ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

Performance Assessment of Stormwater Drainage System in Alamata Town

A Thesis Submitted and Presented to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Degree of Masters of Science in Civil Engineering (Major in Water Supply and Environmental Engineering)

By

Ashenafi Zinabie

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Addis Ababa

Ethiopia

November, 2018

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DECLARATION

I, Ashenafi Zinabie, declare that this thesis is my own work and that it has been presented and will not be presented by me to any other University for similar or any other degree award.

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ACKNOWLEDGMENT

God what you have done and are doing for me is really beyond what I can express; nothing is paid for you except praise!

I would like to express my deepest gratitude and thanks to my advisor Dr. Ing. Geremew Sahilu 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 brother Mr. Birhanu Kebede for reading my thesis and providing me valuable advices and my wife Helen Nega understood why I had to give more time to my study than to her and her understanding have made the hardship easier.

Finally I, would like to thank National Meteorological Service Agency, Ministry of Agriculture , Ministry of Water, Irrigation and Electricity Addis Ababa, Ethiopia and Alamata town municipality, for their help in providing me with the necessary research data.

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LIST OF ABBREVIATIONS

AACRA	Addis Ababa City Road Authority
BMPs	Best Management Practices
CSA	Central Statistical Agency
CN	Curve Number
DEM	Digital Elevation Model
DN	Digital Number
EPA	Environmental Protection Agency
ERA	Ethiopian Roads Authority
FUPCOB	Federal Urban Planning Coordinating Bureau
GIS	Geographic Information System
GPS	Geographical positioning system
HSG	Hydrological Soil Group
M.A.M.S.L	Meters above mean sea level
SCS	Soil Conservation Service
Tc	Time of concentration
IDF	Intensity-Duration-Frequency
LULC	land use land cover
USWD	Urban Stormwater drainage

ABSTRACT

Urbanization of an area invariably leads to increase in overall imperviousness of the area. When land becomes impervious,stormwater will stagnate on the surface thereby affecting the infrastructure, transportation and causing inconvenience to general populace. Stormwater drainage problem is one of the major challenges facing many countries in Ethiopia in general and Alamata town also faced the problem. This study has investigated the overall challenges of the stormwater drainage system in Alamata town.Rapid expansion of built environment, poor urban drainage managements and location of Alamata town being at the foothills of mount Gra-Kahsu are the major problems in the study area. The objective of this study is to evaluate the current stormwater drainage systems and associated problems. This research involves collection of both primary and the secondary data and the collected raw data was edited, coded, classified, and tabulated in order to make it ready for analysis. Furthermore, spatial analyses was conducted using Arc GIS, Bentley Flow master, Google Earth pro, and Auto CAD software's as analytical tools. The land use land cover image was processed for the years 2008 and 2018 by using Arc GIS.10.4.1 and Google earth pro then for each land use/land cover, annual stormwater runoff volume was calculated and digital change detection were evaluated. The results indicate that Annual runoff volume of Built -up area in the study area has increased from 162129.6m^3 in 2008 to 183772.8 m^3 in 2018 which accounts for 13.35% of the total Annual runoff volume. The Vegetation has decreased from 15616.8m^3 in 2008 to 4568.4m^3 in 2018 which accounts for 70.75%. The Bare Land area has increased from 8286.3m^3 in 2008 to 20970.9m^3 in 2018 which accounts for 153.08%. The existing depth and width of the stormwater drainage channel were measured for all sub catchments of the town and used to determine the existing drainage capacity using Bentley Flow master. The hydrological analysis was computed by the SCS method and rational method. The computed discharge values, which were determined by both SCS method and rational method, were compared by dividing the watershed area according to their area of application. The existing condition drainage channel depths of sub-catchments 6,7 and 8 Increase by 68.40%, 160.20% and 121.07%; and the widths by 55.44%, 116.83% and 100.98%, and the Design discharge was also 9.29m^3/s, 16.47m^3/s and 9.13m^3/s respectively.

Key Words:- Urbanization, Stormwater ,Grakahsu Mountain, Bentley Flow master, SCS curve number.

1 INTRODUCTION

1.1 Background

With urbanization, impermeability increases because of the increase in impervious surfaces. This the drainage pattern changes,increases overland flow resulting in flooding and related environmental problems. The impact of this is severe on spatial structures like road. This is because, flooding and its related environmental problems like sheet and gulley erosion, surface flood tends to affect road services and its life span (Mitiku Adisu and Mekdes Hailemikael, 2017).

Insufficient urban stormwater drainage facility represent one of the most common sources of compliant from the citizens in many towns of Ethiopia and this problem is getting worse and worse with the ongoing high rate of urbanization in different parts of the country (Alemu, 2017). Ethiopia is a developing country with a high rate of urbanization and industrialization. This has led to the increase in urban population and increase in physical structures such as buildings, roads and industries. These developments lead to challenges in control of urban floods since it results in more surface flow. In Ethiopian context, where watersheds of many urban centers receive significant amount of annual rainfall and where rainfall intensity is generally high, control of runoff at source, flood protection, and safe disposal of excess water/runoff through proper drainage facilities becomes essential. Drainage problems in urban areas of Ethiopian include flooding, deterioration of roads, land degradation, sedimentation, blockage of drainage facilities and water logging (Asfaw, 2016).

Stormwater drainage is the process of draining excess water from streets, sidewalks, roofs, buildings and other areas. The system used to drain storm water are often referred to as storm drains and are also called storm sewers and drainage wells .

Poor drainage can lead to flooding, resulting in property loss, and people may even be forced to move to escape floodwaters. Flooding may also damage water supply infrastructure and contaminate domestic water sources. Drainage problems include flooding, erosion of roads, land degradation, sedimentation, water logging, blockage of drainage lines, and others. With urbanization impervious surfaces increase, drainage pattern changes, overland flow becomes speedy, flooding and environmental problems such as land degradation increases(Tafete, 2013).

Naturally the channel network in the runoff process is increased with the increase of the watershed area, so as in urban areas with artificial channels. The final receiving system for all run-off is a water way such as: stream or river. The artificial stormwater runoff drainage system takes sewages from the vicinity in its way to the final receiving system (Tafete, 2013).

The absence of adequate integration between road and urban stormwater drainage net-work is also the other challenge in urban areas, because the run-off generated/produced within a particular urban area will not safely be discharged in to the final receiving system. Thus, this will be the source of environmental problems like over topping, erosion, pollution, barrier to traffic and other related problems (Dagnachew, 2009).

Drainage systems are needed in urban environments to ensure the functionality of the urban infrastructure and public health. Runoff caused by rainfall needs to be safely either retained in suitable places inside the urban catchment or conveyed away from the catchment.

Different parts of the Ethiopian highlands receive between 600 and 2700 mm of rainfall annually (Zeleke and Steenhuis, 2005). This heavy rain sometimes creates high flood in the overlaying area which causes loss of property.

Alamata town is like other towns of Ethiopia has a lot of problems including inadequacy and poor quality drainage infrastructure. Stemming from its location at the foot of Gra-kahsu Mountain with absence of proper drainage line along roads in the town, seasonal floods and other environmental problems are most frequently occurring especially on downstream parts of the town. This has resulted in negative impacts on sustainable urban drainage system provision and management. Thus, there is a need of studying the stormwater Assessment in Alamata town to handle the yearly repeating urban stormwater drainage problems with overloading the drainage system and the serious consequences on the environment.

1.2 Statement of the problem

Lack of urban Stormwater drainage (USWD) management represent one of the most common sources of compliant from the residents in many urban centers of Ethiopia, and this problem gets worse and worse with the rate of urbanization.

The location of Alamata town being at the foothills of Mount Grakahsu is the main challenge of stormwater drainage problem and it is always under a risk of over flooding that stormed from the upper part. Heavy rains with high runoff in Alamata town causes stormwater drainage problems from the nearby Mountain range causing damages to houses close to the banks of the streams. This has been the cause for substantial loss of property during the rainy season.

Growth in construction industry i.e. structures such as roads, buildings, pavements which are increased each day, has led to decrease in infiltration process in structured areas and increase in surface runoff hence increase in stormwater over flooding in most parts of areas in the town. In addition the improper and poor maintenance of drainage system due to accumulation of sediments has led to accumulation of stormwater thus result to flooding. The process of urbanization not only destroys the vegetation cover, but also alters the natural course of water flow. The increase in urbanization leads to the construction of more roads, sidewalks, and buildings. This results in reducing natural permeable surface that can infiltrate water into the ground. As a result, the impermeable surface will create more stormwater runoff.

1.3 Objectives

1.3.1 General Objective

The objective of this study is to assess the performance of current stormwater drainage system and associated problems.

1.3.2 Specific objectives

- To evaluate the functionality of the existing stormwater drainage system.
- To assess land use land cover changes effect on the stormwater runoff of the study area.
- To investigate the impact of Grakahsu Mountain on the stormwater drainage of study area.

1.4 Research Questions

- What is the status of current stormwater drainage system in the town?
- What is the effect of land use land cover changes on the stormwater runoff of the study area?
- What is the impact of Grakahsu Mountain on the stormwater drainage system in the study area?

1.5 Significance of the Study

This study is beneficial to the area for future stormwater drainage structures construction by assessing the performances of the existing stormwater drainage structures and proposing mitigation measures to avoid improper functioning. The findings from this research could also provide valuable information that can be used as an input or reference for further studies in this area.

The study is beneficial for academicians and researchers who conduct similar researches on other stormwater drainage structures, urban drainage, stormwater management, local street drainage and land use/land cover effects on runoff.

The result of this study also may help in filling the gaps by identifying problems to Sustainability, taking proper designing of Stormwater drainage system and proper functioning of Drainage schemes in the town. In general, Alamata is the part of which facing the Drainage problems, so further investigation were contribute the solution for stormwater drainage problem and sustainable drainage system for future use in the area.

1.6 Scope and Limitation of the Study

The study is limited to the Performance Assessment of existing stormwater drainage structures and proposing mitigation measures. The main focus of this study includes: investigate the functionality of the existing stormwater drainage systems, identify the impact of Grakahsu Mountain on the stormwater drainage system of the study area, land use land cover change effects on the stormwater runoff volume and identify the alternative effective stormwater measures as well as proposing best management practice for the existing problem. Evaluating the whole catchment is not necessary to come up with solution for the current storm water problem. Therefore, some representative major flood prone areas are selected. The study is limited to some parts of Alamata town (Four Kebele; whole part of Kebele-02, Kebele-03 and same part of Kebele-01 and Kebele-04) which are not including whole parts of the town because Kebele-02 and Kebele-03 are exposed to stormwater drainage problems. This research also does not include structural design of all types of drainage structures except proposing the type and size of required drainage structures.

1.7 Thesis outline

The thesis is organized into five chapters from introduction part to the conclusion and recommendation. The **first chapter** deals with introduction, statement of the problem, the objective of the research, research question, significance of the study, scope and limitation of the study, and the **second chapter** contain information regarding stormwater management,Overview of stormwater discharges,urbanazation effects on surface runoff,Stormwater Best Management practices,Land use land cover change as well as description of different models and Previous studies on Ethiopia. The **third chapter** is about description of the study area, materials, methodology and procedure to be applied in the research from data collection to the result of the analysis. The **forth chapter** includes result and discussion and the last chapter focused on the conclusion and recommendation parts which concludes the study and recommends the possible solutions.

2 LITERATURE REVIEW

2.1 Overview of Stormwater Discharges

Population growth and urban development can create potentially severe problems in urban water management. One of the most important facilities in preserving and improving the urban water environment is an adequate and properly functioning stormwater drainage system Construction of houses, commercial buildings, parking lots, paved roads and streets increases the impervious cover in a watershed and reduces infltration. Also, with urbanization, the spatial pattern of flow in the watershed is altered and there is an increase in the hydraulic efciency of flow through artifcial channels, curbing, gutters and storm drainage and collection systems. Tese factors increase the volume and velocity of runoff and produce larger peak flood discharges from urbanized watersheds than occurred in the pre-urbanized condition. Many urban drainage systems constructed under one level of urbanization are now operating under a higher level of urbanization and have inadequate capacity (Manish Kumar and Rawat, 2015).

2.2 Urban Stormwater Management

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 engineered 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.

2.3 Urbanization effect on surface water flow

2.3.1 Increase in runoff

The volume of water available for runoff increases because of the increase in the impervious cover provided by roofs of buildings, streets, paved parking lots, lined drains which reduce the amount of infiltration. Before urbanization much of the rainfall is absorbed by the surrounding vegetation, soil and ground cover. Rain falling on undisturbed land such as forests, grasslands, and wetlands is partly intercepted by vegetation, partly retained by surface depressions and puddles, and partly infiltrates into the ground but only a small fraction flows overland (Sandwich, 2010).

The runoff coefficient is a measure of the amount of rainfall that is converted to runoff or storm runoff generation. As the percentage of watershed imperviousness increases,the runoff coefficient increases with urbanization.

2.3.2 Decrease in time of concentration

Changes in hydraulic efficiency of stormwater collection systems with artificial channels, storm sewers increase the velocity of flow. In an efficient manner, stormwater from roofs are conveyed to storm drains through gutters and downpipes, stormwater from road surfaces are conveyed to storm drains through curbs and gutters. Thus, drainage systems convey the runoff quickly into receiving waters compared to pre-urbanized setting. The retention period of water is reduced and time concentration of flow at a stream section is drastically reduced (Sandwich, 2010).

2.3.3 The Effects of Urbanization on the Water Cycle

Rain water, either returns to the atmosphere through evapotranspiration or infiltrates the soil, runs off on the surface and likely ends up into a river, ocean or lake (Figure 2.1). The relative proportions depend on the nature of the surface, duration of rainfall and intensity.

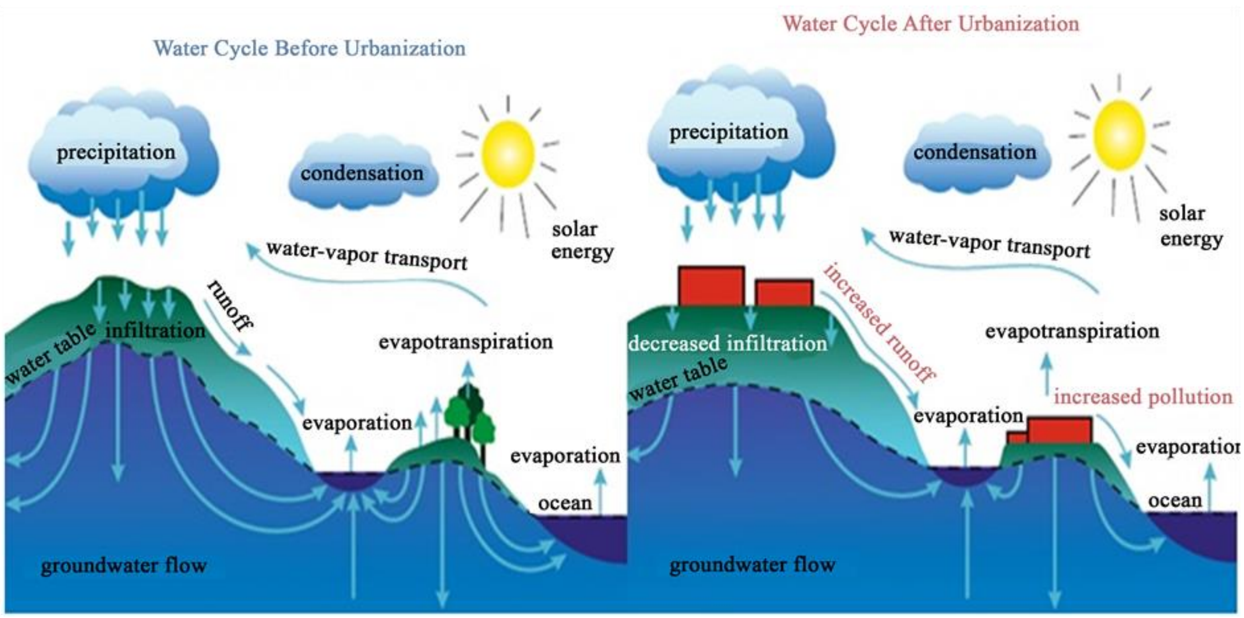

Figure 2-1 Water cycle diagram showing different processes involved before and after urbanization (Source, (Olivier, 2016).

Development of an urban area involves covering the ground with artificial surfaces, and it significantly increases the amount of surface runoff in relation to infiltration and evapotranspiration. This therefore increases the total volume of water reaching the river when or after it rains. As a result, this will reduce water that would be stored within a catchment and contribute to water scarcity. Furthermore, the construction of storm sewers and culvert of natural streams and channels which takes place during urbanization results in water being transmitted into the drainage network more rapidly; this increases outflow velocity. Since a larger runoff is discharged within a shorter interval, peak rate of water inevitably increases, giving rise to the danger of sudden flooding of rivers.These subsequent floods damage human and natural resources as well as properties.

When people develop within a watershed, the hydrologic cycle is affected. The increase in impervious or hard surfaces, including rooftops and pavement (roads, driveways, and parking lots) decreases the amount of water that soaks into the ground or infiltrates. This increases the amount of surface runoff. If infiltration is significantly decreased, groundwater levels may decline, affecting stream flows especially during the dry season. Meanwhile, lowered groundwater levels can result in subsequent well failures. While the effects of urbanization on the water cycle can be major, if wise choices are made during the development process, the impacts can be minimized and future water supply can be protected.

The water cycle, also known as the hydrological cycle, is the continuous exchange of water between land, water bodies, and the atmosphere. Impervious surfaces associated with urbanization alter the natural amount of water that takes each route as topography of land changes by urbanization. The consequences of this change are a decrease in the volume of water that percolates into the ground, and a resulting increase in volume and decrease in quality of surface water. These hydrological changes have significant implications for the quantity of fresh, clean water that is available for use by humans, fish and wildlife (Alemu, 2017).

2.4 Stormwater Best Management Practices (BMP's)

Best Management Practices (BMPs) are schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of State waters. BMPs also include treatment, operating procedures, and practices to control site runoff, spillage or leaks, waste disposal, or drainage from material storage. BMPs include structural and nonstructural controls (Springs, 2014).

