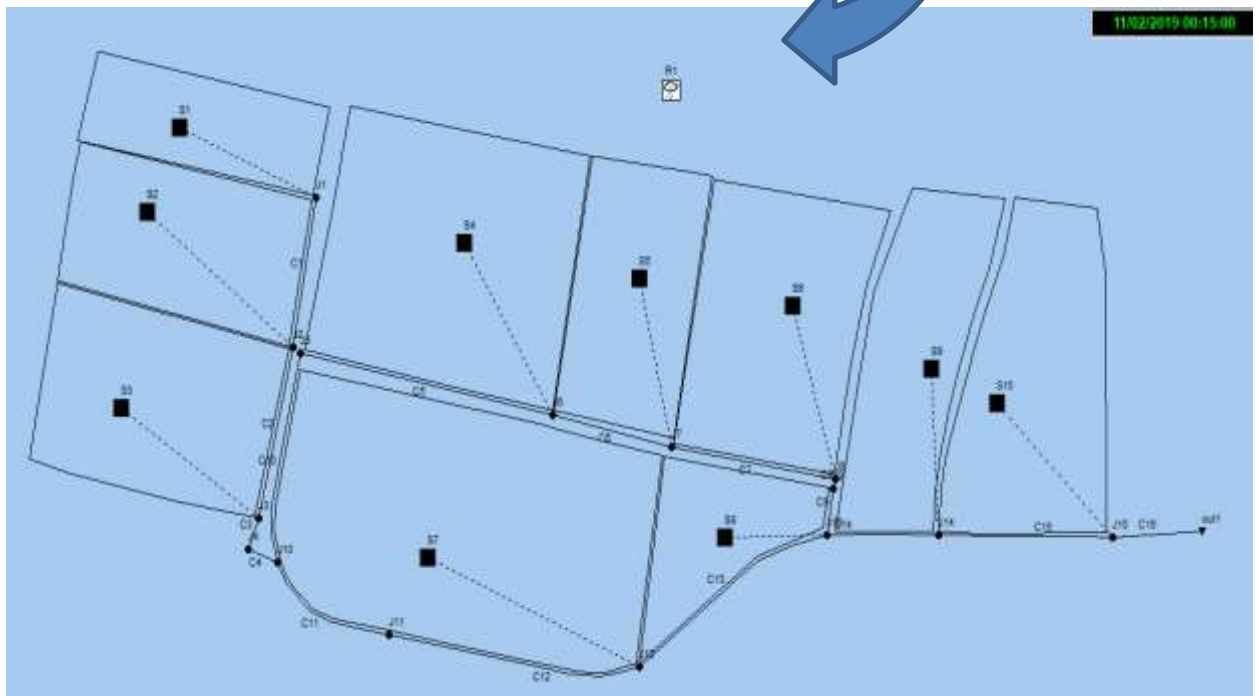
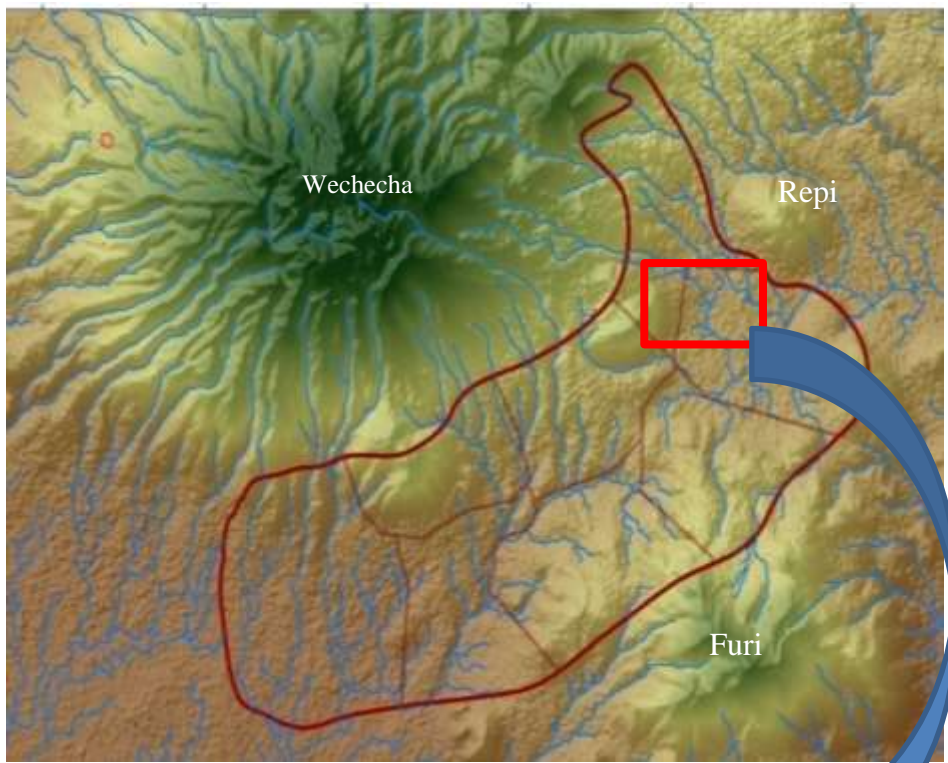


Figure 3-8: Modeled area map

The manholes/Junctions were modeled as rectangular channel with different depth. It had assumed that there are no energy losses in the manholes. The precipitations were introduced into the model by associating each sub-catchment to the rainfall time-series.

### 3.5.2 Model Calibration and Validation

Model calibration is involving determination of model parameters that gives the best possible correspondence between calculated value (by manning equation) and simulated runoff from each sub catchment and each conduit. Validation is the process of representing that a given site specific data is capable of making accurate predictions. This was done by applying the calibrated data using a different data set out of the range of calibration without changing the parameter values. The most parameters used for sensitivity analysis and their allowable range of change proposed by (Li et al, 2014).

Table 3-4: Parameter used for sensitivity analysis

Parameter	Description		Allowed range of change
N-Imperv	Manning’s roughness coeffient for impervious area		0.011-0.015
N-perv	Manning’s roughness coeffient for pervious area		0.05-0.8
Dstore-Imperv	Depth of depression storage in impervious areas(mm)		0-3
Dstore-Perv	Depth of depression storage in pervious areas(mm)		3-10
Conduit roughness	Manning’s roughness coefficient		0.011-0.024
Infiltration method	Green	Suction	3.5
	Ampt	Conductivity	0.5
		Initial deficit	0.25-0.26

There are different allowed ranges for above parameters has offered by several researchers; however the current study mostly used the values represented in Table 4-3.

For the model calibration and validation open rectangular channel from Noke square to Furi Kuwas Meda which drains 27.98 ha of sebeta town was selected and depth was recorded for 10 days to calibrate sensitive parameters and validate SWMM model for the area. Also, 10 day rainfall data parallel to the day that the depth recorded was taken from metrological agency and used for model simulation.

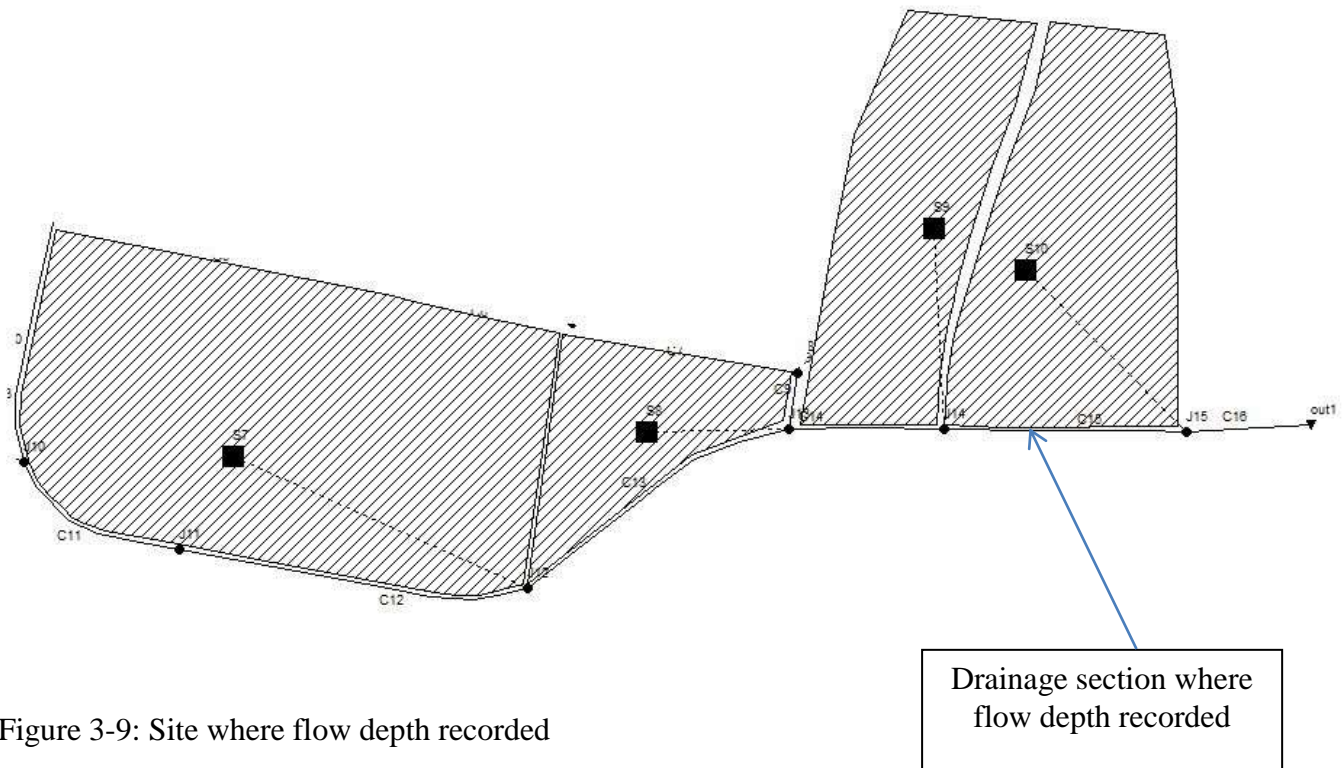


Figure 3-9: Site where flow depth recorded

### 3.5.3 Model performance evaluation criteria

$$\checkmark \text{ Coefficient of determination } (R^2) = \left[ \frac{\sum_{t=1}^n (q_t^{obs} - q_t^{avg.obs})(q_t^{sim} - q_t^{avr.sim})}{\sqrt{\sum_{t=1}^n (q_t^{obs} - q_t^{avg.obs})^2} \sqrt{\sum_{t=1}^n (q_t^{sim} - q_t^{avr.sim})^2}} \right]^2 \quad (3.15)$$

$$\checkmark \text{ The Nash Sutcliffe Coeff. } (R_{NS}) = 1 - \frac{\sum_{t=1}^n (q_t^{obs} - q_t^{sim})^2}{\sum_{t=1}^n (q_t^{obs} - q_t^{avg.obs})^2} \quad (3.16)$$

$$\checkmark \text{ Relative Error } (RE) = \frac{\sum_{t=1}^n |q_t^{obs} - q_t^{sim}|}{\sqrt{\sum_{t=1}^n q_t^{obs}}} \quad (3.17)$$

Where  $q_t^{obs}$  and  $q_t^{avg.obs}$  are the calculated and average flow respectively and  $q_t^{sim}$  and  $q_t^{avg.sim}$  are the simulated and average flow respectively at time  $t$ ,  $t$  is time, and  $n$  is the total number of time steps.

