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SUSTAINABLE URBAN STORM WATER MANAGEMENT AND DRAINAGE SYSTEM MODELLING IN SMALL URBAN CATCHMENT: Case study of Sebeta Town

Submitted in Partial Fulfillment for the Degree of Masters of Science in Civil Engineering Major in Hydraulics Engineering.

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This is to certify that the thesis prepared by Adugna Ejeta, entitled: Sustainable Urban Storm Water Management and Drainage System Modeling in Small Urban Catchment (Case Study of Sebeta Town, Ethiopia) and submitted in partial fulfillment of the requirements for the degree of Master of Sciences in Civil and Environmental Engineering (Major Hydraulic Engineering) complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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CERTIFICATION.

The undersigned certify that he has read the Thesis entitled; Sustainable Urban Storm Water Management and Drainage System Modeling in Small Urban Catchment (Case Study of Sebeta Town, Ethiopia***)*** and here by recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

The objective of the study is to develop sustainable urban storm water management and modeling drainage system using SWMM software. Storm water the part of rain fall that is excess water over flow on road pavement, over drainage system in additionally through block of residential building that makes source of problem for Humans and vehicles transportations. So, Storm water modeling using SWMM, GIS and analysis of Sustainable storm water management technics through integrated approach (Best management practice) is the main methodology used in this study. SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term continuous simulation of runoff quantity primarily in urban areas. Typical application of SWMM is design and sizing of drainage system components for flood control, Sizing of detention facilities and their appurtenances, flood plain mapping of natural channel systems. The catchment study area was found in rainfall region A2. According to IDF curve developed by for the study area the value of intensity for different return period of time I2=60mm/hr, I5=89mm/hr, I10=108mm/hr, I25=132mm/hr, I50=150mm/hr and I100=168mm/hr. Model performance of SWMM is done by the result that we get from SWMM output and runoff measured about fifty days have been evaluated during comparation through using Nash and Sutc liffe efficiency criteria (NSE), coefficient of determination (R2). Since the ERA design manual is focused on T5and T10 return period for ditches in urban area, the measured and simulated value of discharge for return period of T5, NSE value is 0.97, R2 value is 0.99 and forT10 NSE value is 0.701 and R2 value is 0.99. From the above criteria the value of NSE for both T5 and T10 is located between 0.9 and 1 indicate that the model performs very well as well as the value of R2 is located between range value of 0 to 1 which shows best model performance.

Key Words: Sustainable, urban storm water management, drainage system, SWMM, GIS.

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ACRONOMY

GIS=Geographical information system

ERA= Ethiopian road authority

EMS=Ethiopian meteorological service

GSP=Geographical position system

SWMM=Storm water management model

IDF=Intensity duration frequency

NSE=Nash and Sutcliffe efficiency

R2=Coefficient of determination

SUDS= Sustainable urban drainage system

AASHTO=American Association of state highway and transportation officials

EPA= Environmental protection agency

CSO= Combined sewer over flow

BMP= Best management practice

WQCV=Water quality capture volume

EDB= Extended detention basin

PPS=Permeable pavement system

NPS= Non-point source

HEC-HMS=Hydrological modeling system

SWAT=Soil water assessment tools

SCS= Soil conservation service

LIP=Low impact development

IUSM=Integrated urban storm water management

DEM= Digital elevation model

HSG=Hydrological soil group

HBV=Hydrologiska Byrans Vattenbalansavdelning (Hydrological Bureau Water balance Section)

PCC= Physical catchments characteristics

1. INTRODUCTION

1.1 Back ground

The importance of urban storm water drainage system modeling (managing) is constantly increasing due to three global trends: urbanization, population growth, and climate change.

Storm water (surface runoff) is the second major urban flow of concern to the drainage system engineer. The approach of both conventional and sustainable storm water management approach is to direct storm water flows to the nearest receiving watercourse or sewer system as efficiently as possible. But in this study the more emphasized approach is conventional which more acceptable one is. The Sustainable Urban Drainage Systems (SUDS) are methods and techniques that mimic natural ecosystem's ways of handling storm water runoff. The use of these systems has been increasing all over the world as a response to climate change and resulting increase in extreme rain events as well as the multiple benefits presented by SUDS. (Kennedy et al, 2007).

Safe and efficient drainage of storm water is particularly important to maintain public health and safety (due to the potential impact of flooding on life and property) and to protect the receiving water environment (Kennedy et al, 2007).

Urban storm water management and drainage system facilities are the part of the urban infrastructure elements and design of these facilities require attention (Beniyam, 2016). 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 (AASHTO et al, 1991).

Storm water discharges are produced when the capacity of the land to retain precipitation is exceeded and run-off occurs. Run-off will be influenced by rain fall and intensity (millimeter of rain falls per hour)) and duration, antecedent storms and a number of watersheds, and land use characteristics such as slope, soil type, and impervious surfaces and land use land cover (Beniyam, 2016).

The flood problem like over toping of man hole ,siltation of ditch and over toping of pavement road quality emerge as a result of urbanization that increases the variety and amount of pollutants and nutrients in receiving water bodies (Qianqian, 214).

Infrastructure is one of the indispensable elements in the process of urbanization and continuity of an urban growth. It is considered as motor/engine for economic development (Dagnachew, 2011). Infrastructure is important in eradicating poverty through various job creation opportunities and by so doing it enables to speed up economic development and ultimately ensures improved quality of life. But urbanization has effect on peak runoff generation if there is no sustainable urban storm water management system. City has high rate of peak run off than semi urban whereas semi urban has high peak rate of runoff than rural area (Qianqian, 2014). Therefore; proper management of storm water in high urban area is indispensable one.

Storm water is generated by rain fall and consists of that portion of rainfall that runs off from urban surface. Hence, the properties of storm water, in terms of quality and quantity, are intrinsically linked to the natural and characteristic of both the rainfall and the catchment areas (Desalegn, 2011). Therefore, sustainable drains of rain fall runoff from catchments of Sebeta town by supporting storm water management modeling (SWMM) and Arc-GIS is the vital important one over comes the problems of storm water storage by supplying appropriate drainage system.

1.2 Statement of problem

The pattern of urbanization and modernization in Ethiopia has meant increase densification along with urban infrastructure development. This has led to deforestation, use of corrugated roofs and paved surfaces (Mitiku and Mekdes, 2017). The expansion of urban construction without provision of drainage system and improper management of the whole train of town like Sebeta town has excess storm water runoff over the train of road and along across the block of town.

Sebeta town is surrounded by Wechach and Mogle (Furi) Mountain which is steeply or hilly topography is subjected to frequent flooding in rainy season. The over flow of storm water (flood) over the road, through the block of village is forced to impossible to transport vehicles or automobiles and people to stops for some hours to give usual service in the town. In this town there is environmental degradation during heavy rain and after rainy season. These environmental degradations are like flooding base failure, Depressions, Shoving, Edge crack, Shoulder erosion, Abetment damage, and silted accumulation in drainage line system.

During intensified rainfall the storm water is over toping drainage system, on pavement road, it ruptured some dwellers' houses and vast flooding plain through town. One major problem in this area is storm water-related flooding and accumulation of stagnant water, which is created by the low-lying topography, the closeness of shacks along dirt roads, the paucity of proper infrastructure and poorly developed storm water management systems found in this area. Vegetation is removed and replaced by roads, car parks, driveways and rooftops that are impervious to rainfall. The system may exceed the capacity of the sewer

In special zone of Oromia region at Sebeta town, ditch or drainage system structures are not properly functioning, insufficient capacity of road ditches to convey excess water unavailability of drainage structures at proper place, small number of culverts, street flood. The major drainage related problems that are observed in the town includes: lack of drainage lines along most of the roads in the town; lack of appropriate maintenance of the existing drainage facilities (existing drainage channels are either partially or fully filled with silts and causing the storm water to flow over the road surface) and formation of gullies and rills across the existing drainage channels and roads. The presence of lined drainage lines are limited to some parts of the town and in most parts of the town runoff flows over the surface of roads.

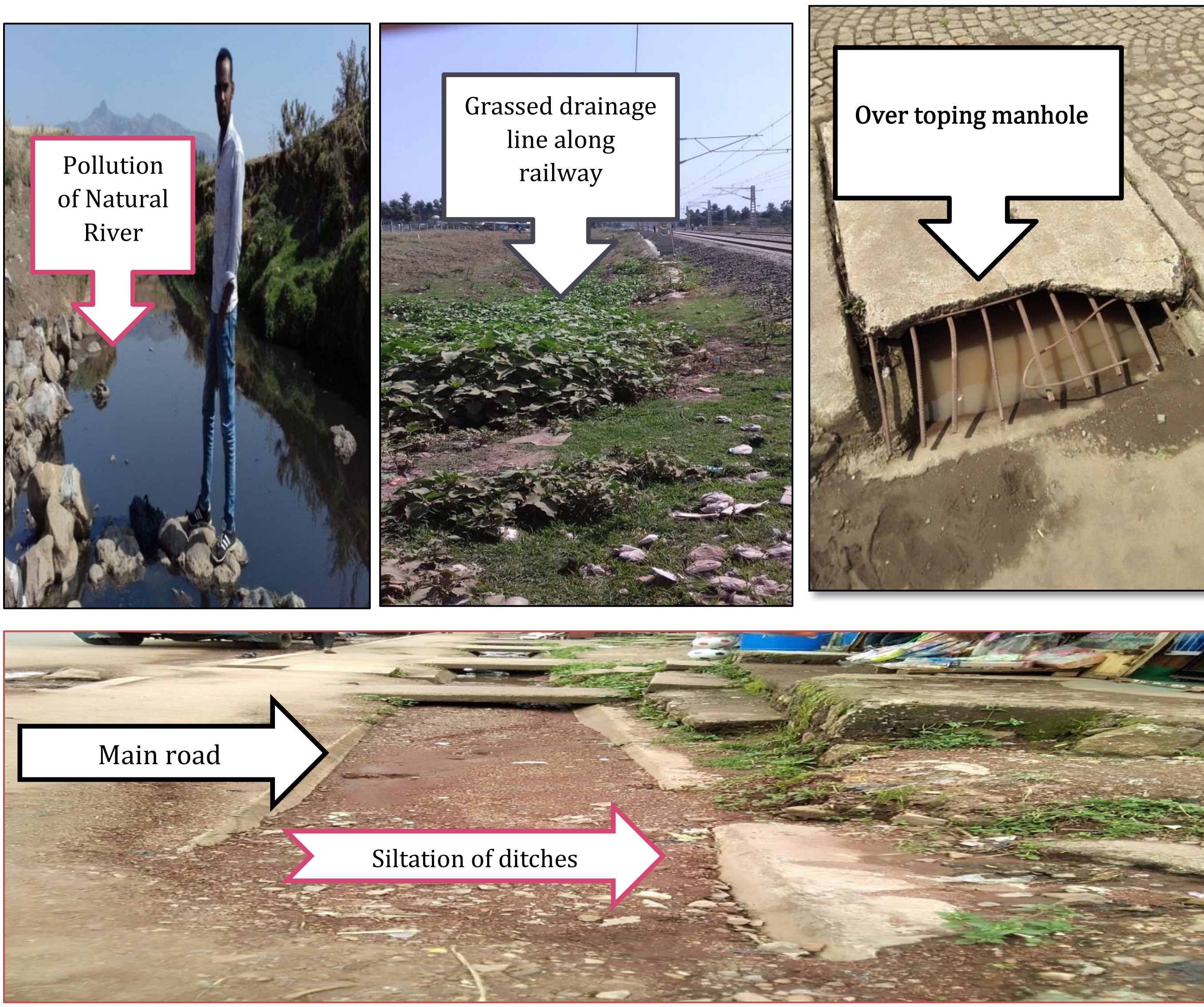


Figure 1-1: Major problem in study area

1.3 Objectives of the Study

General objective of Study

The general objective of this study is to analysis both drainage system structure and best management practice for sustainable urban storm water and modeling drainage system in small urban catchments incase Sebeta town and to take and recommended appropriate storm water or runoff reduction measures.

Specific objective study

In order to achieve the general objective of the Research study, the following specific objectives are set for milestones of the study:

- To compute peak rate of flow and develop proper Drainage Network by applying urban storm water design principles.
- Use different equation for flood estimation and compare with of SWMM model result.
- Discussion about Sustainable Urban Storm Water Management with conventional approach.
- To assess appropriate mitigation measures to reduce storm water or runoff of the catchments area of study.

1.4 Significance of the Research Study

The topic of sustainable storm water management (also known as integrative storm water management) is significant because it incorporates many aspects of geography, namely resource management, hydrology and urban/environmental planning/policy. The implementation of storm water BMPs not only reduces runoff volume of storm water and improves the quality of the water, but reduces the urban heat island effect, creates habitat in the city, and improves upon the aesthetics of the cityscape.

Sustainable storm water management is a relatively new area of study and will benefit by more research and application in different locations, taking into consideration the variability of soil permeability, slopes, and depth to bedrock. These variables are the environmental determinants for site suitability of the various BMP measures.

1. To minimize the possible damage of aesthetic of town, road pavement by flooding through proper sustainable drainage structure provisions.
2. The Sebeta town/kebele can use it as reference while they are preparing their annual plans in relation to spatial and financial plans for roads and urban storm water drainage infrastructure.
3. To reduce the environmental degradation and health safety problems.

4. Concerned body and organizations working in the area of roads and urban storm water drainage infrastructures can use it as a reference for proper design, implementation and maintenance of urban road surface drainage.

1.5 Research Question

The research questions addressed in this research study are:

- What is the importance of sustainable urban storm water management for maintenance of public health?
- Is SWMM has capability for urban storm water modeling rather than another model?
- What mean conventional approach and sustainable approach of storm water management?

1.6 Thesis Layout

This thesis is sub divided in to five major chapters and it has detail information of each sub chapter. Chapter-One: - Deals about the statement of the problem, research question, general and specific objectives of this study. This chapter also provides information on its background about the problem of storm water over the whole study of area.

Chapter-Two: - Briefly reviews the theory of about urban storm water and best management practice of runoff.

Chapter-Three: - Outlines the research methodology employed in this study, and an overview of the selection of storm water model (SWMM) to Sebeta town watershed.

Chapter-four: - widely deals the SWMM model simulation results and discussion and storm water reduction methods in catchment are assessed and appropriate techniques that are remedy measures to the runoff problem of the catchment are specified here.

Chapter-five: -summarizes the entire study by outlining the main conclusions and recommendations.

2. LITERATURE REVIEW

2.1 Urban Storm water management and Sustainable drainage system

2.1.1 Definition of Storm water

Storm water is the part of precipitation that accumulates on earth's surface, ditch of road side, in culvert, on pavement and generally in drainage system. Also, it is pure rain water plus anything the rain carries along with it's a way (Manual. Vol-I Revised, 2016). During rain storms, water that falls onto impervious surfaces flows to the nearest storm drain or local water body. This water can come from events other than a rain storm, such as a snow melt or street wash water, all of which are defined as storm water (Jared, 2011). Throughout this research, storm water runoff, will be synonymous with non-point source pollution. Storm water runoff problems are nothing new to local land-use decision-makers. However, the principal concern about runoff has always been safety, with the focus on directing and draining water off of paved surfaces as quickly and efficiently as possible (Jared, 2011).

In urban areas, rain that falls on the roof of our house, or collects on paved areas like driveways, roads and footpaths is carried away through a system of pipes that separated or mixed from sewerage system. Unlike sewage, storm water is not treated. If storm water was not drained properly, it would cause inconvenience, damage, flooding and further health risks (Butler & Davies, 2000).

2.1.2 Need for urban storm water management

A). Urban Environment

Urban areas are defined by a large percentage of impervious surfaces that are used to move higher densities quickly and efficiently. However, these impervious surfaces generate problems when dealing with storm water since the natural hydrology of the area is disturbed due to urban developments. The creation of cities alters the natural hydrology in a series of steps, from clearing vegetation, installing roads, re-grading surfaces, and the building of actual structures (Jared, 2011).

The changes to water pathways from urban construction have led to important issues regarding storm water along with creation and implementation of best management practices (BMP) that categorized as: (1) structural (such as engineered and constructed systems). (2) Non-structural (institutional, education or pollution prevention practices including Swales, Storm water Wetland, Retention Pond and Extended Detention Basins.

B. Reducing Impacts of urban storm water

The impacts of storm water are hydrological, chemical, biological, and physical. The impacts of greatest concern are sediment and habitat alteration, nutrients, toxic substances, chloride, bacteria, temperature, oxygen-demanding substances and biological integrity (John and James, 2008).

Storm water is moved from urban areas where pollutants such as solids, oxygen-demanding substances, nitrogen and phosphorus, pathogens, petroleum hydrocarbons, metals, and synthetic organics are carried into storm drains and disposed of in local water bodies (Jared, 2011). These pollutants cause environmental damage to the receiving water bodies of the urban area, as well as the surrounding ecosystems that depend on adjacent waters. Therefore, storm water management is the core of amenity ecosystem in urban expansion like Sebeta town.

2.2 Sustainability

"Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."

Brunt land (1987)

Sustainability is a broad concept that provides a critical link between the future lives on earth with the present actions of mankind. The need to embrace sustainability has never been greater than it is now, given the 21st century's rapidly increasing economic and environmental pressures (David, 2009).

Sustainable development requires a systems approach, and multi-disciplinary and multi-participatory global leadership (David, 2009). Sustainability is as much an ethical as it is a technical concept; it must therefore embrace traditional cultures and value systems in each and every community around the world, and technical solutions must be culturally appropriate. By understanding and practicing sustainability at the local level, we may begin to overcome the challenges of flooding occurring in urban and water pollution. This thesis is based on this premise and focuses on sustainability storm water management and Drainage system specifically through appropriate and sustainable storm water management practice method at the local level.

2.2.1 Storm water management Sustainability at local areas

a. Best Management Practice for storm water management sustainability

i. Reduce urban Run-off: The achievement of runoff reduction starts by recognizing that developing or redeveloping land within a watershed inherently increases the imperviousness of the areas and therefore the volume and rate of runoff and the associated pollutant load; and outlines various approaches to reduce or minimize this impact through planning and design techniques.

The extent of impervious land covering the landscape is an important indicator of storm water quantity and quality and the health of urban watersheds. Impervious land coverage is a fundamental characteristic of the urban and suburban environment -- rooftops, roadways, parking areas and other impenetrable surfaces cover soils that, before development, allowed rainwater to infiltrate (Eskader, 2013).

The technics that is related to reduce of urban run-off is encompasses manage watershed impervious area, minimize directly connected impervious areas to storm drainage system and consider coefficient of Runoff reduction areas.

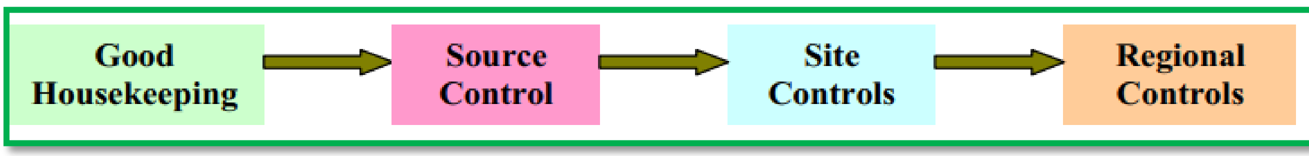


Figure 2-1: Flow chart for Urban Runoff Management (Sharma, 2008).

ii. Protect the existing best management practice: The functions provided by BMPs may include volume reduction, treatment and slow release of the water quality capture volume (WQCV), and combined water quality/flood detention. Ideally, site designs will include a variety of source control and treatment BMPs combined in a "treatment train" that controls pollutants at their sources, reduces runoff volumes, and treats pollutants in runoff. Few Examples list of BMPs for urban storm water management are.

1. **Wet Retention Pond:** are a storm water control structure that provides retention and treatment of contaminated storm water runoff. By capturing and retaining storm water runoff, wet retention ponds control storm water quantity and quality. The ponds natural processes then work to remove pollutants. Retention ponds should be surrounded by natural vegetation to improve bank stability and improve aesthetic benefits.

2. **Extended Detention basin (EDB):** are storm water best management practices that provide general flood protection and can also control extreme floods such as a 1 in 100-year storm event. The basins are typically built during the construction of new land development projects including residential subdivisions or shopping centers. The ponds help manage the excess urban runoff generated by newly constructed impervious surfaces such as roads, parking lots and rooftops.

3. **Permeable Pavement Systems (PPS):** The term Permeable Pavement System, as used in this case, is a general term to describe any one of several pavements that allow movement of water into the layers below the pavement surface. Depending on the design, permeable pavements can be used to promote volume reduction, provide treatment and slow release of the water quality capture volume (WQCV), and reduce effective imperviousness, etc.
4. **Sand Filter:** are used as a step in the water treatment process of water purification. A sand filter is a filtering or infiltrating BMP that consists of a surcharge zone underlain by a sand bed with an under-drain system (when necessary). During a storm, accumulated runoff collects in the surcharge zone and gradually infiltrates into the underlying sand bed, filling the void spaces of the sand. The under drain gradually dewaters the sand bed and discharges the runoff to a nearby channel, swale, or storm sewer.
5. **Green Roof:** Green roofs could be defined as "contained" living systems on top of human made structures. This green space can be below, at, or above grade involving systems where plants are not planted in the ground.
6. **Grass Swale:** Grass swales are densely vegetated trapezoidal or triangular channels with low pitched side slopes designed to convey runoff slowly. Grass swales have low longitudinal slopes and broad cross-sections that convey flow in a slow and shallow manner, thereby facilitating sedimentation and filtering (straining) while limiting erosion. Berms or check dams may be incorporated into grass swales to reduce velocities and encourage settling and infiltration.

b. Sustainable Storm Water Management as Restoration

The idea that urban watersheds can be restored to pre-development conditions is not realistic. Ecological restoration is a widely interpreted term. Restoration is “a singular word offering myriad meanings and rich rhetorical resources. The term is common language for developers, ecologists, academics, planners, environmentalists, and others. However, the term means different things to these different people in different professions and contexts (Alicia, 2009).

2.3 Effect of urbanization on peak run-off and regional water balance.

2.3.1 Effect of urbanization on peak run-off

Urbanization brings with it a range of environmental challenges for the local, regional and wider environment as a direct result of the biochemical physical changes to hydrological systems (Hyeonjun. et al 2014).

Figure 2.2: illustrates the combined effect of covering areas with impervious surfaces like roofs and roads, and carrying rainwater runoff away in a piped system. The result is an increase in the risk of flooding and pollution of the natural watercourse to which the runoff is discharged.

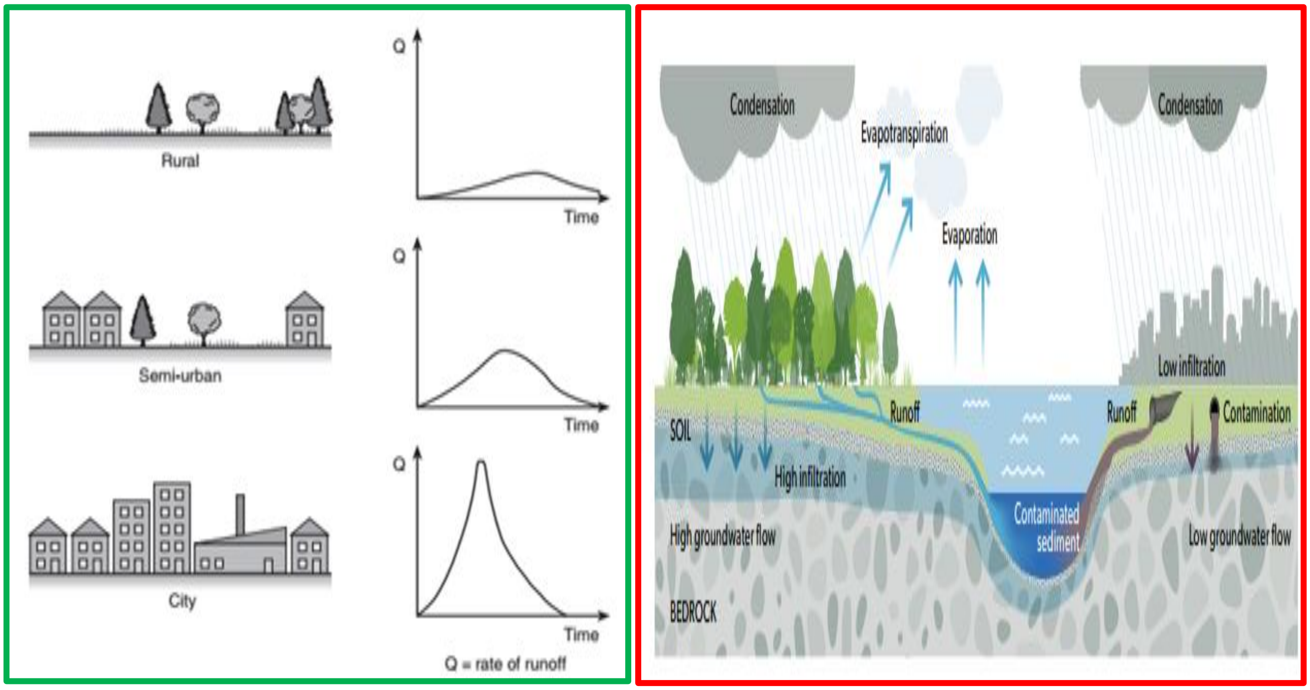


Figure 2-2: Effect of urbanization on peak runoff and water cycle

Source**:** (David Butler & John W. Davies, 2000).