2.4.1 Goals of stormwater BMPs

In existing urbanized areas, BMPs can be implemented to address a range of water quantity and water quality considerations. The applicability of individual practices will vary depending on the needs of the practitioner. For new urban development, BMPs should be designed and implemented so that the post-development peak discharge rate, volume, and pollutant loadings to receiving waters are as close as possible to pre-development values.

In some instances, the application of BMPs can improve water quality and or reduce runoff volume when the watershed had been altered from its natural condition. In order to meet these goals, BMPs are typically implemented to address three factors.

- Flow rate control (peak flow reduction)
- Reduction of runoff volume from urbanizing areas
- Pollutant removal and pollutant source reductions

2.4.2 BMP Selection

BMP selection involves many factors such as physical site characteristics, treatment objectives, aesthetics, safety, maintenance requirements, and cost. The most effective and integrated BMP designs begin by determining areas of a site that are best suited for BMPs (e.g., natural low areas, areas with well-drained soils) and then designing the layout of roads, buildings, and other site features around the existing drainage and water quality resources of the site.

Stormwater management BMP’s can be categorized as either **Nonstructural** or **Structural**

2.5 Non-structural controls

Include a range of pollution prevention, education, or institutional management and development practices designed to limit the conversion of rainfall to runoff and to prevent pollutants from entering runoff at the source of runoff generation.

Non-structural controls are the first line of defenses and include practices such as land use planning and management, wetlands and floodplain protection, public education, fertilizer and pesticide application control, solid waste collection and disposal, street cleaning and “good housekeeping” techniques on construction sites Non-structural measures include concepts such as: -

A. Smart Growth Practices and Conservation Design

Conservation Design and Smart Growth can be utilized to direct development in a way that reduces impacts as much as possible in the most environmentally friendly manner.This can be accomplished by minimizing earth disturbance, reducing the number of lots, lot size, lot distribution and location within the development. Conservation Design also provides for open-space areas that can be used as buffers, infiltration, detention, or reduction areas.

B. Reduce "Man-made" Impacts

The reduction of man-made impacts such as roadways, parking lots, and roof leaders/drains can help considerably to minimize stormwater impacts. Roadways can have their length and width reduced within developments to lessen the amount of impervious surface. Parking lots can be reduced in size by using smaller parking spaces, layout changes, and incorporating infiltration aspects to each lot. Parking lots can also be paved with pervious surface material to allow water infiltration into the lot, or the water can be conveyed off-site to a recharge area. (Pocono North east Resource Conservation and Development Council, 1999).

The main advantages of using non-structural source controls are:-

- Long term sustainability
- Cost-effective
- Minimization or prevention
- Reduced ongoing operation or maintenance liability
- Effective use of all resources – including the community

2.6 Structural controls

Structural Controls include facilities and structures which detain or retain stormwater or provide for infiltration or evaporation of stormwater, for the purpose of or with the result of water quality enhancement (Springs, 2014).

Structural BMPs include engineered and constructed systems that are designed to provide control for water quantity and water quality of stormwater runoff. Structural BMPs can be grouped into several general categories. However, the distinction between BMP types and the terminology used. In particular, the terms "retention" and "detention" are sometimes used interchangeably, although they do have distinct meanings. Stormwater detention is usually defined as providing temporary storage of a runoff volume for subsequent release(Iowa State University, 2009). Retention is generally defined as providing storage of stormwater runoff without subsequent surface discharge.

With the strict interpretation of this definition, retention practices would be limited to those practices that either infiltrate or evaporate runoff, such as infiltration trenches and basins. However, retention is also commonly used to describe practices that retain a runoff volume (and hence have a permanent pool) until it is displaced in part or in total by the runoff event from the next storm (American Society of Civil Engineers, 1994).

A. Detention systems

Detention systems capture a volume of runoff and temporarily detain (withhold) that volume for subsequent release. Traditional detention systems do not retain a significant permanent pool of water between runoff events. Detention systems do not reduce the total volume of surface runoff from a storm event since the entire captured volume is eventually released after the period of detention. The main goal of traditional detention systems is to reduce the peak discharge rate to the downstream conveyance(Iowa State University, 2009).

B. Constructed Wetland systems (stormwater wetlands)

Constructed wetlands are artificial, designed complex vegetative water bodies that can provide treatment (and re-cycling) of both wastewater effluent and stormwater runoff. Surface flow systems (also known as free water systems) are wetlands in which water primarily flows above the ground surface and through the litter layer. They simulate natural marshes, employing shallow channels and basins planted with emergent, submergent and/or floating vegetation through which water flows at shallow depths and low velocities (Springs, 2014).

Stormwater wetlands are best applied in watersheds which have been urbanized or where urban growth is planned. They are best suited to areas where soils have limited infiltration potential or where ground water is present relatively close to the surface. Groundwater flow or other steady sources of flow (such as sump pump discharges) may provide a continuous base flow to support aquatic vegetation.

C. Infiltration controls

An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives stormwater runoff. Runoff is stored in the void space between the stone aggregate and infiltrates through the bottom and into the soil matrix. Infiltration trenches perform well for removal of fine sediment and associated pollutants (Iowa State University, 2009).

D. Porous Pavement Systems

A characteristic of a porous pavements system, which is either a permeable or consists of another stabilized surface, is that it allows stormwater runoff to infiltrate through its surface, into the groundwater(Josep dela and Asrat Yemaneh, 2016).

Permeable pavement systems are durable, load-bearing pervious pavement surfaces with underlying stone beds, which store rainwater before it infiltrates into the soil below. Permeable pavement systems reduce stormwater runoff and remove pollutants by replacing traditional impervious pavement, thereby, allowing rainfall to directly infiltrate through the permeable paver surface into the gravel base and eventually, to the underlying soil.

There are various types of permeable paving techniques, including porous asphalt, pervious concrete and concrete grids. Porous asphalt and pervious concrete appear the same as traditional pavement, but are made permeable by manufacturing the mixtures with reduced amounts of fine materials and incorporated void spaces. Concrete grids are manufactured concrete units with incorporated permeable openings, which vary in size depending on the design.

E. Bio retention Systems

It is a shallow excavated surface depression containing mulch and a prepared soil mix and planted with specially selected native vegetation that captures and treats runoff. During storms, runoffs collect in the depression and gradually filter through the mulch and prepared soil mix and root zone. Also referred to as rain garden, bioswale or biofilter.

Bioretention areas are landscaping features adapted to treat stormwater runoff on the development site. They are commonly located in parking lot islands or within small pockets in residential land uses. Surface runoff is directed into shallow, landscaped depressions.

These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. The filtered runoff can either infiltrate into the native soil or be collected in a perforated underdrain and returned to the storm sewer system. They remove pollutants from runoff through filtration in the soil and uptake by plant roots and can help to reduce runoff volume through evapo-transpiration and full or partial infiltration (Springs, 2014).

E. Grassed Swales

Like grass buffers, use of grass swales instead of hardened channels or storm sewers slows runoff and promotes infiltration, also reducing the effects of imperviousness (Springs, 2014). Grass swales are designed to convey stormwater runoff at a non-erosive velocity, as well as enhance its water quality through infiltration, sedimentation, and filtration. Check dams can be used within the swale to slow the flow rate, promote infiltration, and create small, temporary ponding areas. The vegetation covering the side slopes and channel bottom provide a filtration surface as the runoff is slowly conveyed to a downstream discharge location. The vegetation also serves to reduce flow velocities (Iowa State University, 2009).

F. Green Roofs

Green roofs offer an option for decentralized management of rainwater falling on building roofs. It helps to reduce the volume of runoff, delays and reduces peak stormwater runoff flow rates and can reduce pollutants carried to water bodies through the runoff. Implementation of green roofs does not require additional land and therefore offers a decentralized urban stormwatermanagement option in dense urban areas. Moreover, green roofs visually enhance the quality of life in cities (Josep dela and Asrat Yemaneh, 2016).

Green roofs are permanent rooftop planting systems consisting of live vegetation planted in a lightweight constructed soil mix. Green roofs are designed to reduce stormwater runoff from commercial, industrial, and residential buildings by mimicking natural processes where plants and soils absorb and store rainwater until it is later transpired into the air. Green roofs are especially effective for controlling intense, short-duration storms.

G. Gabion

A large rectangular box of heavy gauge wire mesh which holds large cobbles and boulders can be used as a permeable wall or just used in streams and ponds to change flow patterns, stabilize banks, or prevent erosion. Gabions, wire or synthetic baskets of different forms and sizes fled with stone, can be widely used in erosion-control works. Compared to other materials and elements, they possess significant advantages, and they are often combined with forest vegetation (Matic, 2009).

They can be used in various environments and the control of river erosion is one of them where they can work alone or together with other measures such as vegetation. Stone gabions have a low construction cost since it constitutes only of wires and stones where the latter can be collected from the construction area. However, the filling of stones and the quality of the wire when constructing the basket is important factors to take into account when adapting the gabions to the nature of the area to be protected from erosion (Matic, 2009).

2.7 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 nuisance, damage or Danger to its operating environment. Traditionally, these systems provide man-made impervious pathways for guiding stormwater 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).

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 downpipes. 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).

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 kerb inlets, gutter inlets and combined inlets. The kerb inlet has a vertical opening to catch the gutter flow. Although the gutter may be depressed slightly in front of the kerb 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 kerb and gutter openings, are also common in urban drainage systems(Dayaratne, 2000).

Trunk drainage: - The trunk drainage system generally consists of large open channels to convey the runoff from street drainage to receiving waters. They are generally located in an open area reserved as a drainage easement.

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).

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).

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. The sides of basins are usually sloping earth embankments, suitable for spectator use if they are sport fields(Siriwardene, 2003).

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).

2.8 Solid and Liquid Waste Management

Solid and liquid wastes generated from both animal and domestic sources can significantly impair drinking, irrigation, recreational water and other water sources in rural and urban areas. Waste as a management issue has been evident for over four millennia. Disposal of waste to the biosphere has given way to thinking about, and trying to implement, an integrated waste management approach . Solid waste management is a separate discipline dealing with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid wastes in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations, and that also is responsive to public attitudes. In its scope, solid waste management includes all administrative, financial, legal, planning, and engineering functions involved in the whole spectrum of solutions to problems of solid wastes thrust upon the community by its inhabitants (Syed, 20006).

Generally solid and liquid waste management affects the urban stormwater drainage system of the study area.

2.9 The Overview of Stormwater Management Practices in Alamata

Development in Alamata has progressed rapidly. The problems arise when the urban areas become increasingly impermeable, and disturb the ecosystem. The growth of impervious areas will block the natural purification process and water storage. In other words, such development brings significant effect on the hydrologic and hydraulic characteristics of watershed.Thus, it is not surprising the flash flood occurs in urban areas in Alamata and the problem is becoming worse and more frequent from year to year.

In Alamata , the most common drainage applied over the years is the open channel i.e. the open drainage system. Some of the areas in Alamata have adopted closed drainage channels as an alternative to the open drainage system to carry the stormwater runoff to the receiving watercourse.

2.10 Land use and Land cover Changes

Land cover refers the biophysical coverage of land like natural areas, forests, buildings, lakes and roads. The term land cover describes the types of resources/features present on the surface of the earth. It is the observed (bio) physical over on the earth's surface.

Land use refers to the socioeconomic use that is made of land for different purpose such as agricultural use, commerce, residential use, recreational area; at any place , there may be multiple and alterative land uses. It reflects the character of a society's interaction with its physical environment, fact that becomes obvious when it is possible to see different economic and social systems occupying the similar environments (Lingereh, 2017).

Land use modifications associated with urbanization such as the removal of vegetation, replacement of previously pervious areas with impervious surfaces and drainage channel modifications invariably result in changes to the characteristics of the surface runoff hydrograph. Consequently the hydrologic behavior of a catchment and in turn the stream flow regime undergoes significant changes. The hydrologic changes that urban catchments commonly exhibit are, increased runoff peak, runoff volume and reduced time to peak(Ashantha, 2005).

2.11 Image Classification

Image classification is the process of sorting pixels into finite number of individual classes or categories of data, based on their DN (pixel) values. Classification of remotely sensed data is used to assign corresponding levels with respect to groups with homogeneous characteristics with the aim of discriminating multiple objects from each other within the image. The level is called class. Classification is the most popularly used information extraction technique in digital remote sensing. Image classification is a procedure to automatically categorize all pixels in an image of a terrain into land cover classes. This concept is dealt under the broad subject, namely, Pattern Recognition. Spectral pattern recognition refers to the family of classification procedures that utilizes this pixel-by-pixel spectral information as the basis for automated land cover classification (Lingereh, 2017).

There are two primary methods of image classification utilized by image analysts, which are unsupervised and supervised classification. Unsupervised image classification is a method in which the image interpreting software separates the pixels in an image based upon their reflectance values into classes or clusters with no direction from the analyst. Supervised image classification is a method in which the analyst defines small areas, called training sites, on the image which are representative of each desired land cover category. The delineation of training areas representatives of a cover type is most effective when an image analyst has knowledge of the geography of a region and experience with the spectral properties of the cover classes. The image analyst then trains the software to recognize spectral values or signatures associated with the training sites. After the signatures for each land cover category have been defined, the software then uses these signatures to classify the remaining pixels (H. Gonca Coskun and Ugur Alganci, 2008).

For this study, land use land cover maps were generated based on the pixel based supervised classification through a number of processes. The first step was collection of training samples for each land use land cover classes which typically representative for land use land cover classes.

These samples were collected based on the researcher's personal experience and physiographical knowledge of the study area. Moreover, image enhancement and composition were applied for better determination of land cover classes. The next step was performing the image classification using the Maximum Likelihood Classifier through ArcGIS.

Finally, the accuracy assessment of the classified images were assessed by using the original mosaic and the Google Earth images. For performing this analysis a randomly selected points have been taken as references for the land use land cover maps of 2008 and 2018.

2.12 Accuracy Assessment

Accuracy assessment is a general term for comparing a classification to geographical data that are assumed to be true, in order to determine the accuracy of the classification process. It is performed by comparing a map created by using remote sensing analysis to a reference map based on different information sources such as Google earth. An interpretation is then made of how close the newly produced map from the remotelysensed data matches the reference (source) map. Although the basic approaches to accuracy assessment seems relatively direct and easy, a variety of errors encountered when evaluating an image classification and capturing remotely sensed data. Evaluation of the accuracy of a classified image can be done using an error matrix sometimes called confusion matrix (Getu, 2014).

Google Earth represents a powerful and attractive source of positional data that can be used for investigation and preliminary studies with suitable accuracy and low cost.Since Images from Google Earth with high spatial resolution are free for public and can be used directly in land use land cover mapping in small geographical extend. After image is classified, generating a set of random102 points then the random points were identifying from Google Earth image.

$$\text{Total (overall) accuracy } = \frac{\text{Total number of correctly classified pixels}}{\text{Total number of reference pixels}} * 100$$

$$\text{Kappa Coefficient (Ka)} = \frac{\text{Nzi} - \sum \text{Xi} * \sum \text{Yi}}{\text{N}^2 - \sum \text{Xi} * \sum \text{Yi}}$$

N= Total number of observations

Zi=sum of corrects in the diagonal matrixes.

∑Xi= Sum of all the row total

∑Yi= Sum of all the column total

2.13 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 project and if the input data required is possible to obtain within a reasonable amount of time and price (Beven, 2012). 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 current 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, 2012). The main steps in choosing a model are presented in figure below.

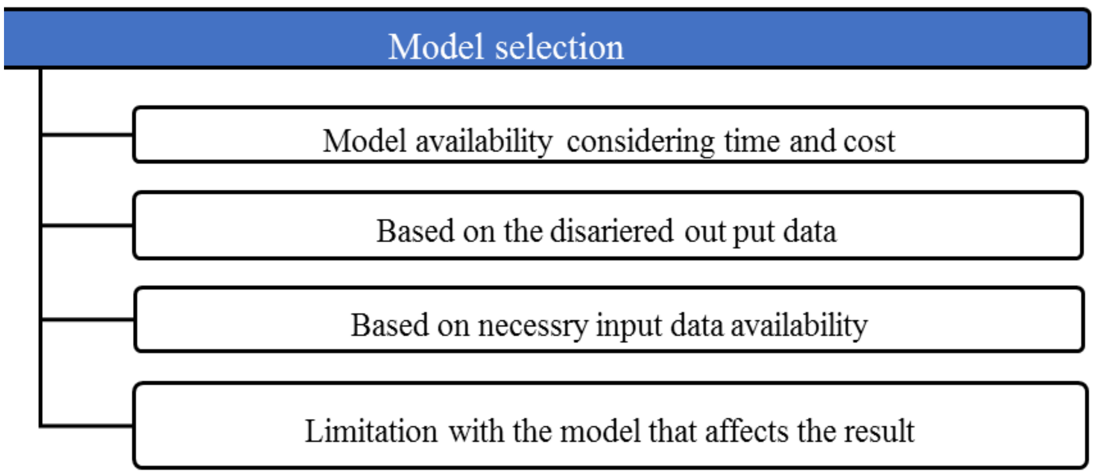

Figure 2-2 Steps to choose a proper model

Based on the above criteria for this thesis Arc GIS, Auto CAD, SCS Curve Number method, Bentley flow master and Google earth pro was used.

A. **Arc GIS: -** The first step in doing any kind of hydrologic modeling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, stream network density. With the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using automated procedures. The processing of DEM to delineate watersheds is referred to as terrain pre-processing. There are several tools available online for terrain pre-processing. In this thesis, Arc Hydro tools were used to process a DEM to delineate stream network and some other watershed characteristics that collectively describe the drainage patterns of a basin. GIS tools are used to convert the DEM into a series of layers, including flow direction, flow accumulation and watershed delineation. This approach was chosen due to the availability of the necessary dataset and GIS approach is faster and more accessible to small and large-scale land managers as the data and tools needed are now widely available to most land management agencies. GIS is applied in order to (i) select appropriate study sites, (ii) delineate study area sub catchments and (iii) To evaluate land use land cover analysis.

B. **Bentley Flow Master: -** Bentley Flow Master is an easy-to-use program that helps civil engineers/hydraulic engineer to undertake hydraulic analysis for analysis of pipes, ditches, open channels, and more and it computes flows related parameters (depth, discharge and velocity) in a given flow system i.e. open channel flow, pipe flow by using well-known formulas such as Darcy-Weisbach, Hazen-Williams and Manning‘s formula.