**Acceptable level of calibration**

- $R^2$  value approach to 1 (one)
- $RE < 30$
- $R_{NS}$  if the value is between 0 and 1 indicates the model is acceptable, if the value is 1 then the model is perfect model and if the value is 0 the model is no better than using as an estimator.

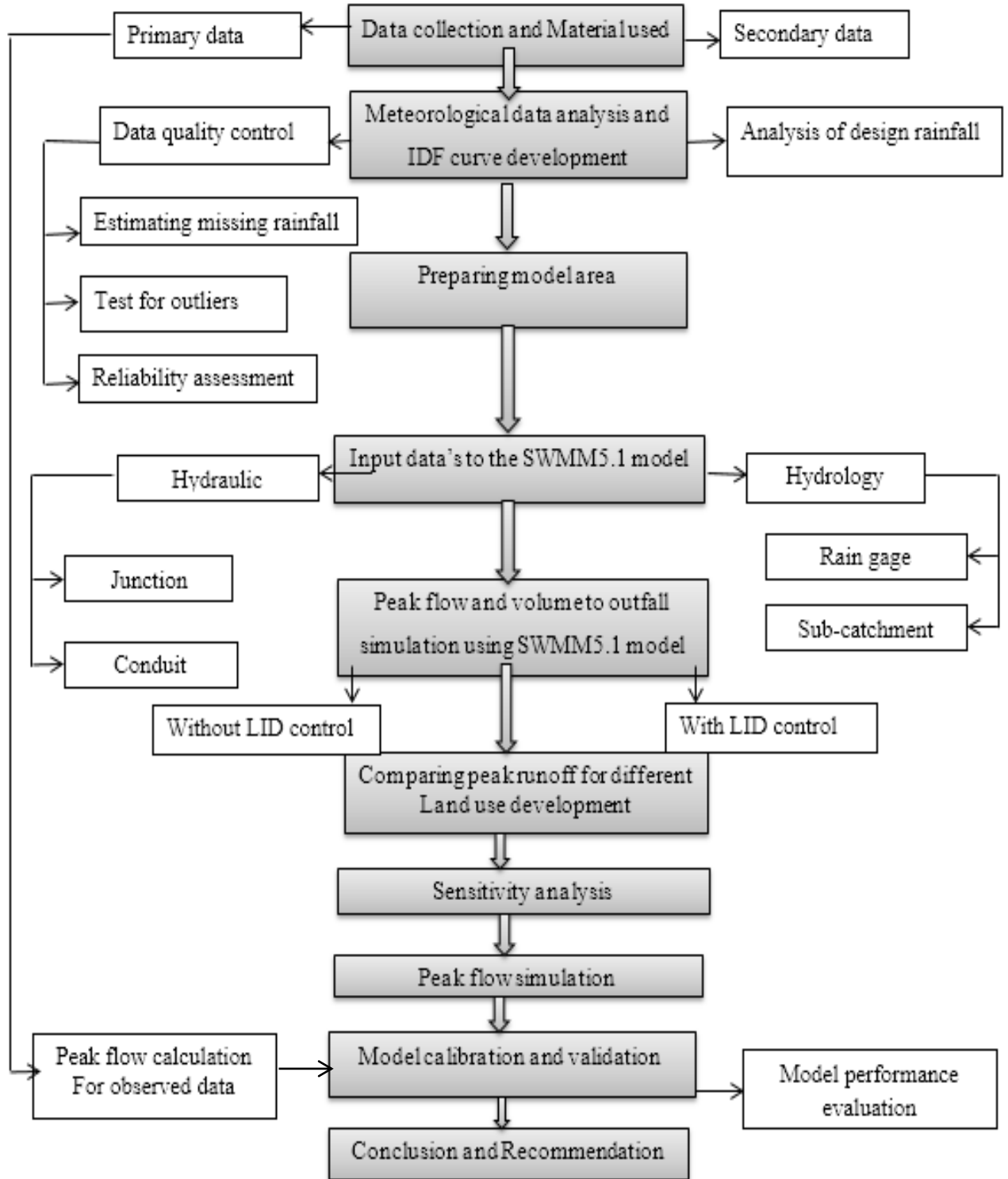


Figure 3-10: Overall framework of methodology's followed.

## CHAPTER 4 RESULTS AND DISCUSSIONS

### 4.1 Hydrology and Hydraulic Results

#### 4.1.1 Result from Outlier Test

As the result below indicates that the highest recorded value from metrological station is 60.2 mm this value is less than the higher outlier 72 mm therefore there is no higher outlier data will have eliminated and also the lowest recorded value from metrological station is 23.3 mm this value is greater than the lowest outlier 21mm therefore there is no lower outlier data will have eliminated. The result of the outliers' test for rainfall depths of Sebeta station is indicated below.

Table 4-1: Outlier test for Sebeta station

Year	Annual max daily Rf (K) mm	X=log(K)
1998	35.3	1.547774705
1999	23.3	1.367355921
2000	38.1	1.580924976
2001	33.1	1.519827994
2002	58.6	1.767897616
2003	58.2	1.764922985
2004	60.2	1.779596491
2005	52.1	1.716837723
2006	46.1	1.663700925
2007	28.8	1.459392488
2008	38.8	1.588831726
2009	51.2	1.709269961
2010	30.2	1.480006943
2011	36.9	1.567026366
2012	35.3	1.547774705
2013	33.6	1.526339277
2014	35.1	1.545307116
2015	43.6	1.639486489
2016	34.3	1.53529412
2017	35.8	1.553883027
Mean= $\bar{X}$		1.59
St. Deviation=S		0.11
<b>Outlier</b>		<b>Rf depth of outlier</b>
<i>High</i>		<i>72 mm</i>
<i>Low</i>		<i>21 mm</i>

#### 4.1.2 Intensity–Duration–Frequency Curves (IDF) Result

The resulting IDF curve from steps shown in the above chapter was used the Annual daily maximum rainfall from Ethiopian Meteorological Agency rainfall gauge located in Sebeta town, 24-hour rainfall data of the years was calculated using the two commonly adopted distribution method .

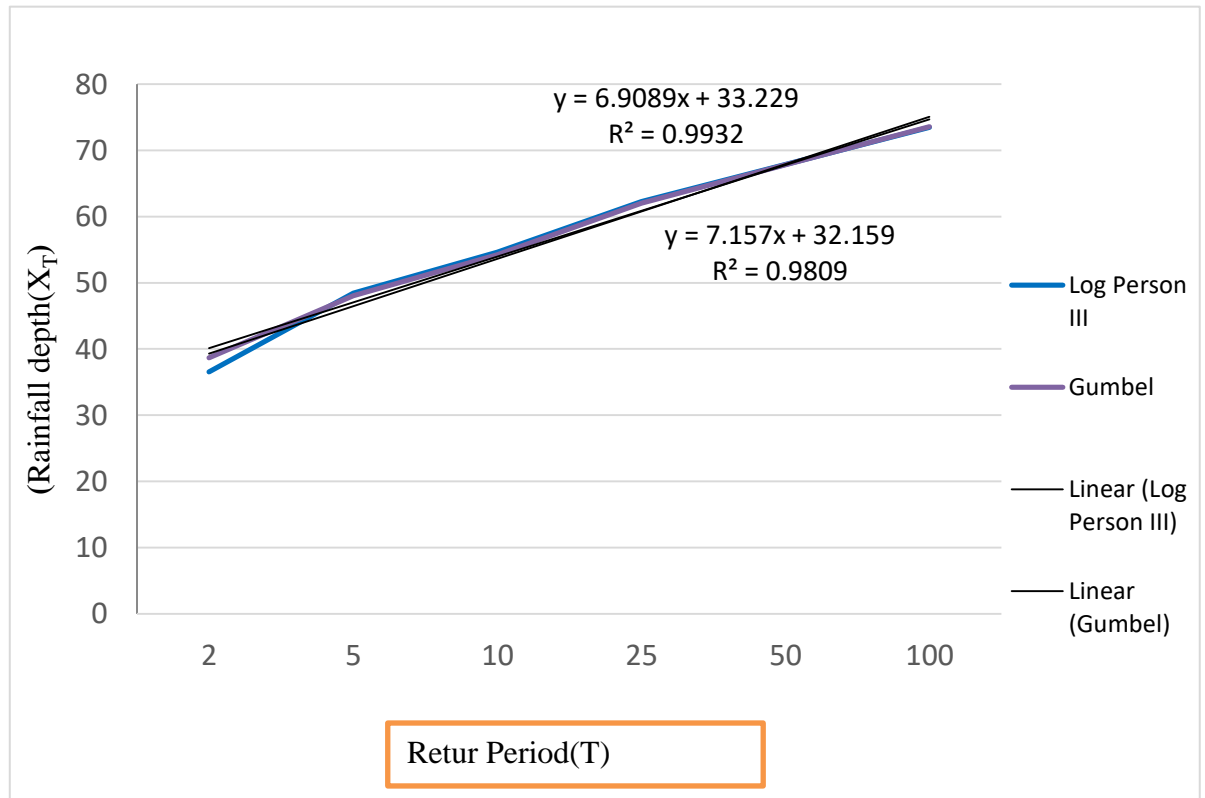


Figure 4-1: Plots of frequency distribution results

After comparing the two method the Gamble method  $R^2 = 0.9932$  this value approximate to one and used for IDF curve development.

## Urbanization Impact Assessment On Stormwater Drainage Performance of Sebeta Town

Rainfall intensity for the design storm was needed to calculate peak runoff rate from a drainage area. For this study IDF curve from hydrological section of sebeta town was applicable, but the developed IDF curve is necessary to interrelated to calculated IDF curve of ERA drainage design manual even the values of rainfall intensity are much difference. In ERA drainage design manual Ethiopia is divided in to several hydrological regions which display similar rainfall patterns. Sebeta town falls in region A2 of this division. The values of rain fall intensity is different because of the data used to develop the IDF curve for this study and for ERA are too difference this is because ERA develop IDF curve for different station (Region A2).