2.3.2 Changes in the regional water balance due to urbanization

On urban areas, several mechanisms (e.g. soil sealing) cause the regional water balance to differ from natural conditions (Fletcher et al., 2012). Some alterations in the hydrologic cycle are demonstrated in Figure 2-3. Most of the water-balance changes related to urbanization are induced by the rising share of impervious surfaces. The effects are further enhanced as even non-sealed surfaces in urban areas often have a practically impervious nature because of compaction.

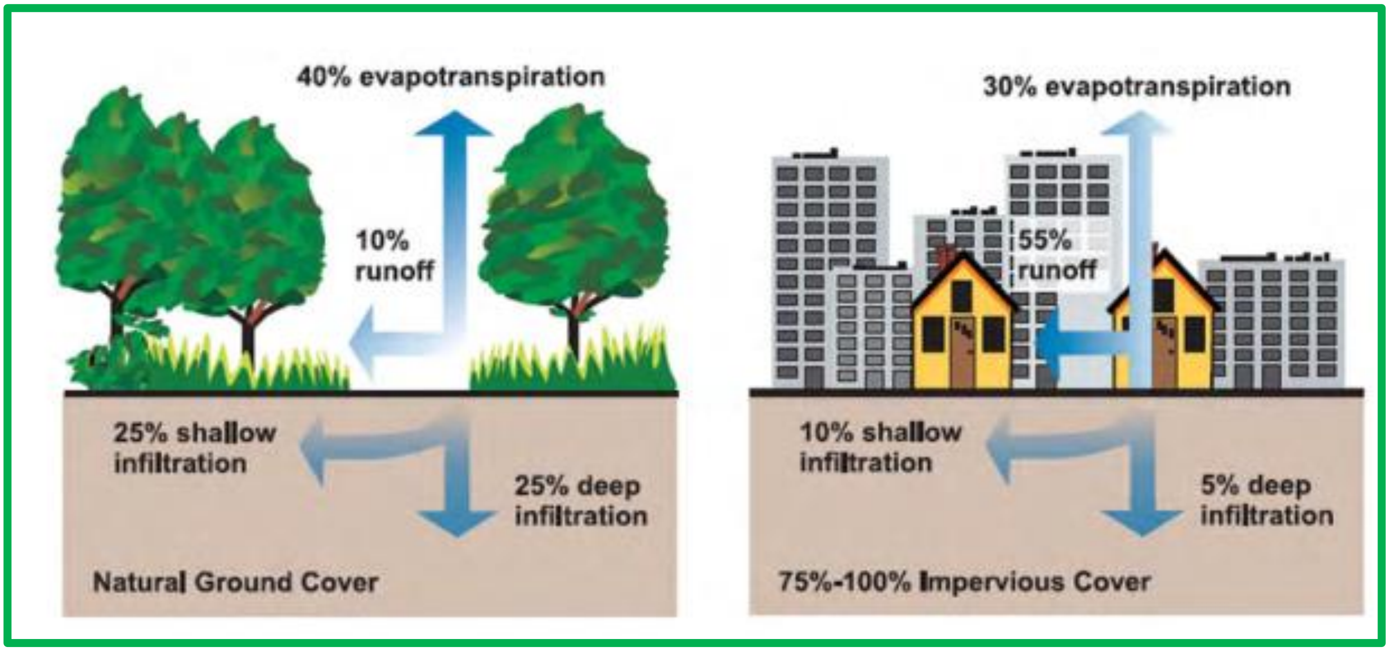


Figure 2-3: Effects of urbanization on urban water cycle (Henri, 2013).

2.4 Uncontrolled urban expansion

The determination of flow limits for future occupation scenarios is not an easy task, due to the difficulty to forecast permeability soil rates. Although many cities already have land occupation rules, there are many areas with informal occupation that does not follow these regulations. Residences located by creeks margins with direct sewage emissions to the water body are frequently found (Adalberto et al**,** 2007). Impermeable surfaces and the construction of drains for rapid storm-water removal are the major causes of urban floods due to traditional urban settlement, pursued without regard for the environment (Eskedar, 2013). Such urbanization patterns make it difficult to control urban drainage, since it not only causes or aggravates local flooding but can also create problems downstream.

The extent of impermeable cover is directly correlated with runoff coefficients and also with population density, so that an indirect method of evaluating the impact of urbanization on drainage is to relate population density with runoff coefficients. There is evidence world-wide that higher urban population density commonly results in greater storm-water generation (Debo and Reese, 2003**).** But many urban planners take no account of this important effect and neglect the wider costs of their storm-water control procedures. Modern urban drainage calls for detention and infiltration areas, contrary to the philosophy of higher population density. Many cities in developing countries have a density index which already causes critical drainage situations. Besides the problems of control in legal settlements, socioeconomic problems lead to the invasion of public areas, forming slums with high population density and high rates of impermeable soil surface (Debo and Reese, 2003).

Urbanization influences hydrology of a place by changing the spatial and temporal characteristics of inputs exerted by land surface. Dense urbanization and development like widening of streets, etc. directly affects the groundwater infiltration by making the land impervious. As a result, rainfall is converted to runoff. In urbanized areas rainfall runoff is the main source of pollution to the receiving water bodies. In densely and unplanned cities of world like Delhi in India the diffuse pollution occurs due to mixing water from drains carrying urban runoff with the drains carrying domestic sewage before it enters the receiving water bodies (INOUD,2008).

2.4.1 Diffuse Pollution

According to (Sharma, 2008) non-point sources (NPS) of pollution are widespread across a catchment or sub-catchment and are mainly due to urban and rural land use activities. Municipal sewage effluent, processed industrial effluents and other discharges do not account for diffuse pollution. Diffuse pollution arises from NPS of pollutants originating from abundant individual negligible point sources. Diffuse pollution or NPS pollution arises from return flow from irrigated agriculture, pastures of animals, run-off from range land, agricultural runoff, rainfall runoff from un sewered and impervious area, wet and dry depositions from atmosphere and runoff from roads and landfill sites. Certain activities like deforestation, wetland drainage, construction, outdoor recreation etc. enhances the extent of diffuse pollution. The extent of diffuse pollution is also affected by climatic conditions, geographic and geologic conditions and land use type. The first flush of the rainfall is most harmful in terms of concentration of pollutants. The different pollutants arising from diffuse pollution are as follows:

a. **Suspended Solids:** due to urban runoff from arable land and due to augmentation of solids from impervious urban surfaces.

b. **Nitrogenous and compounds:** these compounds are carried from rainfall runoff and are emitted due to vehicles, atmospheric deposition and from agricultural fields.

c. **Oil, PAHs and toxic metals:** arise due to urban runoff from roads etc.

d. **Biodegradable organic waste:** arise from agricultural areas and when animal dung or human feces mixes with the rainfall runoff.

Figure 2-4: Urban storm water flooding and River pollution around weleta at D/S of Sebeta town

2.5 Precipitation

Accurate precipitation measurements are crucial for successfully studying and modeling the processes that take place in a catchment. However, these input data always are subject to some degree of uncertainty. This uncertainty is induced by both the methods used for observing precipitation, and the methods used for generalizing the measurements to cover the whole area of the studied system.

The origin of precipitation

Like in natural conditions, precipitation is the most important water input mechanism also in the water balance of urban areas. This study mainly focuses on that part of the hydrologic cycle where water is in close contact with land. The process that brings water into this part of the cycle is precipitation. According to (Dingman 1994), there are four-steps needed in order for precipitation to occur: (I) The air has to cool down to a temperature close to the dew-point, (ii) condensation nuclei need to be present to form cloud droplets or ice crystals, (iii) these droplets or crystals should grow into raindrops, snowflakes or hailstones, (iv) additional water vapor has to be available for the process to be sustained. The cooling of air can occur due to several different reasons. However, the most important is the vertical movement of air masses. As unsaturated air rises, it cools down at a dry adiabatic lapse rate of approximately 1 °C per 100 m. At some level, the rising air reaches the dew point and starts to condensate into droplets or ice crystals. The latent heat deliberated slows down the cooling. Therefore, the air cooling starts to follow the moist adiabatic lapse rate or the saturated adiabatic lapse rate, with typical values ranging from 0.5 °C per 100 m to 0.7 °C per 100 m (Kusisto, 1986).

There are three main mechanisms that can cause the upward movement of air. Accordingly, three basic types of precipitation can be named: cyclonic, convective, and orographic.

2.6 An overview on Flooding

Flood is a hydrologic phenomenon that is characterized by both precipitation and soil water contributions (Mohammad et al 2016). Flooding in urbanized areas has become a very important issue around the world Cities are growing fast and large amounts of impervious surfaces replace the natural landscape as a result of urban development. Impervious surfaces can have an effect on local streams and flooding characteristics.

Floods are natural disasters that have affecting human lives, construction building as well as ecosystem since time immemorial (David, 2061). In UK flooding is listed as major risk on the national risk register with surface water flooding that most likely cause of damage to properties. Climate change and urbanization are both projected to result in an increasing surface water flood events and their associated damages in the future (Katie et al, 2016). Urban runoff quantity and quality constitute problems of both a historical and current nature. Cities have long assumed the responsibility of control of storm water flooding and treatment of point sources (e.g., municipal sewage) of wastewater (Manual Volume-I Hydrology, 2016).

2.6.1 Types of Flooding

According to (Beniyam, 2016**)** Thesis, flooding is categorized as the following parts:

a. Flash Floods: According to (Beniyam, 2016) Thesis a flash flood is a very direct response to rainfall with a very high intensity or sudden massive melting of snow. The area covered by water in a flash flood is relatively small compared to other types of floods. The amount of water that covers the land is usually not very large, but is so concentrated on a small area that it can raise very high. Because of the sudden onset and the high travelling speed of the water, flash floods can be very dangerous. The water can transport large objects like rocks, trees and cars. When a dyke breaks along the sea or along a river, the water may flow in so suddenly and with such speed that you could compare it with a flash flood.

b. Coastal Floods: According to (Beniyam 2016) thesis, a coastal flood is when the coast is flooded by the sea. The cause of such a surge is a severe storm. The storm wind pushes the water up and creates high waves. A storm is formed in al low-pressure area. An interesting fact is that beneath a low-pressure area the sea level is higher. This contributes to the high sea level, but the wind can have a larger effect. A flood starts when waves move inland on an undefended coast or overtop or breach the coastal defense works like dunes and dikes. The waves attack the shore time and again. When it is a sandy coast, each wave in a storm will take sand away. Eventually a dune may collapse that way. Very characteristic of a coastal flood is that the water level drops and rises with the tide. At high tide the water may flow in and at low tide it may recede again. When a sea defense is breached, low tide is the time to repair the breach. In the animation you see the build-up of force by the sea and how the sea floods the coast. This type of floods does not much needed related to this research but, it is one of the flood types.

c. Urban Floods: According to (Beniyam 2016) Thesis**,** urban flooding is specific in the fact that the cause is a lack of drainage in an urban area. As there is little open soil that can be used for water storage nearly all the precipitation needs to be transport to surface water or the sewage system. High intensity rainfall can cause flooding when the city sewage system and draining canals do not have the necessary capacity to drain away the amounts of rain that are falling. Water may even enter the sewage system in one place and then get deposited somewhere else in the city on the streets. Urban floods are a great disturbance of daily life in the city. Roads can be blocked; people can’t go to work or to schools. The economic damages are high but the number of casualties is usually very limited, because of the nature of the flood. The water slowly raises on the city streets. When the city is on flat terrain the flow speed is low and you can still see people driving through it. The water rises relatively slow and the water level usually does not reach life endangering heights.

d. **River floods**: According to (Beniyam 2016) thesis, Rainfall over an extended period and an extended area can cause major rivers to overflow their banks. The water can cover enormous areas. Downstream areas may be affected, even when they didn't receive much rain themselves. With large rivers the process is relatively slow. The rain water enters the river in many ways. Some rain will fall into the river directly, but that alone doesn't make the river rise high. A lot of rain water will run off the surface when the soil is saturated or hard. It will flow to small rivers that flow to larger rivers and these rivers flow into even larger rivers. In this way all the rain that fell in a large area (catchment area) comes together in this one very large river. When there is a lot of rain over a long period, it takes time for all the rainwater to reach the river. While the water level slowly rises, officials can decide to evacuate people before the river overflows. The area that is flooded can be huge. Villages surrounded by large stretches of water were cattle would normally graze. Whole communities can become isolated from the rest of the world as roads are blocked and communications are down. When a dike or a dam breaks and a lot of water is released suddenly, the speed of the water at the breach can be compared with the speed of a flash flood. As a larger area gets covered the speed will be reduced. The water spreads out as much as possible flowing to the lower lying areas before slowly rising. A breach is very dangerous for the people living. Close to it. The strength of the water may carry cars, trees and even houses away and cause loss of live.

e. **Pluvial Floods**: According to (Beniyam 2016) thesis, Pluvial is a type of flooding that can happen in relatively flat areas. Rain water falling in an area is normally stored in the ground, in canals or lakes, or is drained away, or pumped out. When more rainwater enters a water system than can be stored, or can leave the system, flooding occurs. In this case, rain is the source of the flood: not water coming from a river, but water on its way to the river. That's why it is also called" pluvial flood". Puddles and ponds develop on the land, canals are filled to brim and spill over; gradually a layer of water covers the land. It is like urban flooding, but without the sewage systems and in more rural areas. Because of the gradual character people have time to go indoors or leave the area. The layer of water is no more than centimeters or perhaps decimeters high and causes no immediate threat to people's lives. Depending on the economic activity and size of the area that is covered it may cause immense economic damage.

Effect of Natural disasters event based concerning flood

A flood is one the event based hazards that occurs in developing urban area. According to my analysis (my research) recurrent floods in particular area have the most sever impacts on people's lives on road transport in Sebeta town. Refer the following figure 2.5 the major problem of flood around weleta road.

Figure 2-5: Effect of flood around waleta area road

2.6.2 Factors affecting flood Runoff

For all hydrologic analyses, the following factors shall be evaluated and included when they will have a significant effect on the final results:

- Drainage basin characteristics including: size, shape, slope, land use, geology, soil type, surface infiltration, and storage;
- Stream channel characteristics including geometry and configuration, natural and artificial controls, channel modification, aggradation - degradation, and debris;
- Flood plain characteristics; and
- Meteorological characteristics such as precipitation amounts and type (rain, hail, or combinations), storm cell size and distribution characteristics, storm direction, and time rate of precipitation (ERA, 2002).

2.7 Urban Drainage system

Urban Drainage Systems physically involve the collection, storage, conveyance and treat runoff and drainage water in urban regions. This system required in the urban developing cities because of the interface of urban water hydrology and human activities. These interfaces include the different phases of the waste water such as recycling of the waste water from the urban water cycle after fulfilling the needs of the human and distracting the rainfall from the impervious surface to the receiving water bodies. These services either completely artificial or combination of man-made structure and natural sites. It includes detention and retention ponds, streets, inlets and outlets and special arrangements such as energy dissipaters, manholes and others energy dissipaters structure (Verma and Meena, 2016).

2.7.1 Historical Development of Urban Drainage Systems

History of human society and its ancient civilization show suggest that urban drainage systems were constructed with great care. Furthermore, historical accounts show that the objectives of the systems were to collect rainwater, prevent flooding, and convey wastes. They were able to find the systems that met their objectives after trial and error modifications. At the time, planning and design were limited. Few numerical standards existed for urban drainage and engineering calculations were not used during design. Despite the lack of optimization and the use of trial-and-error construction methods, numerous ancient urban drainage systems can be rated very successful. Lewis Mumford summarized the state of ancient urban infrastructure when he stated that ancient sewer systems were an uneconomic combination of refined technical devices and primitive social planning (Anteneh, 2015).

Drainage systems are needed in developing urban areas like Ethiopia because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from the natural cycle to provide a water supply for human life, and the covering of land with impermeable surfaces that divert rainwater away from the local natural system of drainage. These two types of interaction give rise to two types of water that require drainage. The first type, wastewater, is water that has been supplied to support life, maintain a standard of living and satisfy the needs of industry. After use, if not drained properly, it could cause pollution and create health risks. Wastewater contains dissolved material, fine solids and larger solids, originating from WCs, from washing of various sorts, from industry and from other water uses. The second type of water requiring drainage, storm water, is rainwater (or water resulting from any form of precipitation) that has fallen on a built-up area. If storm water were not drained properly, it would cause inconvenience, damage, flooding and further health risks. It contains some pollutants, originating from rain, the air or the catchment surface. Based on removal of storm water and waste water drainage system can be categorized as:

a. **Combined System:** in this system rain water is taken to a sewage treatment plant which may cause the sewage treatment plant to overflow resulting in the discharge of untreated sewage into our rivers.

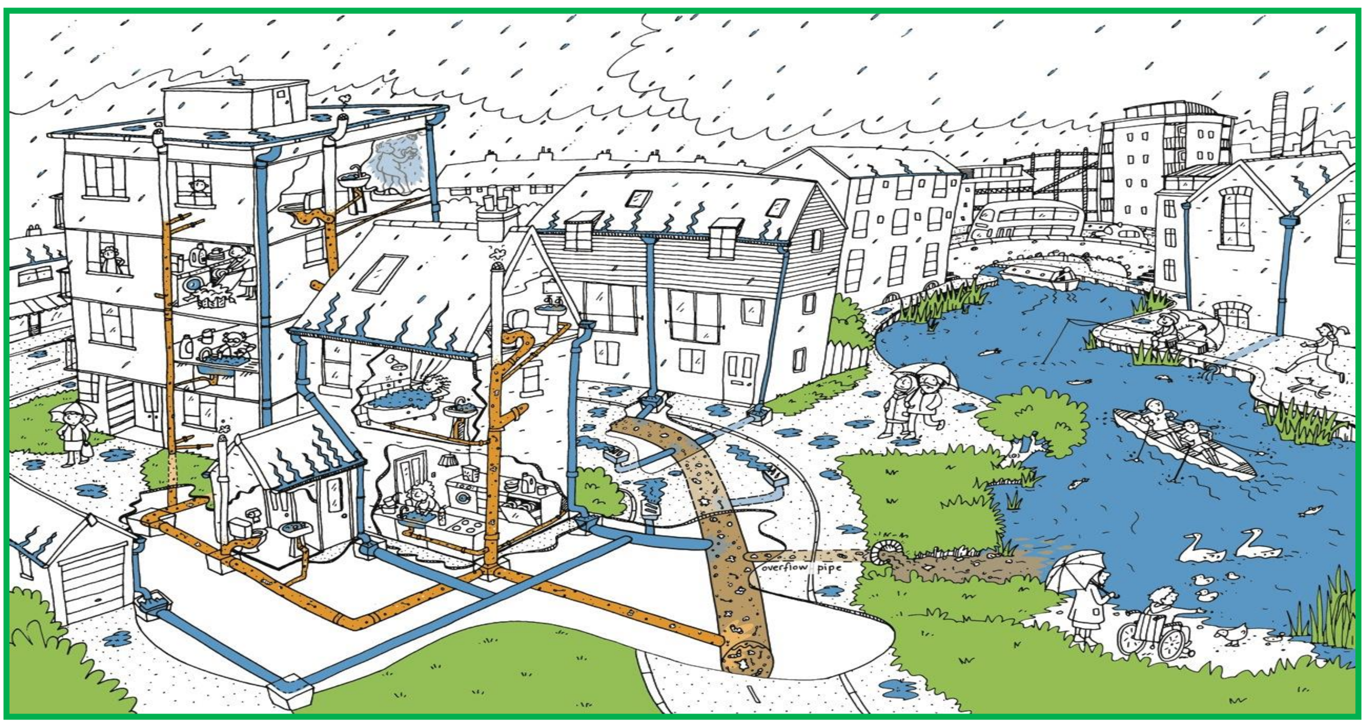


Figure 2-6: combined drainage system

Source: (https://www.thames21.org.uk/combined-sewer-systems/)

b. Separate System: While this system when it rains the rain, water goes into a pipe taking road pollution with it which is then taken out to a nearby waterway.

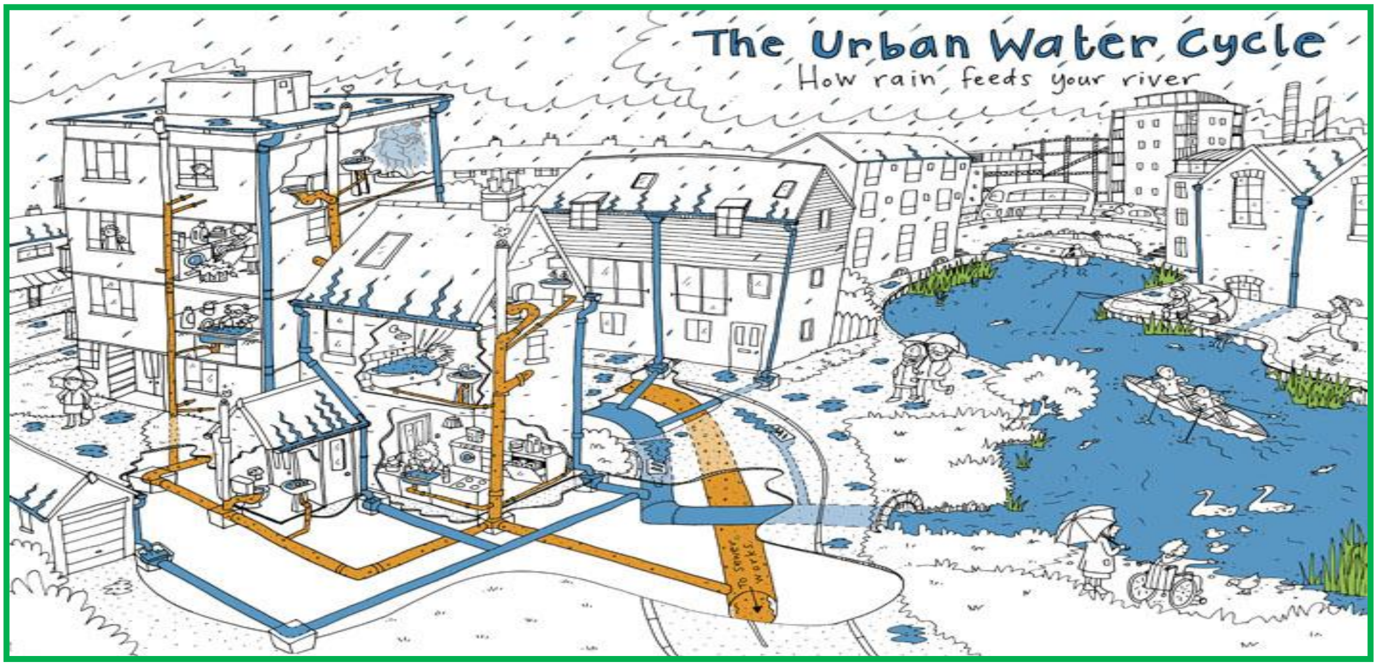


Figure 2-7: Separate drainage system

Source: (https://www.thames21.org.uk/seperate-sewer-systems/)

2.7.2 *Urban* drainage and environmental health

Although flooding problems are prominent during the wet season, other effects of poor drainage are perennial and intrinsically linked to deterioration in sanitation and environmental health conditions (Parkinson, 2002). The implications of these problems are less tangible than inundation by storm water but the effects have major implications on the health and livelihoods of urban populations. In poorly drained areas, urban runoff mixes with sewage from overflowing latrines and sewers, causing pollution and a wide range of problems associated with the increased risk of waterborne diseases. Infiltration of polluted water into low pressure water-supply (Parkinson, 2002) systems can contaminate drinking water, and is frequently a source of gastro-intestinal disease.

2.7.3 Effects of Urbanization to Urban Drainage System

The increase in population density and building density exert the most obvious influence on hydrological processes in an urban area (Shrivastava et al, 2016). Modification of the land surface during urbanization alters the storm-water runoff characteristics. The major modification which alters the runoff process is the impervious surfaces of the catchment such as roofs, sidewalks, roadways and parking lots, which were previously pervious. Another factor is the natural channels, which were in existence before urbanization, are often straightened, deepened and lined to make them hydraulically smoother. Gutters, drains and storm drainage pipes are laid in the urbanized area to convey runoff rapidly to stream channels. These increase flow velocities, which directly affect the timing of the runoff hydrographs. The combined effect of all these changes is to reduce the lag time of runoff. Since a larger volume of runoff (due to urbanization) is discharged within a shorter time interval, the peak discharge inevitably increases.