The need to use Bentley Flow Master hydraulic design software enables:-

- Analyze various hydraulic problems (open channel hydraulics)
- Evaluate different kinds of flow elements
- Flow master basically used to design roadside ditch and/or interception channel

2.14 SCS Curve Number Method

Runoff is very important hydrologic variable in the water resources applications. The occurrence and quantity of runoff are dependent on the characteristics of rainfall event like intensity, duration and distribution. There are number of methods available for finding out the runoff such as Rational method and SCS-CN method. Rational Method is mainly used for the estimation of the maximum discharge of catchment for small drainage areas of up to about 50 ha whereas SCS-CN methods for estimation of runoff are used for relatively large areas. The SCS-CN Method was developed by US Department of Agriculture in which CN is estimated using a combination of land use, soil (Josep dela and Asrat Yemaneh, 2016).

2.15 Hydrological Soil Groups for Ethiopia

Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Permeability and infiltration are the principal data required to classify soils into Hydrologic Soils Conservation Service (SCS) has divided soils into four hydrologic soil groups as follows(Ethiopian Roads Authority, 2013).

Group A:- Sand, loamy sand or sandy loam. Soils having a low runoff potential due to high infiltration rates. These soils primarily consist of deep, well- drained sands and gravels.

Group B:- Silt loam, or loam. Soils having a moderately low runoff potential due to moderate infiltration rates. These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures(Ethiopian Roads Authority, 2013).

Group C: - Sandy clay loam. Soils having a moderately high runoff potential due to slow infiltration rates. These soils primarily consist of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture(Ethiopian Roads Authority, 2013).

Group D: - Clay loam, silty clay loam, sandy clay, silty clay or clay. Soils having a high runoff potential due to very slow infiltration rates. These soils primarily c with high swelling potential, soils with permanently or clay layer at or near the surface, and shallow soils over nearly impervious parent material(Ethiopian Roads Authority, 2013).

2.16 Previous Studies on Ethiopia

Some studies that had conducted in different parts of Ethiopia shown that there were stormwater drainage problems. Among those studies some are:(Mulualem Bekele and K. Naga Sahadeva, 2018) has stated that Performance Assessment of Road Drainage Systems of Burayu Town and found that runoffs run over road surfaces this is due to soil erosion, lack of drainage lines along most of the roads in the town lack of appropriate maintenance of existing drainage facilities, poor waste management system and the drainage channels are filled with or blocked by silt and garbage. (Asfaw, 2016) has stated that Assessment of Stormwater Drainage Systems in Kemise town and found that drainage system is inadequate at different parts of the study area and improper construction alignment problem.

Another researcher (Adugna, 2009) studies on the Study of the Urban Drainage System in Addis Ababa,Yeka Sub-city and found that deforestation of Yeka mountain and pavement of structures are the major problems.

Other researchers (Hassen, 2016) studies on Modeling and analyses of urban flooding in Bole sub city system performance and evaluation of possible improvements using EPA SWMM5 and found that road surface drainage of the study area was inadequate due insufficient road profile, insufficient drainage structures provision, improper maintenance and lack of proper interconnection between the road and drainage infra-structures

3 RESEARCH METHODS AND MATERIALS

3.3 Description of the Study Area

3.3.1 Location

Alamata town is found at a distance 600km from Addis Ababa and 180 km from Mekelle. The Town stretches from 39055'Latitude 12042' longitude and shares border lines on all directions with Raya Alamata Woreda. According to the Woreda Atlas; the total area coverage of the Woreda is 1050 hectare or 10.5 km^2.

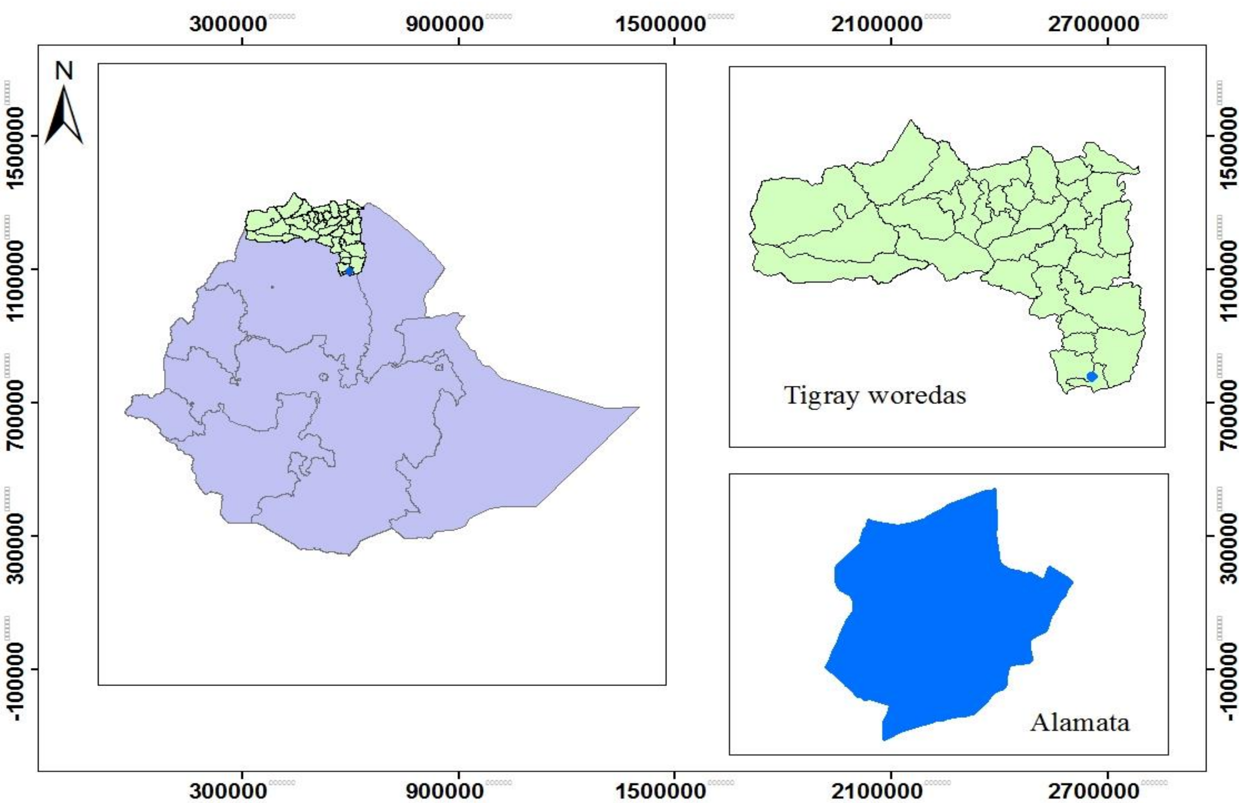

Figure 3-1 Location map of the study area

3.3.2 Topography

The topography of the town can be said gently sloping plain. On average the project area has an elevation of 1500-1700 m a.s.l. The town is surrounded by Grakahsu Mountain and by a very wide field of agricultural land of Woreda Raya Alamata.

3.3.3 Climate

According to climate classification based on altitude and temperature the area belongs to kola. Based on the information found from agricultural office of the Woreda, the mean annual average, maximum and minimum average temperature of this town 22. 4^{0}c.Generally this project area is belongs to moderate temperatures all over the year. The annual rain fall of this area is 691.5 mm during long rain.

3.3.4 Land use of the town

Effective land management helps to associate supply of land with demand for different functions such as industry; housing, commerce and like. Land is the largest economic resource of the town; land use pattern is characterized by random development which mainly geared towards horizontal expansion. Particularly, most areas in the town are not well kept and utilized as per the acceptable standard. Entire area of the town is 1050 hectare. The town has structural plan. But the use of land is not well planned.

3.4 Data Collection

This research involves collection of both primary and the secondary data and was also include information from respective organizations.

Primary data was collected from personal field observation/site investigation and Google earth data with the help of a base map and check list.

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 Meteorological Service Agency Addis Ababa, Ethiopia
Master plan and road network	Alamata town municipality
Digital Elevation Model(30mx30m resolution)	Ministry of water, Irrigation and Electricity Addis Ababa Ethiopia.
Land use/Land cover data	Ministry of Agriculture, Addis Ababa, Ethiopia
Contour map	Alamata town municipality
Soils data	Ministry of Agriculture Addis Ababa, Ethiopia

3.5 Materials Used

The following materials have been used to conduct this thesis:

Tapemeter: - To measure the existing Urban Stormwater Drainage facilities, Road and natural water ways.
Digital camera: - To take photo graph of the existing stormwater drain age system.
Basemap: - 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.
Contour map: -To examine the elevation and flow length of the catchment areas.

3.6 Data Analysis

For accomplishing the objectives of the study and to answering the research questions, the collected raw data was edited, coded, classified, and tabulated in order to make it ready for analysis. Information from primary and secondary sources was analyzed by using qualitative and quantitative methods. Data that have quantitative nature such as average and percentage was computed with Microsoft Excel. Furthermore, spatial analyses were conducted using Arc GIS, Bentley flowMaster, Google earth pro and Auto CAD software as analytical tools.

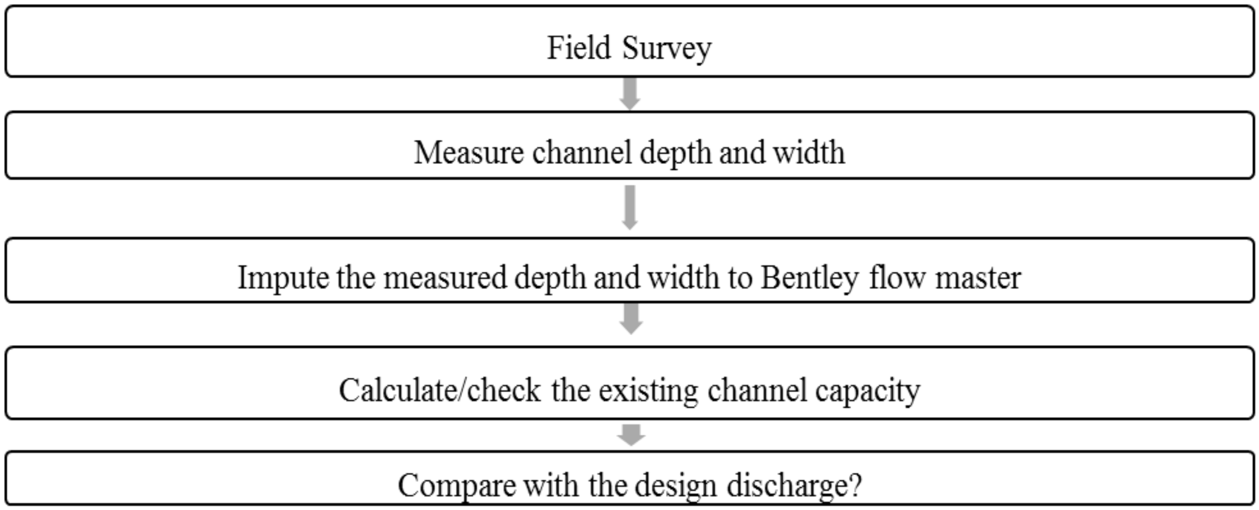

Figure 3-2 Analysis to investigate the functionality of the existing stormwater drainage system

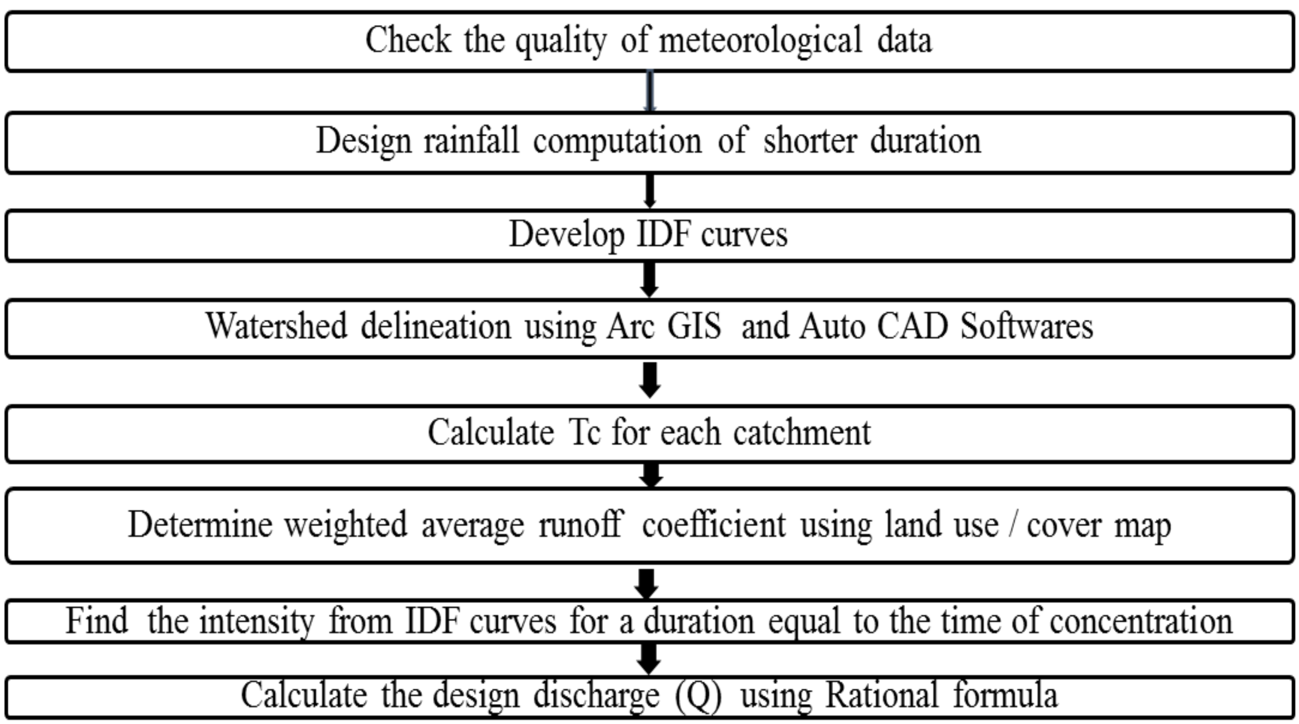

Figure 3-3 Evaluate adequacy of Existing Stormwater drainage system

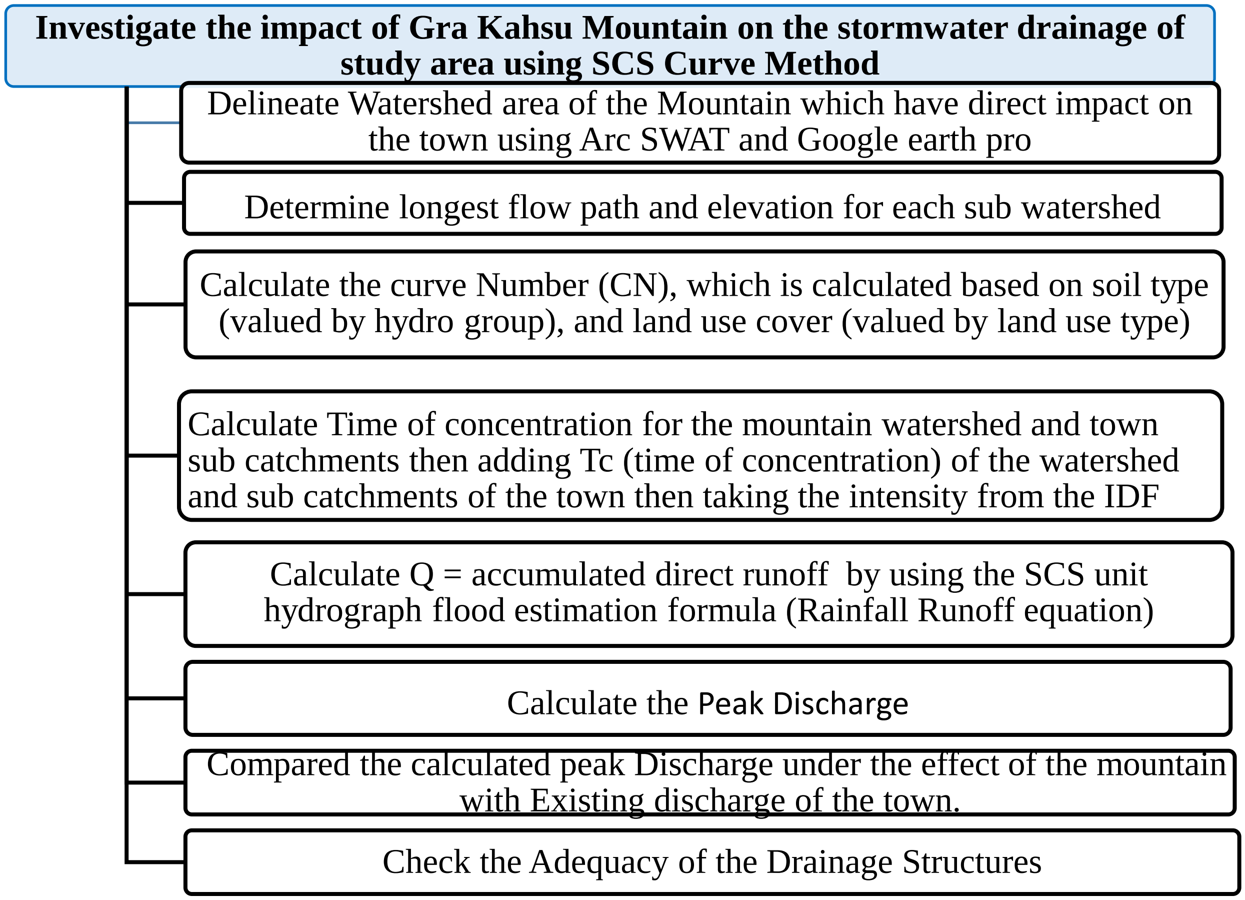

Figure 3-4 Analysis the impact of Grakahsu Mountain on the stormwater drainage of study area

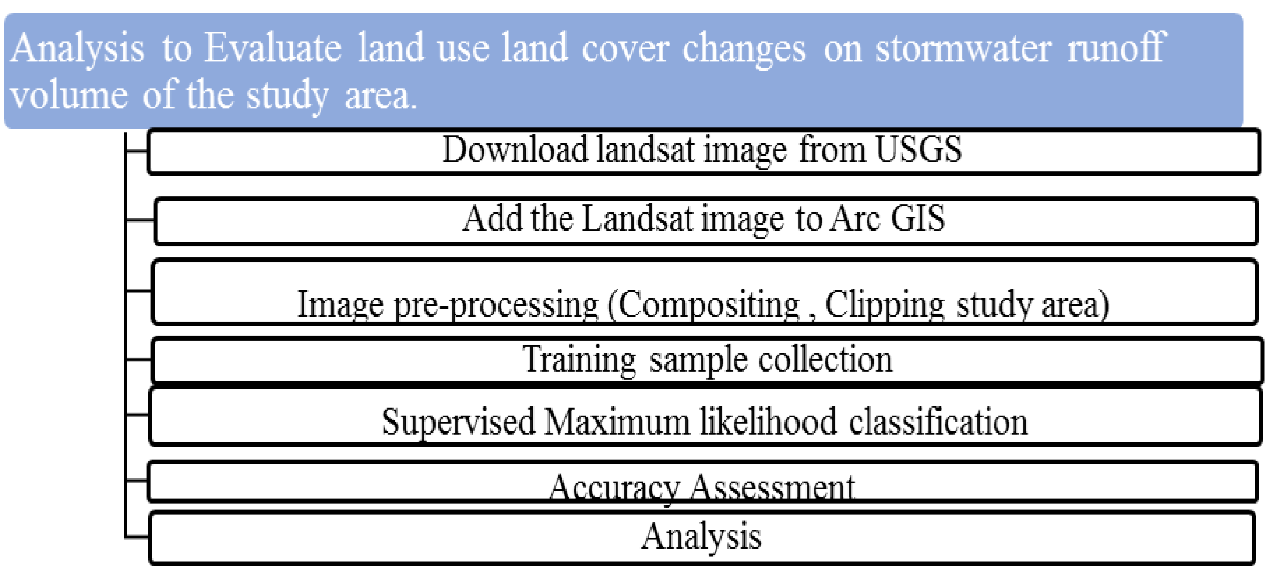

Figure 3-5 Analysis to Evaluate land use land cover changes on stormwater runoff volume of the study area.