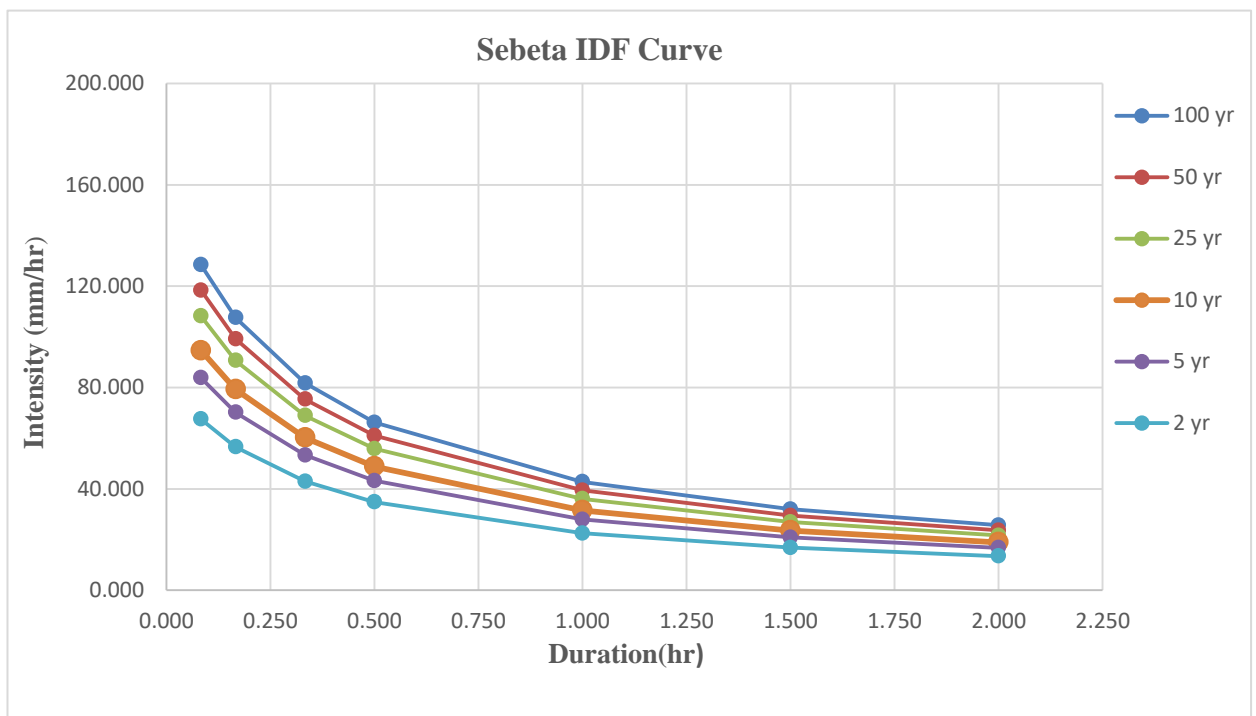


Figure 4-2: Sebeta IDF Curve

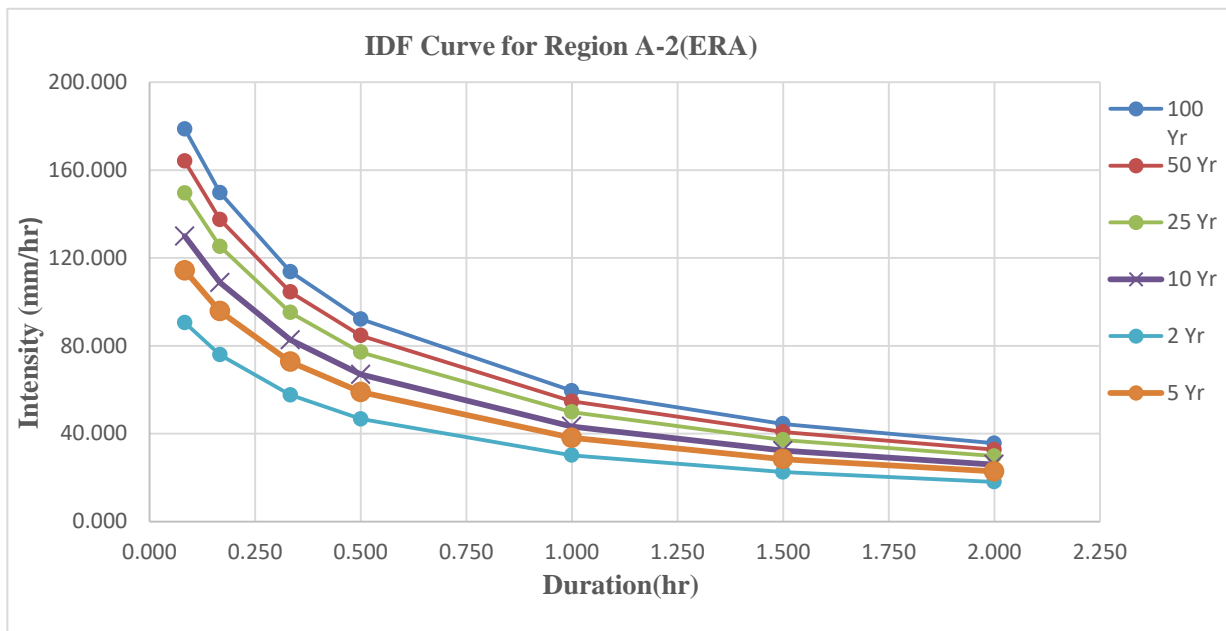


Figure 4-3: IDF curve for Region A-2

(Source: ERA,2013)

## 4.2 Result from SWMM Model

In this study to obtain a fully understanding of the system performance under multiple working condition firstly the model has been run with the continuous rainfall events with different return periods to analyze the current performance and secondly T25 peak flood occurrence used for design of sebeta drainage system, finally by running the hydrological model with the intensity data, the runoff generation within the area was obtained.

### 4.2.1 Result from subcatchment

The catchments have been divided into various sub catchments and Numerical simulation is carried out for 20 year events, taken as extreme events from each year from 1998-2017 rainfall data. The project layout of the catchment used for simulation in SWMM model is shown below.

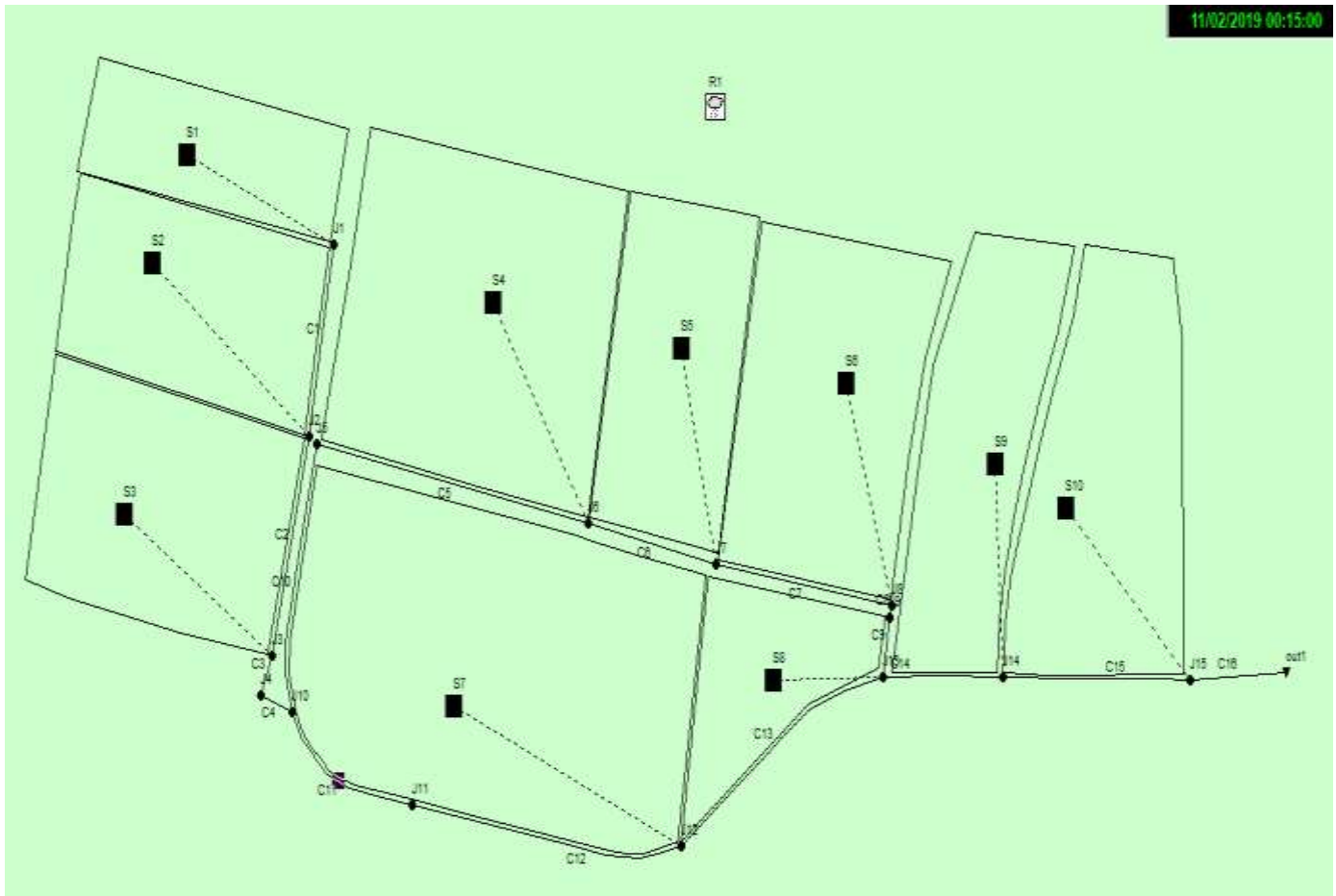


Figure 4-4: Modeled study area project layout

Form the simulation result the total runoff produced from whole sub-catchments by SWMM model is  $6.83\text{m}^3/\text{sec}$ . The runoff obtained in the simulation was used as input data at each node connected to a catchment.

## Urbanization Impact Assessment On Stormwater Drainage Performance of Sebeta Town

Topic: Subcatchment Runoff <span style="float: right;">Click a column header to sort the column.</span>								
Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10 <sup>6</sup> ltr	Peak Runoff CMS	Runoff Coeff
S1	80.45	0.00	0.00	3.68	76.42	2.55	0.41	0.950
S10	80.45	0.00	0.00	8.54	71.52	4.84	0.51	0.889
S2	80.45	0.00	0.00	5.65	74.50	3.94	0.57	0.926
S3	80.45	0.00	0.00	4.94	75.27	4.85	0.78	0.936
S4	80.45	0.00	0.00	2.58	77.39	7.47	1.11	0.962
S5	80.45	0.00	0.00	2.61	77.35	3.79	0.56	0.961
S6	80.45	0.00	0.00	4.34	75.70	5.20	0.74	0.941
S7	80.45	0.00	0.00	2.75	77.20	10.18	1.42	0.960
S8	80.45	0.00	0.00	2.72	77.24	2.24	0.32	0.960
S9	80.45	0.00	0.00	8.08	71.99	3.69	0.41	0.895

Figure 4-5: Peak discharge result for each sub catchment from SWMM model

### 4.2.2 Result from profile plot

The water profile plot is obtained for nodes from junction J1 to J3 and J7 to J9 as shown in figure 4-6 and figure 4-7 respectively. The simulation status report shows the junctions were surcharged (flooded) and the conduits are full this leads to flooding on the surrounding area and cause damages to human life and infrastructure.