The amount of waterborne waste increases in response to the growth in population and building density. The quality of storm-water runoff deteriorates as contaminants are washed from streets, roofs and paved areas. The disposal of both solid and waterborne wastes may also have an adverse effect on surface and groundwater quality. The degradation of the quality of flows in both the drainage networks serving the urban area and the underlying aquifers, gives rise to major hydrological problems. Urbanization also considerably affects the climate of the area. It has been found that precipitation, evaporation and local temperature increase due to urbanization (Hall, 1984). The urban atmosphere is characterized by a marked abundance of dust particles along with Sulphur dioxide and other gases. These contaminants not only reduce the clarity of the atmosphere, thereby decreasing the amount of incoming radiation and sunshine, but also provide an excess of condensation nuclei that may change the nature of city fogs and affect the characteristics of precipitation. Increase of population density and impervious area leads to higher absorption of incoming radiation. Due to urbanization the evaporation may reduce as transpiration (lack of vegetation) and soil moisture (loss of pervious areas) reduces. Reduction of evaporation increases the sensible heat result in temperature increase.

2.8 Related Studies on drainage system issues at Addis Ababa & Bureau town.

In order to establish the fact that existence of drainage system problem in the city and town to understand the works that are done, literatures and different manuals should be reviewed. The literatures and manuals showed no doubt on the existence of drainage system problem in the city. The presentation of the problems in the literature are presented either in the form of malfunctioning of specific component of the urban drainage system due to unavoidable distribution of wasted material and missed design of drainage system related to their carrying capacity of peak discharge. As literature review two and one major studies are carry out on drainage system problem in Addis Ababa and Bureau town respectively in this study. This previous study was performed by post graduate students in Addis Ababa University. The first thesis is titled, "Study of the Urban Drainage System in Addis Ababa, Yeka Sub city" (Dagnachew, 2009**).** The second thesis is titled, "Investigation on Storm Drainage Problem of Addis Ababa - Case Study at Gotera – Wollo Sefer, Saris - Gotera and Ring Road" (Desalegn, 2011) in Addis Ababa city. The last one is titled with Performance Assessment of Road Drainage Systems of Burayu Town (Muallem, 2017).

2.8.1 Function of storm water drainage system and their classification

One of the most drainage system's functions is to collect surface water and/or ground water and direct it away, thereby keeping the ballast bed drained. The drainage system must also protect the substructure from erosion, from becoming sodden, and from losing its load-bearing capacity and stability. Another main objective of storm sewer is to protect;

- Public health and safety
- Environmental protection;
- Sustainable development;
- Occupational health and safety.

Storm water Drain and Sewer systems are provided in order to prevent spread of disease by contact with fecal and other waterborne waste, to protect drinking water sources from contamination by waterborne waste and to carry runoff and surface water away while minimizing hazards to the public and environmental safety. Farther more the impact of storm water drain system and sewers systems on the receiving waters shall meet the requirements of any national or local regulations or the relevant authority. (AASHTO, 1991).

Concerning drainage system classification, the have wide classification but based on their type the may be classified as open ditches, closed ditches with pipe drains, drainage through storm water drainage pipes, Channels and culverts (AASHTO, 1991 et al).

2.8.2 Failures of storm water drainage system structure

Urban drainage systems are in general failing in their functions mainly due to non-stationary climate and rapid urbanization. In principle, there are two different natural causes for the clogging or blockage of drainage structures, namely erosion in the stream caused by high water flows and landslides on the river banks resulting in soil and vegetation being transported with the stream, lack of monitoring waste things like garbage that accumulated in drainage system structure (Mulualem. 2017). The manmade ditches are inherently different from natural channels and often much smaller, erosion mechanisms from natural streams/rivers are applicable to roadway ditches.

The practice of urban drainage in developing countries encounters more serious problems than those of developed countries, because urban development occurs under more difficult socioeconomic, technological and climatic conditions. Developing country like Ethiopia experience accelerated urbanization without adequate investment in infrastructure, and against a background of deficient public services for water treatment, collection and treatment of foul sewage, garbage collection, urban drainage, transport and health. Urban concentrations have environmental consequences in the form of urban flooding and pollution of water courses, soil and air. Settlements are established in inappropriate areas such as those originally set aside for environmental preservation and on steep hillsides and areas liable to flooding (Eskeder, 2013).

The specific factors drawback of modernization of storm water drainage system in developing countries, basically the idea of runoff harvesting and infiltration can be missing understanding among the society. Let us see some of them.

1. The situation of concern for Environment issue is less familiar than concern for conventional sanitary planning system.

2. There is no effective control of expansion of urban development whether is legal or illegal system. **3**. The runoff from storm rainfall is highly contaminated with garbage that thrown by peoples and with none point sources of pollution also runoff transport large quantities of sediment and garbage. This condition is facilitating the failures of drainage system structure.

4. There is a shortage of engineering Knowledge ‘know-how’ concerning modern approaches to peak discharge of urban drainage system and the type of drainage system must be constructed in urban areas.

5. There is a lack of interaction between the population and public administrators seeking solutions to urban drainage system in highly development urbanization problems.

6. Few understandings of the community about the use of drainage structure and the sanitary engineer did not give information about the use of drainage system to local community deeply.

Figure 2-8: Typical Road Failure due to absence of Road side ditch around the Noke in Weleta.
(Source by own survey 2018)

2.8.2.1 Clogs, Silting and Grassed Drain system along main road

Especially ditches along the main road are gets clogged, silting and grassed because of accumulation of debris and sedimentation at in inlet. The becomes silted when the grade (slope) too flat and the mixed fined debris are accumulated at the side of ditches. The implies that the flow through the ditches becomes restricted. To solve the problem of silted and grassed carryout the maintenance activities like clean the ditches every times and rehabilitation it from time to time; stop garbage thrown to ditches and collect the debris with in barriers and burn it; steepened the slope of ditches to facilitate the velocity flow of water through the ditches; check whether the debris passed throw the ditches.

2.8.2.2 Absence of minor drainage structure along the road side

The minor drainage structures important elements of the road structure to be accessible throughout the year without traffic interruption (mulualem, 2017). The effect of missed minor drainage structure on roadways makes the life span carriageway becomes short and to be weak do to accumulation of water (poundage) that infiltrated into the carriageway. The infiltrated water oversaturated the carriageway-wearing course, and sub-grade as a result, the carriageway could not carry traffic as intended.

When drainage system structures are neglected to be constructed at appropriate locations the following damage will be occurred simultaneously.

- Surface water can pond at the edge of the road and weakens the road surface, grades and subgrade of the roads.
- Flood accumulation around the residential area and outbreak of diseases like malaria around the pond age water
- Silt can accumulate at the edge of the road i.e. the silt cannot be washed away through the drainage structure due to unconstructed drainage structure.
- The visibility for road users is reduced, with increased risk of accidents on persons or animals etc.

In order to serve a road properly for the road users in urban areas, drainage system structures should be constructed by considering where the location of the crossing in the watershed is required and how can water, sediment, and wood be transported at that location and how is the catchment configured.

Figure 2-9 : Rectangular type of drainage that is grassed silted and clogs.

2.9 Sustainable urban drainage system (SUDS)

Sustainable urban drainage systems advocate for utilization of nature's way of handling storm water through infiltration, percolation, surface runoff, slow drainage, detention ponds and wetlands (David, 2016)

By mimicking natural drainage regimes, SUDS aim to reduce surface water flooding, improve water quality and enhance the amenity and biodiversity value of the environment. SUDS achieve this by lowering flow rates, increasing water storage capacity and reducing the transport of pollution to the water environment. Four categories according to (David, 2016) for sustainable urban drainage facilities are shown in Figure 2-10 below.

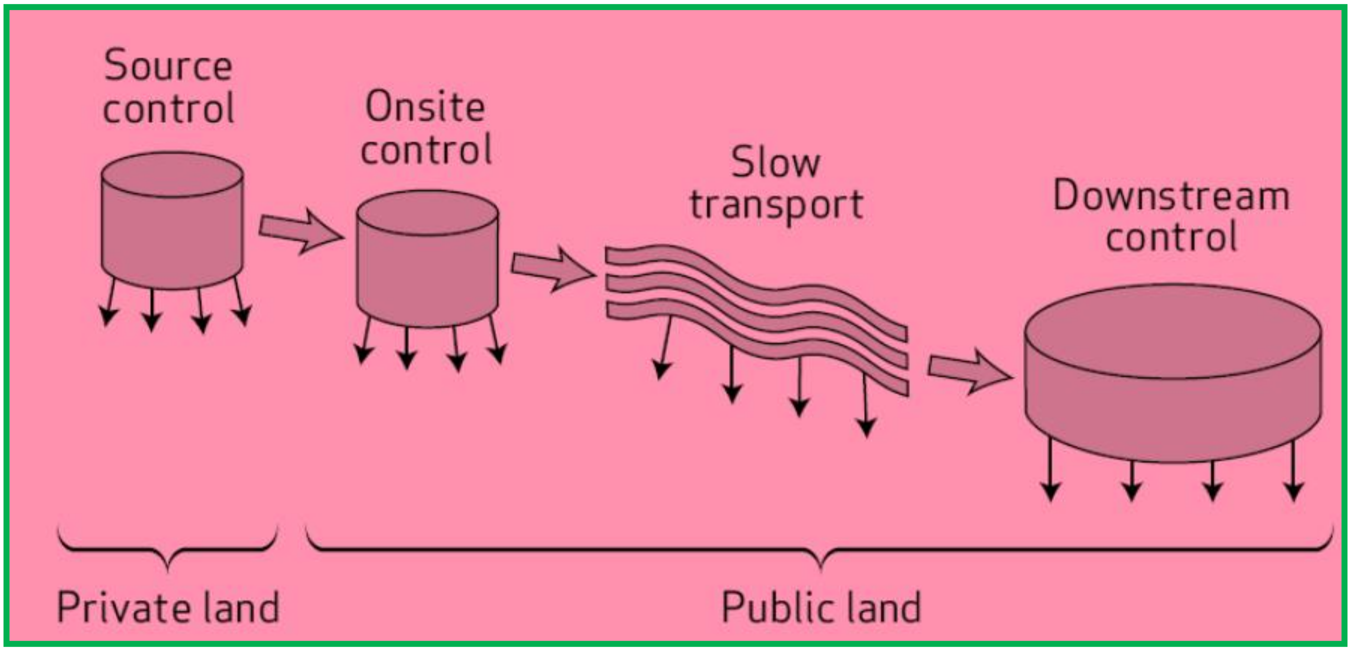


Figure 2-10: Categories of sustainable urban drainage system (SUDS)

During storm Event surface water flow through swales and filter trench that removed entrained pollutants by:

1. Peak river discharge is delayed and reduced by storage of water reuse.
2. Storage in ponds
3. Infiltration of the water to the ground through the infiltration basin and soak ways

These all method is improving the water quality of in rivers and decreases peak river discharge.

2.9.1 How does Sustainable urban drainage system SUDS work?

Sustainable drainage systems use a sequence of techniques that together form a management train. As surface water flows through the system, flow velocity is controlled and pollutants are removed. The management train may include the following stages:

a) **Source control:** This method decreases the volume of water entering the drainage/river network by intercepting run-off water on roofs for subsequent re-use (e.g. for irrigation) or for storage and subsequent evapotranspiration (e.g. green roofs).

b) **Pretreatment:** steps, such as vegetated swales (ditches) or filter trenches, remove pollutants from surface water prior to discharge to watercourses or aquifers.

c) **Retention:** systems delay the discharge of surface water to watercourses by providing storage within ponds, retention basins and wetlands.

d) **Infiltration:** systems, such as infiltration trenches and soak ways mimic natural recharge, allowing water to soak into the ground.

2.9.2 Function of urban storm water drainage system

The most one of the urban storm water drainage system function is to collect, transport, and dispose over flow of surface water/ sub surface water that is originated from paved area, road side and direct it on its way towards to natural stream water course safely. The drainage system must also protect the substructure from erosion, from becoming sodden, and from losing its load-bearing capacity and stability (Biniyam, 2016)**.** Drain and Sewer systems are provided in order to prevent spread of disease by contact with fecal and other waterborne waste, to protect drinking water sources from contamination by waterborne waste and to carry runoff and surface water away while minimizing hazards to the public (AASHTO,1991).

According to (mulualem, 2017) drainage system also it prevents erosion of the back slope by runoff from the hill above. It intercepts water, not allowing it to enter side drain that may cause greater discharge inside. Pipe roughness, outlet conditions including tail water level do not influence flow capacity of culverts operating under inlet control. When the culvert barrel is not capable of conveying as much flow as the inlet opening will accept the outlet, control occurs.

Storm water drainage system structure consists many parts that carryout the above function wisely. This structure includes the following main list.

- Storm drainage facilities, used to collect the runoff of the carriageway and surrounding areas and direct it to the channels like storm drains, gutters, ditches, curbs, inlets and culverts.
- Open channels whether artificial or natural convey the flows of water along road way.
- Culverts and bridges convey flows under road cross-section.

2.9.3 Surface Elevation, Inverted Elevation of Node drainage system and depth of each links

The parameter of surface Elevation, Inverted elevation of node drainage system and depth of conduits are the most important one that used as input parameter of SWMM Software models**.** The surface elevation of junction is obtained with the help of city administration master plan that developed by AutoCAD and the inverted elevation is determine by the measured data of depth links that subtracted the depth of conduit from surface elevation.

The conduit inverted elevation is the bottom of conduit alignment. This elevation is used because this is where the conduit will actually be resting when it is constructed. If you want to build a conduit rack to support these conduits then you will end up specifying a different centerline elevation for each and every different line size. If you specify the invert elevation, then they all use the same invert elevation to be installed on a common horizontal conduit rack. Invert elevations are also used in gravity drain systems such as sewer systems. If the conduit invert is specified at each junction, then the slope can be controlled to ensure that it is always flowing downhill, and no stagnation will occur.

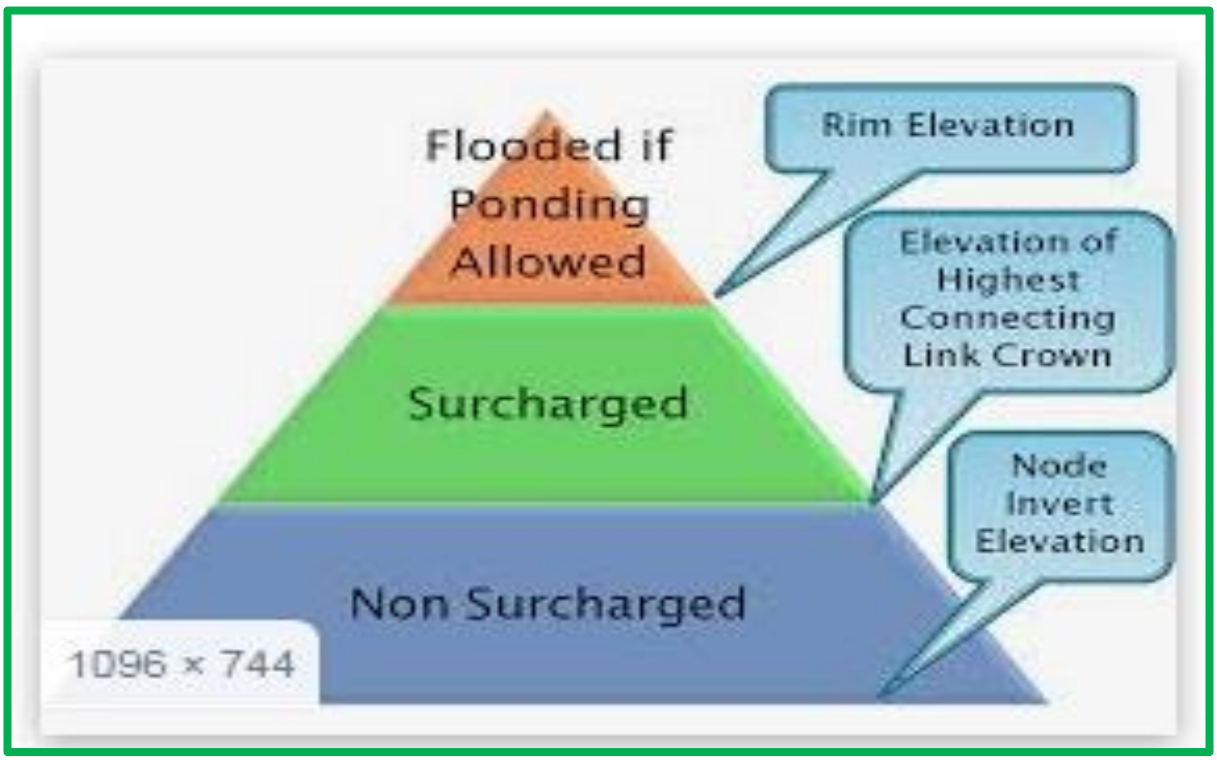


Figure 2-11: Process of flood occurrence through different elevation across cross section of ditch

2.10 Hydrological Equation used for determination of peak discharge.

Related to determination of peak discharge there are many hydrological equations developed in past decades due to advanced technology of hydrological science and expansion of different software from time to time like GIS, SWM, HEC-HMS and SWAT. Among of them rational method: it used for only drainage areas less than 50 hectares (0.5 kilometer2). SCS (soil conservation service): it is used for only drainage areas greater than 50 hectares. Log person type III- preferable for all routine designs provided there is at least 10 years of continuous or synthesized record for 10-year discharge estimates and 25 years for 100-year discharge estimates.

As SWMM and ERA\drainage design manual recommended using Rational and SCS method for peak discharge estimation and the most consulting in the country uses ERA drainage designed manual for hydrology and hydraulic analysis of drainage system structures.

When we speak about peak flood determination there are two broad general methods are grouped. Those are deterministic and statistical methods. In statistical method follow of the techniques and procedures of modern statistical analysis to actual or synthetic data and fit the required design parameters directly. Statistical method does not require much objective judgments and experience to apply. But in deterministic method usually require a large amount of judgments and experience to be used effectively. In addition to this deterministic the physical aspect of rainfall- runoff process either conceptually or empirically, where the relationship between rainfall and runoff is quantified based on measured data and experience which does not applicable where un gage data.

In many cases, Sebeta town has the whole minor drainage structure which has unavailable data of gauge. Therefore, rational method is applied to determination of peak discharge of each sub catchments that divided by either GIS or SWMM.

The situation of hydraulics flow assumes that uniform and steady flow which means flow velocity, pressure, depth of flow and density is constant with related to distance and time respectively. But

This not possible in Sebeta area due to topographical undulation that makes flow varied. In actual drainage system the flow at each inlet is variables so that flow condition is not really stead and uniform. So, Hydrological equation is applied to determine the property of storm drainage system.

2.10.1 Rational method for determination of peak discharge

The Rational Method is most accurate for estimating the design storm peak runoff for areas up to 50 hectares (0.5 km2). This method, while first introduced in 1889, is still widely used. Even though it has come under frequent criticism for its simplistic approach, no other drainage design method has achieved such widespread use (Kuichling, 1889). When we use the rational method in this thesis some precautions shall be considered this includes:

- To obtain a good topographic map and define the boundaries of the catchment area in question. A field inspection of the area should also be made to determine if the natural drainage divides have been altered.
- In determining the runoff coefficient C value for the catchment area, thought shall be given to future changes in land use that might occur during the service life of the proposed facility that could result in an inadequate drainage system. Also, the effects of upstream detention structures must be taken into account.
- The direction of flow across the catchments should be identified from GIS.
- Determine the time of concentration and select appropriate runoff of coefficient.
- Compute the peak discharge of each watershed for desired frequency using equation ($Q=0.0027CIA$)……………………………………………………………………..Eq. 2-1

  Where,

  Q=peak discharge (m3/se)

  C= Runoff coefficient

  I=Rainfall intensity (mm/hr).

  A=Watershed area (ha)

Some of characteristics that rational method has generally limit its use to 50 hectares include:

1. The rate of runoff resulting from any rainfall intensity is a maximum when the rainfall intensity lasts as long as or longer than the time of concentration. That is, the entire catchment area does not contribute to the peak discharge until the time of concentration has elapsed.

This assumption limits the size of the drainage basin that can be evaluated by the Rational Method. For large catchment areas, the time of concentration can be so large that constant rainfall intensities for such long periods do not occur and shorter more intense rainfalls can produce larger peak flows. Further, in semi-arid and arid regions, storm cells are relatively small with extreme intensity variations thus making the Rational Method inappropriate for catchment areas greater than 50 hectares.

2. The fraction of rainfall that becomes runoff (C) is independent of rainfall intensity or volume.

This assumption is only reasonable for impervious areas, such as streets, rooftops, and parking lots. For pervious areas, the fraction of runoff does vary with rainfall intensity and the accumulated volume of rainfall.

3. The peak rate of runoff is sufficient information for the design of drainage system structure.

2.11 Hydrological Modeling

2.11.1 Over view of hydrological models

Hydrological models are characterizations of the real world system. Modeling of the rainfall-runoff processes of hydrology is needed for many different reasons the main reasons are being limited range of hydrological measurement techniques and limited range of measurements in space and time (Yared, 2019). Therefore, it is necessary to develop a means of extrapolating from those available measurements in space and time to ungagged catchments and into the future to assess the likely impact of future hydrological changes. A wide range of hydrological models are used by the researchers, however, the applications of those models are highly dependent on the purposes for which the modeling is made. Beven (2000) stated that many rainfall-runoff models are carried out purely for purposes as a means of enhancing knowledge about hydrological systems. He also added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Before developing the hydrological models, it is very important to understand how the catchment responds to rainfall under Many hydrological and formation of runoff. Models are developed to describe the hydrology, erosion and runoff processes. These models are generally meant to describe the physical processes controlling the transformation of precipitation to runoff and detachment and transport of none point source pollutant.

Hydrological models are a simplification of a real-world system (e.g., surface water, soil water, wetland, and groundwater) that aids in understanding, predicting, and managing water resources. Both the flow and quality of water are commonly studied using hydrologic models.

Researchers and practitioners currently use wide ranges of rainfall runoff models; however, the applications of these models are highly dependent on the purposes for which the modeling is made. Many Rainfall runoff models are used merely for research purposes in order to enhance the knowledge and understanding about the hydrological processes that govern a real-world system. Other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to take the most effective decision for planning and operation while considering the interactions of physical, ecological, economic, and social aspects of a real world system. Examples of some of the implications of latter type of Rainfall runoff models are: real time flood forecasting and warning, estimating flood frequencies, flood routing and inundation prediction, impact assessment of climate and land use change and integrated watershed management. The development of Rainfall runoff models could be recognized based on the importance of available data, which provides the learning data set for calibrating the nonlinear behavior of these models. These data are used as a priori knowledge in the model with the logic that gives the flexibility to the model to extrapolate the Rainfall runoff process for some future time. This line of thinking, known as batch model calibration (using batch of data for calibration), has been challenged by another philosophy that availability of observation continuously gives the opportunity to the model components (state variables and even parameters) to be updated (corrected) sequentially. This is thought to give more flexibility for taking advantage of the temporal organization and structure of information content for better compliance of the model output with observed system response.

Hydrological models are mathematical descriptions of components of the hydrologic cycle. They have been developed for many different reasons and therefore have many different forms. However, hydrological models are in general designed to meet one of the two primary objectives. The first objective of the watershed hydrologic modeling is to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may these phenomena. The other objective is for hydrologic prediction. They are also providing valuable information for studying potential impacts of changes in land use and land cover or climate that affect the drainage system. According to (Hydrological catchment modeling: past, present and future. (E. Todini, 2007) based on process description, the hydrological models can be classified in to three main categories.

2.11.1.1 Lumped models

Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. These models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models.

2.11.1.2 Distributed models

Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amount of (often-unavailable) data. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy.

2.11.1.3 Semi-distributed models

Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub-basins. The main advantage of these models is that their structure is more physically based than the structure of lumped models, and they are less demanding on input data than fully distributed models. SWAT (Arnold et al., 1993), HEC-HMS (USACE, 2001), HBV (Bergström, 1995), are considered as semi-distributed models. Hydrologic models can be further divided into event-driven models, continuous-process models, or models capable of simulating both short-term and continuous events. Event-driven models are designed to simulate individual precipitation-runoff events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long term runoff-volume forecasting and for estimates of water yield (Cunderlik, 2003). Generally, for this study, semi-distributed models are selected because of their structure is more physically based than he structure of lumped model, and they are less demanding on input data than fully distributed models.

2.12 The EPA Storm Water Management Model (SWMM) Software

Storm water modeling has significant consequences for urban hydrology, water quality, and flood risk, and has changed substantially over history, but it is unknown how these paradigm shifts play out at the local scale and whether local changes in storm water infrastructure use follow similar trajectories across cities drainage systems (Rebecca, 2016). Storm water management practices, when properly selected, modeling, and implemented, can be utilized to mitigate the adverse hydrologic and hydraulic impacts caused by drainage facilities, thereby protecting downstream areas from increased flooding, erosion, and water quality degradation (Nejib, 2016).