3.7 Hydraulic and Hydrological Analysis

A. Meteorological data Availability

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 on these stations has been collected and analyzed using two methods of distribution analysis namely Log Pearson-III and Gumbel's Methods.Due to the rain gage station in the study area is one the outlier test is appropriate to check the quality of the data.

B. Estimating missing rainfall data

Due to the absence of observer or instrumental failure rainfall data record occasionally are 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 orography on rainfall, distance between the rainfall stations and the variation of rainfall amount recorded on the stations.

Among different method Normal ratio method was one of them which was recommended to estimate missing rainfall data in regions where annual rainfall between stations differ by more than 10%. (Silesh, 2011).

$$\mathbf{Pz} = \frac{\mathbf{1}}{\mathbf{3}}\left(\mathbf{P1}\frac{\mathbf{Nz}}{\mathbf{N1}} + \mathbf{P2}\frac{\mathbf{Nz}}{\mathbf{N2}} + \mathbf{P3}\frac{\mathbf{Nz}}{\mathbf{N3}}\right) \tag{3.1}$$

Where: P_z-missing rainfall data (daily, monthly or yearly) P_1, P_2 and P_3 – rainfall data at nearest different station (daily, monthly or yearly)

N_z - mean annual rainfall at missed station

N_1, N_2, and N_3- mean annual rainfall at different nearest station

C. Check the quality of data

Check on outliers has been undertaken on the recoded rainfall data to identify any low or high outliers. Outliers are data points, which depart significantly from the trend of the remaining data. The outlier test is done to check whether the adopted data is within the limited range or not. The daily heaviest rainfall data of Alamata meteorological station from 1992 to 2016 was taken for the design. Hence, 25 years of daily heaviest rainfall data is available. These data was also checked for its consistency by higher and lower outlier testes using the equations (Subramanya, 2008).

Test for Higher outlier

$$\textbf{Higher outlier YH} = \textbf{Yavg} + \textbf{Kn} * \boldsymbol{\delta}\textbf{n} - \textbf{1} \quad (3.2)$$

Where: Yavg = mean of data in log unity

Kn= from table for sample size N (Subramanya, 2008).

$\delta n - 1$ = standard deviation

Higher outlier test=$\mathbf{10^{YH}}$ (3.3)

Test for Lower outlier

$$\mathrm{YL} = \mathrm{Yavg} - \mathrm{Kn} * \delta\mathrm{n} - 1 \quad (3.4)$$

Lower outlier= 10^{YL} (3.5)

D. Checking Data Reliability

Relative standards less than 10% the data series could be regarded as reliabile adequate (Subramanya, 2008).

$$\text{Relative standard} = \frac{\delta n}{x-} * 100 \quad (3.4)$$

Where:- δn =standard devotion

X^{-} = mean of data (3.5)

3.8 Design Rainfall Analysis

3.8.1 Estimation of average depth of Rainfall

The most hydrological problems require knowledge of the average depth of rainfall over a significant area such as a basin. The rain catch at one station in a basin may be different from that of other stations in the same basin.

A. Point Rainfall

Point rainfall is precipitation occurring at a single point in space as opposed to areal precipitation which is precipitation over a region. For point precipitation frequency analysis, the annual maximum precipitation for a given duration is selected by applying statistical analysis to historical records for each duration frequency analysis is performed on the data to derive the design precipitation depths for various return periods.

B. Area Rainfall

Area rainfall requires a method of estimating aerial average rainfall over a basin by using Arithmetic average method to be used for this research by judgment consideration of quality and nature of the data, and the importance and required precision of the result rainfall data used. Therefore, arithmetic mean method is appropriate for the study area and were used for estimation annual runoff volume in 25 year is the sum of average depth of rainfall over a Alamata town catchment it is found in appendixes.

C. Return period

Return period, also called recurrence interval is a term commonly used in hydrology. It is the average time interval between the occurrence of storms and floods of a given magnitude. The selection of the design return period depends on economic balance between the costs of periodic repair or replacement of the structure, potential flood hazard to property, expected level of service, budgetary constraints as well as the magnitude and risk associated with damage from larger flood events. (Ethiopian Roads Authority, 2008). Based on the above criterions for this study 25 year return period was used.

3.8.2 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 town station for different return periods was determined using Log Pearson Type III distributions and Gumbel method analysis (Subramanya, 2008). The rainfall depths obtained from gauging station are of 24hr duration depth. Design and analysis of drainage structures require rainfall intensity duration relationship of shorter duration.

Because rainfall data of shorter duration is an available appropriate IDF derivation for shorter duration is required (Ethiopian Roads Authority, 2013)suggests the following equation.

A. Log Pearson Type III distributions

$$\mathbf{YT = Yavg + KT * Sy} \tag{3.6}$$

Where: YT = Log XT –logarithm of Rainfall depth (X T) at return period T years [mm]

Yavg= Mean value of logarithmic rainfall data (daily) [mm]

Sy = Standard deviation [mm]

B. Gumbel method analysis

$$\mathbf{XT = Xmean + K * Sy} \tag{3.7}$$

$$\mathbf{Sy = \frac{\sqrt{\sum y^2 - 1/n(\sum y^2)}}{n-1}} \tag{3.8}$$

Sy=Stander deviations of sample size N
K= frequency factors expressed as

$$\mathbf{K = \frac{Yt - Yn}{Sn}} \tag{3.9}$$

Yn and Sn reduced standard deviations, as sample N in the table (Chow, 1998)

3.9 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 of 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.

$$\mathbf{RRt} = \frac{\mathbf{t}}{\mathbf{24}}\left[\frac{(\mathbf{b}+\mathbf{24})^{\mathbf{n}}}{(\mathbf{b}+\mathbf{t})^{\mathbf{n}}}\right] \qquad (3.10)$$

Where: R_{Rt}= Rainfall depth ratio R_t: R_{24}

Rt= Rainfall depth in a given duration t

R24 = 24hr rainfall depth Coefficients b = 0.3 and n = 0.78 - 1.09

Substituting Intensity (mm/hr.) in the above equation

$$\mathbf{It} = \mathbf{Rt/t} = \frac{\mathbf{R24}}{\mathbf{24}}\left[\frac{(\mathbf{b}+\mathbf{24})^{\mathbf{n}}}{(\mathbf{b}+\mathbf{t})^{\mathbf{n}}}\right]$$

The methods employed to develop IDF curve for the shorter duration events using the above equations are as follows. Among many frequency analyses Log Pearson type III better R^2value, so for this thesis Log Pearson type III distribution was selected. Using the trend line equation obtained from Log Pearson type III distribution method of frequency analysis, i.e. y = 0.2715x + 59.841where y is 24-hour rainfall depth (R_{24}) of a return period x under consideration, R_{24} is calculated for 2, 5, 10, 25, 50 and 100 year return period.

3.10 Stream network and catchment delineation using Arc SWAT

This tool allows the user to delineate subwatersheds based on an automatic procedure using Digital Elevation Model (DEM) data. User specified parameters provide limits that influence the size and number of subwatersheds created. In addition, users have the option of importing pre-defined watershed boundaries and an associated stream network.

Procedures to delineate watershed using Arc SWAT

- Load the DEM
- Define the working area (Mask)
- Load the stream network to be used for the delineation
- Preprocess the DEM
- Specify the minimum sub-watershed area (critical source area)
- Review and edit the stream network points
- Run the calculation of the subbasin parameters

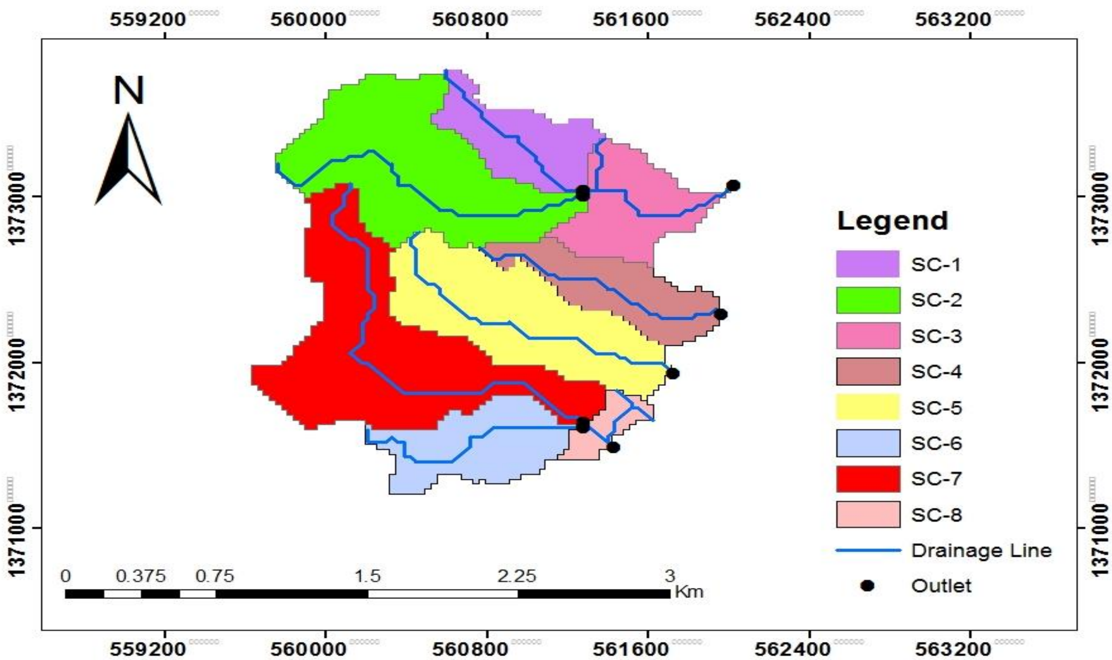

Figure 3-2 Catchment delineation of Alamata Town

3.11 Hydrological Equations for Determining Peak runoff

3.11.1 Rational Method

This method is widely used for peak discharge determination from smaller catchments (less than 50 ha or 0.5Km^2 area) as recommended by ERA drainage design manual. The equation of rational formula is function of catchment area, runoff coefficient and time of concentration. The equation is expressed as:

$$Q = 0.00278\, CIA \qquad (3.11)$$

Where Q = Discharge at outlet (m3/s)

C =Runoff Coefficient

I =Maximum probable rainfall Intensity (mm/hr.)

A =Catchment Area (hectares)

A. Runoff Coefficient

The runoff coefficient is the most important variable in the rational method of rainfall to runoff transformation. A weightage method is employed to obtain the representative runoff coefficient i.e. the individual areas multiplied by their specific runoff coefficient and their values added together and divided by the cumulative area (Zewdu, 2015).

Equation below is used to determine weighted average runoff coefficient values for each catchment area under rational method using land use map of Landsat 2018 land use land cover of Alamata town.

$$\mathbf{Cwigted} = \frac{\sum(\mathbf{Ai} * \mathbf{Ci})}{\mathbf{AT}} \tag{3.12}$$

Where Ci- Runoff coefficient for a given hydrologic soil group area

Ai -Area under each hydrologic soil group

AT -Total catchment area considered of town\

A. Rainfall Intensity

The rainfall intensity (I) is the average rainfall rate in mm/hr. for a duration equal to the time of concentration for a selected return period. Once a particular return period has been selected for design and a time of concentration calculated for the catchment area, the rainfall intensity can be determined from Rainfall-Intensity-Duration curves(Ethiopian Roads Authority, 2002).

B. Catchment Area

Like Rational method, the catchment area can be determined from Base maps and site observation. However, for large catchment areas Alamata town is necessary to divide the area into sub-catchment areas using Arc SWAT and Auto CAD 2007 to account for common outlet of the town by over laying the natural drainage system and master plan of the town using Arc GIS.

C. Time of Concentration

The time of concentration (Tc) is used in the Rational Method to determine the critical rainfall duration, which can then be combined with an appropriate rainfall intensity duration frequency (IDF) relation to establish the required design rainfall intensity. Tc is the time required for water to flow from the most remote point of the basin to the location being analyzed (Ethiopian Roads Authority, 2013). Runoff is assumed to reach a peak at the time of concentration Tc when the Entire watershed is contributing to flow at the outlet. The time of concentration to any point in a storm drainage system is the sum of the inlet time (the time it takes for flow from the remotest point to reach the sewer inlet), and the flow time $f_{t.}$ in the upstream sewers connected to the outer point. The velocity of flow depends on the catchment characteristics and slope of the water course by using manning equation. Many empirical equations are available for calculating time of concentration for a watershed (Addis Ababa City Road Authority, 2004). Among many that two equations are used for this thesis.

A. Sheet flow
B. Time of Travel

A. **Sheet flow Time:-**Sheet flow is flow over plan surfaces. It usually occurs in the headwater of the streams (usually for the first 100 m run). With sheet flow, the friction value (Manning’s roughness coefficient) which take into account the effect of raindrop impact, drag over the plan and other ground cover barriers has a significant impact on the overall sheet flow travel time determination.Manning’s kinematic solution is used to compute sheet flow travel time(Meadows, 2008).

$$\mathbf{Tt} = [(\mathbf{0.091} * (\mathbf{n} * \mathbf{L})\text{^}\mathbf{0.8})/((\mathbf{P2})\text{^}\mathbf{0.5} * \mathbf{0.}\boldsymbol{S}\text{^}\mathbf{0.4})] \qquad (3.13)$$

Where: Tat = travel time, hr.

n = Manning's roughness coefficient

L = flow length, m

P_2 = 2-year, 24-hour rainfall, mm

S = slope of hydraulic grade line (land slope), m/m based on topographic map

B. **Time of Travel:-**The time required by the water to flow in the drain channel from the mouth to the point under consideration or the point of concentration is called as time of travel. Average flow velocity is usually determined using manning's equation information can be used to estimate average flow velocity. When the channel section and roughness coefficient (Manning's n) are available, then the velocity can be computed using the Manning Equation.

$$\mathbf{V = \frac{R^{\frac{2}{3}} * S^{\frac{1}{2}}}{n}} \tag{3.14}$$

Where: V= average velocity, m/s

R= hydraulic radius, m (equal to a/pw)

A = cross sectional flow area, m

Pw = wetted perimeter,

S = slope of the hydraulic grade line, m/m

n = Manning's roughness coefficient

$$\mathbf{Tt = \frac{L}{3600V}} \tag{3.15}$$

Where=Tt = Travel time, hr., L = flow length, m, V = average velocity, m/s and 3600 =conversion factor from seconds to hours the basin and the outlet.

3.11.2 Estimation of Runoff by using SCS Curve Number Method

The Soil Conservation Service (SCS) model developed by United States Department of agriculture (USDA) computes direct runoff through an empirical equation that requires the rainfall and a watershed coefficient as inputs. The watershed coefficient is called as the curve number (CN), which represents the runoff potential of the land cover soil complex. This model involves relationship between land cover, hydrologic soil class and curve number(Bansode, 2014). Normally thesis model computes direct runoff with the help of following relationship.

$$qp = qu * A * Q \tag{3.16}$$

Where qp = peak discharge, m^3/s

qu = unit peak discharge, $m^3/s/km^2/mm$

A = drainage area, Km^2

Q = Depth of runoff, mm

The unit peak discharge is obtained from the following equation, which requires the time of concentration (t_c) in hours and the initial abstraction rainfall (Ia/p) ratio as input(Urgessa, 2016).

$$qu = \alpha * 10^{C0 + C1logtc + C2(\text{logtc})\ 2} \qquad (3.17)$$

Where C_0, C_1 and C_2 = regression coefficients for various Ia/p ratios:α= unit conversion factor equal to 0.000431 in SI unit.

A relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous hydrologic and vegetative cover conditions. The equation was developed mainly for small catchment areas for which daily rainfall and catchment area data are ordinarily available. It was developed from recorded storm data that included total amount of rainfall in a calendar day but not its distribution with respect to time. The SCS runoff equation is therefore a method of estimating direct runoff from 24-hour or 1-day storm rainfall (Urgessa, 2016).

$$\mathbf{Q} = \frac{(\mathbf{P-Ia})}{(\mathbf{P-Ia})+\mathbf{S}}^{\mathbf{2}} \qquad (3.18)$$

Where: Q = accumulated direct runoff, mm

P = accumulated rainfall (potential maximum runoff), mm

Ia = initial abstraction including surface storage, interception, and infiltration prior to runoff, mm, S = potential maximum retention, mm. The relationship between I_A and S was developed from experimental area data. It removes the necessity for estimating the I_a for common usage(Urgessa, 2016). The empirical relationship used in the SCS runoff equation is

$$\mathbf{Ia = 0.2 * S} \qquad (3.19)$$

The accumulated direct runoff expressed as

$$\mathbf{Q} = \frac{(\mathbf{P-0.2S})^{\mathbf{2}}}{(\mathbf{P+0.8S})} \qquad (3.20)$$

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

$$\mathbf{S} = \frac{\mathbf{25400}}{\mathbf{CN}} - \mathbf{254} \qquad (3.21)$$

According ERA, drainage manual for antecedent moisture conditions (AMC) in Ethiopia, dry for region D_1, wet for region B_1, and average AMC for other region is used.

For antecedent moisture conditions (AMC) in Ethiopia, Ethiopian Road Authority Drainage manual suggests to use average AMC for most regions including Alamata.

3.12 Calculating stormwater runoff Volume from Land use and Land Cover

A. Image Classification

For this study, land use land cover maps were generated based on the pixel based supervised classification through a number of processes. The first step was collection of training samples for each land use land cover classes which typically representative for land use land cover classes.
These samples were collected based on the researcher's personal experience and physiographical knowledge of the study area. Moreover, image enhancement and composition were applied for better determination of land use land cover classes. The next step was performing the image classification using the Maximum Likelihood Classifier through ArcGIS.
Based on the Landsat images from different periods of times, Google earth pro, and the physical observation and background knowledge of the town, classified the land use and land Cover into three different classes. The land use land cover image processed for the years 2008 and 2018 by using Arc- GIS.10.4.1 with Google earth pro and for each land use and land cover, annual stormwater runoff volume was calculated.
The following are the three different classes

- Built-up area:- which include all buildings and developed areas,
- Vegetation cover which includes all green vegetation cover,
- Bare land which contains all undeveloped land without vegetation cover.

Finally, the accuracy assessment of the classified images were assessed by using the original mosaic and the Google Earth images. For performing this analysis a randomly selected points have been taken as references for the land use land cover maps of 2008 and 2018.

B. Accuracy Assessment

Google Earth represents a powerful and attractive source of positional data that can be used for investigation and preliminary studies with suitable accuracy and low cost.Since Images from

Google Earth with high spatial resolution are free for public and can be used directly in land use land cover mapping in small geographical extend. After image is classified, generating a set of random102 points then the random points were identifying from Google Earth image.

$$\text{Total (overall) accuracy} = \frac{\text{Total number of correctly classified pixels}}{\text{Total number of reference pixels}} * 100 \qquad (3.22)$$

$$\text{Kappa Coefficient (Ka)} = \frac{\text{Nzi} - \sum \text{Xi} * \sum \text{Yi}}{\text{N}^2 - \sum \text{Xi} * \sum \text{Yi}} \qquad (3.23)$$

N= Total number of observations

Zi=sum of corrects in the diagonal matrixes.

$\sum$Xi= Sum of all the row total

$\sum$Yi= Sum of all the column total

Annual runoff volume was determined by the Equation: -

Volume Runoff = Surface Area x Runoff Coefficient x Rainfall Depth

$$\mathbf{V = Alulc * C * RD} \qquad (3.24)$$

Where Alulc = Area of Land use and Land cover of town

C = Composite Runoff Coefficient

R_D = Rainfall depth in mm

4 RESULTS AND DISCUSSIONS

4.1 Existing Drainage in Alamata Town

Existing storm drainage facilities in Alamata town are generally classified into closed and open drainage lines. Closed drainage lines are found in some areas especially along main roads of Addis Ababa, Mekele and Gra-kahsu (Korem) road. Open drainage channels, constructed by masonry are found along sub-mains and local roads. In many localities, access roads serve as wide open channels with severe erosion and flooding problems. The current open ditch drainage channel has minimized the size and creates inconvenience for the pedestrian walkway.

As investigates from the field survey the main challenges of the Existing drainage channel are:-

- The coverage is still at its low level
- The open ditch drainage facilities are creating problem for pedestrians like children and elderly people in particular;
- Most ditches have not proper slope;
- The drainage systems are not well connected;
- Some parts of the town do not have drainage systems;
- The drainage systems are fill by solid wastes and sand hence resulting in overflowing;

Figure 4-1 Calvert filled by sand

Figure 4-2 Drainage line filled by grass and sediment

Figure 4-3 Houses under risk of flood

4.2 Topography and Impervious surface

As illustrated in the map (figure 4-4 below) the upper part of the watershed is characterized by steep type of slope (>20 %). Consequently, the middle part of the watershed is categorized as a flat (0 - 5 %) kind of topography which covers. The characteristic of the slope has impact on the velocity and infiltration rate of stormwater. Stormwater from the upper part of the watershed flows with high velocity causing fragmentation of cobblestone and damaged the drainage channel. Additionally, areas that are found in the middle part of the watershed are affected by flood causing water logging in the local streets. The steeply character of the topography has influenced the stormwater to increase its velocity and decrease amount of infiltration. As runoff speed generally increases with steepness of slope. According to site observation, the drainage system provided along the local streets of this area doesn't consider this slope character of the area. Therefore, stormwater in this area flows with high velocity in the provided drainage systems. When the velocity of stormwater increases it creates different impacts like erosion and flooding on the houses which reside along the local streets. Besides, due to the highly impervious layers as a result of rocky nature of the area, mainly in the hilly parts of Gra-kahsu Mountain, the rain fall does not infiltrate in to the ground. This result in increased its velocity and decrease amount of infiltration.

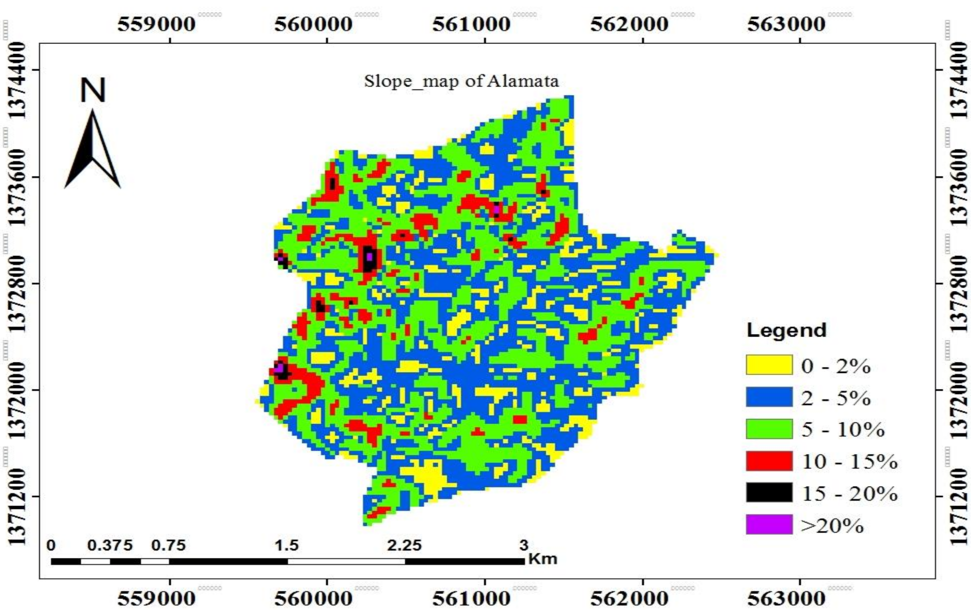

Figure 4-4 Slope map of Alamata town

4.3 Hydrology and Hydraulic Results

4.3.1 Intensity–Duration–Frequency Curves (IDF)

The resulting IDF curve from steps shown in section 3.6.2 was used the daily maximum rainfall from Ethiopian Meteorological Agency rainfall gauge located in Alamata town, 24-hour rainfall data of 25 years was calculated using Log Pearson type- III distribution method because it has better R^2 values.

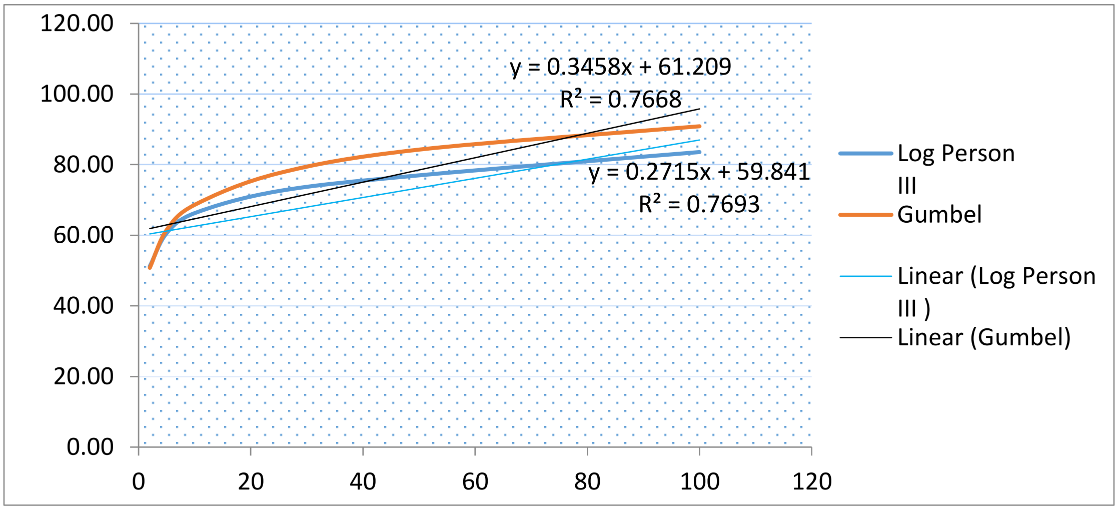

Figure 4-5 Plots of Frequency Analysis Results

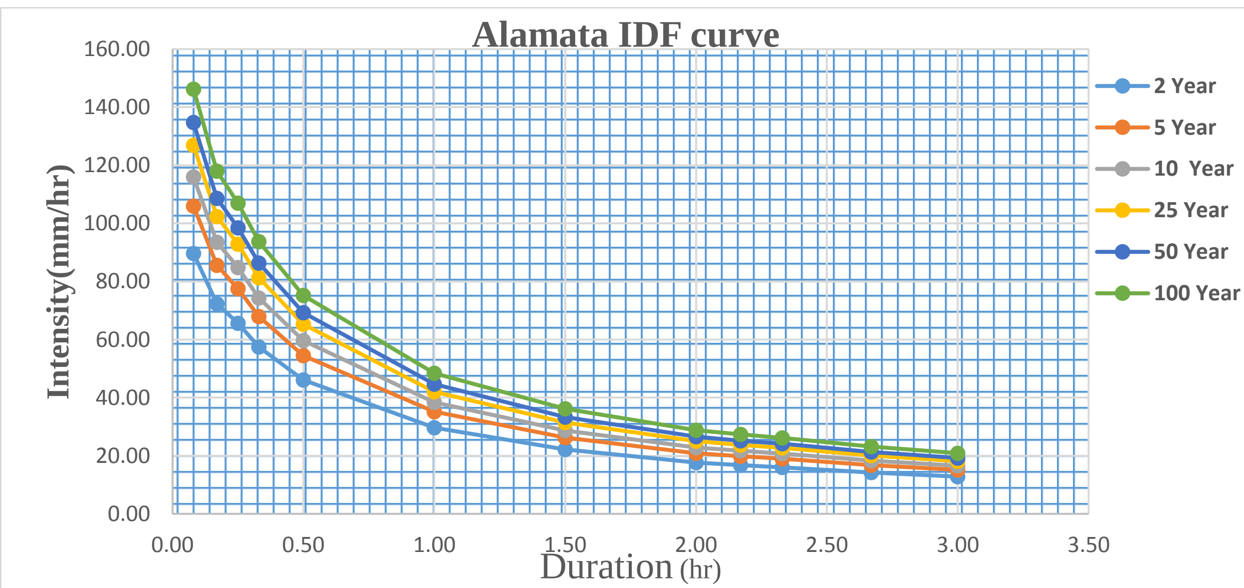

Figure 4-6 Alamata IDF curve

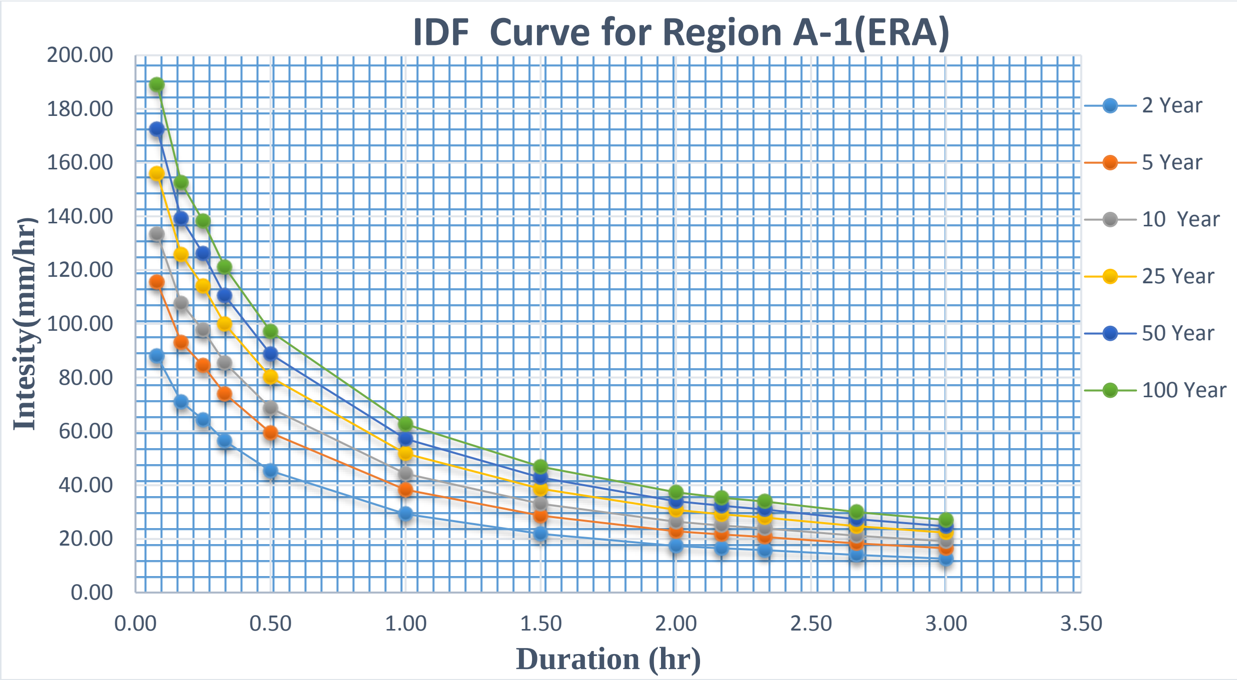

Figure 4-7 IDF curve for Region A-1 (Source; ERA,2013)

Rainfall intensity for the design storm is needed to calculate peak runoff rate from a drainage area for the design of stormwater structures using the rational and SCS Curve Number method. For this study IDF curve from hydrological section of Alamata town is applicable, but the developed IDF curve is necessary to interrelated calculated IDF curve with 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. Alamata town falls in region A_1 of this division.

The values of rain fall intensity is much 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 A_1).

4.3.2 Catchment area and Stream Network Delineation using Arc SWAT

Arc SWAT tools were used to process a DEM to delineate Natural Drainage line, stream network and some other watershed characteristics that collectively describe the drainage patterns of a basin.

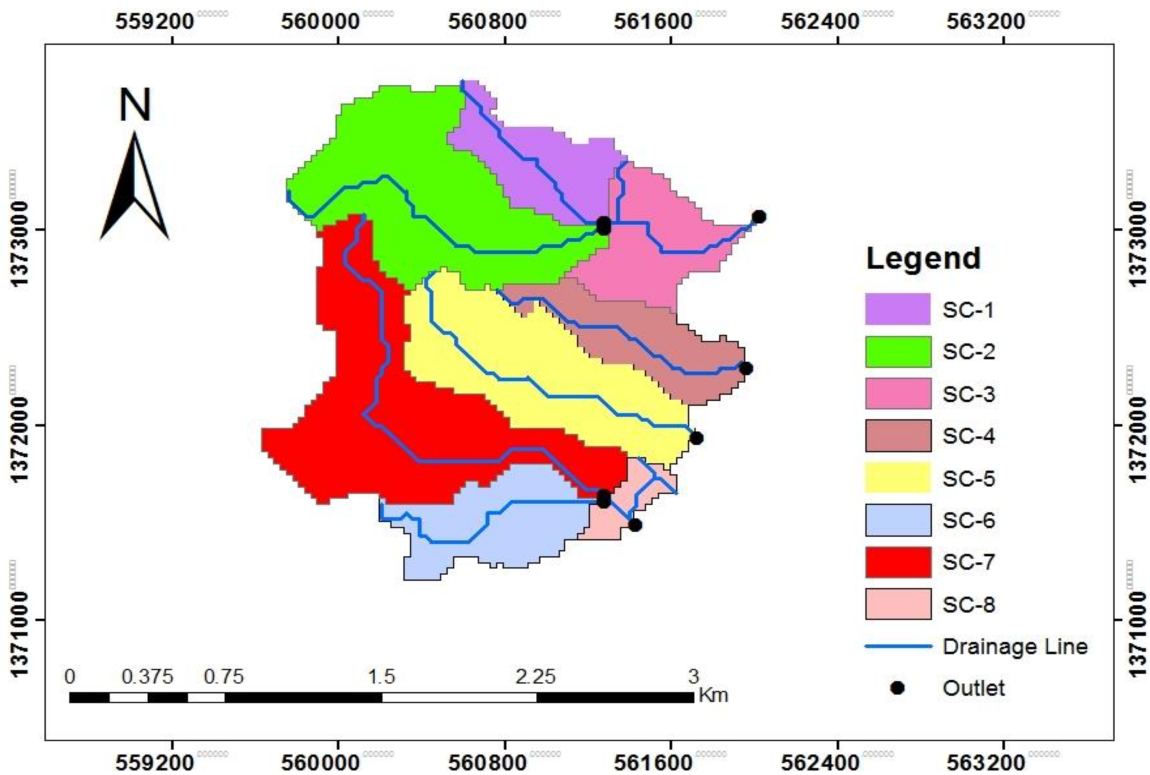

Figure 4-8 Alamata Town catchment area delineation

4.3.3 Estimation of Catchment Parameters

After the watershed areas delineation, watershed properties like the land use coverage, soil type Slope and other parameters that are used for this thesis was checked.