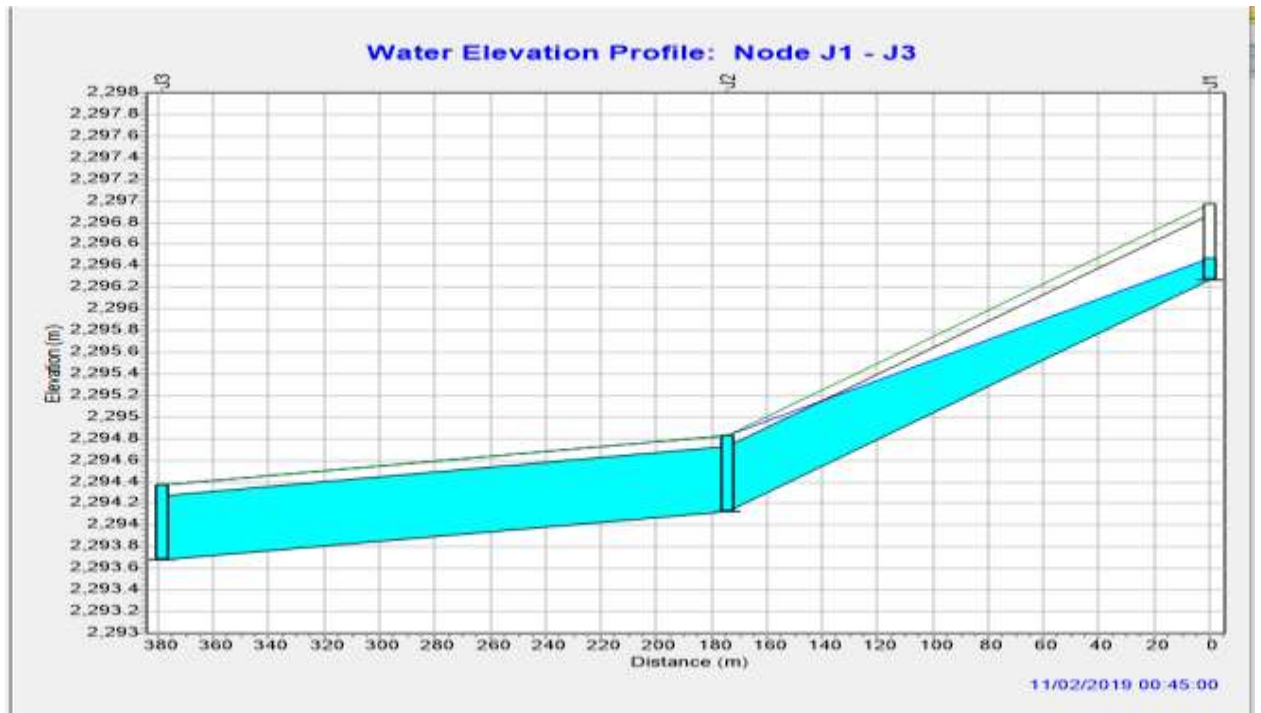


Figure 4-6: Water elevation profile at Node J1-J3

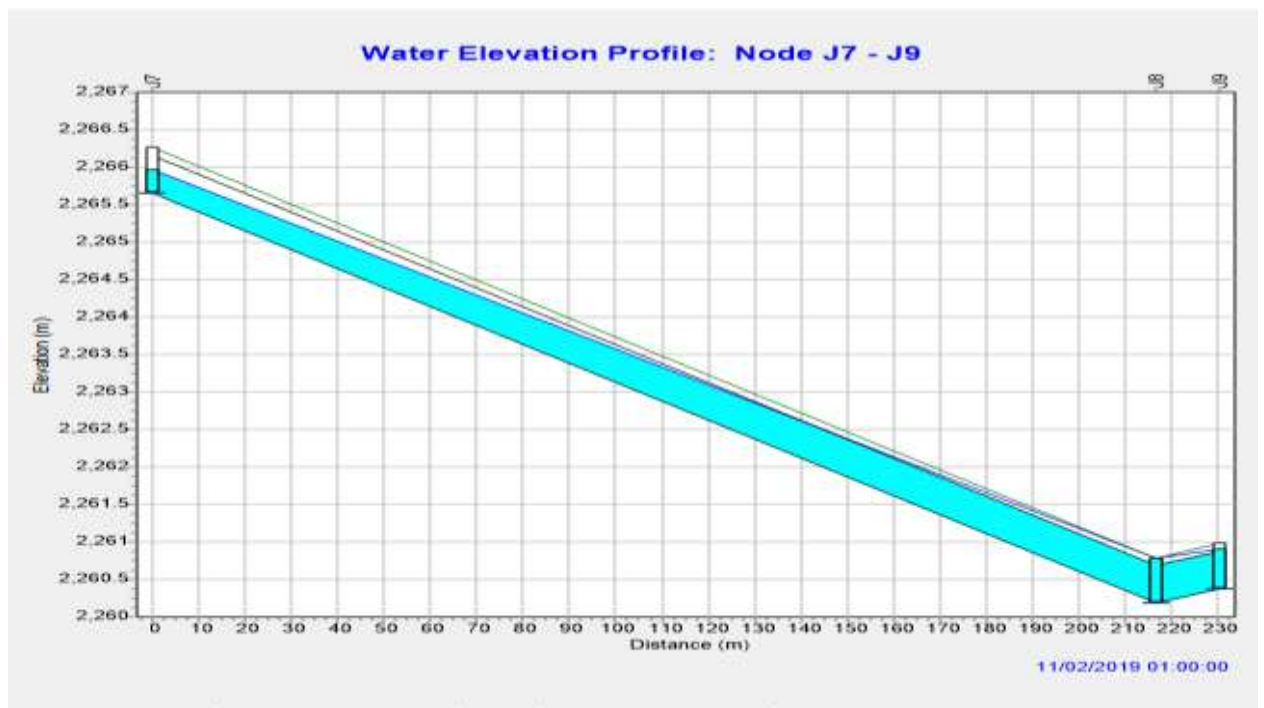


Figure 4-7: Water elevation profile at Node J7-J9

### 4.2.3 Result from node flooding

From simulation result, it was observed that the drainage system have nodes flooded and overflow thereby resulting damages to road surface material and flooding in the area. The simulation status report shows that the sections between junctions 2, 3, 8 and 9 are surcharged.

Topic: <b>Node Flooding</b> <span>Click a column header to sort the column.</span>						
Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10 <sup>6</sup> ltr	Maximum Poned Depth Meters
J2	1.81	0.496	0	00:45	1.768	0.000
J3	0.44	0.059	0	00:45	0.045	0.000
J8	9.38	4.360	0	01:00	30.804	0.000
J9	0.01	0.382	0	00:23	0.002	0.000

Figure 4-8: Node flooding

### 4.2.4 Result from storm drain outfall

There is an out let structure in study area the flow from the drainage system is flow to this out let structures and the amount of discharge to the outlet structure was computed using SWMM model and the average flow is 0.468 m<sup>3</sup>/s and total volume to outfall is 15.840\*10<sup>3</sup> m<sup>3</sup> were occurred from all 10 sub catchment as shown in the figure below.

Topic: <b>Outfall Loading</b> <span>Click a column header to sort the column.</span>				
Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS	Total Volume 10 <sup>6</sup> ltr
out1	15.05	0.468	1.884	15.840

Figure 4-9: Outfall loading result

### 4.3 Comparison of model result for different period land development

The SWMM model was run for different period land development and the model output result was shown in the table below, The total peak runoff value of the study area land use for the year of 2008 GC is 4.8 (m<sup>3</sup>/s) and the total peak runoff value as a result of the existing land use of the study area is 6.83 (m<sup>3</sup>/s) this show that there is increasing magnitude change of peak run off due to the development (urbanization) of the study area. Generally the current land use peak run off increased by 2.03 (m<sup>3</sup>/s) than the earlier land use of the study area.

Name of sub catchments	Peak runoff value of 2008 year land use (m <sup>3</sup> /s)	Peak runoff value of existing land use (m <sup>3</sup> /s)	Change in peak runoff(m <sup>3</sup> /s)
S1	0.34	0.41	0.07
S10	0.31	0.51	0.2
S2	0.56	0.57	0.01
S3	0.53	0.78	0.25
S4	1	1.11	0.11
S5	0.44	0.56	0.12
S6	0.49	0.74	0.25
S7	0.82	1.42	0.6
S8	0.13	0.32	0.19
S9	0.18	0.41	0.23

Table 4-2: Change of peak runoff for different period land development

#### 4.4 Result of model calibration and validation

For model calibration it's necessary to conduct a detailed sensitivity analysis to evaluate the main parameters of the model. Sensitivity parameter evaluation and adjusting sensitivity parameter was done and the last sensitive values used for the SWMM model were show in table below.

Table 4-3: Sensitivity parameter used for the calibration of model

Parameter	Description	Allowed range of change	Initial values	Used values (sensitivity parameters)
N-Imperv	Manning's roughness coeffient for impervious area	0.011-0.015	0.011	0.015
N-perv	Manning's roughness coeffient for pervious area	0.05-0.8	0.1	0.4
Dstore-Imperv	Depth of depression storage in impervious areas(mm)	0-3	1	3
Dstore-Perv	Depth of depression storage in pervious areas(mm)	3-10	3	9
Conduit roughness	Manning's roughness coeffient	0.011-0.024	0.012	0.012
Infiltration method	Green	Suction	3.5	3.5
	Ampt	Conductivity	0.5	0.5
		Initial deficit	0.25-0.26	0.25

The model calibrated with the peak flow rate value that obtained by Manning equation the value is 1.043 m<sup>3</sup>/s and the value simulated with SWMM model after the sensitive parameters fixed, were 1.146 m<sup>3</sup>/s. and the depth recorded at selected site near the out let was used for the determined the flow rate in the drainage for the validation of the model for the area. The result of the simulated and calculated (observed) flow rate for validation is shown below in the table.

Table 4-4: Flow rate for validation

Date	Recorded flow average depth(m)	Simulated flows rate (using SWMM5) CMS	Calculated (observed) flow rate (using manning's) CMS
23/06/2019	0.58	0.42	0.409
26/06/2019	0.64	1.197	1.088
3/07/2019	0.72	1.198	1.254
15/07/2019	0.48	0.771	0.763
19/07/2019	0.61	1.23	1.026

- As shown in the above table the result obtained is approximately equal and the model was validated.

The model performance measured using Coefficient of Determination ( $R^2$ ), Nash-Sutcliffe Efficiency ( $R_{NS}$ ) and Relative Error (RE). The results are  $R^2=0.95$  the value approach to one so the model is acceptable,  $R_{NS}=0.91$  this value is between 0 and 1 so the model is acceptable and  $RE=12.95\%$  this value is less than 30% so the model is acceptable. The calibration and validation result indicated that the model structure and parameters matched the runoff-producing pattern and the calibrated model was suitable for simulating storm runoff in the study area.

#### **4.5 Stormwater management system**

Urbanization follows an increase in impervious surfaces, where the water is unable to penetrate. This means that stormwater runs on the hardened surfaces without any retardation. Low impact development (LID) technique used to depress the negative influence of water quantity of the runoff process caused by urbanization. The stormwater management model (SWMM) has also widely used to model SUDS through its low – Impact Development (LID) method. For this study 3 types of LID technique used those were Bio retention cell, infiltration trenches and permeable pavement.