Urban water management goes much beyond providing water and sanitation services and overseeing related infrastructure. It also includes mitigating the risk of floods, landslides and other water-mediated disasters, as well as managing solid waste and storm water drainage. Conventionally, these services have been delivered in isolation. Yet, greater integration is a key to safeguarding cities and water resources (URA dept, 2013). Poor management storm water increases total flow, flow rate, flow velocity and depth of water in downstream channels. In addition to storm water peak discharge and volume impacts, roadway construction or modification usually increases non-point source pollution primarily due to the increased impervious area. Properly modeling storm water management facilities, particularly detention/recharge basins, swales, and ponds can also be used to mitigate non-point source pollution impacts by providing extended containment durations, thereby allowing settlement of suspended solids.

Vegetation with native, non-invasive grasses, shrubs and possibly trees may be required to achieve compatibility with the surrounding environment (Urban Storm Water Drainage Modeling Manual for Ethiopia, 2013).

The natural water cycle is altered by human activity in two main forms: water is extracted for Water supply for human activity and the natural drainage is altered by the shift in land use with more impervious areas (Butler & Davies, 2000). Hence, it raises the need to drainage of wastewater and storm water. However, storm water becomes more important when it comes to flooding since the quantity of water is much higher. The storm water results from all kind of precipitation (snow melt, rainfall, etc...) and comprises the water flowing in the surface (Butler & Davies, 2000). Therefore, the characteristics of both the rainfall and the catchment area represent important factors in the storm water properties.

2.12.1 EPA SWMM 5.1 Soft ware

What is SWMM?

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas (User manual, 2015). The runoff component of SWMM operates on a collection of sub catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps (User manual, 2015).

2.12.2 Modeling capability of SWMM

SWMM accounts for various hydrologic processes that produce runoff from urban areas. These include:

- Time-varying rainfall
- Evaporation of standing surface water
- Rainfall interception from depression storage
- Infiltration of rainfall into unsaturated soil layers
- Percolation of infiltrated water into groundwater layers
- Interflow between groundwater and the drainage system
- Capture and retention of rainfall/runoff with various types of low impact development (LID) practices.

Spatial variability in all of these processes is achieved by dividing a study area into a collection of smaller, homogeneous sub catchment areas, each containing its own fraction of pervious and impervious sub-areas. Overland flow can be routed between sub-areas, between sub catchments, or between entry points of a drainage system. SWMM also contains a flexible set of hydraulic modeling capabilities used to route runoff and external inflows through a drainage system network of pipes, channels, storage/treatment units and diversion structures.

2.12.3 Storm water management (SWMM) software evaluation method

The performance of a model must be evaluated on the extent of its accuracy, consistency and adaptability (Go swami, 1986). A forecast efficiency criterion is therefore necessary to judge the performance of the model. Assessing performance of a hydrologic model requires subjective and/or objective estimates of the closeness of the simulated behavior of the model to observations.

In this thesis work, the model performance in simulating observed discharge has been evaluated during comparation through using Nash and Sutcliffe efficiency criteria (NSE), coefficient of determination (R2), and through graphical inspection of simulated data. The R2and NSE simulation efficiency measure how well trends in the measured data are reproduced by the simulated results over a specified time period and for a specified time step.

The Nash and Sutcliffe Efficiency (NSE) is a measure of efficiency that relates the goodness-offit of the model to the variance of measured data. NSE can range from - ∞ to 1 and an efficiency of 1 indicates a perfect match between observed and simulated discharges. NSE value between 0.9 and 1 indicate that the model performs very well while values between 0.6 and 0.8 indicate the model performs well (Abe you, 2008)

2.12.4 Typical Applications of SWMM

Since its inception, SWMM has been used in thousands of sewer and storm water studies throughout the world. Typical applications include:

- Design and sizing of drainage system components for flood control.
- Sizing of detention facilities and their appurtenances for flood control and water quality protection.
- Flood plain mapping of natural channel systems.
- Designing control strategies for minimizing combined sewer overflows.
- Evaluating the impact of inflow and infiltration on sanitary sewer overflows.
- Generating non-point source pollutant loadings for waste load allocation studies.
- Evaluating the effectiveness of BMPs for reducing wet weather pollutant loadings.

2.13 Integrated Urban Storm Water Management (IUSM)

The aim of integrated urban storm water management (IUSM) is to bring together all the issues and stakeholders surrounding the effective drainage of the urban area, taking into account both the quantity of flows to be dealt with and the quality of the receiving water bodies (J. Ellis and D Revit, 2006). The stakeholder benefits of implementing sustainable storm water management and BMP/SUDS controls are discussed for plot, site and sub-catchment (neighborhood) scales.

When storm water controls are considered early, they can be effectively integrated into site design and planning. There are often opportunities to use existing or proposed site features for storm water controls and/or repeat small-scale storm water controls over an entire site. Small-scale controls are typically low-cost and cumulatively very effective (SWQDM, 2007).

3. METHODOLOGY AND MATERIAL

3.1 General Description of study Area

The study area, Sebeta town is one of the reforming cities of Oromia found in the South West Shewa zone between Wechach and Mogle Mountain of Oromia National Regional State, 24 kilometers away from Addis Ababa along the Addis Ababa-Jimma highway. The town was established in 1933 E.C. The main roads in the city are the Addis Ababa-Jimma and Alemgena-Hosaina (Wolayita-Soddo) national highways. Astronomically, the town lies between 8° 52` to 8° 59` North latitude and 38° 34` to 38° 41` East longitude and an elevation of 2,356 meters (7730 feet) a.m.sl.. The city`s administration falls into nine kebeles namely kebele 01(Sebeta), Alemgena (02), Furi (04), Wolete (03), Dima (05), Dalati (06), Sebeta (07), Karabu (08) and 09 with considerable decision-making power in local affairs. The Kebeles are the lowest administrative units within the administrative structure of the city. (Source: Sebeta city Administration)

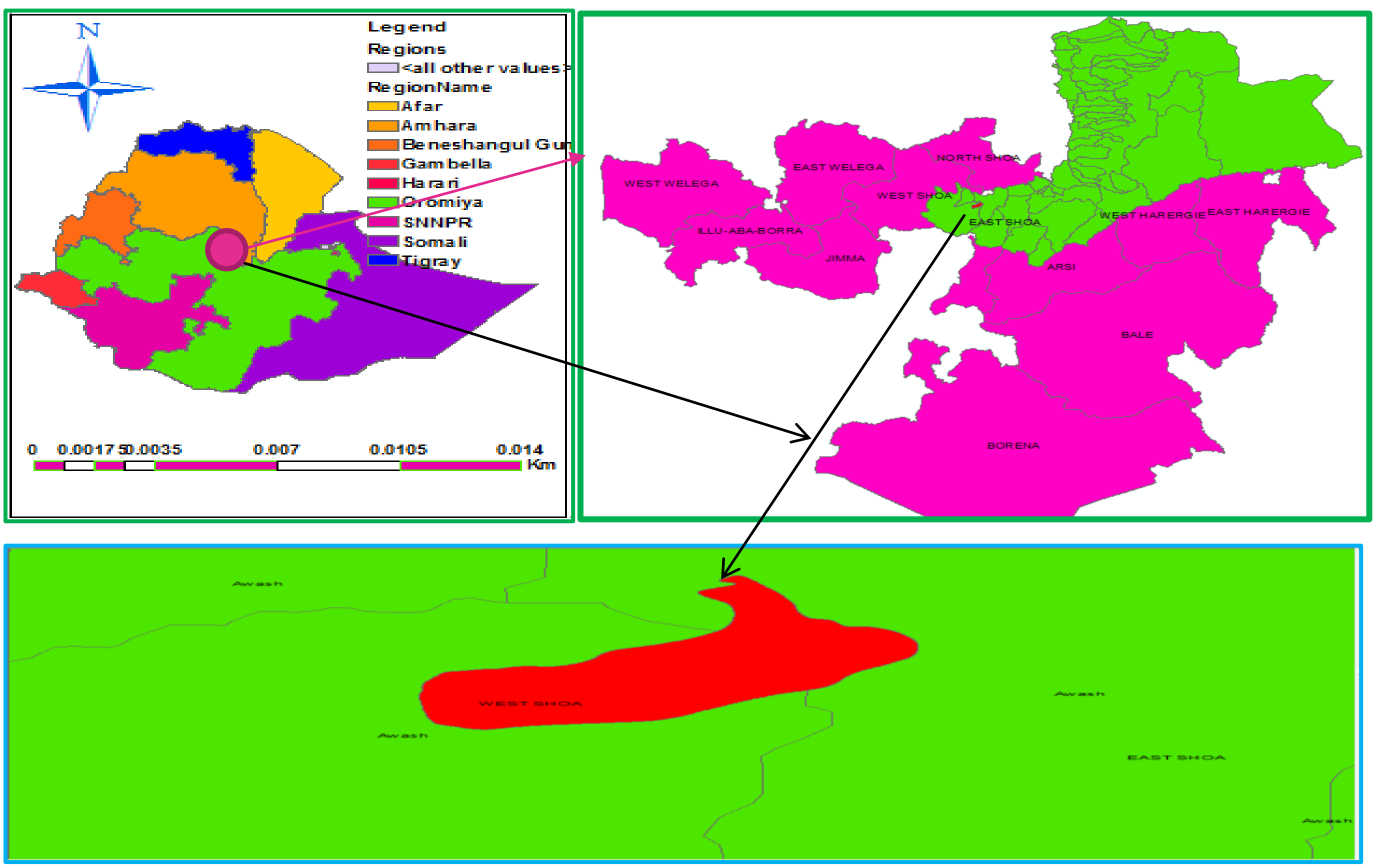


Figure 3-1: Location map of Study Area

3.1.1 Topography

The built-up area of study area, Sebeta town is the combination of eight kebela that is extended about 9km^2 areas excluding 09 kebeles which is considerable decision-making power in local affairs (ULGDP, 2017). According to DEM (30*30) of Sebeta and ministry of urban development the principal natural constraints for physical features of town is flat topography of land that bounded Wechacha and Mogle mountain feasible for affection of flooding over settlement of Sebeta town. The major or the dominant soil that covers this study area is black soil. The overall catchments area greatly dominated by Lithosiol (D) major soil and covered the edge of catchments by small bush of trees. In addition to this the settlement of the infrastructure is especially building is settled densely unplanned manner.

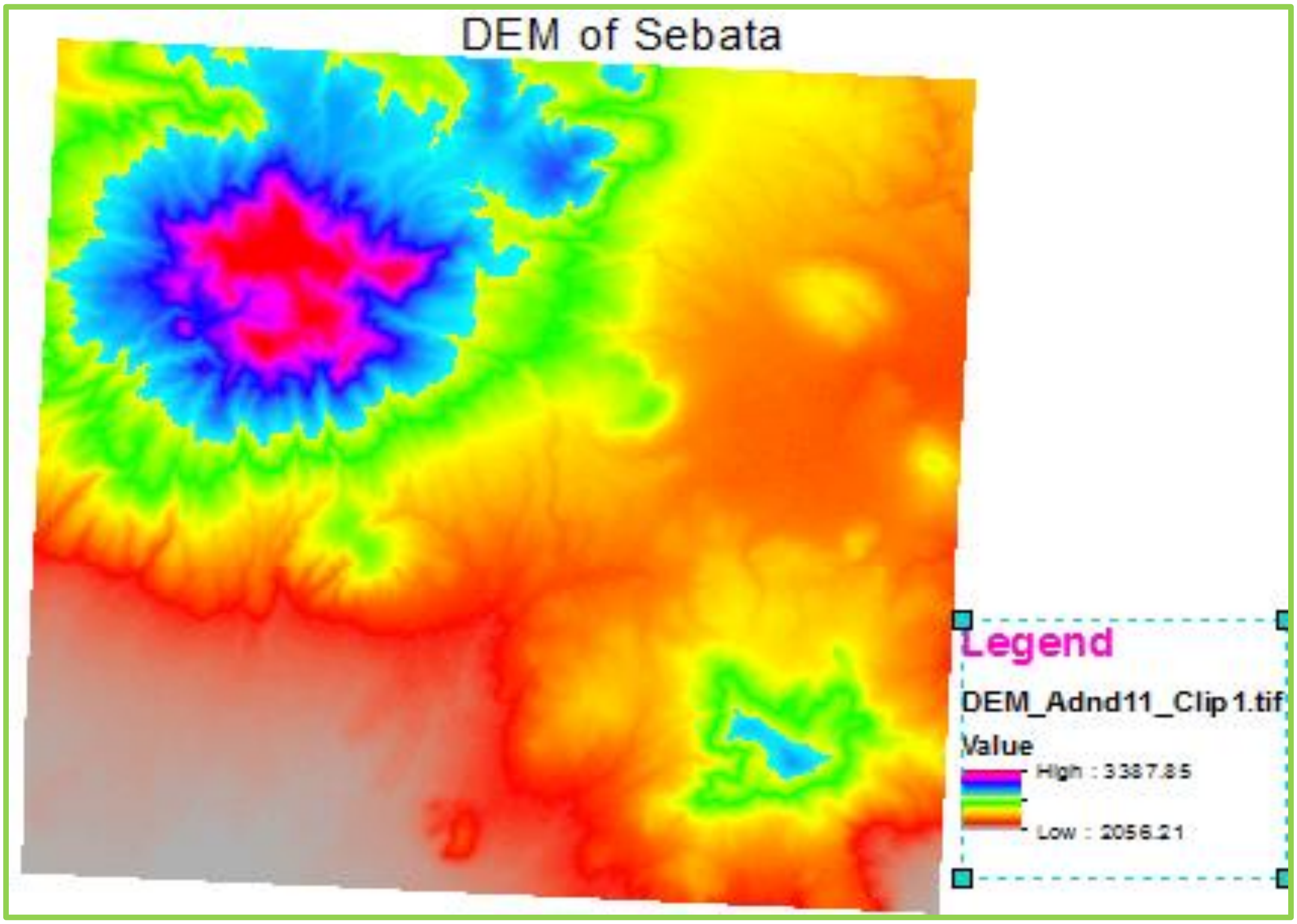


Figure 3-2: DEM of Sebeta Town (30×30m) (Source: Ministry of water irrigation & Electricity)

3.1.2 Climate of the Study Area

The climate of Ethiopia is mainly controlled by seasonal migration of Inter-tropical convergence zone (ITCZ) and its associated atmospheric circulation but the topography has also an effect on the local climate (Mengist, 2016). The traditional climate classification of the country is based on altitude and temperature shows the presence of five climatic zones namely: Wurch (cold climate at more than 3000 m altitude), Dega (temperate like climate-highland with 2500-3000 m altitude), Woina Dega (warm 1500-2500 m altitude), Kola (hot and arid type, less than 1500 m in altitude), and Bereha (hot and hyper-arid type) climate (NMSA, 2010).

Since, the Sebeta town elevation is 2240m-3387.85m a.m.s.l from low land to highland which is lies between 2500-3000m is classified as Dega (temperate climate) ranges from semi-arid in lowland to humid in the highland of study area. The minimum and maximum annual precipitation of study area is 835.3and 3131.1mm respectively.

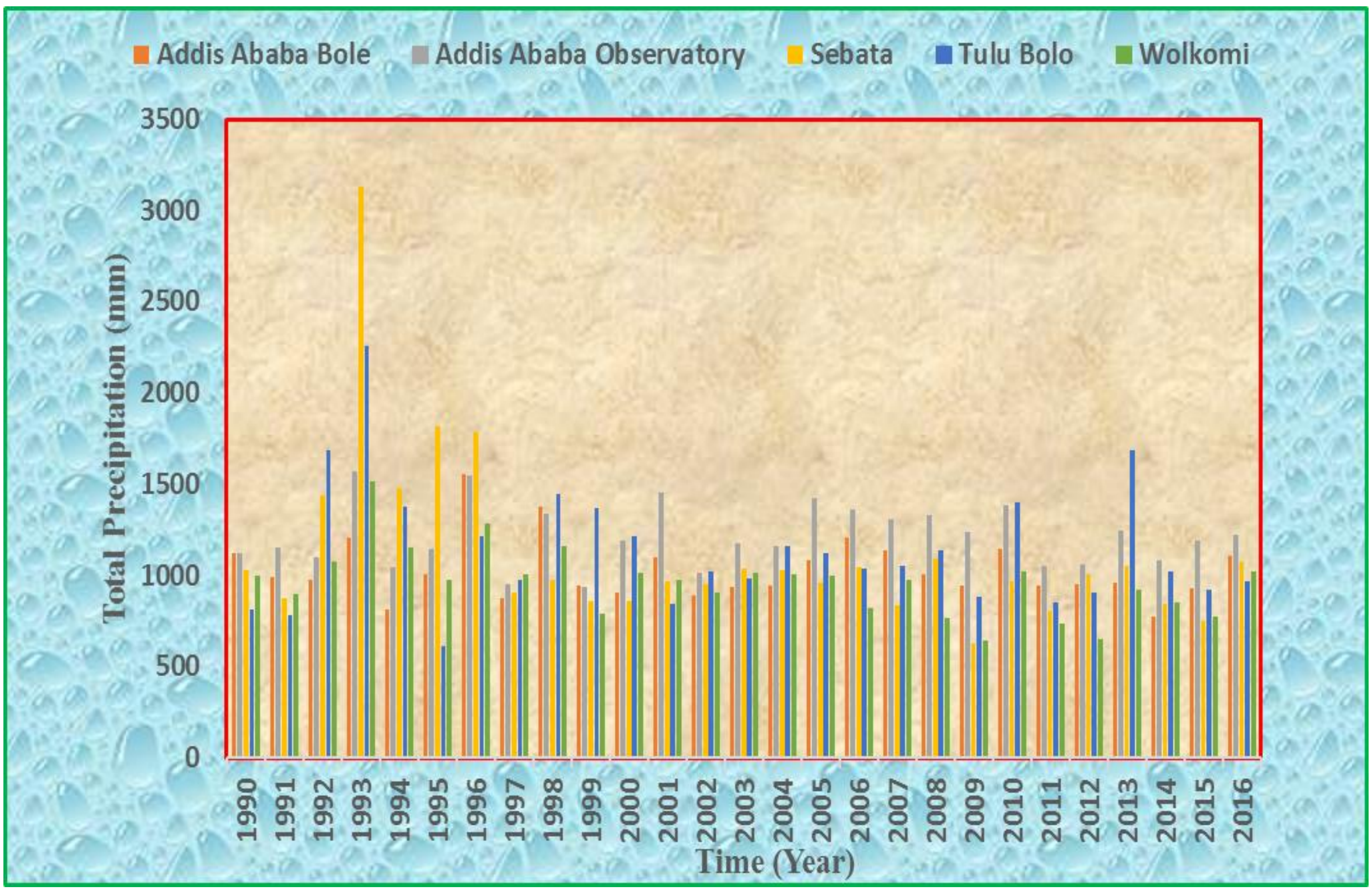


Figure 3-3: Total annual precipitation of selection station at Sebeta catchment

3.1.3 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 Groups (HSG). Based on infiltration rates, the Soil Conservation Service (SCS) has divided soils into four hydrologic soil groups as follows:

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.

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.

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 consist of clays with high swelling potential, soils with permanently-high water tables, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

3.1.4 Soil Characteristics of Study area

The development of soils depends primarily on geologic and climatic conditions. In Ethiopia, 17 major soil units have been identified (EMA, 1988). The FAO Soil Map of Ethiopia classifies 19 soil units, which do not all coincide spatially with the EMA soil map. For this research, since the FAO classification system is recent, the FAO classification (FAO, 1998) is selected. The type of soil at the study area is Lithosoils of hydrologic soil group D.

3.1.5 Land use and Land Cover of Study area

In the Sebeta catchment the land use and land cover are rapidly change due to high expansion of urban and high population growth in the basin. Residence area is the most dominant on the catchment. The vegetation cover is mostly a dry acacia thorn bush of varying density. These provide a certain amount of grazing for cattle and burnt to and encourage regeneration of grass. The densest vegetation is found at the middle of town where it stands of dens riverine forest and bush occurs.

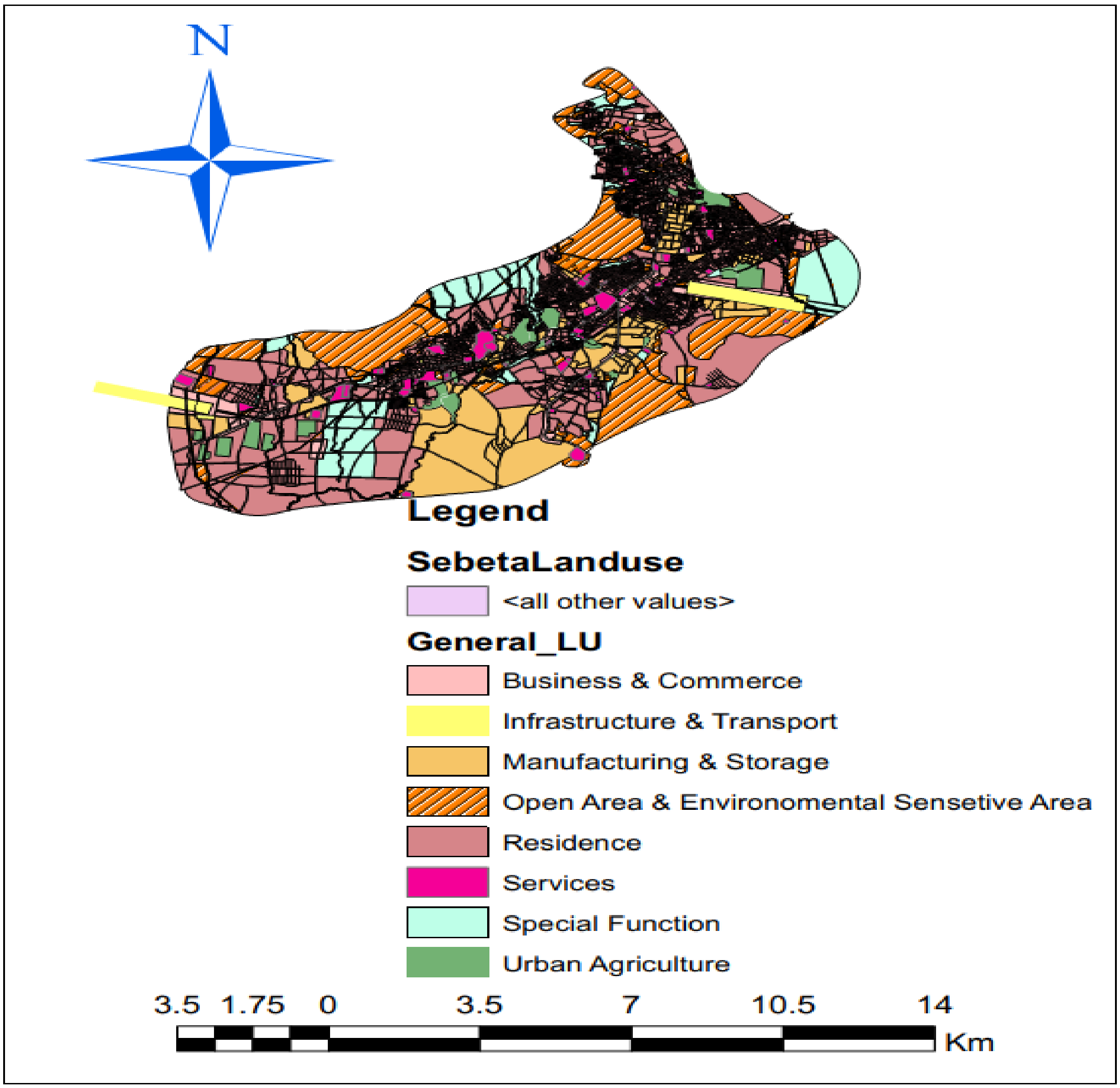


Figure 3-4: Land use land cover of Sebeta Town.

3.2 Data Collection and Analysis

3.2.1 Meteorological Data Collection

For this study, more information and data collection were obtained via two sources which include: primary and secondary data sources.

A. Primary data collection

i) By city Administration representative interview related to drainage system problems orally.

Interview for concerning body like head of municipality and water bureau concerning the most likely causes, effect of water drainage challenges as well as environmental challenges relating to the improper utilization of the drainage systems in the chosen locations.

ii) Flood measurement and measuring dimension of drainage system at each subcatchements

The dimension of each drainage including depth, width and length measuring at each junction and node is the input of SWMM software therefore; through the my own survey taking the dimension about 5days over all the site and measuring the flood event about 15 days with the help of V-notch weir discharge measurement. This V-notch discharge measurement according to the figure 3.6 has 1m and 50cm depth, 90^o and 2; 50m length.