A. Runoff Coefficient

A weightage method is employed to obtain the representative runoff coefficient i.e. the individual areas multiplied by their specific runoff coefficient and their values added together and divided by the cumulative area.

Table 4-1 Land use composition of the study area

Land use/cover categories	Area(m^2)	Area (ha)	Runoff Coefficient	Ai*Ci
Built -up Area	4254000.000	425.4	0.8	340.32
Vegetation	423000	42.3	0.25	10.575
Bare Land	863000	86.3	0.45	38.835
Total	5540000.000	554		389.73
Representative C=				0.70

B. Time of Concentration

Most methods define Tc as the sum of the travel times with-in various consecutive flow segments in the drainage basin. These segments generally consist of the overland flow (Sheet flow Time) segment and the channel or pipe flow segment.

Sheet flow Time:- It usually occurs in the headwater of the streams (usually for the first 100 m run), but from topographic map obtained 100 m Sheet flow, natural range and short grass slope of 0.015 m/m, and length of 100 m and Manning's roughness coefficient is 0.015. The 2-year, 24-hour rainfall depth is calculated to be 33.466 mm. Hence, from Equation travel time for sheet flow is determined as:

$$\mathrm{Tt} = [(0.091 * (\mathrm{n} * \mathrm{L})\text{^}0.8)/((\mathrm{P2})\text{^}0.5 * \mathrm{S}\text{^}0.4)]$$

$$\mathrm{Tt1} = \left\{\frac{0.091 * (0.015 * 100)^{0.8}}{(33.466)^{0.4} + 0.02^{0.4}}\right\} = 0.10\mathrm{hr}$$

Open Channels Flow:-For channel flow, natural stream channel, winding with weeds and pools, slope is 0.02m/m and length is 3394m. By direct measuring the average bottom width of the stream channel is 1.2 m.

Velocity through the channel **V** = $\frac{R^{\frac{2}{3}} * S^{\frac{1}{2}}}{n}$= $(0.3^{2/3}*0.02^{1/2})/0.015 = 4.23$m/s

$\mathrm{Tt2} = \frac{L}{3600*V}$= 1085/ (3600*4.23) =0.071hr.

The time of concentration is the sum of all Tt values for the various consecutive flow segments

Total Time of Concentration (Tc) $=Tt_1+Tt_2$=0.10hr+0.071hr=0.17hr

By the same processes, Time of Concentration for the other catchments is determined.

4.4 Hydraulic Analysis

4.4.1 Adequacy of Existing Drainage Structures

The current conditions of hydraulic calculation are performed and evaluated by collected the data of existing stormwater drainage structure using field survey. The existing depth and width of the stormwater drainage channel were measured for all sub catchments of the town and used to determine the existing drainage capacity using Bentley Flow master described in table 4.2 for all the respective sub catchments.

Current condition Hydraulic Performance of Alamata Town

Cross Section for Rectangular Channel Sub- Catchment - 1

Project Description	
Friction Method	Manning Formula
Solve for	Discharge and Velocity
Input Data	
Roughness Coefficient	0.015
Channel Slope	0.02m/m
Normal Depth	0.60m
Bottom Width	1.20m
Results	
Discharge	3.04m^3/s
Flow Area	0.72m^2
Wetted Perimeter	2.40m

Hydraulic Radius	0.30m
Velocity	4.23m/s

Table 4-2 Current condition Hydraulic performance of Alamata Town

Label	Normal Depth (m)	Bottom Width (m)	Channel Slope (m/m)	Flow Area (m²)	Roughness Coefficient	Wetted Perimeter (m)	Hydraulic Radius (m)	Velocity (m/s)	Discharge (m³/s)
SC-1	0.60	1.20	0.02000	0.72	0.015	2.40	0.30	4.23	3.04
SC-2	0.60	1.30	0.01500	0.78	0.015	2.50	0.31	3.76	2.93
SC-3	0.30	0.60	0.01400	0.18	0.015	1.20	0.15	2.23	0.40
SC-4	0.50	1.00	0.01400	0.50	0.015	2.00	0.25	3.13	1.57
SC-5	0.50	1.20	0.01500	0.60	0.015	2.20	0.27	3.43	2.06
SC-6	0.50	1.20	0.01800	0.60	0.015	2.20	0.27	3.76	2.26
SC-7	0.50	1.10	0.01500	0.55	0.015	2.10	0.26	3.34	1.84
SC-8	0.50	1.10	0.01100	0.55	0.015	2.10	0.26	2.86	1.57

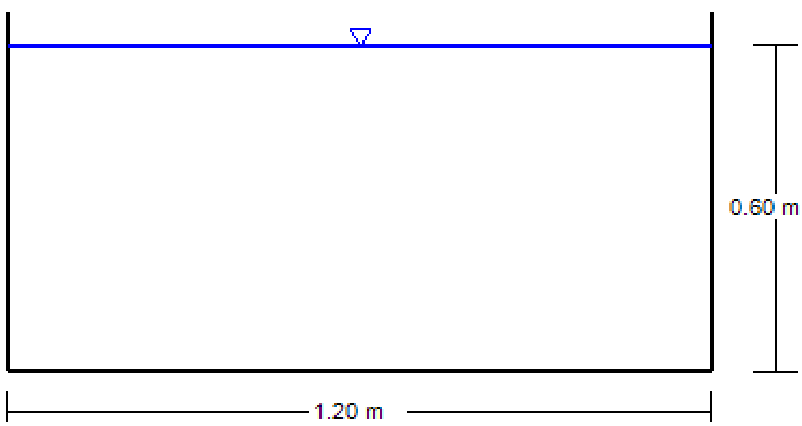

Figure 4-9 Cross section for Rectangular Channel Sub- Catchment – 1

4.5 Investigate the impact of Gra-Kahsu Mountain on the stormwater drainage of study area Using SCS Curve Number method.

To evaluate the impact of Grakahsu Mountain on the urban stormwater drainage system of the town as described in the methodology fist delineate the watershed which had direct impact on drainage system using Arc GIS 10.4.1.

A. Determine Catchment Area

The catchment area of the Mountain was delineated using ArcSWAT which have direct impact on the urban stormwater drainage system of the town sub catchments as shown in the figure 4.9.Then add the area of the Mountain sub catchments and town sub catchments which have direct impact of Mountain watershed.

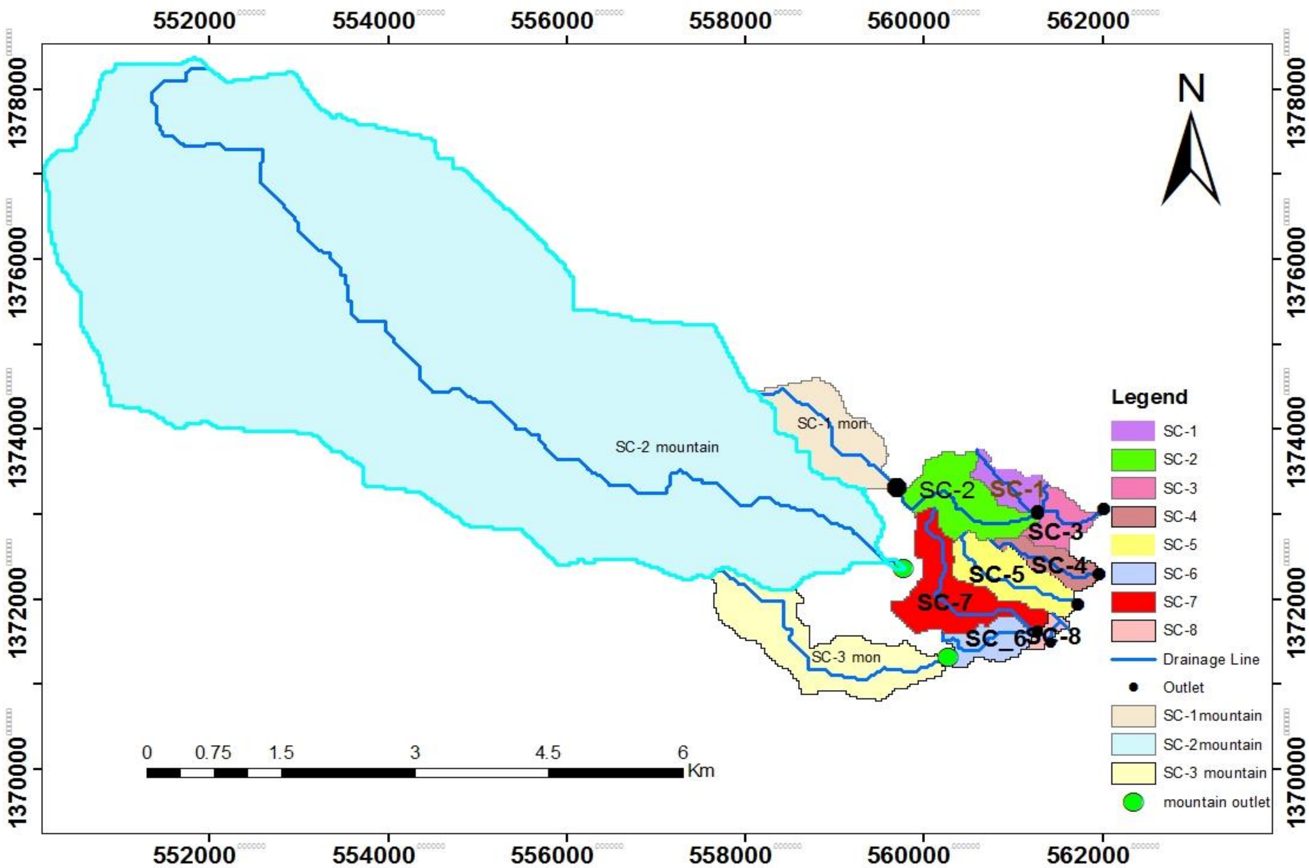

Figure 4-10 Watershed delineation of Grakahsu Mountain

Table 4-3 Sub catchment area Mountainand and Town

Mountain		Town		Total Area (km²)=Mountain+Town
Sub-catchment	Area (km²)	Sub- catchment	Area(km²)	
SC-1	1.08	SC-6	0.3678	1.45
SC-2	30.19	SC-7	0.986	31.18
SC-3	1.65	SC-8	0.091	1.74

B. Determine longest flow path and elevation

The longest flow path and elevation was determined using ArcSWAT from the delineated watershed of Gra-kahsu Mountain.

Table 4-4 Longest flow path and elevation

Sub-catchment	Area (km²)	Elevation @U/S(m)	Elevation @D/S(m)	Length (Km)	Length (m)	Slope (m/m)
1	1.08	2165	1611	1.54	6014.23	0.09
2	30.19	3233	1543	2.79	33346.22	0.05
3	1.65	2247	1544	10.28	9348.85	0.08

C. Determine Catchment area Property

Based on the catchment area property (soil type and land use) the Curve Number was determined CN=70.13 as shown in the Appendix.

D. Calculate Time of concentration

Kiripach, formula was adopted in estimating Tc because Kirp1ch formula is used to calculate time of concentration in gullied watersheds.

$$\mathbf{Tc = 0.0078 * L^{0.77} * S^{-0.385} = \quad Tc = 0.0078 * 6.014^{0.77} * 0.092^{-0.385} = 0.08hr}$$

Where: Tc = in hours

L = Maximum length of flow (km)

S= The difference in elevation between the outlet and the Remote point (m)/length(m)

Total Tc=Tc of Mountain SC + Tc of town sub-catchment

Total Tc=0.08hr+0.21hr=0.29hr

Table 4-5 Time of concentration for sub catchment of Mountain and Town

Mountain		Town		
Sub-catchment	Tc(hr)	Sub- catchment	Tc(hr)	Total Tc(hr)=Mountain+Town
SC-1	0.08	SC-6	0.20	0.28
SC-2	0.37	SC-7	0.34	0.71
SC-3	0.12	SC-8	0.17	0.29

E. Calculate peak flood

The following equation were used for the estimation of the peak discharge in SCS method Design Peak Discharge, $qp = qu * Q * A$

Table 4-6 Peak flood estimation using SCS Curve Number method for sub-catchment 6

Year	25 Year
Intensity (mm/hr)	56
p_1=tc(hr)*I(mm/hr)	39.76
Ia	0.857
(p-Ia)^2	1513.443
(p-Ia)+S	144.041
Q=(P-Ia)^2/(P-Ia)+S(mm)	10.507
qu=α10^Co+C1logtc+C2(logtc)^2	0.082
qu*A*Q	9.294

4.5.1 Adequacy of Existing Drainage Structures and its Proposed

Based on the hydraulic calculation of the result drainage capacity of existing system were checked and presented in Table 4.9 to compare with proposed discharge this process also done first by determining the peak discharge for each existing catchment from the measured depth and width of the stormwater drainage channel for all sub catchments of the town as described in the methodology part of this study. The design capacity of the rest sub catchments of the town by taking the intensity for 25 year return period from the IDF was determined by Rational formula. This discharge was also compared with existing discharge of the town was determined from the measured depth and width of the stormwater drainage channel for all sub catchments of the town. Then for this Existing and Design discharge drainage size (channel depth and width) was determine.

A. Drainage Size determination for proposed

By used manning equation determined the size of the drainage channel based on the parameter

$$Q = \frac{A * R\hat{}2/3 * S\hat{}1/2}{n}$$

A rectangular channel=b*y for most economical rectangular channel b=2*y

A rectangular channel=$2y^2$ P=2y+2y=4y and R=$\frac{2y^2}{4y} = 0.5y$

$$\frac{Q*n}{S^{1/2}} = y^{8/3}$$

$$y=(\frac{Q*n}{S^{1/2}})^{8/3}$$

$$y=(\frac{8.69*0.015}{0.02^{\frac{1}{2}}})^{\frac{8}{3}} = 0.97\text{m and width b} = 2 * \text{y} = 2 * .0.97 = 1.94\text{m}$$

$$\%\ \text{Additional Depth} = (\frac{\text{Proposed Depth} - \text{Existing Depth}}{\text{Existing Depth}}) * 100$$

$$\%\ \text{Additional Depth} = \left(\frac{0.97 - 0.60}{0.60}\right) * 100 = 61.58\%$$

$$\% \text{ Additional width} = \left(\frac{Proposed\ width - \ Existing\ width}{Existing\ width}\right) * 100$$

$$\% \text{ Additional width} = \left(\frac{1.94 - \ 1.2}{1.2}\right) * 100 = 61.58\%$$

For the other catchments by used the same procedure the results are presented on table 4-7 below.

Table 4-7 Existing, Proposed, Additional depth and width results

Existing Condition				**Proposed Condition**				
Sub-Catchment	Depth (m)	Width (m)	Existing Discharge (m^3/s)	Design Discharge (m^3/s)	Depth (m)	Width (m)	% Additional Depth	% Additional Width
SC-1	0.60	1.20	3.04	8.69	0.97	1.94	61.58	61.58
SC-2	0.60	1.30	2.93	7.71	0.98	1.96	63.09	50.55
SC-3	0.30	0.60	0.40	8.05	1.01	2.02	235.86	235.86
SC-4	0.50	1.00	1.57	8.56	1.01	2.01	101.13	101.13
SC-5	0.50	1.20	2.06	8.37	1.02	2.03	103.14	69.28
SC-6	0.60	1.30	2.26	9.29	1.01	2.02	68.40	55.44
SC-7	0.50	1.20	1.84	16.47	1.30	2.60	160.20	116.83
SC-8	0.50	1.10	1.57	9.13	1.11	2.21	121.07	100.98

For both the town sub catchments and Gra-kahsu sub catchments contributing areas for sub-catchments of town are the Mountain and town sub catchments that has direct impact on the sub catchments of the town as described in the table 4-9 by adding Tc (time of concentration) of the watershed and sub catchments of the town then taking the intensity for 25 year return period from the IDF and calculate the design discharge. The design capacity of the drainage channel (under the effect of the Mountain) was determined using SCS curve number where in this case sub catchments 1,2 and 3 of the Mountain contribute runoff to the town sub catchments 6,7 and 8 respectively.

The existing condition drainage channel depths of catchments 6,7 and 8 Increase by 68.40%, 160.20% and 121.07%; and the widths by 55.44%, 116.83%and 100.98%, respectively, and the Design discharge was also 9.29m^3/s, 16.47m^3/s and 9.13m^3/s respectively as described in the above table 4-7. Why focus on these sub catchments was due to Grakahsu Mountain affects these sub catchments.

4.6 Evaluation of land use land cover changes effect on the stormwater runoff volume of the study area.

The land use land cover image processed for the years 2008 and 2018 by using ArcGIS.10.4.1 and Google earth pro for each land use and land cover, annual stormwater runoff volume was calculated and digital change detection were evaluated.