- Bio retention cell are depressed landscapes into which runoff is directed and allowed to pond, filter, and infiltrate. The use of bio-retention areas is appropriate in relatively small catchments, typically in the region of 1000-4000 m<sup>2</sup>. Several smaller bio-retention areas can be linked together for larger catchments (Endicott & Walker, 2003; Woods-Ballard et al., 2007).
- Infiltration trenches are structures that provide storage and facilitate infiltration of runoff into the subsurface. Runoff from the study area was routed through an infiltration trench in the LID area. They can be simulated as a rectangular, fully pervious sub-catchment whose depression storage depth equals the equivalent depth of the pore space available within the trench (Seema Bardhipur.2014).
- Permeable pavement the pavement consists of less fine aggregates than traditional concrete or asphalt, and the larger pore spaces that result allow for temporary storage of runoff (Seema Bardhipur.2014).

#### 4.5.1 Result of LID simulations

The results for LID scenarios bio-retention cell, Permeable pavement and infiltration trenches are compared with the current conditions (before applying of LID) of the model peak runoff and total volume to outfall result. The LID implemented for S7, S8, S9 and S10 and from the total area 28 ha area of the selected sub catchments the area used for design is 0.2 ha for each sub catchments. .

Table 4-5: Result of low impact developing (LID)

Item	Current condition	Bio-retention Cell		Permeable pavement		Infiltration trench	
		value	%	Value	%	Value	%
Peak runoff (m <sup>3</sup> /s)	2.66	1.8	32.33	2.4	9.77	1.99	25.19
Total volume to outfall (10 <sup>3</sup> m <sup>3</sup> )	15.184	12.924	18.41	13.744	13.24	12.799	19.2

In comparison to the current conditions, bio-retention scenario considered on the selected four sub catchment where reduce total peak runoff by 32.33% and outfall volume by 18.41% , the permeable pavement scenario where reduce total peak runoff by 9.77% and volume to outfall by 13.24 % and the infiltration trench scenario as well as considered on the same sub catchments and reduced total peak runoff by 25.19 % and volume to outfall by 19.2 % as compared to current conditions as shown on the above table. The same study done by Kamal Ahmed, 2017 and used to compare the simulation results before and after LID structure installation the study area infiltration trench was indicates the peak runoff and total volume reduced to (20.95% and 17.5%) respectively for two sub-catchments.

The results of the model simulation shows that the significance of using LID in improving the urban drainage system. Therefore for this study bio-retention cell is effective in reducing peak runoff and volume to outfall.

## 5 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusion

The study assessed urbanization impact on stormwater drainage performance in the most affected parts of Sebeta town. Accordingly, SWMM model was successfully used to model the study area flood prone area.

To analyze flow routing and infiltration processes Dynamic wave routing and Green Ampt approaches were applied and the model results show that there are nodes flooded at four critical junctions in the drainage system and there are also overflow sections. Thus the site drainage facilities are significantly undersized for current levels of development.

The model simulated for different period land development and the result indicates there is positive change of peak run off due to the development (urbanization) of the study area.

The model calibration and validation were done, the result obtained approximately equal and the model was validated.

The performance of model was carried out and the total simulation accuracy of the runoff and network system assessed by statistical methods, where  $R^2=0.95$ ,  $R_{NS}=0.91$  and  $RE=12.95\%$ . So the SWMM mode is the powerful tool for analyzing the impact of urbanization on stormwater drainage performance for the study area.

In this study the SWMM model simulated with and without implementing LID and different technics of LID implemented from that Bio-retention cell is effective as it reduces the peak runoff by 32.33% and volume to outfall by 18.41.

Generally it can be concluded that the drainage system of the study area found to be inadequate due to Inadequate size of the drainage system, improper construction of drainage canal and improper functioning of drainage network due to poor management this leads resulting damages to road surfacing material and flooding problems in the area.

## 5.2 Recommendation

SWMM models result shows flooding risk is very high due to there are improper settlements as a result Implementing LID system is suitable option to reduce the peak flows in the system and to solve flooding problems.

Immediate cleaning of all debris and waste from all segments of the existing drainage line before the starting rainy season further prevent the problem that might lead to flooding of the model area with subsequent damage to property and infrastructure.

In order to regulate the flow from hill areas it's recommended to prepare interceptor channels at the foot of the hill.

Developing the skill of community regarding to LID control is necessary, Because Community participation plays its own role in flood risk assessment, in planning and implementation of stormwater management control system.

For proper disposal of stormwater the existing drainage system must be properly manage and clean.

The present study has thoroughly evaluated the applicability of SWMM in urban drainage modeling. However, most of the urban areas are influenced by the runoff generated from natural streams. Hence hydrodynamic modeling of such streams using existing tools like HEC-RAS is recommended as a future study.

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APPENDIX

Appendix 1: Daily rainfall data of Sebeta station from 1998 to 2017

Name	Geogr1	Geogr2	Elevation	Element	Year	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
Sebeta	38.63	8.92	2220	PRECIP	1998	1	0	0	0	0	0	0	0	0	35.3	3.5	0	29.3	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1998	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1998	3	0	2.1	0	0	0	5.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1998	4	0	0	0.4	0	0	0	0	0	0	0	0	0	7.2	0	0	5.3	0	0	6.5	0	0	0	0	0	0	0	0	0	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1998	5	0	26.5	20.3	18.7	0	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1998	6	17.5	0	0	29.3	0	35.3	0	0	6.5	17.3	0	0	10.5	0	0	3.5	0	0	0	0	5.7	0	0	0	0	0	0	0	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1998	7	8.5	0	0	0	2.5	0	3	16.5	13.5	0	11.5	0	10.9	0	4.2	5.3	17.9	35.3	0	8.5	0	7.3	10.5	0	6.5	7.5	0	8.5	24.9	7.5	4.2		
Sebeta	38.63	8.92	2220	PRECIP	1998	8	7.5	0	12.6	5.3	0	9.5	0	10.7	13.8	2.4	0.5	3.5	6.5	14.5	0	0	0	0	5.3	19.4	0	14.5	10.5	10.7	6.5	0	5.4	0	17.5	21.4	15.5	3.5	
Sebeta	38.63	8.92	2220	PRECIP	1998	9	4	2.5	15.5	0	10.8	4.3	6.3	15.8	0	3.5	2.1	0	0	11.5	2.4	0	0	4.3	0	6.5	3.2	6.5	0	1.3	0	2.1	3.2	0	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1998	10	0	0	0	13.5	0	3.1	0	10.2	13.1	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1998	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1998	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	3	10.5	3.2	0	0	0	0	14.5	7.3	0	0	0	0	5.3	0	7.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	5	0	0	10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.3	0	0	9.5	0	0	2.1	0	0.5	0	13	8.9	6.5	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	6	0	0.5	6.8	0	0	2	0	0	0	8.9	0	2.1	9.1	6.1	0	0	0	2.5	2.6	6.7	3.6	3.3	4.5	11.3	5.1	1.3	17	1.8	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1999	7	12.8	3.3	1	16.5	6.2	19.9	15.7	12.8	5.8	14.6	15.2	0	0	13.9	13	7.2	9.5	2.6	7.3	0	14.8	3.2	0	3.3	0.6	0.2	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	8	0	7.5	13	4.9	5	4.8	2.5	16.8	3.1	16	18	12.2	17.2	0	19	4.2	0.9	0	0	7.6	2.4	13.1	6.9	5.2	0	18	0	1.8	14.3	5.1	1.9		
Sebeta	38.63	8.92	2220	PRECIP	1999	9	1.2	0	3	2.4	0	0	0	0	0	0	7.5	0	7.3	2.5	0	4.2	1.2	6.8	16.5	12.3	3.6	2.2	0	1.1	5.4	0	0	0	0	0	0		
Sebeta	38.63	8.92	2220	PRECIP	1999	10	4.9	2.4	17.4	2.4	0	9.6	5.3	8.8	14.7	13.6	8.4	2.3	0	0	0	0	0	0	2.5	9.8	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	1999	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	2000	1																																	
Sebeta	38.63	8.92	2220	PRECIP	2000	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	2000	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2000	4	2.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2000	5	1.5	1.3	16.5	3.5	1.5	2.6	0	6.8	3.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2000	6	0	0	3.6	10.1	0	2.9	0	3.1	6.8	0	0	15.2	0	7.6	2.7	0	3.1	0	0	10.5	0	1.2	2.6	12.9	2.6	1.6	3.3	3.9	0	0	0	0	
Sebeta	38.63	8.92	2220	PRECIP	2000	7	17.9	1.6	7.9	3.9	4.9	11.3	0	17.5	0	0	3.5	0	4.3	0	9.4	4.7	2.3	0	3.1	3.7	9.1	0	10.2	0	11	1.9	35.4	0	2.7	7.2	0	0	
Sebeta	38.63	8.92	2220	PRECIP	2000	8	0	2.5	3.4	2.3	2.4	0	15.2	6.4	1.9	14.2	15.1	8.7	7.9	7.4	3.2	10	9.7	11.9	12.6	4.9	0	6.4	4.5	4.4	0	0	4.6	0	1.1	19.6	0	0	
Sebeta	38.63	8.92	2220	PRECIP	2000	9	1.1	0	0	2.6	16.2	0	4.9	1.3	9.4	0	4.8	3.2	7.2	0	5.1	1.5	0	2.8	26.4	4.7	5.8	14.2	2.6	0	1.5	17	14	1.5	30.1	38.1	0	0	
Sebeta	38.63	8.92	2220	PRECIP	2000	10	0	0	9.7	0	0	0	0	0	0	6.8	0	0	0	0	4.6	0	0	0	1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2000	11	0	0	0	0	0	0	0.3	20.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2000	12	0	0	0	0	0	0	0	0	0	3.4	7.1	9.2	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2001	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2001	2																																	
Sebeta	38.63	8.92	2220	PRECIP	2001	3	0	0	0	0	0	14.4	0	22.1	5.6	12.2	4.9	16.1	0	0	0	0	0	0	9.9	1.5	5.1	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2001	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2001	5	4.4	24.6	0	0	9.6	27.3	0	0	3.2	5.7	12	8.2	2	0	9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.63	8.92	2220	PRECIP	2001	6	0	0	0	0	4.5	0	5.7	2.9	0	0	3.4	13.4	0.5	0.7	0	17	7.7	1.3	5.3	4.8	5.1	0	6.6	0.5	3.8	13	0.5	0	5.9	14	0	0	
Sebeta	38.63	8.92	2220	PRECIP	2001	7	33.1	7.2	1.3	16.1	0.3	4.5	0	2.1	10.1	10.5	5.4	0	12.7	28	0	16	9	10.4	19.6	6.5	0	2.3	9.5	5	9.7	27	2.5	1.6	0	0.5	22	0	
Sebeta	38.63	8.92	2220	PRECIP	2001	8	8.1	5.5	0	0	2.9	0	0	4.2	9.4	3.9	0	0	16.5	5.1	6.1	0	0	0	21.1	5.9	11.1	0	3.7	0.5	0	11	0	0	0	0	0	0	
Sebeta	38.63																																						