The equation of V-notch weir is given by:

$$Q=8/15cd \tan\Theta/2\sqrt{2g}h^{5/2} \quad \text{Eq 3.1}$$

Where Cd= Discharge of coefficient use 0.585 for 90o weir,

ϴ=angle of weir in degrees, h= head over crest

iii) Study Area Observations: From time to time observation of study area to gather information Such as major area problem of drainage system, damage drainage system with the help of discussion with residents was also made a measuring the cross section of the existing drainage structures and capturing different drainage system structure. In addition to this gathering information is carried out about the overall performance of drainage structures during the rainy season and recorded. This also gave an insight to the major challenges encountered within these areas of study.

B. This is the second type of source of data that we gather the information of causes of poor drainage challenges and unconstructed storm water drainage event runoff with respect to precipitation. It includes Journal articles, books, manuals and conference proceedings etc. Both quantitative and qualitative techniques in data collection and analysis were utilized as main instruments.

The weather data were collected from Ethiopian National Metrological Agency (ENMA) which is one of input of SWMM model. This data collected were based on their homogeneity of the outline, which can be representative to the Sebeta catchment. The location of weather data for four stations as shown below.

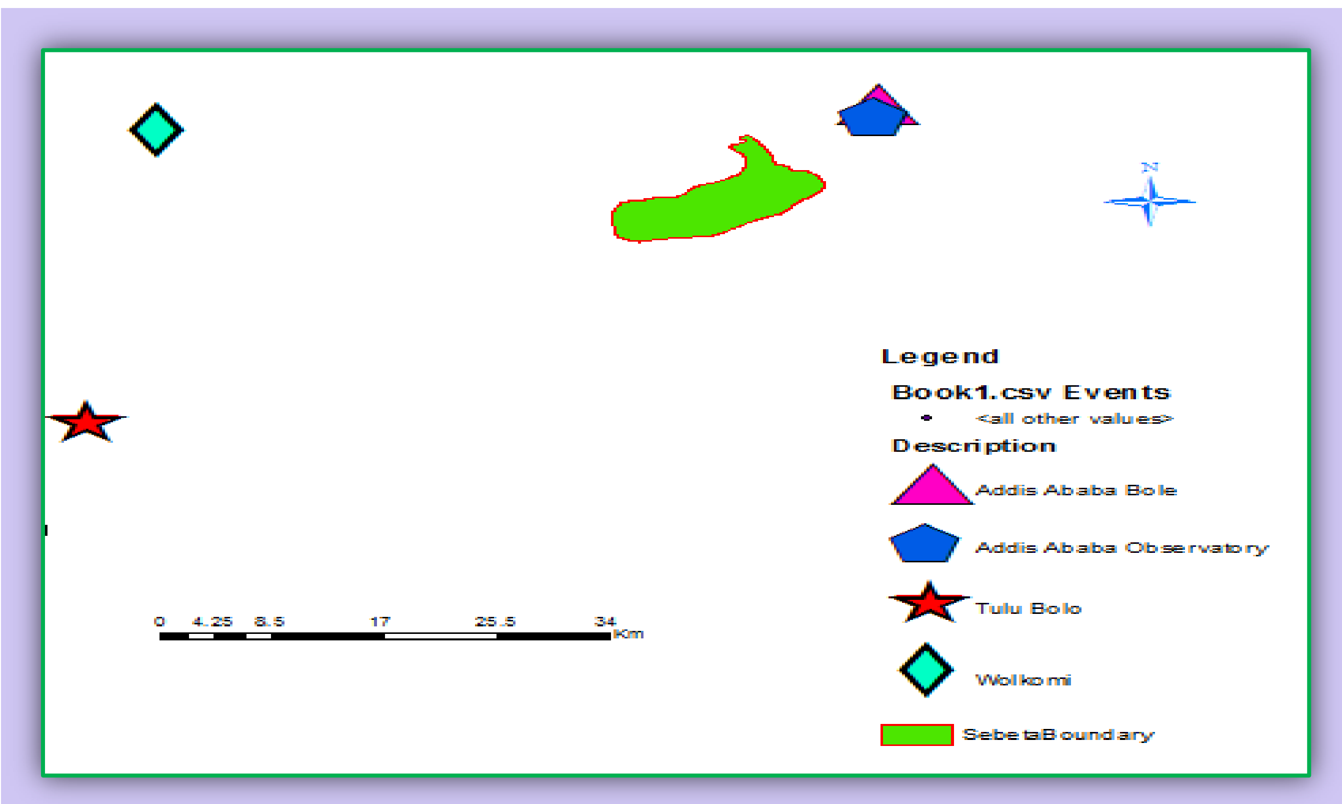


Figure 3-5: Selected Station around the study area for rainfall data quality analysis

Table 3.1: Summary of selected rainfall stations nearby the study area

S/No	Station Name	Latitude	Longitude	Altitude	Year of Data Used	%Missed Data	Sub-Basin
1	Addis Ababa Bole	9.03	38.75	2354	1990-2016	2.241	Awash
2	Addis Ababa Observatory	9.02	38.74	2386	1990-2016	0.771	Awash
3	Tulu Bolo	8.6545	38.206	2190	1990-2016	6.855	Awash
4	Wolkomi	9.002	38.25	2165	1990-2016	22.166	Awash
	Study Area Sebeta	8.93	38.63	2240	1990-2016	13.040	Awash

The metrological data collection covers from 1990 to 2016 years. Metrological station also referenced using latitude, longitude and elevation data. The precipitation Sebeta catchment is characterized by a bimodal pattern maximum precipitation during June, July and August respectively.

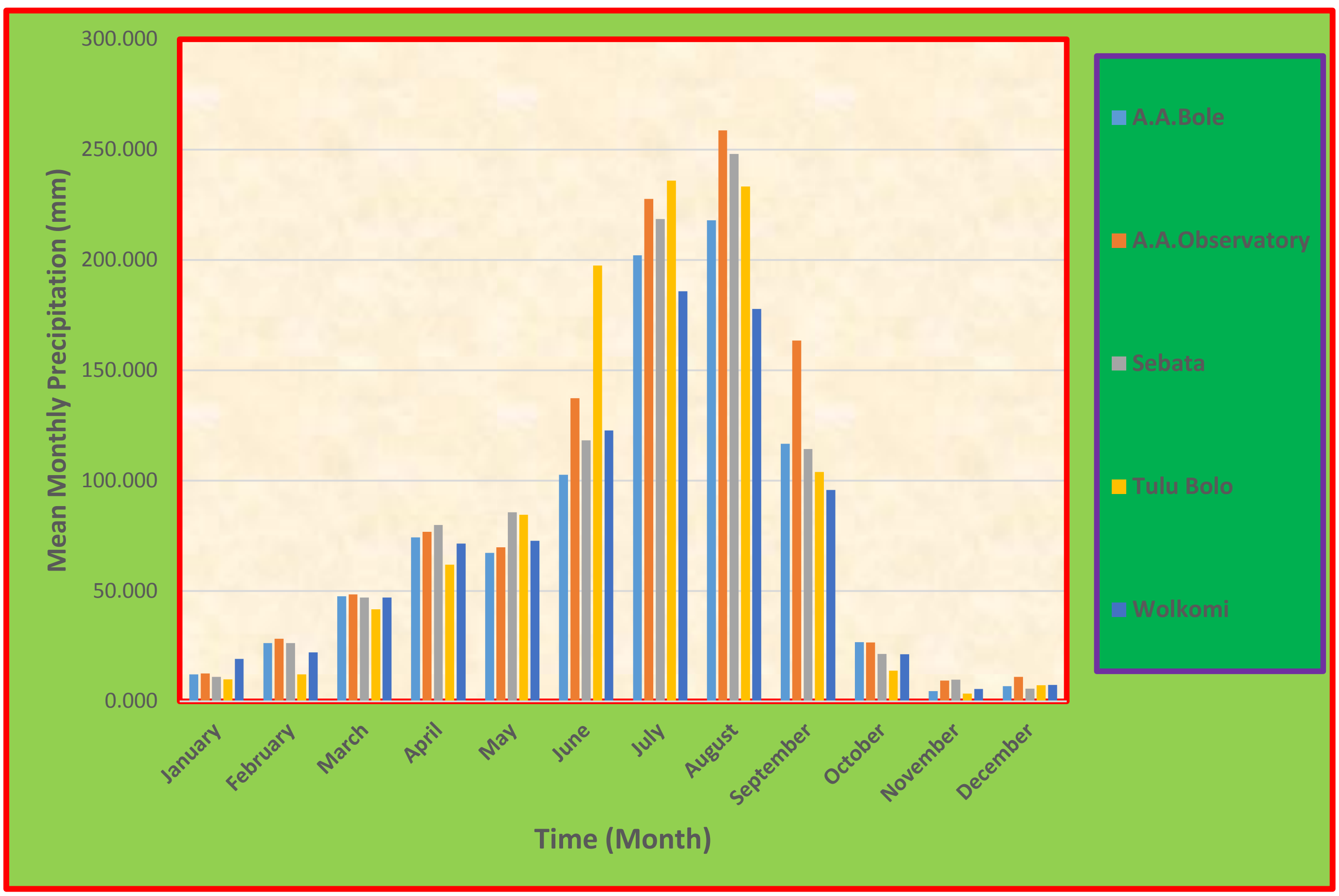


Figure 3-6: Mean Monthly Precipitation of Selected Station for Study Area

The maximum and minimum temperature represented the basin was also collected for five station including study area and the average monthly maximum and minimum temperature of each station shown in the Figure 3.5 and 3.6 respectively. The mean monthly minimum temperature of selected station is highly during December. While the mean monthly maximum temperature of station is different with in duration. For example, Addis Ababa Bole has mean monthly maximum temperature during March and May, Addis Ababa Observatory during February, March and May, Tulu Bolo During March, April and May, Wolkomi and Sebeta during March and May.

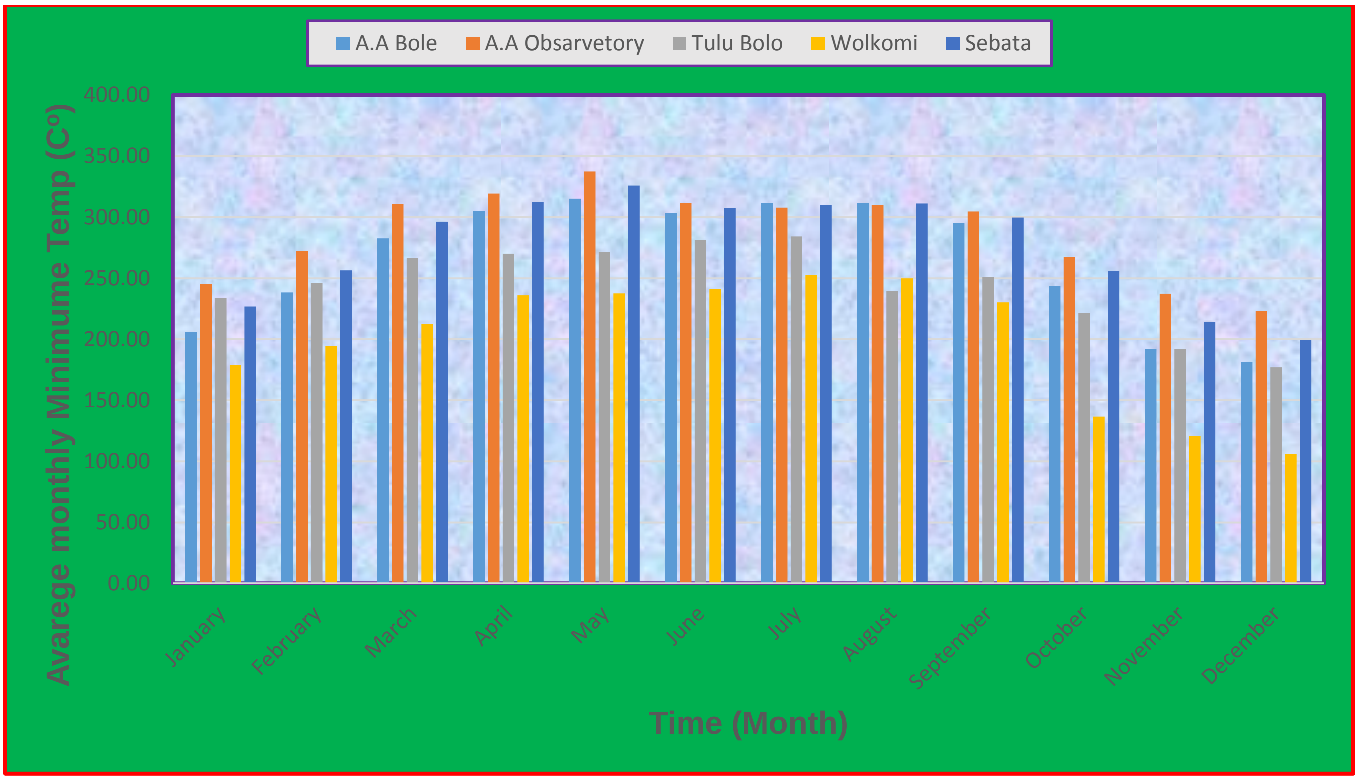


Figure 3-7: Mean monthly minimum temperature in the selected station

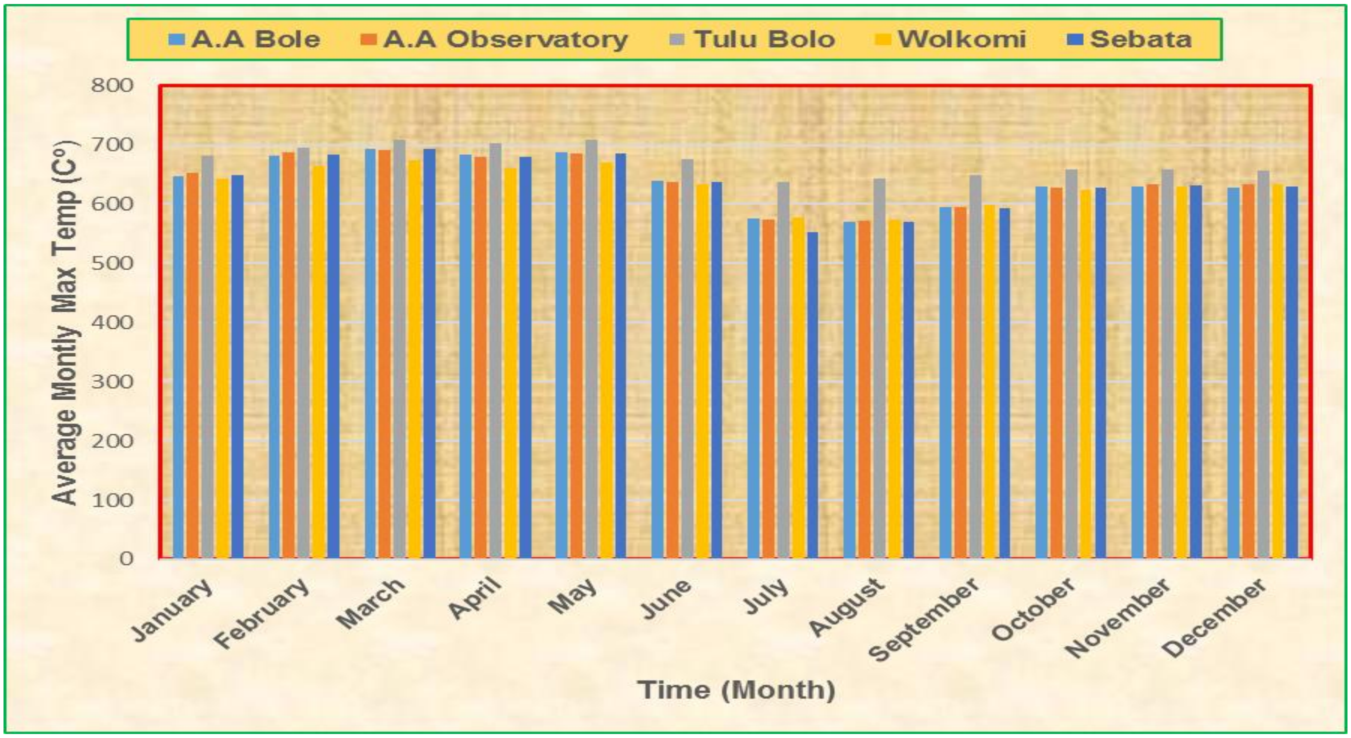


Figure 3-8: Mean monthly maximum temperature in the selected stations

3.2.2 Metrological data Analysis

3.2.2.1 Filling Missing data

Precipitation plays a significant role in modeling of storm drain with in drainage system structure and it is the major needed in an area of urban expansion development (N.D.K. Dayawansa1 and M. D. Ratnasiri1, 2007). However, all weather stations not have fulfilled observation data because some weather stations may have instrumental error or failures and others have lack of record observers. Missed data sometimes prevent to obtain quantitative and qualitative data of the study area. For gauges station it requires periodic observation, the failure or absence of the observer to make the necessary visit to the gauge, destruction of recording gauges, and instrument failure because of mechanical or electrical malfunctioning can result in missing of metrological data. Any such causes of instrument failure reduce the length and information content of the precipitation record. Therefore, it should need selecting which station best matches with the records of the station in site using less percentage of missing data. After that it should be necessary to estimate or fill in this missing record.

The missing precipitation station was estimated from the observation of precipitation at some other station as close to as evenly space around station with the missing record as possible. There are numbers methods to fill the missing data. Some of that arithmetic means method, normal ration method, and inverse distance weighing method and regression method. Arithmetic mean method can be used to fill the missing data when the normal annual precipitation is below or equal to 10% of the station which data are being recorded. The normal ration method is used when the normal annual precipitation any of index station different from that of precipitation station by more than 10%. When there is no normal annual precipitation for the station, inverse distance weighing method can be used to fill the missing data. Another method is regression/Excel STAT used to fill the missed data from nearest station to another station. For this study arithmetic mean and normal ratio method used. According to (Richard. H, 1998) the two formulas are described below.

1. Arithmetic mean method

   $\mathbf{PX} = (\mathbf{P1}+\mathbf{P2}+\mathbf{P3}\ldots\mathbf{Pn})/\ \mathbf{N}$……………………………………………………Eq. 3-2

   Where:

   Px = the precipitation from the station with the missed recorded

   P1, P2, P3 and Pn are the corresponding index station.

   N = number of index station

2. The normal ration method is used when the surrounding gauged have the normal annual precipitation exceeded 10% consider gauged.

   $PX = Nx /N (P1/ N1 + P2 /N2 + P3/ N3 + Pn /Nn$ …………………………………Eq.3-3

   Where:

   Px = Missing value precipitation to be computed

   P1, P2, P3 …Pn = Rain fall neighboring station during missing period

   N1, N2, N3 … Nn = Average value of rain fall for the neighboring station

   N = Number of stations used to in the computation

   Nx = Average value of the rainfall for the station in question for the recording period

3.2.2.2 Check Consistency of the selection Station

If the condition relevant to the recording of rain gauged stations has undergone significant change during the period of record, inconsistency would arise in rain fall data of a station. There are a lot of factors that affect the consistency of precipitation record at a given weather station. This factor includes the rain gauge has been installed at different size in the past, the rainfall depth is being recorded continuously between previous and the current site, change of exposure condition of gauge due to growth of trees or construction of tall building in the possibility of gage site.

To check a given weather station data time series observational data is relatively consistent and homogeneous and the periodic data are proportional to an appropriate simultaneous period. This station data proportionality can be tested by construction of double mass curve analysis in which accumulated rainfall/precipitation data is plotted against the mean value of all neighborhood stations. Double mass curve techniques method helped in determining the best realistic correlation of stations located near or within watershed. This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent (Subramanian, 2008)**.** If it has error should be corrected by using the following formula:

P_{cx}=Px (Mc/Ma)…………………………………………………………….Eq.3-4

Where:

Pcx = correct precipitation at any time t1 at station x

Px = original record precipitation at any time t1 at station x

Mc = correct slop of the double mass curve

Ma = original slop of double mass curve

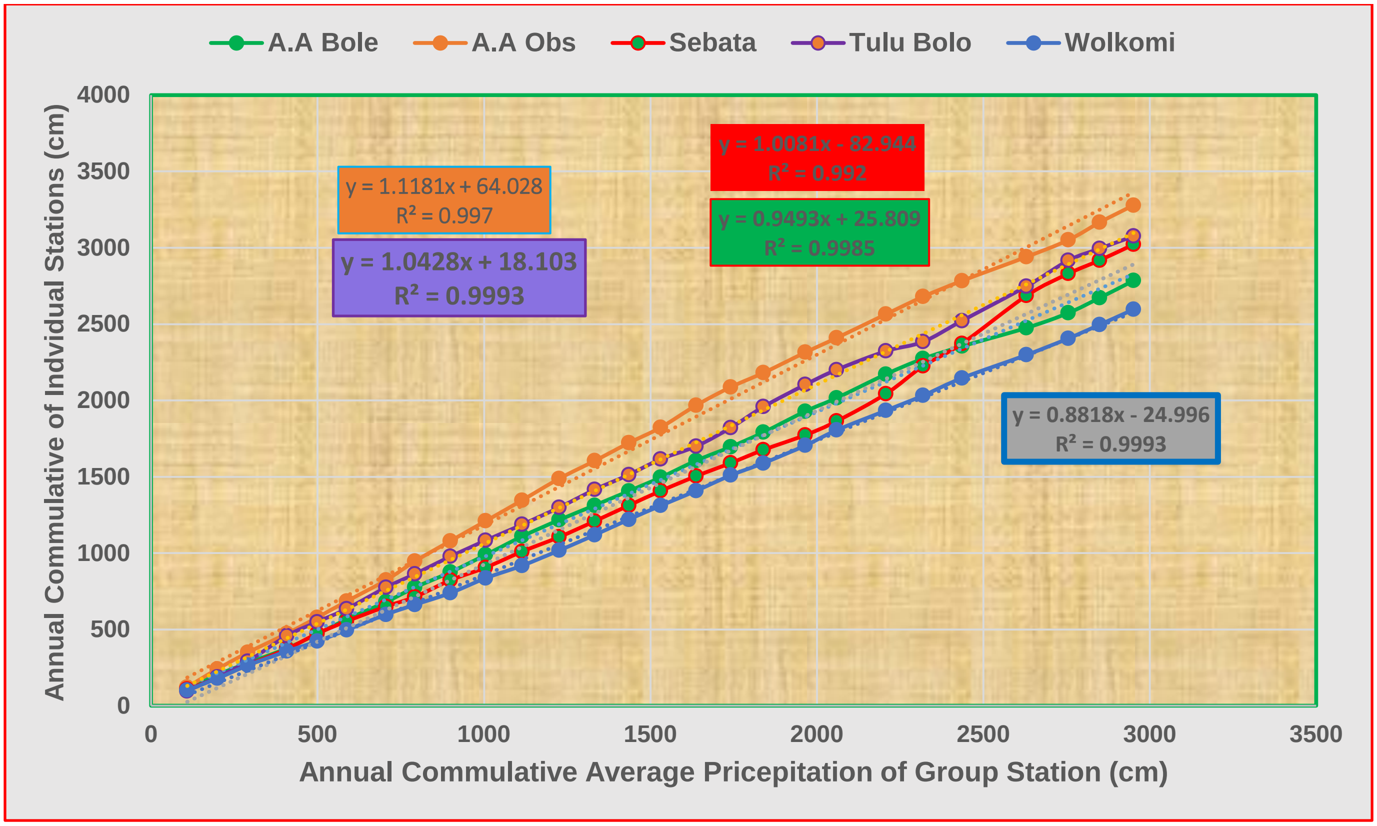


Figure 3-9: Double mass curve plot for selected metrological station

3.2.2.3 Data quality checking by Outliers test

An outlier is an observation that deviates significantly from the bulk of the data, which may be due to errors in data collection, or recording, or due to natural causes (Ramachandra etal, 2000). The presence of outliers in the data causes difficulties when fitting a distribution to the data. Low and high outliers are both possible and have different effects on the analysis. Outliers in maximum daily rainfall can play a considerable role in unreal analysis leading to unreal predictions. Therefore, accurate statistical determination of data to find outliers is very important. Outlier detection methods can be generally divided into three groups: univariate, two-variate, and multivariate detection methods. Multivariate outlier detection method consists of multivariate determination of each observation according to a blend of variables. Also, there are various methods in order to perform univariate outlier detection which can be classified into range and statistical tests.in range methods, observations distribution is determined and data out of a given range are considered outliers; in statistical methods, all outlier detection methods are based upon the principle that an outlier is a doubtful observation which is somewhat or fully out of the subject because the data were not made by hypothetical models of random variable. In this thesis I used one of the univarity tests (Grubbs and Beck (1972) test (G-B). In this test the quantities *xH* and *XL* are calculated by using Eq 3-5 and 3-6

$$x_L = \exp(\bar{x} - k_N s)$$ ………………………………………………………Eq 3-5

$$x_H = \exp(\bar{x} + k_N s)$$ ……………………………………………………..Eq 3-6

Where x and *s* are the mean and standard deviation of the natural logarithms of the sample, respectively, and *kN* is the G-B statistic tabulated for various sample sizes and significance levels by Grubbs and Beck (1972). At the 10% significance level, the following approximation proposed by Pilon et al. (1985) is used, where *N* is the sample size.

$$k_N = -3.62201 + 6.28446N^{1/4} - 2.49835N^{1/2} + 0.491436N^{3/4} - 0.037911N$$ Eq…….3-7

Sample values greater than xH are considered to be high outliers, while those less than XL is considered to be low outliers. The calculation of higher outliers and lower outliers as shown at appendix of table A-8.