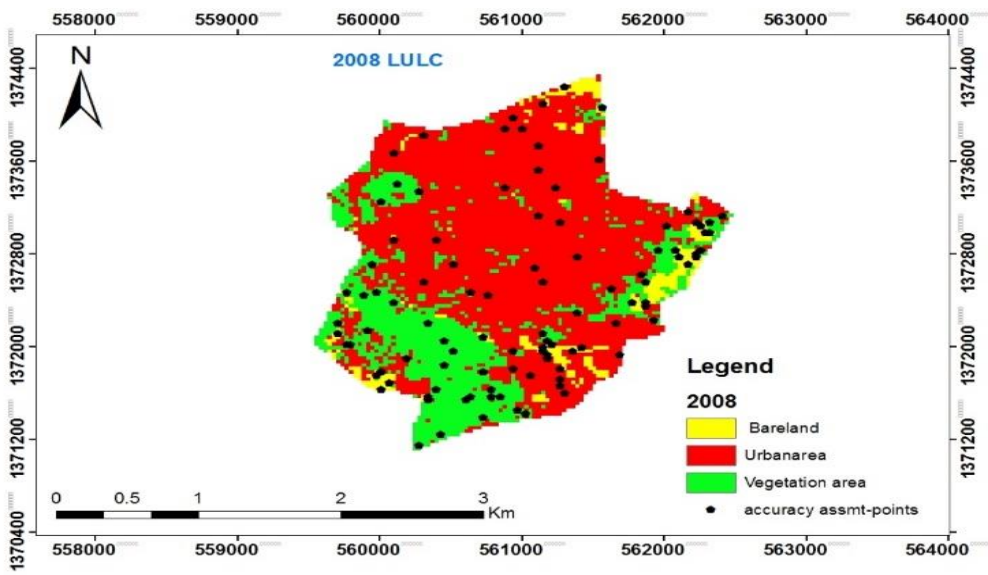

Figure 4-11 Classified map of Alamata Town for the year 2008, revealing a relatively smaller Bare land area surrounded by vast Built up and Vegetation area.

Annual runoff volume for the year 2008 was determined by the Equation (3.21)

$$V = A_{lulc} * C * RD$$

A_{lulc} = Area of Land use and Land cover of town=3753000m^2

C = Composite Runoff Coefficient for Built -up Area=0.8

R_D = Rainfall depth in mm = 54.04mm=0.05404m

V=3753000m^2*0.8*0.054m=162129.6m^3

For the other Lulc by used the same procedure the results are presented on table 4-10 below.

Table 4-10 Annual runoff Volume estimation from land use land cover map for the year 2008

Land use/cover categories	Area(m^2)	runoff coefficient	Rainfall depth (m)	Volume runoff(m^3)
Built -up Area	3753000	0.8	0.054	162129.6
Vegetation	1446000	0.2	0.054	15616.8
Bare Land	341000	0.45	0.054	8286.3

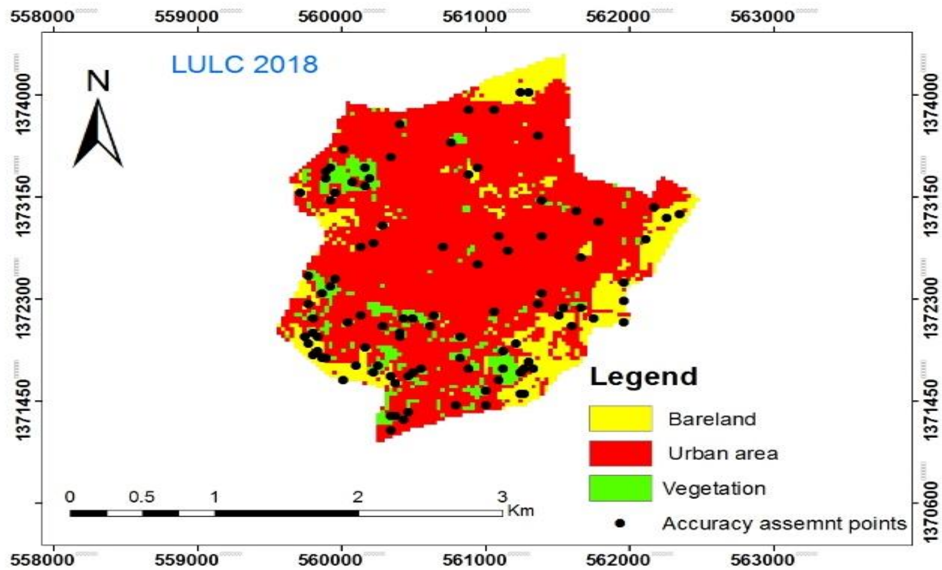

Figure 4-12 Classified map of Alamata Town for the year 2018, revealing a relatively smaller Vegetation area surrounded by vast built -up area.

Annual runoff volume for the year 2018 was determined by the Equation (3.21)

$$V = A_{lulc} * C * RD$$

A_{lulc} = Area of Land use and Land cover of town=4254000m^2

C = Composite Runoff Coefficient for Built -up Area=0.8

R_D = Rainfall depth in mm = 54.04mm=0.05404m

V=4254000m^2*0.8*0.054m=183772.8m^3

For the other Lulc by used the same procedure the results are presented on table 4-10 below.

Table 4-8 Annual runoff Volume estimation from land use land cover map for the year 2018

Land use/cover categories	Area(m^2)	runoff coefficient	Rainfall Depth (m)	Volume runoff(m^3)
Built -up Area	4254000	0.8	0.054	183772.8
Vegetation	423000	0.2	0.054	4568.4
Bare Land	863000	0.45	0.054	20970.9

The results indicate that Annual runoff volume of Built -up area in the study area has increased from 162129.6m^3 in 2008 to 183772.8 m^3 in 2018 which accounts for 13.35% of the total Annual runoff volume. The Vegetation has decreased from 15616.8m^3 in 2008 to 4568.4m^3 in 2018 which accounts for 70.75%. The Bare Land area has increased from 8286.3m^3 in 2008 to 20970.9m^3 in 2018 which accounts for 153.08%.

Table 4-9 Amount of area change in different land use/cover categories during 2008 to 2018

Land use/ cover categories	2008		2018		Change 2008–2018	
	Area(m^2)	Area (%)	Area(m^2)	Area (%)	Area(m^2)	Area (%)
Built -up Area	3753000	67.74	4254000	76.79	501000	9.04
Vegetation	1446000	26.10	423000	7.64	-1023000	-18.47
Bare Land	341000	6.16	863000	15.58	522000	9.42
Total	5540000		5540000			

The results indicate that the Built -up area in the study area has increased from 3753000m^2 in 2008 to 4254000m^2 in 2018 which accounts for 9.04% of the total study area. The Vegetation has decreased from 1446000m^2 in 2008 to 423000m^2 in 2018 which accounts for 18.47%. The Bare Land area has increased from 341000m^2 in 2008 to 863000m^2 in 2018 which accounts for 9.42%.

4.7 Accuracy Assessment of Classifications

The results of the land cover classifications derived from remotely sensed data are compared by an accuracy assessment. An accuracy assessment analysis was performed by producing an error matrix that compared the interpreted land cover map and a map contains the result of ground truth investigation. Generally the following steps were performed (1) creating random points on Arc map (2) Conversion to kml file to over lay on Google map (3) Collecting features type (4)

Producing supervised classification (5) Ground truthing on the field and (6) evaluation of classification errors by producing confusion matrix table.

Google Earth represents a powerful and attractive source of positional data that can be used for investigation and preliminary studies with suitable accuracy and low cost.Since Images from Google Earth with high spatial resolution are free for public and can be used directly in land use land cover mapping in small geographical extend. After image is classified, generating a set of random102 points then the random points were identifying from Google Earth image.

Table 4-10 Accuracy assessment land use land cover in 2008

	Urban	Vegetation	Bare land	Total raster value
Urban	31	2	1	34
Vegetation	3	29	2	34
Barren land	3	3	28	34
Total Aerial	37	34	31	102

Total (overall) accuracy $= \frac{31+29+28}{102} * 100 = 86.3\%$

$$\text{Kappa Coefficient (Ka)} = \frac{102 * (31 + 29 + 38) - \{(34 * 37) + (34 * 34) + (34 * 31)\}}{102^2 - \{(37 * 34) + (34 * 34) + (31 * 34)\}} = 0.794$$

Ka=0.794*100=79.4% **:- it is acceptable**

Table 4-11 Accuracy assessment land use land cover in 2018

	Urban	Vegetation	Bare land	Total raster value
Urban	25	4	5	34
Vegetation	2	30	2	34
Bare land	2	0	32	34
Total Aerial	29	34	39	102

Total (overall) accuracy $= \frac{25+30+32}{102} * 100 = 85.3\%$

$$\text{Kappa Coefficient (Ka)} = \frac{\mathbf{102*(25+22+28)-\{(34*29)+(34*34)+(34*39)\}}}{\mathbf{102^2-\{(29*34)+(34*34)+(39*34)\}}} = 0.779$$

Ka= 0.779*100=**77.9%** :- it is acceptable

4.8 Best Management Paractices (BMPs)

This section provides proposed best management practices to solve the problem of urban stormwater drainage that has been affected the drainage system. Typically, there is not a single answer to the question of which BMPs should be selected for a site. There are usually multiple solutions ranging from standalone BMPs to treatment trains that combine multiple BMPs to achieve the water quality and stormwater management objectives. In order to select specific BMP for the area which has a problem, there are factors as described in the Literature Review.

It was noted that the existing sections are not sufficient in most of the places to accommodate the runoff. The inundation of the study area is also may be the blockage of the drains in various points. Hence periodical maintenance of existing drains is essential.

If Gra-kahsu Mountain were fully covered by forest the value of run-off coefficient "C" would decrease, this allows flood to infiltrate in to the soil instead of flood generation. The implications of reduced runoff as a result of good vegetation cover on Gra-kahsu Mountain are the ongoing soil erosion would be reduced, impact of runoff on the urban stormwater drainage system would be reduced. Applying different Structural measures of BMPs like teracess, in the Mountain, retaining walls on the river banks like gabion, detention systems, infiltration controls, Porous Pavement Systems and Gabion.Non-structural BMPs that are recommended to control the stormwater from the Mountain are; Reduce Man-made impacts, Detention systems, Bio retention Systems, Grassed Swales and Gabion, covering the mountain with vegetation, area exclosure, gully treatment.

Structural and non- structural Best management practices (BMPS) that are important to control the urban stormwater impacts of the town are Smart Growth Practices and Conservation Design, Reduce Man-made impacts, Detention systems, Infiltration controls, Porous Pavement Systems and Gabion.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

According to the result of this thesis the existing drainage system has extensive defects and requires immediate rehabilitation or reconstruction, and also maintaining major drainage works. There is inadequate and low coverage of drainage system coupled with poor physical condition and ineffectiveness of drainage system development in the town.

The current conditions of hydraulic calculation are performed and evaluated by collected the data of existing stormwater drainage structure using field survey. The width and depth of channel are measured data based on the geometry of the channel by using tapemeter measurement and slope from topographic map of town, then by using the measured values the Existing condition of the drainage channel was Evaluated by Bentley flow master. According to the result of this thesis the storm drainage facility are inadequate to convey the peak discharge for required design period.

Capacities of most of the drainage system can not handle the current runoff that flows over the area. The design capacity of the drainage channel (under the effect of the Mountain) was determined using SCS curve number where in this case watershed 1,2 and 3 of the Mountain contribute runoff to the town sub catchments 6,7 and 8 respectively. The design capacity of the rest sub catchments of the town which are not affected by the Mountain was calculated by taking the intensity for 25 year return period from the IDF and was determined by Rational formula. This discharge was also compared with existing discharge of the town was determined from the measured depth and width of the stormwater drainage channel for all sub catchments of the town. Then for this existing and design discharge drainage size (channel depth and width) was determine. The existing condition drainage channel depths of catchments 6,7 and 8 Increase by 68.40%, 160.20% and 121.07%; and the widths by 55.44%, 116.83%and 100.98%, and the design discharge was also 9.29m^3/s, 16.47m^3/s and 9.13m^3/s respectively. Why focus on these sub catchments was due to Grakahsu Mountain affects these sub catchments.

Generally, the performance of these stormwater drainages were not satisfactory. Therefore, it is recognized that its capacity has shown lower results which needs some adjustment or improvement to give the best service, and needs a serious of regular maintenance and also provide drainage networking for the areas without drainage systems for its complete service.

According to the result of this thesis land use landcover practices in the study area of stormwater runoff have significantly changed in 18 years. The results indicate that Annual runoff volume of Built -up area in the study area has increased from 162129.6m^3 in 2008 to 183772.8 m^3 in 2018 which accounts for 13.35% of the total Annual runoff volume. The Vegetation has decreased from 15616.8m^3 in 2008 to 4568.4m^3 in 2018 which accounts for 70.75%. The bare land area has increased from 8286.3m^3 in 2008 to 20970.9m^3 in 2018 which accounts for 153.08%. Generaliy Alamata areas according to the land use land cover map, is cover with various activities. It is clearly seen that a lot of land use in the areas under study is covered with residential, commercial activities and recreational activities. Therefore in results and analysis it is noted that the area under study has a high runoff coefficients this is because large fraction of area is impervious. Continuous increment of residential and roads constructions on flood prone area have led to reduction of infiltration process hence promote runoff both on the surface water systems and sewers. These scenarios have led to increase of urban flooding.

5.2 Recommendation

- Flooding is one of the critical problem in the town and one of the recommended solution strategies to tackle the problem is the afforestation program of the sloppy terrains of Gra-kasu Mountain.
- Alamata is located at the downhill of the mountain, so Vegetate slopes with native or drought tolerant vegetation.
- Control flows from the mountain in landscaping and/or other controls prior to reaching existing natural drainage systems.
- The main road or the major arterial of the town which is the Addis Ababa Mekele, Mohoni and Gogudo road, passing through the center of the town, is large enough presently to meet the expected demand. However, the current open ditch drainage channels has minimized the size and creates problem of over flooding and for the commercial activity along the road, so it is advisable to cover the drainage lines for control flooding problem, the space could be used for street side parking and functioning pedestrian walkway.
- Regular maintenance and frequent clearance of drainage lines should be at regular terms for sustainable storm water drainage system.
- The existing ditches are opened ditches which may cause access difficulties and using usable areas, to control this problem they are proposed to be covered by concrete covers.
- Appropriate land use planning should be done for the watershed prior to any developmental project being conducted in the area.
- At SC- 6, 7 and 8 runoff contribution for the town is high, therefore to avoid this problem Well built, maintained drainage and construct BMPs will promote reduction in flooding in the flood prone areas.
- There is no organized data regarding stormwater drainage structures in Ethiopia which is essential to investigate the structure in detail. Therefore, data should be organized.
- Compost leaves, sticks, or other collected vegetation or dispose of at a permitted landfill. Do not dispose of collected vegetation into waterways or storm drainage systems.
- Clean storm drain inlets, and other conveyance structures in high waste product load areas just before the wet season to remove sediments and debris accumulated during the summer.
- Consider modification of storm channel characteristics to improve channel hydraulics.

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APPENDIXES

Appendix 1. Design rainfall, frequency, and IDF curve and 24-hr Rainfall depth

Table 1.1 Max rainfall data from 1987-2016 and its statistical calculation

S.No	**Year**	**Max Daily Rainfall**	**Descending Order**	**Rank**	**Logarithmic Value/Yo/**	New Rainfall (X)	log(X)
1	1992	55.4	80.2	1	1.904	80.2	1.904
2	1993	39	73.7	2	1.867	73.7	1.867
3	1994	50	73.7	3	1.867	73.7	1.867
4	1995	46	73.7	4	1.867	73.7	1.867
5	1996	62	66.2	5	1.821	66.2	1.821
6	1997	58.5	64.7	6	1.811	64.7	1.811
7	1998	66.2	62	7	1.792	62	1.792
8	1999	44.5	62	8	1.792	62	1.792
9	2000	64.7	58.5	9	1.767	58.5	1.767
10	2001	53.1	58	10	1.763	58	1.763
11	2002	55.2	55.4	11	1.744	55.4	1.744
12	2003	48	55.2	12	1.742	55.2	1.742
13	2004	58	53.1	13	1.725	53.1	1.725
14	2005	37.3	53	14	1.724	53	1.724
15	2006	62	50	15	1.699	50	1.699
16	2007	33.3	48	16	1.681	48	1.681
17	2008	27.7	47.8	17	1.679	47.8	1.679
18	2009	47.8	46	18	1.663	46	1.663
19	2010	80.2	45.3	19	1.656	45.3	1.656
20	2011	45.3	44.5	20	1.648	44.5	1.648
21	2012	73.7	42.7	21	1.630	42.7	1.630
22	2013	73.7	39	22	1.591	39	1.591
23	2014	73.7	37.3	23	1.572	37.3	1.572
24	2015	53	33.3	24	1.522	33.3	1.522
25	2016	42.7	27.7	25	1.442		
Mean			54.04		1.719		1.730
	STANDARD DEVIATION		12.568		0.101		0.101
	SKEWNESS COEFFICIENT				-0.163		-0.163

A. Test for Higher outlier

For data N=25, $\delta n - 1$=0.10 and Kn=2.563

Higher outlier test YH= $\bar{Y}$+Kn*$\delta n - 1$ =1.71+ 2.563*0.10=1.9663

Higher outlier test= $10^{YH} = 10^{1.9663}$=92.533715

The highest recorded value from meteorological station is (80.2 mm) which was less than the higher outlier test (92.5337 mm). Therefore, no higher outlier data eliminated.

B. Test for Lower outlier

YL=$\bar{Y}$- Kn*$\delta n - 1$

YL= 1.71-2.563*0.10= 1.4537

YL= $10^{1.4537}$=28.425

The lower recorded value from meteorological station is (27.7 mm) which was less than the lower outlier test (28.425 mm). Therefore, the lowest value from recorded data (27.7 mm) was excluded from the hydrological analysis.

C. Checking Data Reliability

For data N=25

$\delta n - 1$=11.25723

Mean (X^{-}) =51.55666

Standard error of mean ($\delta n - 1$) =$\frac{11.25723}{\sqrt{25}}$=2.055

Relative standard (δn) =$\frac{\boldsymbol{\delta n - 1}}{X-}$*100=$\frac{2.055}{51.55666} * 100 = 3.986$ %< 10% hence the data series could be regarded as reliable.