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Sebeta	38.83	8.92	2220	PRECIP	2011	8	15.6	0	10.1	8.2	6.4	9.2	3.8	7.1	5.5	18.9	22.4	13.5	7.8	5.2	4.4	3.6	7.3	8.8	4.9	2.1	5.2	3.9	6.6	4.3	4.6	9.8	3.4	10.3	6.4	3.2	0	
Sebeta	38.83	8.92	2220	PRECIP	2011	9	0	8.2	5.9	0.8	0.8	0.5	2.4	1.6	3.8	2.1	4.8	7.1	3.3	5.5	3.8	0	6.9	4.1	10.2	0	0	0.1	0.8	2.1	1.5	0	0	0	0	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2011	10	0	0	3.1	0	0	0	0	0	8.9	0	0	0	0	1.2	7.3	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2011	11																																
Sebeta	38.83	8.92	2220	PRECIP	2012	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2012	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2012	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.1	0	0	0	0	0	0	0.3	4.8	8.8	4.8	
Sebeta	38.83	8.92	2220	PRECIP	2012	4	3.3	4.1	19.1	11.3	15.6	12.7	6.6	10.7	20.1	0	0	0	1.3	6.6	2.1	3.1	16.1	5.4	13.8	0	0	3.1	13.1	7.7	5.3	8.1	4.5	11.2	0	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2012	5	0	0	0	0	17.2	0	13.4	12.4	8.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2012	6	5.1	0	3.1	6.9	8.8	6.2	4.3	3.9	0	0	7.4	1.5	0	0	2.1	0	1.1	3.2	5.1	2.1	5.5	0	0	3.8	1.5	7.4	3.4	0	4.1	2.1		
Sebeta	38.83	8.92	2220	PRECIP	2012	7							0.1	4.8	17	4.1	16.8	4.5	14.7	4.7	6.7	7.4	4.5	4.2	5.4	6.2	6.7	3.8	6.5	14.8	17	1.4	3.8	5.6	10.2	10.1	4.6	
Sebeta	38.83	8.92	2220	PRECIP	2012	8	0	7.3	6.8	3.8	0	0	1	0	5	1.2	4.2	0	8.1	1.5	13	33	17.9	0	0	14	4.5	7.2	5.1	3	15	12	0	3.8	0	5	3.2	
Sebeta	38.83	8.92	2220	PRECIP	2012	9	23	8.5	0.6	14	6.8	5.4	0	0	0.7	0	13.5	6.5	0	6.1	15	0	0	2.6	0	35.3	0	8.2	3	10	0	0	0	2.3	19	15.8		
Sebeta	38.83	8.92	2220	PRECIP	2012	10																																
Sebeta	38.83	8.92	2220	PRECIP	2012	11																																
Sebeta	38.83	8.92	2220	PRECIP	2012	12																																
Sebeta	38.83	8.92	2220	PRECIP	2013	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2013	2	0	0	0	0	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2013	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33.6	7.4	4.4	0	1	12.8	0	0.2	1	11	0	3.9	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2013	4	1.4	0	0	0	6	3.6	6.3	6.3	0	10.5	0	2.1	0	12.2	0	2	13.1	6.3	0	2.1	8.7	0	14	0	2.7	0	0	0	8.8	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2013	5	0	0	0	7.3	17.3	13	1.3	0	9.4	0	0	0	4.1	0	0	0	0	0	0	0	1	1.7	3.8	10	23	0.4	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2013	6	4.1	9.7	0	0	0	0	0	0	6.7	8.8	0	12.4	1.1	6.1	9.7	0	0	1.7	2.1	0	1.1	0.1	6.1	0	3	1	10	4.4	3.2	6.2		
Sebeta	38.83	8.92	2220	PRECIP	2013	7	14	18.2	1.4	1.7	26.8	2.6	1.7	9.8	0	0	0	0	0	0	13	6.2	0.5	2.3	2	16.5	0.6	14.8	0	3.9	0	5.1	13	0	0	2.3	0	
Sebeta	38.83	8.92	2220	PRECIP	2013	8	28.5	0	1.9	5.1	25.9	18.3	0.4	4.4	2.3	12.6	8.9	4.5	9.8	0	0	6.3	23.5	6.9	4.2	2.1	0	18.5	14.9	6	3.6	8.8	0.8	4.8	7.8	1	7.5	
Sebeta	38.83	8.92	2220	PRECIP	2013	9	0	14.2	11	16.5	9.5	0	5.8	0.3	7.4	0	0	15.1	2.2	0	0	21	2.2	0	0	0	1.2	3.1	1	3.8	0	0	0	0	0	0	10	
Sebeta	38.83	8.92	2220	PRECIP	2013	10	8.5	3	0	2.8	10	0	2.1	0	0	1	0	0	0	0	9.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2013	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2013	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2014	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2014	2	0	0	0	0	22	0	1.3	0	0	0	0	0	0	0	0	0	0	1.5	0	0	0	0	0	8.2	2.8	0	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2014	3	0	0	0	0	0	0	0	0	0	0	0	1.2	5.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.1
Sebeta	38.83	8.92	2220	PRECIP	2014	4	2	1.8	10	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.4	0
Sebeta	38.83	8.92	2220	PRECIP	2014	5	4.5	9.1	22.3	0	0	0	0	0	8.2	4.6	0	0	0	0	0	0	0	0	2.9	0	11.7	26.4	0.8	7.8	4.2	3.6	8	4.1	1.2	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2014	6	8	0	0	0	0	0	0	0	0	0	0	0	0	4.6	0	0	1.6	0	0	9.5	4	7.3	14.3	4.8	7.7	4.4	7.3	1.9	8			
Sebeta	38.83	8.92	2220	PRECIP	2014	7	1	10	7	5.5	17.1	7.7	7.3	6.3	9.8	5.7	0	4.2	0	4.3	3.3	8	9.6	0.1	9.8	0	0	0	0	0	0	4.6	17	14.9	0	2.5	4.3	
Sebeta	38.83	8.92	2220	PRECIP	2014	8	0.5	15.5	0	35.1	3.8	3.9	10.9	2.6	4.3	4.5	13.3	9.3	7.7	0	12	8.6	6.2	21.8	6.1	19.1	5.3	3.1	0	4.5	27	2.6	0	0	2.4	6.2	7.5	
Sebeta	38.83	8.92	2220	PRECIP	2014	9	0	1.8	0	14.8	14.1	0	3.1	2.4	0	6.1	14.5	4.5	19.1	0	4.5	1.4	0	1.1	6.5	1.1	3.1	0	3.3	0	3.4	17	8.3	0	0	0	0	
Sebeta	38.83	8.92	2220	PRECIP	2014	10	0	3.9	0	0	4.5	0	0	0	0	21.5	8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2014	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sebeta	38.83	8.92	2220	PRECIP	2014	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0





Appendix 2: Table of correlation of data

A) Correlating of Ayertena Station Monthly Rainfall Data with Sebeta Station Monthly Rainfall Data

	Sum of Ayertena Month Rf	Sum of Sebeta Month Rf
Sum of Ayertena Month Rf	1	0.735115444521776
Sum of Sebeta Month Rf	0.735115444521776	1

B) Correlating of AA Bole Station Monthly Rainfall Data with Sebeta Station Monthly Rainfall Data

	Sum of Sebeta Month Rf	Sum of AA Bole Month Rf
Sum of Sebeta Month Rf	1	0.827984303500377
Sum of AA Bole Month Rf	0.827984303500377	1

Appendix 3: Max rainfall data from 1998-2017 and its statistical calculation

No	Year	Maximum Daily Rainfall	Descending Order(X)	Rank(X)	Y=Log (X)
1	1998	35.3	60.2	1	1.779596491
2	1999	23.3	58.6	2	1.767897616
3	2000	38.1	58.2	3	1.764922985
4	2001	33.1	52.1	4	1.716837723
5	2002	58.6	51.2	5	1.709269961
6	2003	58.2	46.1	6	1.663700925
7	2004	60.2	43.6	7	1.639486489
8	2005	52.1	38.8	8	1.588831726
9	2006	46.1	38.1	9	1.580924976
10	2007	28.8	36.9	10	1.567026366
11	2008	38.8	35.8	11	1.553883027
12	2009	51.2	35.3	12	1.547774705
13	2010	30.2	35.3	13	1.547774705
14	2011	36.9	35.1	14	1.545307116
15	2012	35.3	34.3	15	1.53529412
16	2013	33.6	33.6	16	1.526339277
17	2014	35.1	33.1	17	1.519827994
18	2015	43.6	30.2	18	1.480006943
19	2016	34.3	28.8	19	1.459392488
20	2017	35.8	23.3	20	1.367355921
	Average_ ( $\bar{X}$ )	40.43			
	St. Dev_ ( $\sigma_x$ )	10.577			
			Average_ $\bar{Y}$		1.593072578
			St. Dev (Sy)		0.111065073
			Coficient of Skness(Cs)		0.180689596

Appendix 4: Skew coefficient for different return period

**TABLE 12.3.1**  
 **$K_T$  values for Pearson Type III distribution (positive skew)**

Skew coefficient $C_s$ or $C_{II}$	Return period in years						
	2	5	10	25	50	100	200
	Exceedence probability						
	0.50	0.20	0.10	0.04	0.02	0.01	0.005
3.0	-0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.9	-0.390	0.440	1.195	2.277	3.134	4.013	4.909
2.8	-0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.7	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.360	0.518	1.250	2.262	3.048	3.845	4.652
2.4	-0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.3	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.1	-0.319	0.592	1.294	2.230	2.942	3.656	4.372
2.0	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	-0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	-0.180	0.745	1.341	2.066	2.585	3.087	3.575
1.0	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.9	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.7	-0.116	0.790	1.333	1.967	2.407	2.824	3.223
0.6	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.5	-0.083	0.808	1.323	1.910	2.311	2.686	3.041
0.4	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.3	-0.050	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.1	-0.017	0.836	1.292	1.785	2.107	2.400	2.670
0.0	0	0.842	1.282	1.751	2.054	2.326	2.576

(Source: Vent Chow)

Appendix 5:- Log-Pearson Type III distribution frequency analysis calculation

Return Period (T)	$\bar{Y}$	$S_y$	$K_T$	$Y_T = \bar{Y} + K_T * S_y$	$X_T = 10^{Y_T}$ (mm)
2	1.593072578	0.111065073	-0.272	1.562865196	36.5
5	1.593072578	0.111065073	0.831	1.685385271	48.5
10	1.593072578	0.111065073	1.299	1.737375214	54.6
25	1.593072578	0.111065073	1.812	1.794281126	62.3
50	1.593072578	0.111065073	2.149	1.831746821	67.9
100	1.593072578	0.111065073	2.458	1.866081247	73.5

Appendix 6: Gumbel distribution frequency analysis calculation

Return Period (T)	Mean rainfall data $\bar{X}$ (mm)	Frequency Factor $K_T$	Standard Deviation ( $\sigma_x$ )	$X_T = \bar{X} + K_T * \sigma_x$ (mm)
2	40.43	0.164279839	10.577	38.7
5	40.43	0.719449619	10.577	48
10	40.43	1.304555416	10.577	54.2
25	40.43	2.043838142	10.577	62
50	40.43	2.5922803	10.577	67.8
100	40.43	3.136672847	10.577	73.6

Appendix 7: Rainfall depth and Return period

Return Period (Year)	Rainfall depth (mm)	
	Log Person III	Gumbel
2	36.5	38.7
5	48.5	48
10	54.6	54.2
25	62.3	62
50	67.9	67.8
100	73.5	73.6