3.2.2.4 Checking Homogeneity of Selection Station by Non- Dimensional Parameterization

The homogeneity of parameters analysis is important to the variation of the statistical properties of the time series. The causes of variation can be either human or natural. These include alterations to land use and relocation of the observation station. Therefore, in order to select the representative meteorological station for the analysis of rainfall estimation, checking homogeneity of group stations are important and the homogeneity of the selected gauging stations monthly rainfall records were carried out by non-dimensional.

$Pi = Pi/\bar{\bar{P}} * 100$…………………………………...Eq 3-8

Where:

Pi= is non- dimensional value of precipitation for the month in the station i

Pi= is over year’s average monthly precipitation for the station i

$\bar{\bar{P}}$= is over year average yearly precipitation for station i

The selection station is plotted for compares for each other and the same- mode and pattern of the stations are observed and hence group station selected is homogenies.

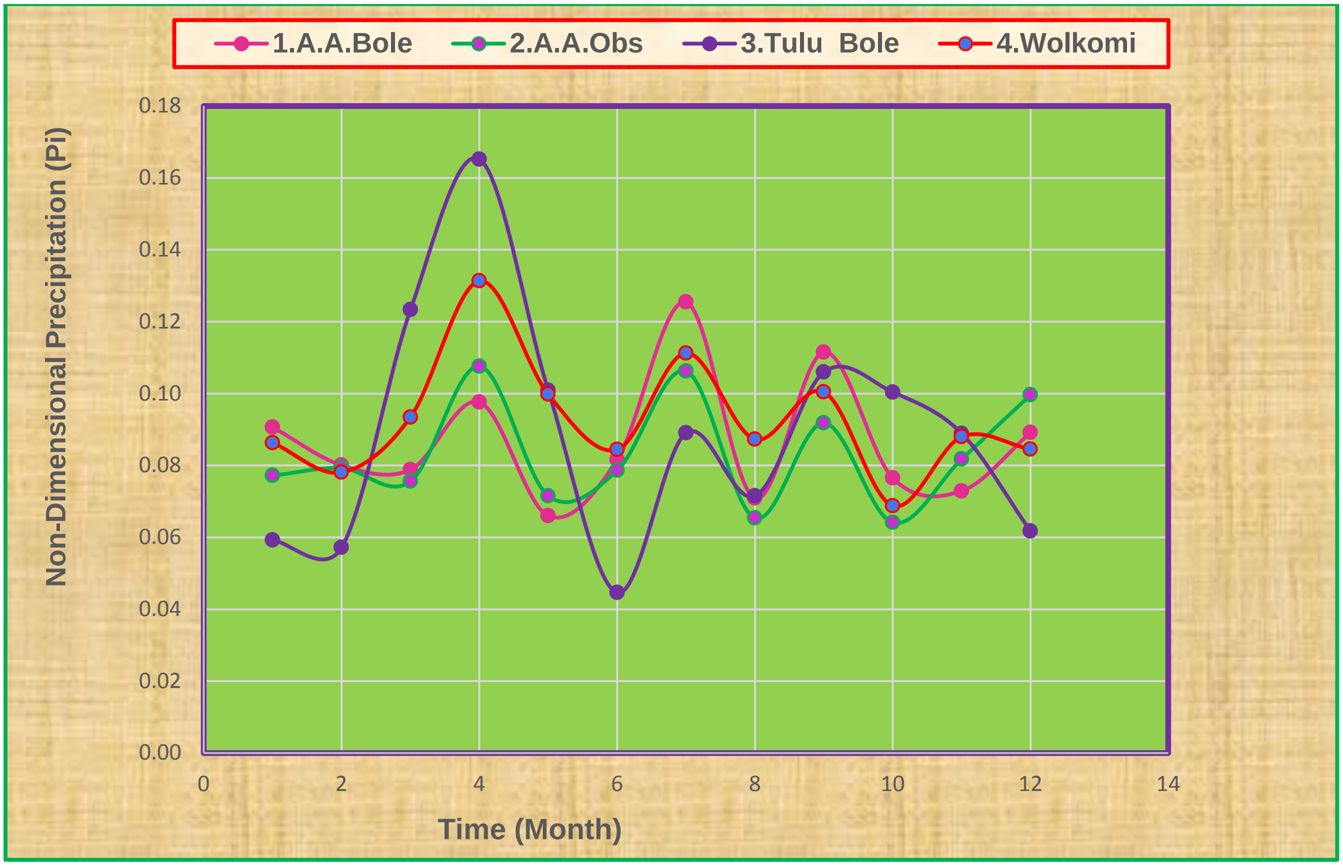


Figure 3-10: Homogeneity Test for Selected Station

3.2.2.5 Rainfall Intensity –Duration- Frequency (IDF) Analysis

Intensity -Duration- Frequency (IDF) Curve relations are useful to determine the depth of storm rainfall of different return periods and durations. The Intensity-Duration-Frequency (IDF) relationship of rainfall amount is one of the most commonly used tools for planning, designing and operation of Storm rain fall of a given area. The IDF curve was used to estimate the magnitude of the rainfall intensity of a given return period within 25 km radius of the principal station. For areas that are further away than 25 km from the principal station (un-gauged area), regional IDF parameters that have been developed by (ERA, 2002) is used to estimate the magnitude of intensity values for drainage structures. For urban area IDF is help any designer of drainage system to determine the capacity of drainage (discharge) and intensity related to time given from its graph.

Step develops Intensity duration frequency curve (IDF)

Step1: Determine the 16 catchments area in 112ha (1.12km^2)

Step2: Determine Catchment Property

Land cover	Soil Type	Hydrologic soil group	Rainfall Region	AMC
Business and commerce	Lithosol	D	A2	Normal

Step3: Determine the maximum rainfall using normal and Gumble (extreme value I) distribution

T-return period	2	5	10	25	50	100
Pt	1044.383	1546.668	1879.224	2299.409	2611.127	2920.543
Pt-24hrs	43.516	64.444	78.301	95.809	108.797	121.689

Step 4: Calculate Time of concentration

The time of concentration in rural area divide in to two sections as specified the following

1) Time of concentration for overland flow

$Tc = 0.604(CvL/S^{0.5})^{0.467}$ ……………………………………………………….Eq 3-9

Where:

CV = roughness coefficient of land use

L = hydraulic length of catchment, measured along flow path from the catchment boundary to the point where the flood needs to be determined.

S = Slope of the catchment or S=H/1000L (m/m)

Tc=Time of construction (hrs.)

2) **Time of concentration for defined water course**

Tc= (0.87L2/1000Sav)^0.835……………………………………………………….Eq3-10

L = hydraulic length of catchments, measured along flow path from the catchment boundary to the point where the flood needs to be determined (km).

Sav = average slope (m/m)

Sav= (H0.85L-H0.1Ll)/1000*.75L…………………………………………………Eq3-11

H 0.10L = elevation height at 10% of the length of the watercourse (m)

H 0.85L = elevation height at 85% of the length of the watercourse (m)

Step 5: Determine rainfall intensity

Therefore the IDF parameters are calculated using equation (3- 5) below.

$$I_t = \frac{(b+24)^n}{(b+t)^n} * I_{24}$$ ....…………………….......................................Eq.3-12

Where: I= rainfall intensity at required duration (mm/hr)

t= duration of rainfall (minutes)

I24= daily rainfall intensity (mm/hr)

b= time constant in minutes

n= an exponent usually less than one

According to (ERA, 2002), the study area falls under IDF region A2. Then using the value of coefficients (b=0.33 & n=0.7) the storm rainfall depth has been calculated and summarized. As mention in Table-A-6: Values of Intensity calculation we can develop the following graph

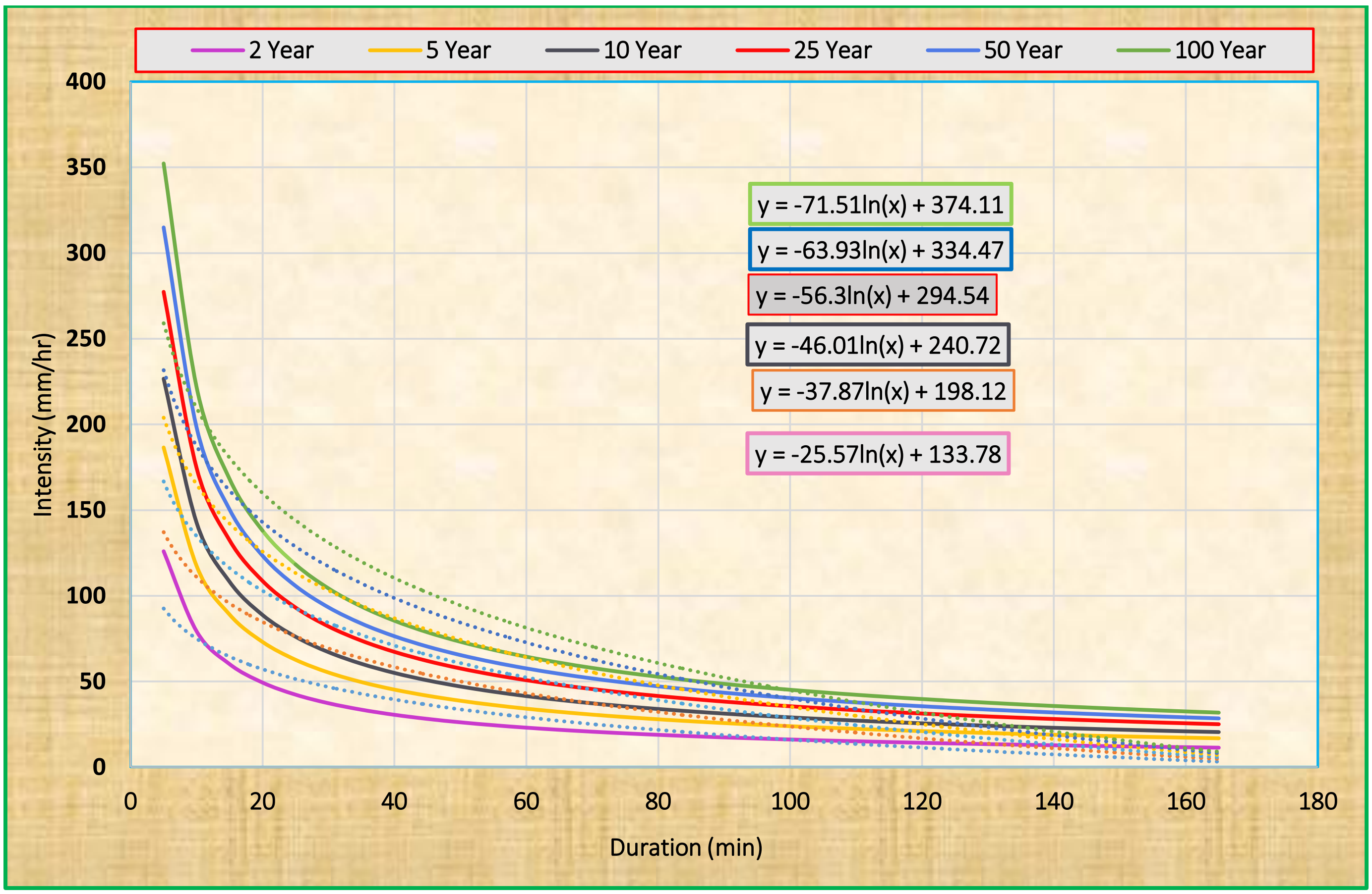


Figure 3-11: IDF Curve of Sebeta Town or Study Area

3.3 Material used

Before undertaking processing of any research, the researcher has to identify type of data that is required for the specified study. The available and the crucial data for this research such as

- ✓ Spatial data such as Digital Elevation Model (DEM) of 30m*30m data is used as an input data for ARC-GIS software for catchment delineation and estimation of catchment characteristic.
- ✓ ARC-GIS to obtain hydrological and physical parameters and spatial information of the catchments of the study area.
- ✓ Google Earth Software, master plan of town to verify water shed and divides of catchments of the study area.
- ✓ Digital camera, GPS device, and measuring tape that used to measured depth, width and diameter of drainage structure at selected area.
- ✓ Hydrological and meteorological data and etc.
- ✓ Inverted elevation of drainage structure at different station that used as raw input of SWMM software.
- ✓ Auxiliary material such as ETO Calculator, micro soft Excel, Tab computer.
- ✓ Storm water management software (SWMM).

3.4 Hydrological Equation for Determination of peak Discharge of Each sub catchments

3.4.1 Rational Method for determination of peak discharge

The Rational Method is widely used to estimate the peak surface runoff rate for design of a variety of drainage structures, such as a length of storm sewer, a storm water inlet, or a storm water detention pond (Harlan, 2011). The Rational Method is most suitable for small urban watersheds that don't have storage such as ponds or swamps and for an area up to 50 hectares (0.5 square km). This method, while first introduced in 1889, is still widely used. Even though it has come under frequent criticism for its simplistic approach, no other drainage design method has achieved such widespread use (Drainage design manual, 2013).

The rational formula estimates the peak rate of runoff at any location in a catchment area as a function of the catchment area; runoff coefficient; and mean rainfall intensity, for duration equal to the time of concentration. The rational formula is expressed as:

$$Q=0.00278CIA \qquad \text{Eq3-13}$$

Where:

Q = maximum rate of runoff, m3/s

C = runoff coefficient representing a ratio of runoff to rainfall (see the table at appendix)

I = average rainfall intensity for a duration equal to the time of concentration, for a selected return period, mm/hr,

A =Sub catchment area in the location, ha,

Characteristics of Rational Method

Characteristics of the Rational Method that generally limit its use to 50 hectares include

a. The rate of runoff resulting from any rainfall intensity is a maximum when the rainfall intensity lasts as long as or longer than the time of concentration. That is, the entire catchment area does not contribute to the peak discharge until the time of concentration has elapsed.

This assumption limits the size of the drainage basin that can be evaluated by the rational method. For large catchment areas, the time of concentration can be so large that constant rainfall intensities for such long periods do not occur and shorter more intense rainfalls can produce larger peak flows. Further, in semi-arid and arid regions, storm cells are relatively small with extreme intensity variations thus making the Rational Method inappropriate for catchment areas greater than 50 hectares.

b. The frequency of peak discharges is the same as that of the rainfall intensity for the given time of concentration. Frequencies of peak discharges depend on rainfall frequencies, antecedent moisture conditions in the catchment area, and the response characteristics of the drainage system. For small and largely impervious areas, rainfall frequency is the dominant factor. For larger drainage basins, the response characteristics control. For catchment areas with few impervious surfaces (little urban development), antecedent moisture conditions usually govern, especially for rainfall events with a return period of 10 years or less.

c. The fraction of rainfall that becomes runoff (C) is independent of rainfall intensity or volume.

This assumption is only reasonable for impervious areas, such as streets, rooftops, and parking lots. For pervious areas, the fraction of runoff does vary with rainfall intensity and the accumulated volume of rainfall. Thus, the application of the Rational Method requires the selection of a coefficient that is appropriate for the storm, soil, and land use conditions. Many guidelines and tables have been established, but seldom, if ever, have they been supported with empirical evidence.

d. The peak rate of runoff is sufficient information for the modeling of urban drainage area.

Modern drainage practice includes detention of urban storm runoff to reduce the peak rate of runoff downstream. Using only the peak rate of runoff, the Rational Method severely limits the evaluation of design alternatives available in urban and in some instances, rural drainage design.

Steps to Peak flood Estimation using the Rational Method

The following procedure outlines the rational method for estimating peak discharge:

- Determine the sub catchments area in hectares (km2)
- Determine the time of concentration, with consideration for future characteristics of the watershed
- Assure consistency with the assumptions and limitations for application of the Rational Method;
- Determine the rainfall IDF coefficients. Extract the Rainfall Intensity-Duration Frequency Coefficients b, and n values from the list in Hydrology according to the locality in Ethiopia and the design frequency;
- Use Equation 3-12 to calculate the rainfall intensity in mm/hr or to developed IDF of figure 3-12
- Select or develop appropriate runoff coefficients for the watershed. Where the watershed comprises more than one characteristic, you must estimate C values for each area segment individually. You may then estimate a weighted C value; and
- Calculate the peak discharge for the watershed for the desired frequency using Equation 3-6.

Runoff Coefficient

The runoff coefficient (C) is the variable of the Rational Method least susceptible to precise determination and requires judgment and understanding on the part of the designer. A typical coefficient represents the integrated effects of many drainage basin parameters such as soil groups, land use, and average land slope. Runoff coefficients are theoretically restricted to the range of 0 to 1.0. According to ERA manual recommended we can us runoff coefficient as Table 3.2 related to land use land cover of area.

Runoff Factors

Runoff is rainfall excess or effective rainfall - the amount by which rainfall exceeds the capability of the land to infiltrate or otherwise retain the rainwater. The principal physical catchment area characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope

Table 3.2: Selected runoff coefficient values under different surface conditions

Description	Runoff Coefficient
Business	
Downtown Areas	0.70—0.95
Neighborhood Areas	0.50—0.70
Residential	
Single-family	0.30—0.50
Multi-family detached	0.40—0.60
Multi-family attached	0.60—0.75
Residential suburban	0.25—0.40
Apartments	0.50—0.70
Parks, cemetaries	0.10—0.25
Playgrounds	0.20—0.35
Railroad yards	0.20—0.40
Unimproved areas	0.10—0.30
Drives and walks	0.75—0.85
Roofs	0.75—0.95
Streets	
Asphalt	0.70—0.95
Concrete	0.80—0.95
Brick	0.70—0.85
Lawns; sandy soils	
Flat, 2% slopes	0.05—0.10
Average, 2%—7% slopes	0.10—0.15
Steep, 7% slopes	0.15—0.20
Lawns; heavy soils	
Flat, 2% slopes	0.13—0.17
Average, 2%—7% slopes	0.18—0.22
Steep, 7% slopes	0.25—0.35

Catchments Area

A catchment area is determined from topographic maps; DEM data's and field surveys. For large catchment areas it might be necessary to divide the area into sub-catchment areas to account for major land use changes, obtain analysis results at different points within the catchment area, or locate storm water drainage structures and assess their effects on the flood flows. A field inspection of existing or proposed drainage systems shall be made to determine if the natural drainage divides have been altered. These alterations could make significant changes in the size and slope of the sub catchment area. Since the study area is somewhat large it should be divided into sub catchments. Therefore, the study area is divided into 16 sub catchments and it has 19 junctions as well as 19 conduits. This catchment is selected based on the prone area that includes furi and Weleta which they are highly affected by flood always.

The catchment is divided based on the drainage line and the out let that is more appropriate for SWMM software.

Time of Concentration

Time of concentration is defined as the time required for water to travel from the remotest area of hydraulically distant point of the water contributing area to the drainage system under consideration.

Using Rational method need to Time of concentration (Tc) for determination of each sub catchment peak discharge. To determine time of concentration for different types of flow such as overland flow, Sheet flow, Shallow concentrated flow and open channel flow has their own formulas. Among of them that formula that developed by Kirby and Kirpich formulae for overland flow.

$Tc=0.604(RL/S^{0.5})^{0.467}$ ……………………………………………………………Eq3-14: Kirby formula

Where, Tc - Time of concentration in hours

L - Length of overland flow in kilometers

S - Slope in m/m

R - Roughness coefficient

$Tc=0.0013*m\ (L^{0.77}/S^{0.385})$ ………………………………………..............................Eq.3-15: Kirpich Formula

Where, Tc-Time of concentration in hours

L - Length

Coefficient, (m=one for bare earth, m=two for grass and m=0.4 for asphalt).

3.5 Hydraulic modeling of open channels

An open channel is a conduit in which water is conveyed with a free surface. Although closed conduits such as culverts and storm drains are open channels when flowing partially full, the term is generally applied to natural and improved watercourses, gutters, ditches, and channels.

Figure 3-12: Typical rectangular ditch west of Sebeta

3.5.1 Equation used in hydraulic modeling of open channel flow

The following equations are those most commonly used to analyze open channel flow and are included here.

Continuity Equation: The continuity equation is the statement of mass in fluid mechanics.

For the special case of one dimensional, steady flow of an incompressible fluid, it assumes the form:

$Q=A1V1=A2V2$……………………………………………..Eq.3-16

Where,

Q = discharge, m3/s

A = cross-sectional area of flow, m2

V = mean cross-sectional velocity, m/s

Manning's Equation –For a given depth of flow in a channel with a steady, uniform flow, the mean velocity, V, can be computed with Manning's equation:

$V = (1/n)\, R^{2/3} S^{1/2}$ Eq.3-17

For a given channel geometry, slope, and roughness, and a specified value of discharge Q, a unique value of depth occurs in steady uniform flow is computed from Manning's Equation:

$Q = (1/n)\, AR2/3S1/2$..Eq.3-18

Where:

Q = discharge, m3/s

n = Manning's roughness coefficient

A = cross-sectional area of flow, m2

R = hydraulic radius = A/P, m

P = wetted perimeter, m

S = channel slope, m/m

Sustainable urban storm water drainage system is challenging and hence needs an ample of methodology.

3.6 Water shed delineation using Hydrological modeling (Arc-GIS&DEM)

Hydrological modeling starts from delineating streams and watersheds, and obtaining watershed properties such as area, slope, flow length, flow direction, stream network, etc. Using digital elevation models (DEM) and computer programs have made it possible to perform automated analysis.

Since the study area has 8 Kebeles and divided this area into different region as appropriate for modeling drainage structure based on ERA manual guide lines. According to ERA manuals 2013, they recommended best method to calculate or model the urban storm of drainage structure is rational method and SCS (Soil conservation service) method. This is because it is applicable for areas which do not have sufficient rainfall and stream flow records. The have their own criteria to apply them.

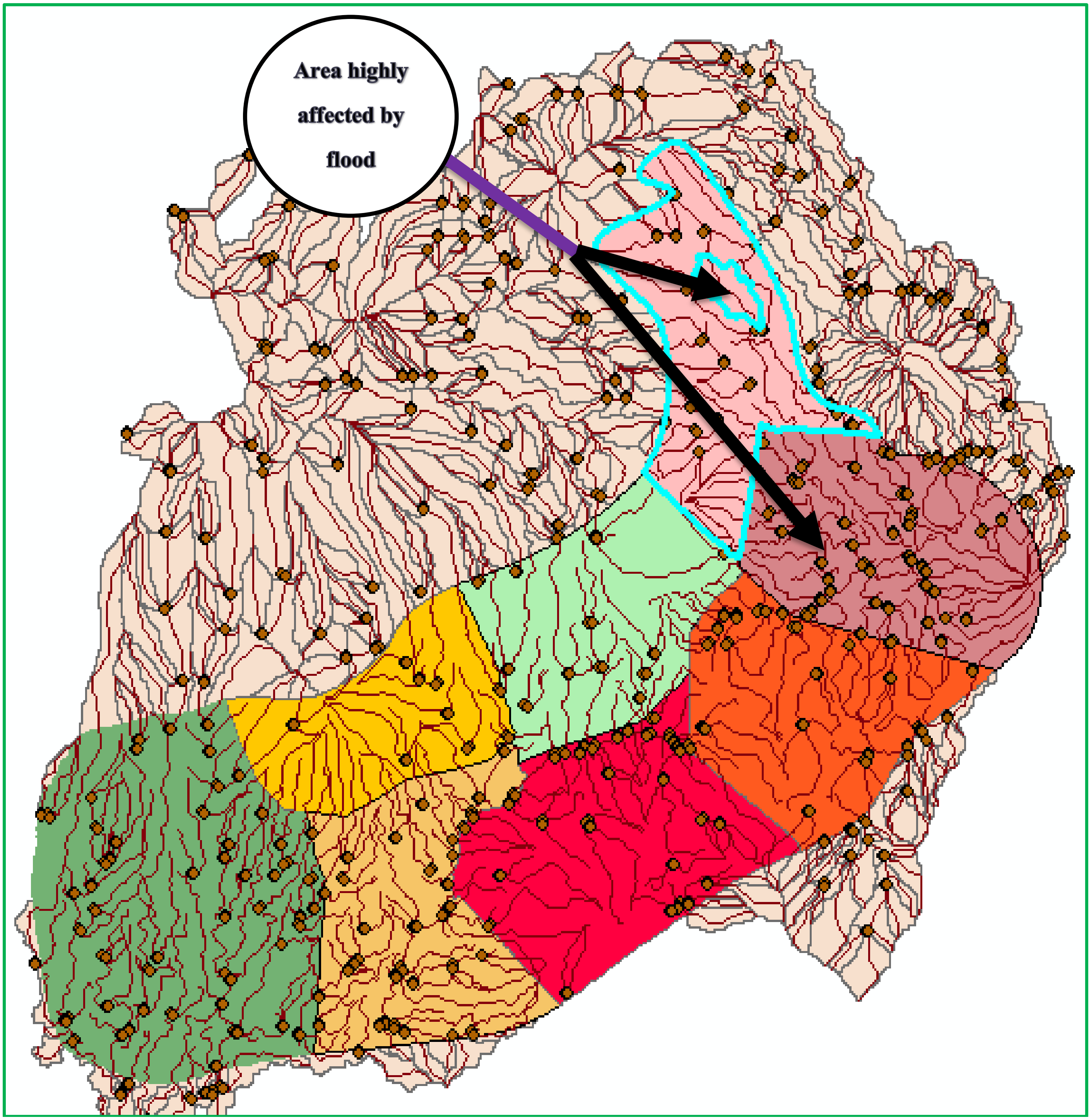


Figure 3-13: Water shed of containing many outlets that affected by flood.