Table 1.2 Outlier test kn value

simple size		simple size	Value	simple size	Value	simple size	Value
size N	Kn	N	Kn	N	Kn	N	Kn
10	2.036	24	2.467	38	2.661	60	2.837
11	2.088	25	2.467	39	2.671	65	2.866
12	2.134	26	2.502	40	2.682	70	2.893
13	2.175	27	2.519	41	2.692	75	2.917
14	2.213	28	2.534	42	2.7	80	2.94
15	2.247	29	2.549	43	2.71	85	2.917
16	2.309	30	2.563	44	2.719	90	2.961
17	2.309	31	2.577	45	2.727	95	2.981
18	2.361	32	2.591	46	2.736	100	3
19	2.385	33	2.604	47	2.744	110	3.017
20	2.408	34	2.619	48	2.744	120	3.078
21	2.408	35	2.628	49	2.753	130	3.107
22	2.429	36	2.639	50	2.76	140	3.214
23	2.448	37	2.65	55	2.768		

Table1.3 Yearly Extreme Series and Frequency Analysis Calculations Log-Pearson Type IIII distribution

Return period(T)	X^{-}	$\delta n-1$	KT	$YT = X^{-} + KT * \delta n - 1$	XT=10^YT
2	1.7110006	0.08538	-0.017	1.709549134	51.23292295
5			0.836	1.782378613	60.58688343
10			1.292	1.821312074	66.26925287
25			1.751	1.860501677	72.52732783
50			2.054	1.886371937	76.97894189
100			2.472	1.922060943	83.57202844

Table 1.4 Yearly Extreme Series and Frequency Analysis Calculations Gumbel distribution

Return Period (T)	X^{-}	$\delta n-1$	Yn	Sy	YT	KT	XT=X⁻+ KT∗Sy
2	52.3793	10.49875	0.5353	1.1086	0.366513	-0.15225246	50.78084915
5					1.49994	0.870142513	61.51472282
10					2.250367	1.547056946	68.62148114
25					3.198534	2.402340123	77.6008891
50					3.901939	3.036838048	84.26232693
100					4.600149	3.666650938	90.87457774

Table 1.5 Design Point Rainfall and return period

Return Period (Year)	Design Point Rainfall	
	Log Person III	Gumbel
2	51.23	50.78
5	60.59	61.51
10	66.27	68.62
25	72.53	77.60
50	76.98	84.26
100	83.57	90.87

Table 1.6 Rainfall of shorter duration using Log-Pearson III

Duration(min)	T =Year	2	5	10	25	50	100
	R24 =	51.23	60.59	66.27	72.53	76.98	83.57
5		89.65762	106.02704	115.9711925	126.9228	134.7131483	146.3
10		72.32883	85.53442366	93.55659229	102.3915	108.6761533	118
15		65.57814	77.55121079	84.82464368	92.83498	98.53304562	107
20		57.44297	67.93074808	74.30188958	81.31852	86.30972272	93.7
30		46.10963	54.52819508	59.64232759	65.2746	69.2810477	75.21
60		29.7151	35.14039239	38.43616667	42.06585	44.6477863	48.47
90		22.20093	26.25431615	28.71667624	31.42851	33.35754148	36.21

120		17.67536	20.90247478	22.86289224	25.02193	26.55773495	28.83
130		16.76285	19.82335817	21.68256661	23.73014	25.18665841	27.34
140		16.05152	18.98215661	20.76246978	22.72315	24.11786591	26.18
160		14.19939	16.79187031	18.36675922	20.10121	21.33498764	23.16
180		12.80823	15.14672086	16.56731322	18.13183	19.24473547	20.89

Table 1.7 Meteorology station in Ethiopia (Years of record through 2010)

Meteorological Region	Station	Years of Record	Meteorological Region	Station	Years of Record
A1	Axum	17		Bedele	39
	Mekele	46		Gore	56
	Maychew	32	B	Nekempte	40
A2	Gondar	52		Jima	54
	Debre Tabor	15		Arba Minch	23
	Bahir Dar	45		Sodo	49
	DeberMarkos	55		Awasa	36
	Fitche	44		Kombolcha	57
	Addis Ababa	57	C	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

Table 1.8 Rainfall of shorter duration using log-Pearson III

Duration(mint)	T =Year	2	5	10	25	50	100
	R24 =	50.3	66.02	76.28	89.13	98.63	108.06
5		88.025	115.535	133.490	155.978	172.603	189.105
10		71.012	93.205	107.689	125.831	139.242	152.555
15		64.384	84.506	97.638	114.086	126.246	138.317
20		56.397	74.022	85.526	99.934	110.585	121.158
30		45.270	59.418	68.652	80.217	88.767	97.254
60		29.174	38.292	44.242	51.695	57.205	62.675
90		21.797	28.609	33.055	38.623	42.740	46.826
120		17.354	22.777	26.317	30.750	34.027	37.281
130		16.458	21.601	24.958	29.162	32.271	35.356
140		15.759	20.684	23.899	27.925	30.901	33.856
160		13.941	18.298	21.141	24.703	27.336	29.949
180		12.575	16.505	19.070	22.283	24.658	27.015

Appendices 2; Peak discharge Estimation for Alamata town catchment using Rational method.

Time of concentration

Sheet flow Time:-Sheet flow is flow over plan surfaces. It usually occurs in the headwater of the streams (usually for the first 100 m run), but from topographic map obtained 100 m Sheet flow, natural range and short grass slope of 0.015 m/m, and length of 100 m and Manning's roughness coefficient is 0.15. The 2-year, 24-hour rainfall depth is calculated to be 33.466 mm. Hence, from Equation travel time for sheet flow is determined as:

$$Tt = [(0.091 * (n * L)^{0.8})/((P2)^{0.5} * S^{0.4})]$$

$$Tt1 = \left[\frac{0.091*(0.15*100)^{0.8}}{(33.466)^{0.5}*0.015^{0.4}}\right]=0.104hr$$

Open Channels Flow:-For channel flow, natural stream channel, winding with weeds and pools, slope is 0.02m/m and length is 593 m. By direct measuring the average bottom width of the stream channel is 1.2 m, side slopes are 1V:1H, 10- year storm depth is observed from flood mark and measured to be 0.6 m. From hydrology of open channel flow for Ditch in clay and sandy loam, bottom, and cross section; grass on slopes. Manning's roughness coefficient for channels = 0.04

Velocity through the channel $\mathbf{V} = \frac{R^{\frac{2}{3}} * S^{\frac{1}{2}}}{n}$= $(0.3^{2/3} * 0.015^{1/2})/0.013 = 4.22$m/s

$Tt2 = \frac{L}{3600*V}$= 593/ (3600*4.22) =0.39 hr.

The time of concentration is the sum of all Tt values for the various consecutive flow segments

Total Time of Concentration (Tc) $=Tt_1+Tt_2=0.104hr+0.039hr=0.133hr$

By the same processes, Time of Concentration for the other catchments is determined.

Table 2.1. Time of concentration result in drainage system

Sub-catchment	Overland flow timeTC_1(Hr)	Open Channels Flow TC_2(Hr)	Total Tc(Hr)	Total Tc(min)
SC-1	0.10	0.07	0.18	10.52
SC_2	0.12	0.14	0.26	15.54
SC-3	0.12	0.15	0.27	16.24
SC-4	0.11	0.12	0.23	13.81
SC-5	0.12	0.15	0.27	16.02
SC-6	0.11	0.10	0.21	12.50
SC-7	0.12	0.22	0.34	20.19
SC-8	0.13	0.04	0.17	10.34

Table 2.2. Runoff coefficient based on hydrologic soil group (ERA, 2013)

Terrain Type	Soil type			
	A	B	C	D
Flat<2%	0.04 to0.09	0.07 to 0.12	0.11 to0.16	0.15 to 0.20
Rolling 2% to 6%	0.09 to 0.14	0.12 to 0.17	0.16 to 0.21	0.20 to 0.25
Mountainous 6% to	0.13 to0.18	0.18 to0.24	0.23 to0.31	0.28 to 0.38

15%				
Escarpment> 15%	0.18 to0.22	0.24 to 0.30	0.3 to0.4	0.38 to 0.48

Table 2.3. Runoff Coefficient for Use in Rational Method Source: (ERA, 2013).

Type of Drainage Area	Runoff Coefficient (C)
Business:	
Downtown areas	0.70 - 0.95
Neighborhood areas	0.50 - 0.70
Residential:	
Single-family areas	0.30 - 0.50
Multi-units, detached	0.40 - 0.60
Multi-units, attached	0.60 - 0.75
Suburban	0.25 - 0.40
Apartment dwelling areas	0.50 - 0.70
Industrial:	
Light areas	0.50 - 0.80
Heavy areas	0.60 - 0.90
Parks, cemeteries	0.10 - 0.25
Playgrounds	0.20 - 0.40
Railroad yard areas	0.20 - 0.40
Unimproved areas	0.10 - 0.30
Lawns:	
Sandy soil, flat, 2%	0.05 - 0.10
Sandy soil, average, 2 - 7%	0.10 - 0.15
Sandy soil, steep, 7%	0.15 - 0.20
Heavy soil, flat, 2%	0.13 - 0.17
Heavy soil, average, 2 - 7%	0.18 - 0.22
Heavy soil, steep, 7%	0.25 - 0.35
Streets:	
Asphaltic	0.70 - 0.95
Concrete	0.80 - 0.95

Brick	0.70 - 0.85
Drives and walks	0.75 - 0.85
Roofs	0.75 - 0.95

Table 2-4.Typical Range of Manning'sCoefficient (n) for Channels and Pipes(FHWA, 2014)

Conduit Material	Manning's n*
Closed Conduits	
Concrete pipe	0.010 - 0.015
CMP	0.011 - 0.037
Plastic pipe (smooth)	0.009 - 0.015
Plastic pipe (corrugated)	0.018 - 0.025
Pavement/gutter sections	0.012 - 0.016
Small Open Channels	
Concrete	0.011 - 0.015
Rubble or riprap	0.020 - 0.035
Vegetation	0.020 - 0.150
Bare Soil	0.016 - 0.025
Rock Cut	0.025 - 0.045
Natural channels (minor streams, top width at flood stage <30 m (100 ft))	
Fairly regular section	0.025 - 0.050
Irregular section with pools	0.040 - 0.150

Appendices 3; Storm water drainage depth and width fixing for current and proposed condition of drainage system.

Table 3.1 Current condition Hydraulic performance of Alamata Town

Label	Normal Depth (m)	Bottom Width (m)	Channel Slope (m/m)	Flow Area (m²)	Roughness Coefficient	Wetted Perimeter (m)	Hydraulic Radius (m)	Velocity (m/s)	Discharge (m³/s)
SC-1	0.60	1.20	0.02000	0.72	0.015	2.40	0.30	4.23	3.04
SC-2	0.60	1.30	0.01500	0.78	0.015	2.50	0.31	3.76	2.93
SC-3	0.30	0.60	0.01400	0.18	0.015	1.20	0.15	2.23	0.40
SC-4	0.50	1.00	0.01400	0.50	0.015	2.00	0.25	3.13	1.57
SC-5	0.50	1.20	0.01500	0.60	0.015	2.20	0.27	3.43	2.06
SC-6	0.50	1.20	0.01800	0.60	0.015	2.20	0.27	3.76	2.26
SC-7	0.50	1.10	0.01500	0.55	0.015	2.10	0.26	3.34	1.84
SC-8	0.50	1.10	0.01100	0.55	0.015	2.10	0.26	2.86	1.57

Table 3-2 Existing, Proposed, Additional depth and width results

Existing Condition				Proposed Condition				
Sub-Catchment	Depth (m)	Width (m)	Existing Discharge (m^3/s)	Design Discharge (m^3/s)	Depth (m)	Width (m)	% Additional Depth	% Additional Width
SC-1	0.60	1.20	3.04	8.69	0.97	1.94	61.58	61.58
SC-2	0.60	1.30	2.93	7.71	0.98	1.96	63.09	50.55
SC-3	0.30	0.60	0.40	8.05	1.01	2.02	235.86	235.86
SC-4	0.50	1.00	1.57	8.56	1.01	2.01	101.13	101.13
SC-5	0.50	1.20	2.06	8.37	1.02	2.03	103.14	69.28
SC-6	0.60	1.30	2.26	9.29	1.01	2.02	68.40	55.44
SC-7	0.50	1.20	1.84	16.47	1.30	2.60	160.20	116.83
SC-8	0.50	1.10	1.57	9.13	1.11	2.21	121.07	100.98

Appendices 4; Peak Runoff Determination Using Rational Formula and SCS Curve Number method

Peak runoff determination using SCS Curve Number method

Soil Map of the Area:-The soil map of watershed was prepared with the help of ArcGIS from the Ethio Soil map which determined from Ministry of Agriculture. In this study four types of soil (eutric cambi soils, Litho soils, eutric rego soils, Litho soils) was present which comes under the hydrologic soil groups B,D, A and D respectively.

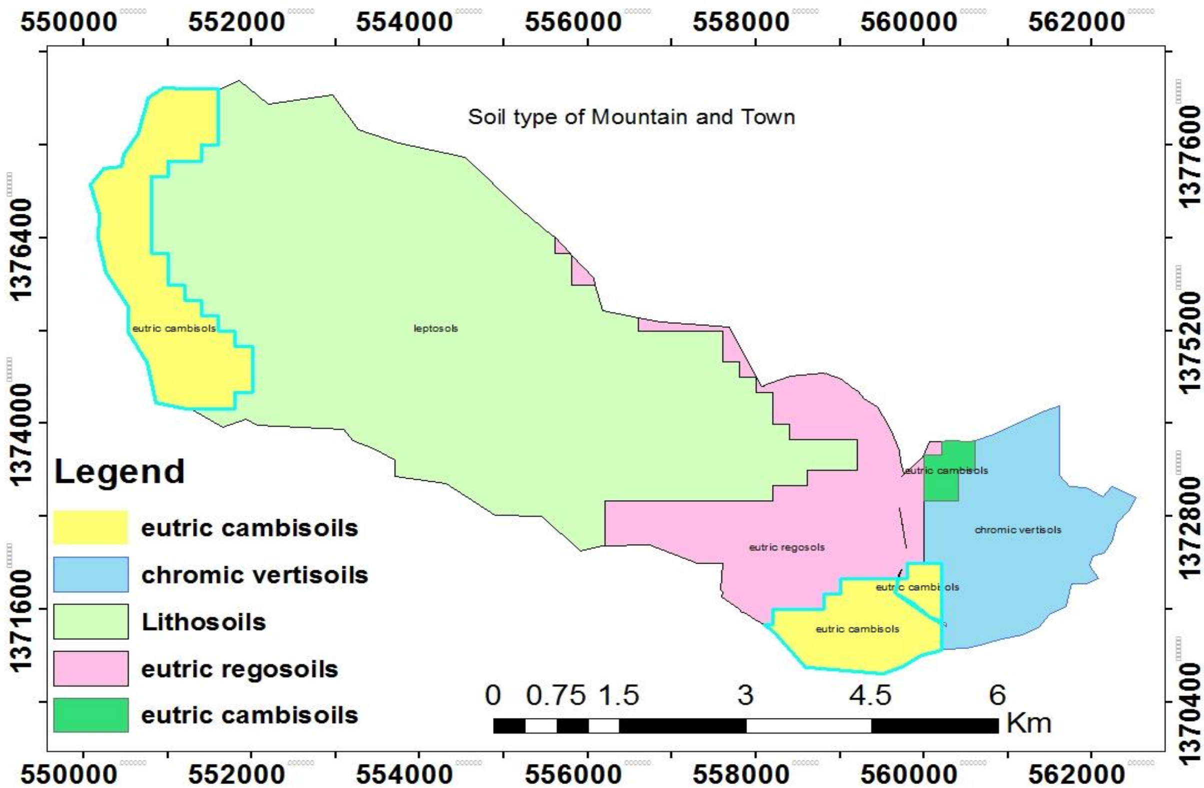

Figure 4-1 Soil map of Gra-kahsu Mountain and Alamata Town

LULC Map:-Likely to soil map the LULC map was generated from Ethiopian land use /cover map through the application of GIS software. For this study area six land use/land cover classes were identified these are Cultivation, Shrubland, Woodland, Grassland, Bareland and Natural Forest. Catchment area from Grakahsu mountain watershed largely dominated by Cultivation land and Shrubland.

Table 4-1 Catchment area properties

Land Cover	Area (km²)	Weight (Ai/At)	Soil Type	Hydrologic Soil Group	Rainfall Region	AMC	Curve Number (CN)	Weighted CN	CN
Cultivation	493	0.79	eutric cambisoils	B	Rainfall Region A1	II	72	56.721	70.13
Shrub land	124.6	0.20	Lithosoils	D			63	12.548	
Wood land	6.28	0.01	eutric cambisoils	B			66	0.662	
Grass land	1.4	0.001	eutric regosoils	A			63	0.141	
Bare land	0.36	0.001	Lithosoils	D			93	0.053	
Natural Forest	0.12	0.001	eutric cambisoils	B			71	0.014	

Table 4-2 Peak flood estimation using SCS Curve Number method for mountain subcatchment 1

Year	25 Year
Intensity (mm/hr)	56
p_1=tc(hr)*I(mm/hr)	39.76
Ia	0.857
(p-Ia)^2	1513.443409
(p-Ia)+S	144.0410402
Q=(P-Ia)^2/(P-Ia)+S(mm)	10.50702916
qu=α10^Co+C1logtc+C2(logtc)^2	0.081991569
qu*A*Q	9.293878048

Table 4-3 Peak flood estimation using SCS Curve Number method for mountain subcatchment 2

Year	25 Year
Intensity (mm/hr)	84
p_1=tc(hr)*I(mm/hr)	23.52
Ia	0.857
(p-Ia)^2	513.611569
(p-Ia)+S	127.8010402
Q=(P-Ia)^2/(P-Ia)+S(mm)	4.018837157
qu=α10^Co+C_1logtc+C_2(logtc)^2	0.131435516
qu*A*Q	16.46983523

Table 4-4 Peak flood estimation using SCS Curve Number method for mountain subcatchment 3

Year	25 Year
Intensity (mm/hr)	84
p_1=tc(hr)*I(mm/hr)	24.36
Ia	0.857
(p-Ia)^2	552.391009
(p-Ia)+S	128.6410402
Q=(P-Ia)^2/(P-Ia)+S(mm)	4.294049615
qu=α10^Co+C_1logtc+C_2(logtc)^2	0.129139263
qu*A*Q	9.133313037