Appendix 8: Meteorology station in Ethiopia (Years of record through 2010)

Meteorological Region	Station	Years of Record	Meteorological Region	Station	Years of Record
A1	Axum	17	B	Bedele	39
	Mekele	46		Gore	56
	Maychew	32		Nekempte	40
A2	Gondar	52	C	Jima	54
	Debre Tabor	15		Arba Minch	23
	Bahir Dar	45		Sodo	49
	DeberMarkos	55		Awasa	36
	Fitche	44		Kombolcha	57
	Addis Ababa	57		Woldiya	29
	DebreZeit	55		Sirinka	27
A3	Nazareth	46	D1	Gode	33
	Kulums	43		KebreDihar	40
	Robe/Bale	29		Kibremengist	33
A4	Metehara	24	D2	Negele	51
	Dire Dawa	58		Moyale	29
	Mieso	42		Yabelo	34

(Source Ethiopia road authority drainage design manual, 2013)

Appendix 9: Depth and intensity for a given return period for sebeta

Duration (min)	Duration (hr)	Rainfall Ratio	Depth for given Return periods(mm)						Intensity for given return periods(mm/hr)					
			2 years	5 years	10 years	25 years	50 years	100 years	2 years	5 years	10 years	25 years	50 years	100 years
5	0.083	0.145	5.624	6.983	7.882	9.019	9.862	10.699	67.490	83.794	94.589	108.227	118.346	128.389
10	0.167	0.244	9.423	11.700	13.207	15.111	16.524	17.926	56.540	70.198	79.241	90.667	99.144	107.557
20	0.333	0.370	14.318	17.776	20.066	22.960	25.106	27.237	42.953	53.329	60.199	68.879	75.318	81.710
30	0.500	0.450	17.404	21.608	24.392	27.909	30.518	33.108	34.808	43.217	48.784	55.818	61.037	66.216
60	1.000	0.581	22.486	27.918	31.514	36.058	39.430	42.776	22.486	27.918	31.514	36.058	39.430	42.776
90	1.500	0.650	25.166	31.245	35.270	40.355	44.128	47.873	16.777	20.830	23.513	26.904	29.419	31.915
120	2.000	0.696	26.911	33.412	37.717	43.155	47.190	51.194	13.456	16.706	18.858	21.578	23.595	25.597

Appendix 10: Rainfall depth for different Regions

24 hr Rainfall depth (mm) Vs Frequency (yr)								
Return period years	2	5	10	25	50	100	200	500
RR-A1	50.3	66.02	76.28	89.13	98.63	108.06	117.48	130.00
RR-A2	51.92	65.52	74.45	85.70	94.07	102.45	110.91	122.27
RR-A3	47.54	59.61	67.66	77.92	85.62	93.34	101.13	111.58
RR-A4	50.39	63.83	72.28	82.55	89.97	97.20	104.32	113.63
RR-B1	58.87	71.26	79.29	89.35	96.84	104.37	112.02	122.41
RR-B2	55.26	66.95	79.68	92.03	101.29	110.61	120.07	132.87
RR-C	56.52	71.04	80.54	92.52	101.48	110.50	119.66	132.06
RR-D	56.23	76.84	90.37	107.46	120.23	133.05	146.00	163.44

(Source: Ethiopian Roads Authority Drainage Design Manual, 2013)

Appendix 11: Depth and intensity for a given return period for region A-2 (ERA)

Duration (min)	Duration (hr)	Rainfall Ratio	Depth for given Return periods(mm)						Intensity for given return periods(mm/hr)					
			2 years	5 years	10 years	25 years	50 years	100 years	2 years	5 years	10 years	25 years	50 years	100 years
5	0.083	0.145	7.547	9.524	10.822	12.457	13.674	14.892	90.563	114.28	129.861	149.485	164.084	178.701
10	0.167	0.244	12.645	15.957	18.132	20.872	22.910	24.951	75.869	95.742	108.791	125.230	137.461	149.706
20	0.333	0.370	19.212	24.245	27.549	31.712	34.809	37.910	57.637	72.734	82.648	95.136	104.428	113.731
30	0.500	0.450	23.354	29.471	33.488	38.548	42.313	46.082	46.708	58.942	66.976	77.096	84.626	92.165
60	1.000	0.581	30.173	38.077	43.266	49.804	54.668	59.538	30.173	38.077	43.266	49.804	54.668	59.538
90	1.500	0.650	33.769	42.614	48.422	55.739	61.183	66.633	22.513	28.409	32.282	37.160	40.789	44.422
120	2.000	0.696	36.111	45.570	51.781	59.606	65.428	71.256	18.056	22.785	25.891	29.803	32.714	35.628

Appendix 12: Recommended Percentage Imperviousness for different land uses

Land Use or Surface Characteristics	Percentage Imperviousness
<b>Business:</b>	
Commercial areas	95
Neighborhood areas	85
<b>Residential:</b>	
Single-family	*
Multi-unit (detached)	60
Multi-unit (attached)	75
Half-acre lot or larger	*
Apartments	80
<b>Industrial:</b>	
Light areas	80
Heavy areas	90
Parks, cemeteries	5
Playgrounds	10
Schools	50
Railroad yard areas	15
<b>Undeveloped Areas:</b>	
Historic flow analysis	2
Greenbelts, agricultural	2
Off-site flow analysis	45
<b>Streets:</b>	
Paved	100
Gravel (packed)	40
Drive and walks	90
Roofs	90
Lawns, sandy soil	0
Lawns, clayey soil	0

(Source, Colorado drainage criteria manual (v. 1))

Appendix 13: Equation used for percentage of imperviousness determination

$$\varphi = \frac{(A_1 * \varphi_1 + A_2 * \varphi_2 + \dots + A_n * \varphi_n)}{(A_1 + A_2 + \dots + A_n)}$$

Where  $\varphi$  =imperviousness of the whole sub catchment,

$\varphi_n$  = imperviousness of each type of surface,

$A_n$  =area of each surface

Appendix 14: Model input data's

No	Name	S_node	E_node	Depth	Width	Length(m)
1	C1	J1	J2	0.6	0.83	173.92
2	C2	J2	J3	0.6	0.6	204.66
3	C3	J3	J4	0.6	0.6	36.06
4	C4	J4	J10	0.6	0.6	44.98
5	C5	J5	J6	0.5	1.2	338.48
6	C6	J6	J7	0.5	1.2	162.86
7	C7	J7	J8	0.5	1.2	216.75
8	C8	J8	J9	0.5	1.2	13.64
9	C9	J9	J13	0.4	1	51.17
10	C10	J5	J10	0.7	0.5	249.08
11	C11	J10	J11	0.7	0.7	175.11
12	C12	J11	J12	0.7	0.7	334.9
13	C13	J12	J13	0.7	1.16	297.7
14	C14	J13	J14	0.75	0.9	142.32
15	C15	J14	J15	0.75	0.9	235.44
16	C16	J15	out1	0.8	0.9	118.99

No	Junctions	Elevation of the junction(m)	Depth	Inverted elevation(m)
1	J1	2296.974352	0.7	2296.274352
2	J2	2294.825645	0.7	2294.125645
3	J3	2294.377764	0.7	2293.677764
4	J4	2294.113722	0.7	2293.413722
5	J5	2296.000000	0.6	2295.400000
6	J6	2273.580388	0.6	2272.980388
7	J7	2266.264114	0.6	2265.664114
8	J8	2260.785112	0.6	2260.185112
9	J9	2260.981962	0.6	2260.381962
10	J10	2291.259391	0.8	2290.459391
11	J11	2278.054666	0.8	2277.254666
12	J12	2268.000000	0.8	2267.200000
13	J13	2264.200000	0.8	2263.400000
14	J14	2261.500000	0.8	2260.700000
15	J15	2259.700000	0.9	2258.800000

Appendix 15:- Top map of the study area for existing land use



Appendix 16:- Top map of the study area for the year 2008 G.C.



Appendix 17: For model calibration recorder depth used.

Date	Recorded depth(m)	Average flow depth(m)
16/06/2019	0.49	0.618
18/06/2019	0.68	
8/07/2019	0.70	
9/07/2019	0.56	
20/07/2019	0.66	

Appendix 18:-calculation for determination of velocity and flow rate for model validation

Date	Width(m)	Record Depth(m)	Drainage length (m)	Slop(s)	Roughness (n)	Area(m <sup>2</sup> )	Perimeter (m)	hydraulic radius(R)	Velocity(m/s)	Discharge Q(m <sup>3</sup> /sec)
23/06/2019	0.6	0.58	1185.47	0.0267	0.020	0.208	1.76	0.118	1.968	0.409
26/06/2019	0.6	0.64				0.384	1.88	0.204	2.834	1.088
3/07/2019	0.6	0.72				0.432	2.04	0.212	2.903	1.254
15/07/2019	0.6	0.48				0.288	1.56	0.185	2.649	0.763
19/07/2019	0.6	0.61				0.366	1.82	0.201	2.804	1.026

Appendix 19:- Calculation of three error functions of model

a) Coefficient of determination( $R^2$ )

Recorded average depth(m)	Simulated flow rate (using SWMM5) CMS	Calculated (observed) flow rate (using manning's) CMS	$q_t^{ob} - q_t^{avrob}$	$q_t^{sim} - q_t^{avrsim}$	$(q_t^{ob} - q_t^{avrob}) * (q_t^{sim} - q_t^{avrsim})$	$(q_t^{ob} - q_t^{avrob})^2$	$(q_t^{sim} - q_t^{avrsim})^2$
0.58	0.42	0.409	-0.509	-0.5432	0.276489	0.259081	0.295066
0.64	1.197	1.088	0.170	0.2338	0.039746	0.028900	0.054662
0.72	1.198	1.254	0.336	0.2348	0.078893	0.112896	0.055131
0.48	0.771	0.763	-0.155	-0.1922	0.029791	0.024025	0.036941
0.61	1.23	1.026	0.108	0.2040	0.022032	0.011664	0.041616
Total	4.816	4.54	-0.050	-0.0628	0.446951	0.436566	0.483417
Average	0.9632	0.908	-0.010	-0.0126			

$$\text{Coefficient of determination } (R^2) = \left[ \frac{\sum_{t=1}^n (q_t^{obs} - q_t^{avrg.obs})(q_t^{sim} - q_t^{avr.sim})}{\sqrt{\sum_{t=1}^n (q_t^{obs} - q_t^{avrg.obs})^2} \sqrt{\sum_{t=1}^n (q_t^{sim} - q_t^{avr.sim})^2}} \right]^2$$

$$= ((0.446951) / (0.660731 * 0.695282))^2 = 0.9466$$

$$R^2 = 0.95$$

b) The Nash-Sutcliffe coefficient( $R_{NS}$ )