3.6.1 Identification of Water shed area that highly prone by flooding

As I consulting local community and city administration from eight kebeles they gave information that two kebeles highly affected by flood these kebeles incudes Weleta and Furi. As we see from the following figure the weleta area is extended from exit of Addis Ababa along the main road from Addis Ababa to Jimma road that including noke Square as Furi is contained industrial area that mainly located along Addis Ababa to Jimma road but it extended to Jamo to Addis Ababa.

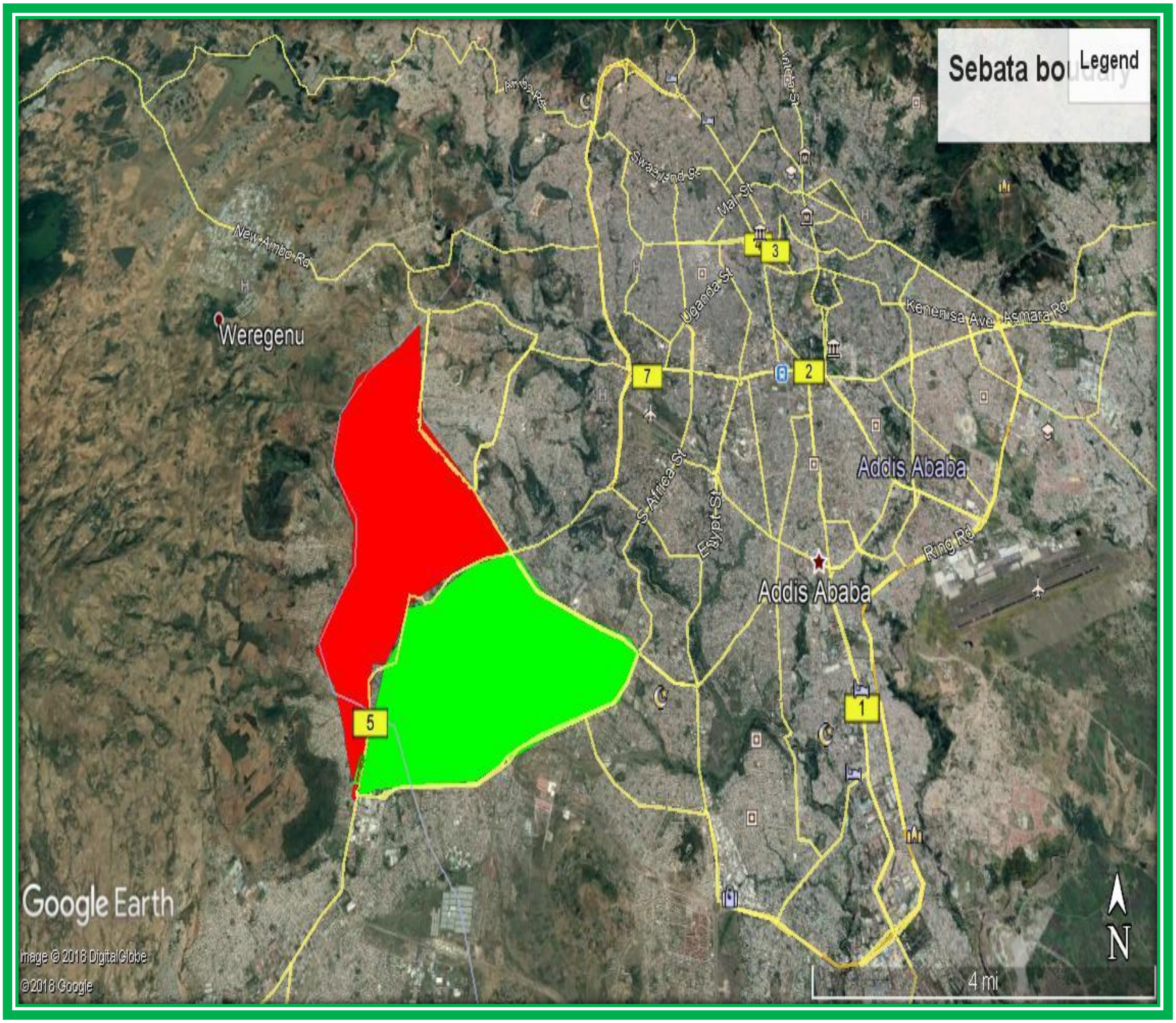


Figure 3-14: Highly Affected area by flood

3.7 Modeling Rainfall Runoff and Drainage system Using EP SWMM5.1

3.7.1 EP Storm water management Software (SWMM 5.1)

SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub catchment areas that receive precipitation and generate runoff and pollutant loads. In this thesis I focused on generation of runoff from precipitation that over flow of drainage system as well as surface of the subbasements. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub catchment, and the flow rate, flow depth.

SWMM model is continuous modeling software can be performed for hydrology and hydraulics process such as rainfall- runoff calculations (infiltration and evaporation losses), groundwater and its interactions with surface water, snowmelt and accumulation of snow, water quality buildup and wash-off, scour and deposition of pollutants in conduits, pollutants removal in treatment device, and fully dynamic routing of flows and pollutants .It involves typical application of continuous simulation i.e. design and analysis of Low impact development (LID), simulation of the effectiveness of detention / retention facilities , simulation of rain derived infiltration and inflow (RDII), simulation of wetlands, establishing water quality loads to receiving waters, long term changes in stream morphology , hydro-modification, duration and number of exceedances meeting water quality objectives.

It is conceptualized model used in drainage system as a series of water and stuff flow between different compartments of the environment. These environment components include

1. The Atmosphere compartment: In this compartment, rainfall falls from the atmosphere and deposited on the land surface compartment and rain-gages are used input in the SWMM.

2. The Land surface compartment: It represented the one or more than sub catchments of the region which receives water and transferred to the groundwater compartment and some water flow as surface runoff.

Figure 3-15: SWMM conceptualized model for typical urban drainage system.

The Transport compartment: It includes the conveyance elements (channels, pipes, regulators, pumps) and storage/ treatment plants that bring water to outfall or to treatments plants. Inflow for this compartment involves surface water runoff, groundwater flow, sewage water. In SWMM, they are modeled as Node and link objects.

There two objects in the SWMM either its visual or non- visual objects. Following objects might be arrange together to represent a storm water drainage system.

1. Rain-gages: This provides the rainfall data type, recording time interval, source of rainfall data, and name of rainfall data sources. Modeling accuracy (or even more specifically, for a successful calibration of SWMM), it is essential that rain gages be located within and adjacent to the catchment

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

3. Junction nodes: it represents the convergence of natural surface channel, manholes in a series system or

pipe fittings. The primary input parameters for a junction are invert elevation, height to ground surface, ponded surface area when flooded, and external inflow data.

4. Outfall Nodes: These are terminal nodes define the final downstream boundaries under dynamic wave flow routing. It behaves as junction for other flow routing. The input parameters for outfall nodes include invert elevation, boundary condition type and stage description and presence of a flap gate to prevent backflow through the outfall.

5. Flow divider Nodes: It only active under Kinematic wave routing. The important inputs for flow divider nodes are junction parameters, name of the link receiving the diverted flow and method used for computing the amount of diverted flow.

6. Storage units: It represents physically storage facilities. The primary inputs of storage units are invert elevation, maximum depth, depth-surface area data, evaporation potential, ponded surface area when flooded, and external inflow data.

7. Conduits: They are pipe or channels move water from one node to another node. The common shape of conduits define in SWMM are rectangular, trapezoidal, or user-defined irregular cross section shape. The Manning's equation used to express the relationship between discharge (Q), cross-sectional area (A), hydraulics radius (R), and slope (*S*) for all conduits.

$$Q=1/nR^{2/3}S^{1/2} \quad \text{......Eq.3-19}$$

Where, Q= Discharge flow rate of Conduit m^3/se,

R=Hydraulic radius,

S=longitudinal slope,

n=roughness of coefficient,

8. Land-uses: It involves activities are residential, commercial, industrial and undeveloped regions. Its characteristics might be including lawns, roof areas, paved roads, soils, rooftops etc. Land-use usually reports the variation in pollutants buildup and wash off rates from the catchment.

3.7.2 Model Selection criteria

When choosing the model, special attention should be paid to the possibility of using a verified model which can be easily implemented (Edinburgh, 2008).

For simulation of runoff there are more models to simulate. Like SWMM, ARC SWAT, HEC –HMS and HBV (Hydrologiska Byråns Vattenbalansavdelning) models. From those models I select for this thesis

SWMM (storm water management model) because this thesis is flood modeling in urban areas and the SWMM software is more comfortable for flood modeling and analyses to fix the drainage size by considering the pervious and impervious areas. The model is readily available, relatively less time consuming and no need of money to gain this model. But Arch SWAT Software is used to model and analyze flood especially for rural areas with a large catchments and HEC-HMS is used to simulate the discharge of a river. HBV -models designed to run on a daily time step (shorter time steps are available as an option) and to simulate river runoff in river basins of various sizes.

3.7.3 Governing Equation of SWMM

SWMM conceptualizes a sub catchment as a rectangular surface that has a uniform slope *S* and a width *W* that drains to a single outlet channel as shown in Figure below. Overland flow is generated by modeling the sub catchment as a nonlinear reservoir, as sketched

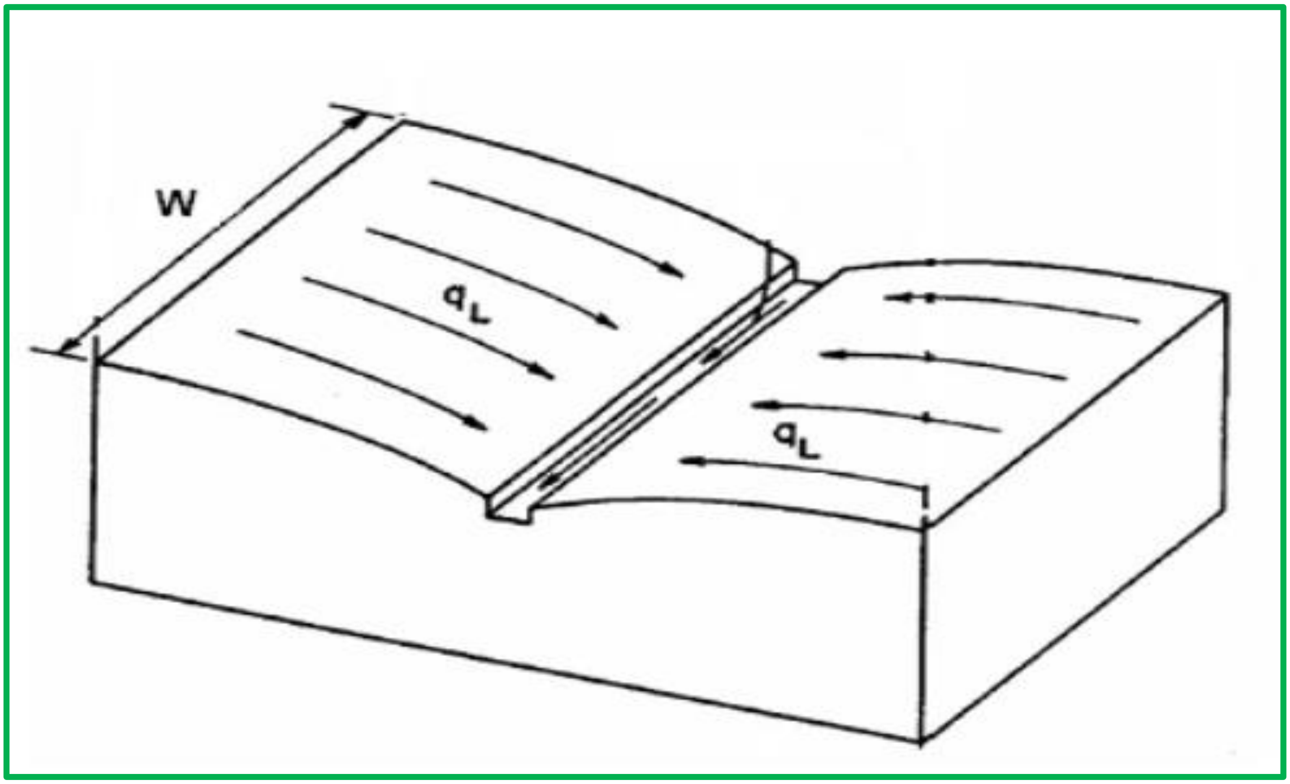


Figure 3-16: Idealized representation of a sub catchment.

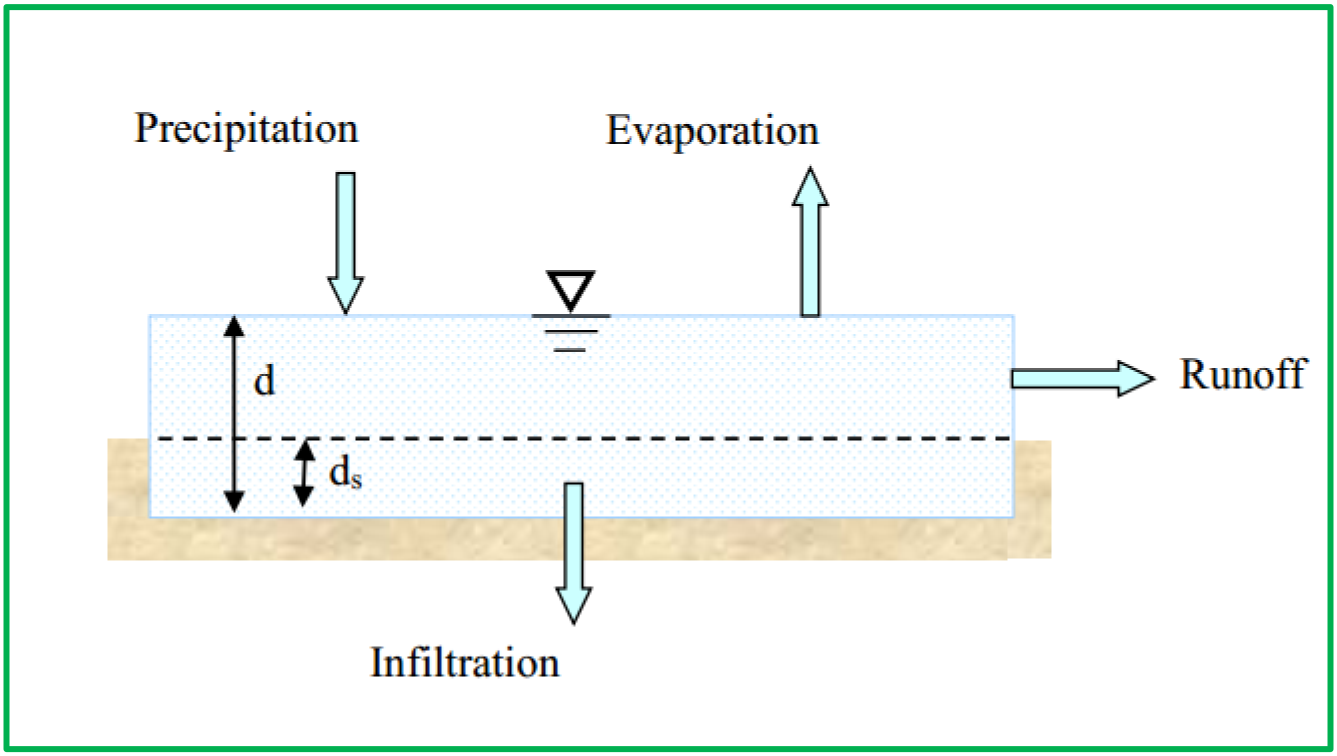


Figure 3-17: Nonlinear reservoir model of a sub catchment.

In this representation, the sub catchment experiences inflow from precipitation (rainfall and snowmelt) and losses from evaporation and infiltration. The net excess ponds atop the sub catchment surface to a depth *d*. Ponded water above the depression storage depth *ds* can become runoff outflow *q*. Depression storage accounts for initial rainfall abstractions such as surface ponding, interception by flat roofs and vegetation, and surface wetting (Rossman, 2016).

From conservation of mass, the net change in depth *d* per unit of time *t* is simply the difference between inflow and outflow rates over the sub catchment

$$\frac{\partial d}{\partial t} = i - e - f - q$$ ……………………………………………………………………………….Eq.3-20

Where:

i = rate of rainfall + snowmelt (m/s)

e = surface evaporation rate (m/s)

f = infiltration rate (m/s)

q = runoff rate (m/s).

3.7.4 SWMM Performance Indices

The performance of a model must be evaluated on the extent of its accuracy, consistency and adaptability (Negasa, 2013). A forecast efficiency criterion is therefore necessary to judge the performance of the model. Assessing storm rainfall runoff modeling requires subjective and/or objective estimates of the closeness of the simulated behavior of the model to observations.

In this thesis work, the model performance in simulating observed from each sub catchment's discharge has been evaluated during calibration and validation through using **Nash and Sutcliffe efficiency criteria (NSE) and coefficient of determination (R_2).** The R2and NSE simulation efficiency measure how well trends in the calculated data are reproduced by the simulated results over a specified time period and for a specified time step.

Nash-Sutcliffe Efficiency, NSE:

The Nash and Sutcliffe Efficiency (NSE) is a measure of efficiency that relates the goodness-of fit of the model to the variance of measured data. NSE can range from - ∞ to 1 and an efficiency of 1 indicates a perfect match between observed and simulated discharges. NSE value between 0.9 and 1 indicate that the model performs very well while values between 0.6 and 0.8 indicate the model performs well (Abeyou, 2008).

The NSE efficiency, proposed by Nash and Sutcliffe (Nash, 1970), is defined as:

$$NSE = 1 - \frac{\sum_{i=1}^{n}[Q_o - Q_s]^2}{\sum_{i=1}^{n}[Q_o - \overline{Q}_o]^2}$$

....Eq.3-21

Where Qo= is measured discharge

Qs=Simulated flow

$\overline{Q}_o$ =average of calculated flow

Coefficient of Determination, R2:

The coefficient of determination R2is defined as the squared value of the coefficient of correlation. It is estimated as:

$$R^2 = \frac{\{\sum_{i=1}^{n}(Q_s - \overline{Q}_s)(Q_o - \overline{Q}_o)\}^2}{\{\sum_{i=1}^{n}(Q_s - \overline{Q}_s)^2\}\{\sum_{i=1}^{n}(Q_o - \overline{Q}_o)^2\}}$$

....Eq.3-22

Where, Qo= measured discharge,

Qs= Simulated flow,

Qo= Average of measured discharge and

Q_s= Average of simulated flow.

The range of values for R2 is 1.0 (best) to 0.0

Model set up procedure

- Set the coordinates of area map/image if there is needed
- Draw network representative and describe sub catchments or export the shape file of subbasements from AutoCAD or GIS file to SWMM model.
- Edit the properties of the object that make up the system
- Describe how the system is operated
- Select a set of analysis options

➡ Run Simulation for Rainfall/Runoff and Flow routing

3.7.5 Model calibration and validation

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time (Haileyesus, 2011). This involves comparing the model results, the measured value and rational value obtain of each peak discharge of sub catchment as well as the discharge of each Node link or Conduits that by using Rational and Manning equations.

Generally speaking, model calibration is involving determination of model parameters that gives the best possible correspondence between calculated value and simulated runoff from each sub catchment and each conduit.

Parameters are calibrated following a certain order. This order ought to be the following:

Sub catchment Runoff

- **Model calibration: Manually**
  - Using rational formula result from sub catchment runoff calculation
  - Trial and error method and Statistical method
  - Approximate the mark of flood interpreted by using V-notch discharge measurement.

4. RESULT AND DISCUSSION

4.1 RAINFALL DATA QUALITY ANALYSIS OF STUDY AREA

The daily rainfall data of study area is collected from NMSA about 27 years. Since this data is has some error including it should be analysis in different manner.

Homogeneity Test:

The homogeneity of parameters analysis is important to the variation of the statistical properties of the time series. The causes of variation can be either human or natural. These include alterations to land use and relocation of the observation station. Using Equation 3.8 homogeneity test is developed for five station of study area. According to this figure the graph of all station is similar trend pattern that shows homogeneity of the rainfall data of all station.

Inconsistence Test:

It is done by double mass curve method, plotting a cumulative data of station to be checked for homogeneity against a cumulative of other nearby stations. According to this figure the all station R2 approximately 1 which shows good plotting if it has error it may correct by equation 23 but it has no error this facilitate no further need of correction.

Filling Missing Data:

There are many missing data both for rainfall and climate data in the stations we used for the analysis. The missing data of station like Addis Ababa bole ,Addis Ababa observatory and Tulu bolo less than 10% and Wolkomi and Sebeta has greater than 10% therefore For rainfall filling we have used both arithmetic equation and normal ratio method selecting those infilling and nearby stations based on the correlation of the stations.

4.2 Outliers data check analysis

Rain fall data used for input is should be detected by using outliers test. As the daily maximum rain fall data is detected by outliers test by help of range value (mean, standard deviation and coefficient of variance). As it is examine the value of higher outliers rain fall depth is 128.8mm and the value of lower outlier’s 15.85mm. One observation of data x=151.4 mm (year 1995) is greater than XH and it considered as higher outliers. Since the value of lower outliers 15.85mm which is lower than the one observation of 23.3mm (year 1999) then we conclude that no outlier is detected.

No		Outlier	RF Depth
1	Higher	2.11	128.80
2	Lower	1.20	15.85
3	CV=Sdev/Xmean		0.106016

4.3 Rational method of determination of peak flood

4.3.1 Intensity –duration frequency curve (IDF)

The result that obtains from IDF curve in the section 3.2.2.4 is discussed as the following manner. The IDF curve is developed from 24 hour rainfall data of 27 years that means from 1990- 2016 that obtain from Ethiopian Meteorological Agency rainfall gauge located in Sebeta town, Ethiopia (NMAS). To develop the IDF curve the appropriate method to use is to analysis the maximum mean annual rainfall by using Normal distribution and Gumble (extreme value I) distribution method.

For this reason using the equation 3-5 we can calculate the intensity of rainfall for a given return period of time.

For thesis calculated IDF curve for specific study area (Sebeta) is applicable for modeling the urban storm drainage system but, regional IDF curve that ERA develop consists of the result of this study. The study area (Sebeta) is found in region A2 which is developed by ERA that is more comfortable to compare the result get by own intensity and ERA. But the data range system may different to develop IDF curve in order to calculate intensity of rainfall for a given duration of return period. Even though the data ranges used for the study and Ethiopian Road Authorities are not the same, the IDF curve developed by ERA is presented here for comparison.

The value that I compared may be too different because the rainfall data to develop IDF curve of sebeta town from 1990 -2016 and ERA used three years (up to 2013) less than of study area.

Basic concept of IDF curve

Defining rainfall intensity or volume form of rainfall is basic different format of SWMM software for modeling urban storm water drainage system. Rainfall intensity for urban storm and drainage system modeling and calculating the peak runoff rate from a drainage area using rational method. For this thesis IDF curve of sebeta town T2, T5, T10, T25, T50 and T100 is applicable but the developed value of IDF should be correlated with the ERA IDF curve developed. But their values are may be much difference. In ERA drainage design manual Ethiopia is divided into several hydrological regions which display similar rainfall patterns. Sebeta Town falls in region A2 of this division as mentioned in the previous section.

According to IDF curve figure of the following the study area the value of intensity for duration time of 5 minute, 15 minute of T5 and T10 return period is 79.145mm/hr,61.38mm/hr and 96.1645mm/hr and 74.5768mm/hr respectively.