Recorded average depth(m)	Simulated flow rate (using SWMM5) CMS	Calculated (observed) flow rate (using manning's) CMS	$(q_t^{ob} - q_t^{smi})^2$	$(q_t^{ob} - q_t^{avrob})^2$
0.58	0.42	0.409	0.000	0.2490
0.64	1.197	1.088	0.012	0.0324
0.72	1.198	1.254	0.003	0.1197
0.48	0.771	0.763	0.000	0.0210
0.61	1.23	1.026	0.042	0.0139
Total	4.816	4.54	0.057	0.4361
Average	0.9632	0.908		

$$\text{The Nash Sutcliffe Coeff. } (R_{NS}) = 1 - \frac{\sum_{t=1}^n (q_t^{obs} - q_t^{sim})^2}{\sqrt{\sum_{t=1}^n (q_t^{obs} - q_t^{avrg.obs})^2}}$$

$$R_{NS} = 1 - (0.057/0.660379) = 1 - 0.086314$$

$$R_{NS} = 0.91$$

c) Relative error (RE)

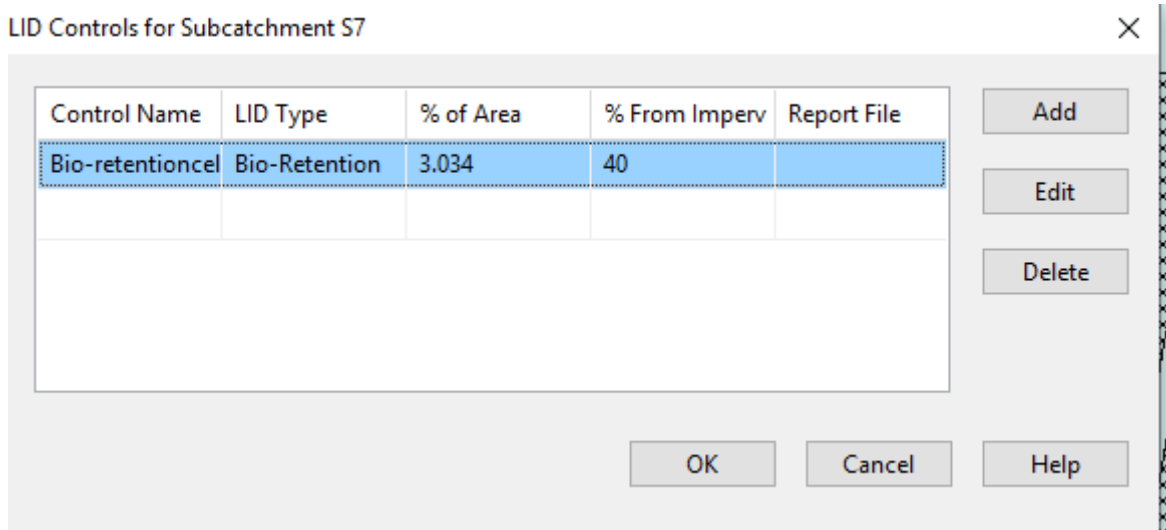
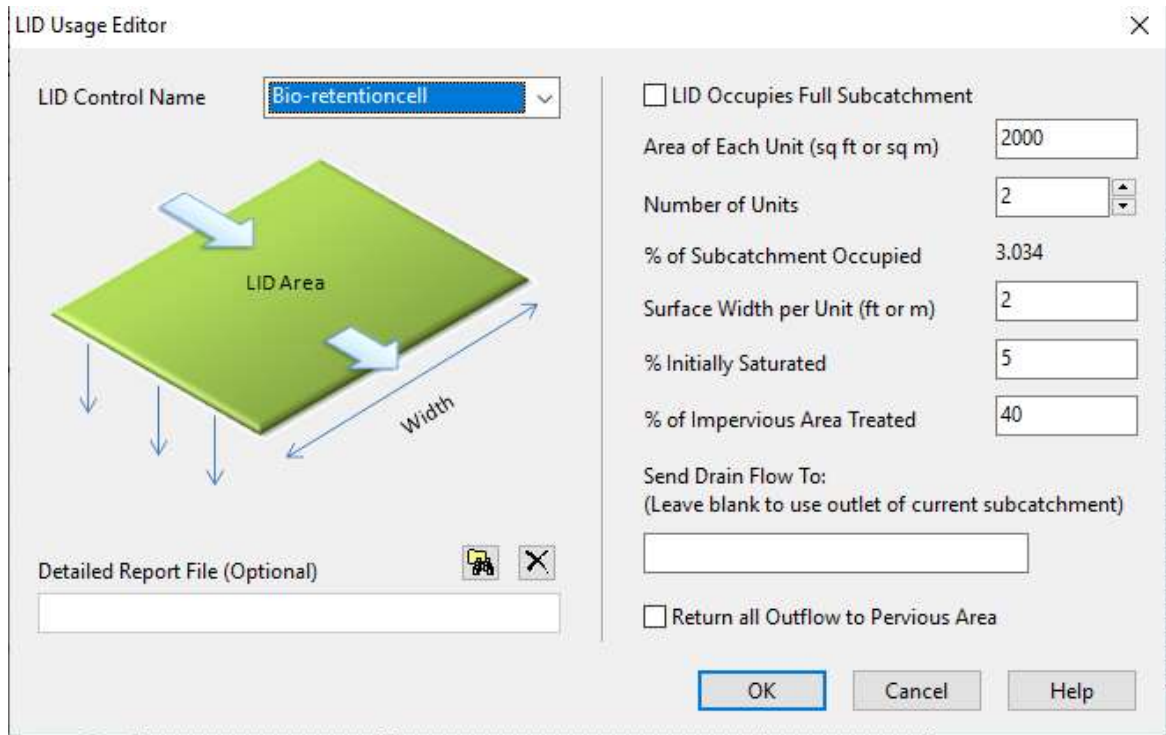
Recorded average depth(m)	Simulated flow rate (using SWMM5) CMS	Calculated (observed) flow rate (using manning's) CMS	$q_t^{ob} - q_t^{smi}$
0.58	0.42	0.409	-0.011
0.64	1.197	1.088	-0.109
0.72	1.198	1.254	0.056
0.48	0.771	0.763	-0.008
0.61	1.23	1.026	-0.204
Total	4.816	4.54	-0.276
Average	0.9632	0.908	

$$\text{Relative Error (RE)} = \frac{\sum_{t=1}^n |q_t^{obs} - q_t^{sim}|}{\sqrt{\sum_{t=1}^n q_t^{obs}}}$$

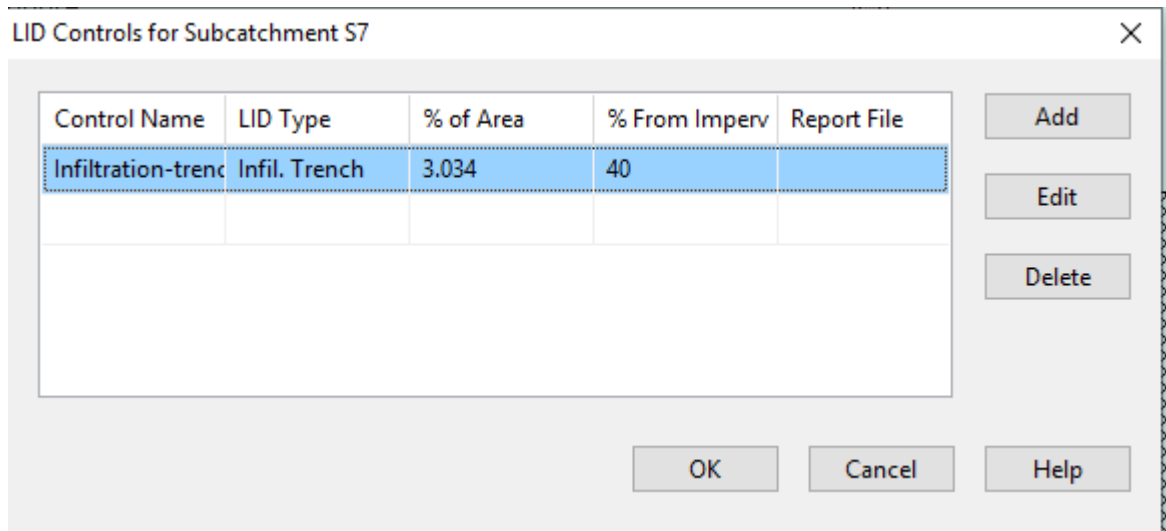
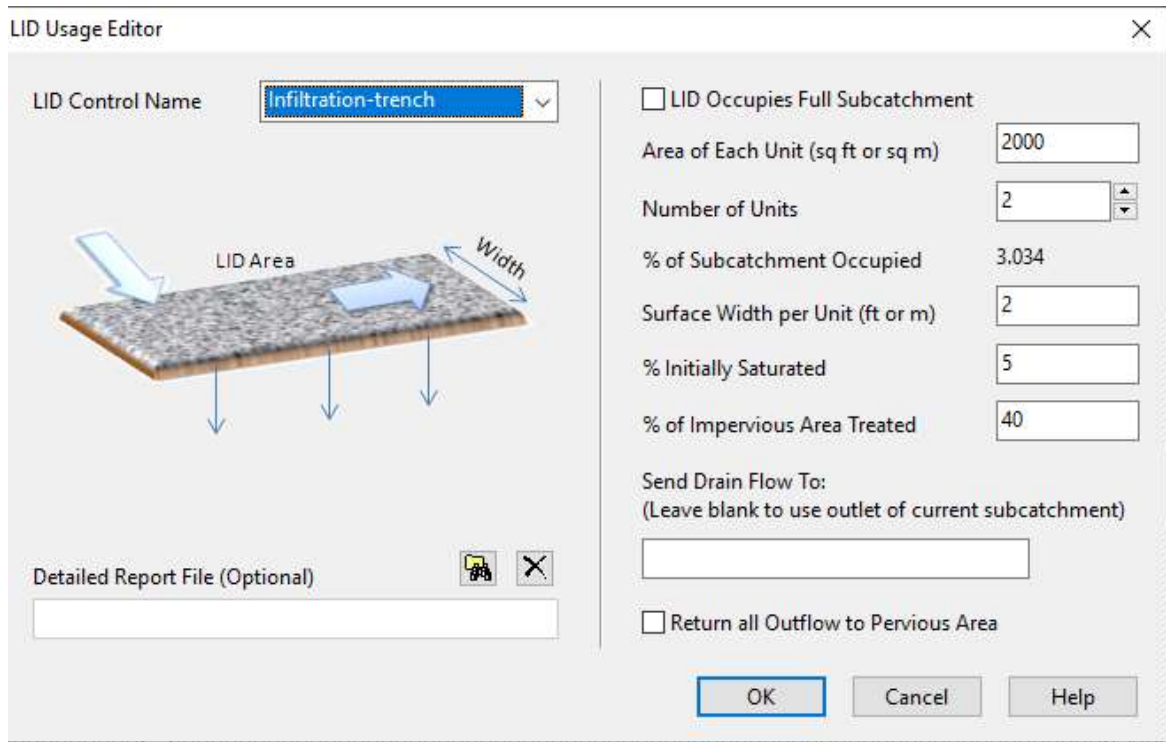
$$RE = (-0.276) \div (2.131) = 0.1295$$

$$RE = 12.95\%$$

Appendix 20:-LID control editorial in SWMM5.1 model (for bio-retention cell)



Urbanization Impact Assessment On Stormwater Drainage Performance of Sebeta Town  
 Appendix 21:-LID control editorial in SWMM5.1 model (for infiltration trench)



Appendix 22:-Area proposed to construct bio-retention cell