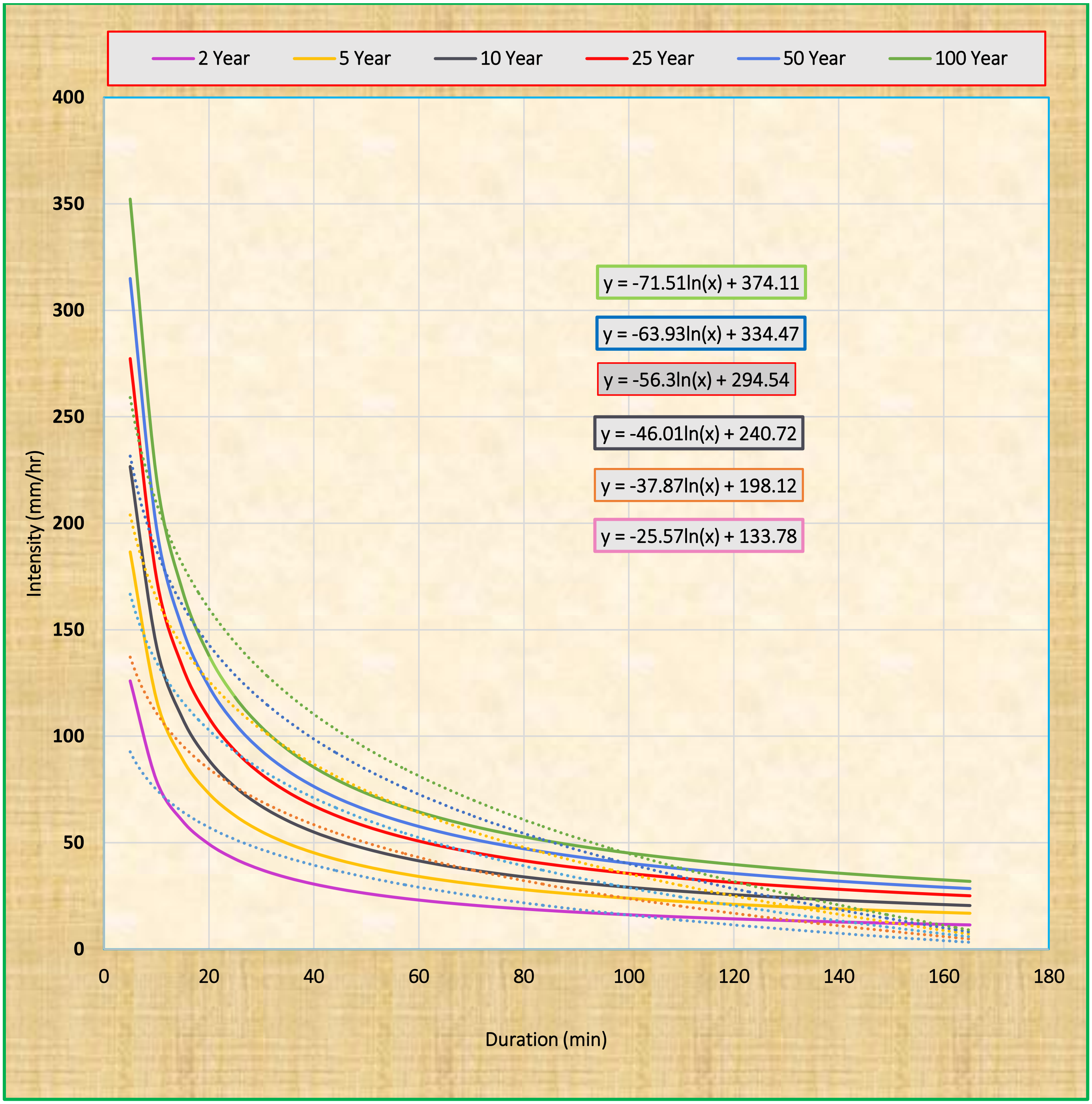


Figure 4-1: IDF Curve for Sebeta town

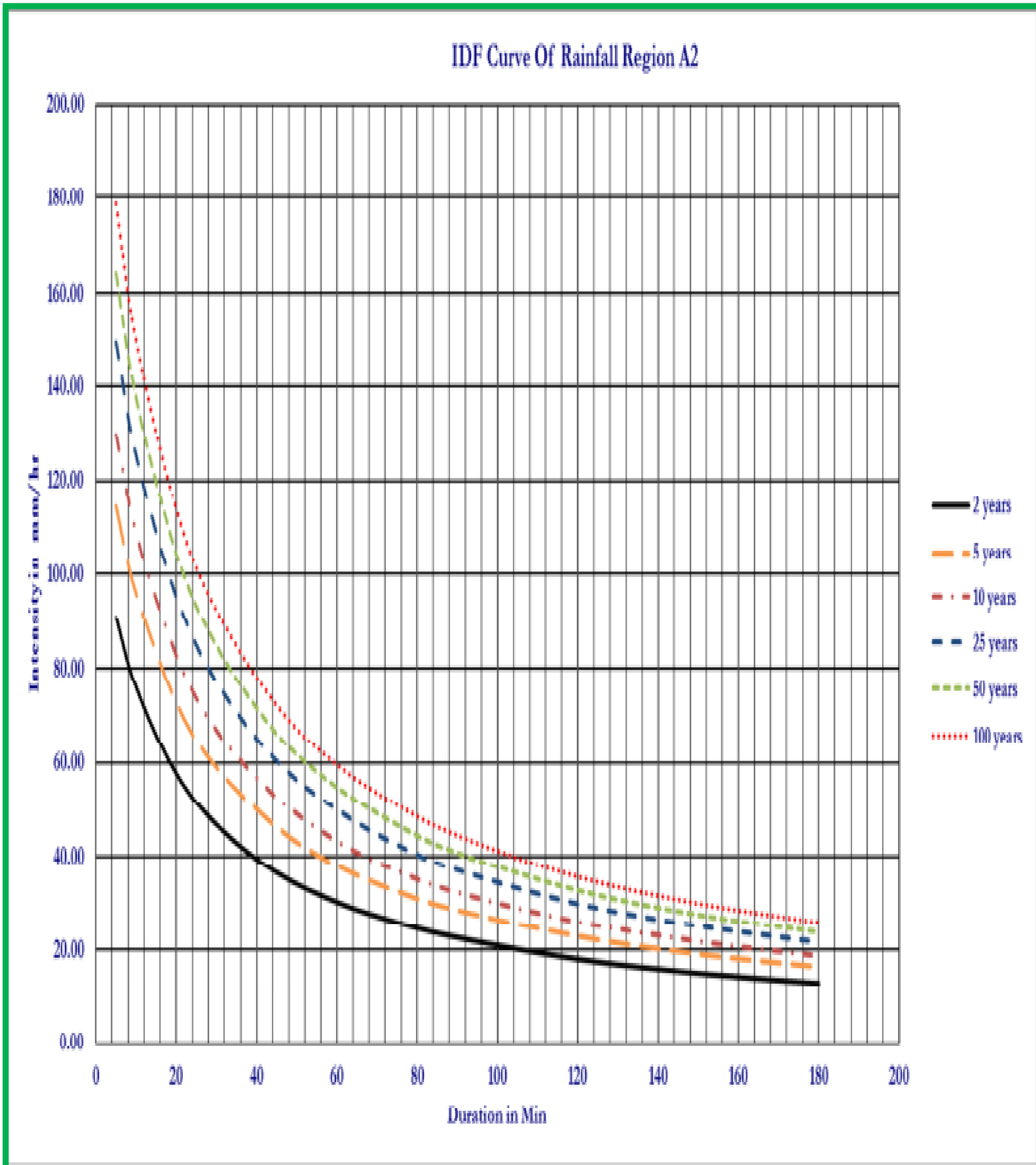


Figure 4-2: Intensity-Duration-Frequency curves for the regional A2 developed by ERA

Table 4.1: Comparison of IDF curve results with ERA IDF develop for station

Duration	Comparison of IDF curve results with ERA IDF develop for station											
	Self T-2	ERA T-2	Self T-5	ERA T-5	Self T-10	ERA T-10	Self T-25	ERA T-25	Self T-50	ERA T-50	Self T-100	ERA T-100
15	100.12	102.20	147.39	148.60	188.19	185.20	232.38	213.50	250.33	241.40	268.14	269.10
30	88.89	90.40	125.98	131.50	167.11	178.00	182.11	188.70	199.24	213.50	224.29	237.80
45	75.56	78.70	116.45	114.40	160.65	170.90	161.98	163.90	170.38	185.60	208.72	206.50
60	66.89	67.00	100.18	97.30	161.47	163.70	150.74	139.10	157.62	157.70	164.44	175.20
75	54.67	55.20	77.58	80.30	149.50	156.50	123.43	114.30	129.32	129.70	135.17	143.90
90	44.56	43.50	64.97	63.20	191.26	149.30	88.25	89.60	103.43	101.80	118.58	112.60
105	36.45	31.70	45.78	46.10	138.07	142.20	58.35	64.80	69.01	73.90	83.63	81.30
120	18.32	20.00	30.89	29.00	135.57	135.00	39.29	40.00	45.53	46.00	49.75	50.00

4.3.2 Rational equation for determination of peak runoff Sub catchment

Table 4.2: peak discharge of sub catchments of study area for 10 years return period

No	Name of Sub catchments	Area of sub catchment (ha)	Coefficients of runoff	Intensity of rainfall (mm/hr.)	Discharge=0.0078CIA (m3/se)
1	S1	1.15	0.33	87.49	0.26
2	S2	2.68	0.33	92.42	0.63
3	S3	1.09	0.33	72.86	0.20
4	S4	0.89	0.33	100.30	0.23
5	S5	0.36	0.33	103.43	0.09
6	S6	4.82	0.33	43.45	0.53
7	S7	14.24	0.33	58.22	2.10
8	S8	11.62	0.33	74.18	2.19
9	S9	9.49	0.33	48.52	1.17
10	S10	31.8	0.65	45.53	7.34
11	S11	14.68	0.65	34.70	2.58
12	S12	13.25	0.65	31.68	2.13
13	S13	2.87	0.65	45.76	0.67
14	S14	1.1	0.33	71.55	0.20
15	S15	1.47	0.33	74.92	0.28
16	S16	0.49	0.33	75.33	0.09

One of the simplest and the most common method used for estimating peak flow discharges in small watersheds is the rational method. This method is most accurate for urban watersheds smaller than 60ha (Mohammed, 2012). Rational method is also included in many modeling tools such as SWAT (Soil and Water Assessment Tool). Applying the rational equation to each of sub catchment study area the value of peak discharge is obtain according to the above table.

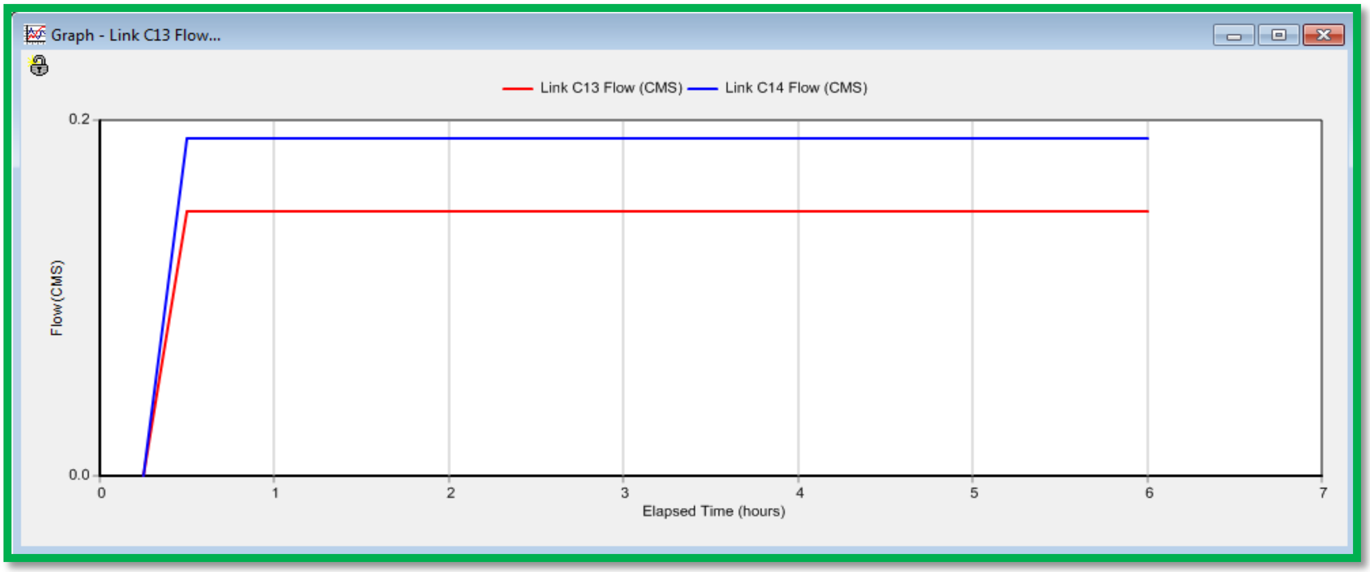
4.3.3 Manning equation for determination of flow rate of conduit.

This method deploys the hydraulic characteristics of the stream influencing the maximum discharge, such as velocity of flow, slope of the stream, cross sectional area of the stream and shape and roughness of the stream. From the whole catchment the parameters of drainage structure like area, perimeter, velocity and discharge value is mention as the following table.

Table 4.3: Drainage system parameters value from manning result.

No	Name of conduit	A (m2)=LW	P(m)=B+2h	V(m/se)=1/nR2/3S1/2	S	Discharge Q (m3/se)=AV
1	C1	0.3	1.6	2.16	0.017	0.65
2	C2	0.3	1.6	1.81	0.012	0.54
3	C3	0.374	1.91	2.03	0.015	0.76
4	C4	0.374	1.91	2.02	0.014	0.75
5	C5	0.855	2.75	2.85	0.015	2.44
6	C6	0.95	2.95	2.87	0.015	2.73
7	C7	0.855	2.75	2.44	0.011	2.09
8	C8	0.664	2.43	2.09	0.01	1.39
9	C9	0.39	1.9	1.57	0.008	0.61
10	C10	0.675	2.4	1.75	0.007	1.18
11	C11	0.4	1.8	1.52	0.007	0.61
12	C12	0.546	2.18	1.34	0.005	0.73
13	C13	0.304	1.56	1.34	0.006	0.41
14	C14	0.364	1.74	1.19	0.005	0.43
15	C15	0.812	2.56	1.87	0.006	1.52
16	C16	0.684	2.42	1.52	0.005	1.04
17	C17	0.5576	2.32	1.38	0.005	0.77
18	C18	0.48	2.2	1.27	0.005	0.61
19	C19	0.5525	2.35	1.48	0.006	0.82

The values of sample flow rate conduit from two place flow verses elapsed time look like the following graph.



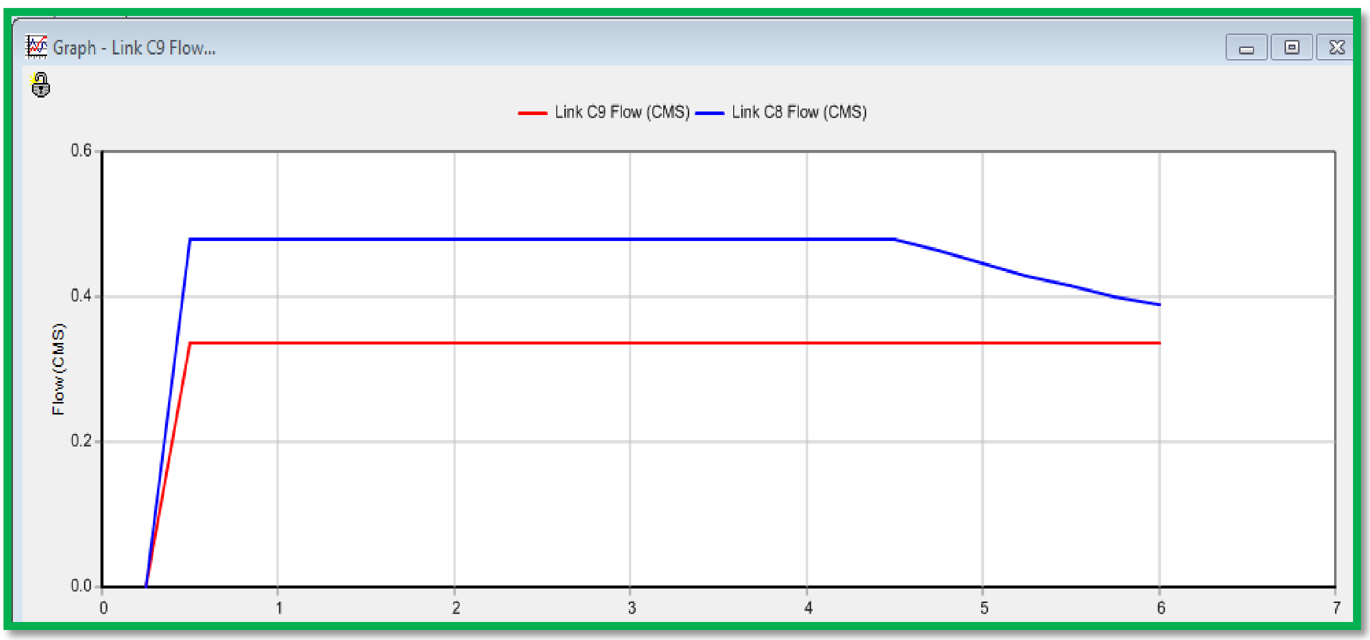


Figure 4-3: Flow rate of C8, C9, C13 and C14 verses Elapsed time

4.4 Characteristics of existing drainage line of study area.

Sebeta town is one the oromia special zone that is nearest to the capital city of Ethiopia Addis Ababa but, this town has been developed intensified manner without provision drainage line system which is the important component of developing urban area. As the result of modeling existing drainage line by the help of GIS (Geographical information system) from exit of Addis Ababa to exit of sebeta town or Kebela (01) ,existing drainage line is more dense around the Noke square (Furi and Weleta) and more less towards to kebele 01. But, from Storm water management model (SWMM) more junctions is over flooded around the dense of drainage line because as additional to model I survey the area about 15 days and I obtain miss interconnection of drainage line system relatively more broken of drainage line system.

According to the following figure 4.4: existing drainage line of study area, the drainage line is less connected to each other consequently over flooding of drainage system.

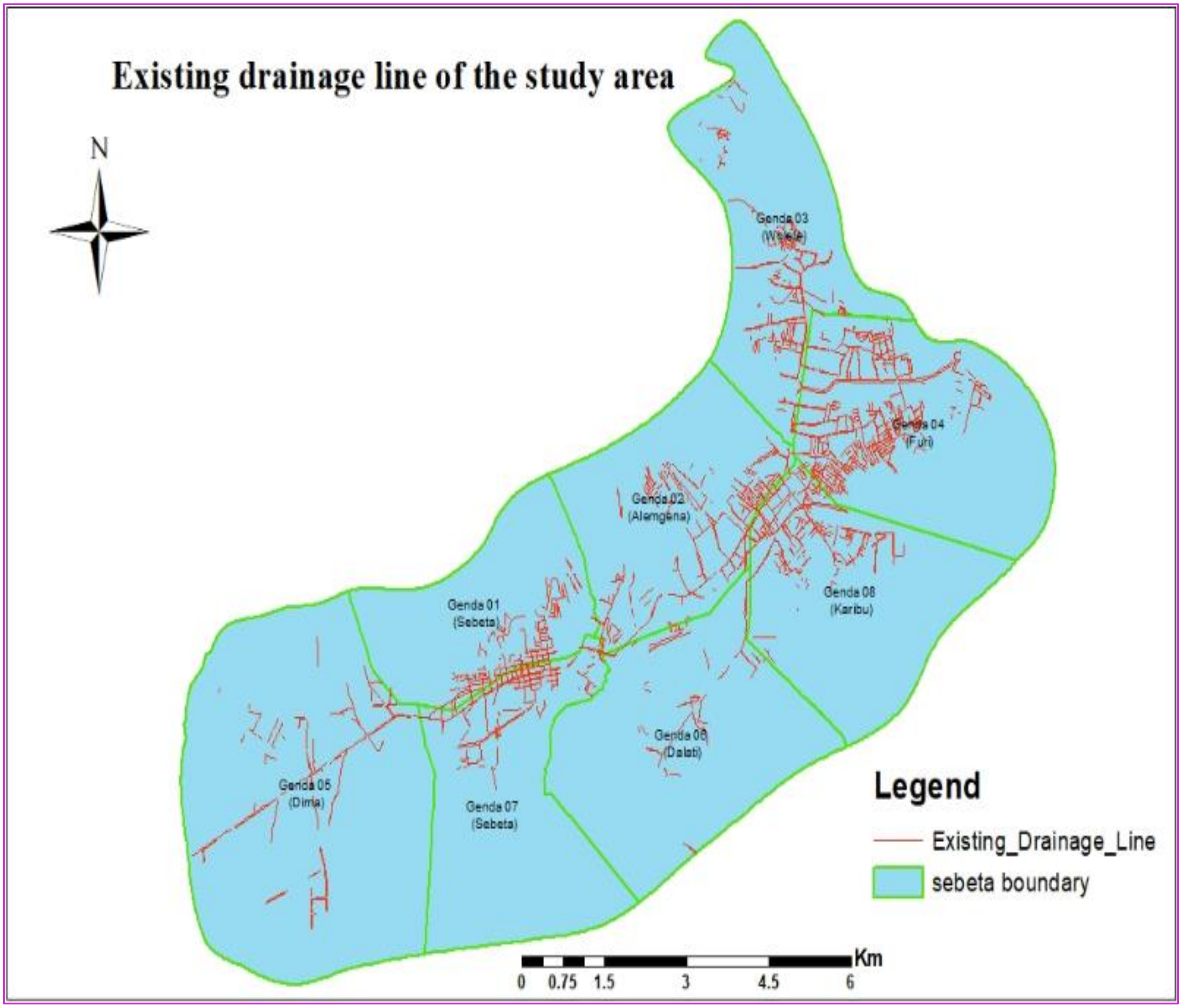


Figure 4-4: Existing drainage line of study area modeled by GIS

4.5 Physical catchment characteristics of study area

Generally runoff and discharge yield of drainage system in the watershed are affected by the physical catchment characteristics (PCC). The physical catchment characteristics of the sebeta town Catchment outlet were determined from DEM 30m and surface elevation is determine from master plan that developed by city administration. The climatic characteristics, geography and physiographic, land use and cover conditions affects the physical characteristics of the catchment. The climatic characteristics of study area and the selected station around the study area is similar because the coefficient of determination of each station is approximately 1 from double mass curve and from homogeneity test the pattern of graph shows similar pattern. The slope of the Sebeta town Catchment also showed steeped from DEM and from contour of catchments area. The drainage density of the Sebeta town Catchment also shows varied from place to place which shows interrupted network drainage system at some place it shows spaced while at some other it is highly dense characteristics. The land use and land cover conditions in the Sebeta town Catchment are mainly dominated by Commerce and business land followed by residence for sebeta town Catchment.

The result of sub catchment characteristics shown as the table 4.4

Table 4.4: Physical catchment characteristics.

No	Name of subcatchement	**Characteristics of subcatchement**					
		Min Ele (m)	Max Ele (m)	Mean Ele (m)	Length (m)	Area (ha)	% Slope
1	S1	2308	2316	2312	173.53	1.15	4.61
2	S2	2308	2320	2314	173.62	2.68	6.912
3	S3	2304	2316	2310	145.16	1.09	8.267
4	S4	2300	2304	2302	102.16	0.89	3.9154
5	S5	2296	2300	2298	74.44	0.36	5.373
6	S6	2300	2316	2308	415.35	4.82	3.852
7	S7	2296	2312	2304	453.02	14.24	3.532
8	S8	2300	2336	2318	372.08	11.62	9.675
9	S9	2284	2296	2290	576.11	9.49	2.083
10	S10	2272	2296	2284	671.31	31.8	3.576
11	S11	2272	2296	2284	484.61	14.68	4.95
12	S12	2268	2292	2280	489.61	13.25	4.9
13	S13	2268	2292	2280	232.68	2.87	4.9
14	S14	2264	2268	2266	186.99	1.1	2.14
15	S15	2264	2268	2266	173.27	1.47	2.14
16	S16	2264	2268	2266	96.58	0.49	2.14

4.6 Storm water management model (SWMM 5.1) result

SWMM is one of the most widely used open-source models available for simulating urban drainage systems. The major advantage of SWMM is that it incorporates the capabilities of both hydrological and hydraulic models. The model covers the study area about 112ha of subcatchements which is mainly consists of impervious surface area resulting greater than 50% of impermeable area and the length of network simulation modeling is 45km.

4.6.1 Description of the network model.

As previously mentioned, the modeled area is divided into 16 sub-catchments and flows from asphaltic road and walkway and pavements. The network consists of 19 nodes means Junctions and 2 outfalls, 19 links, see Figure below.

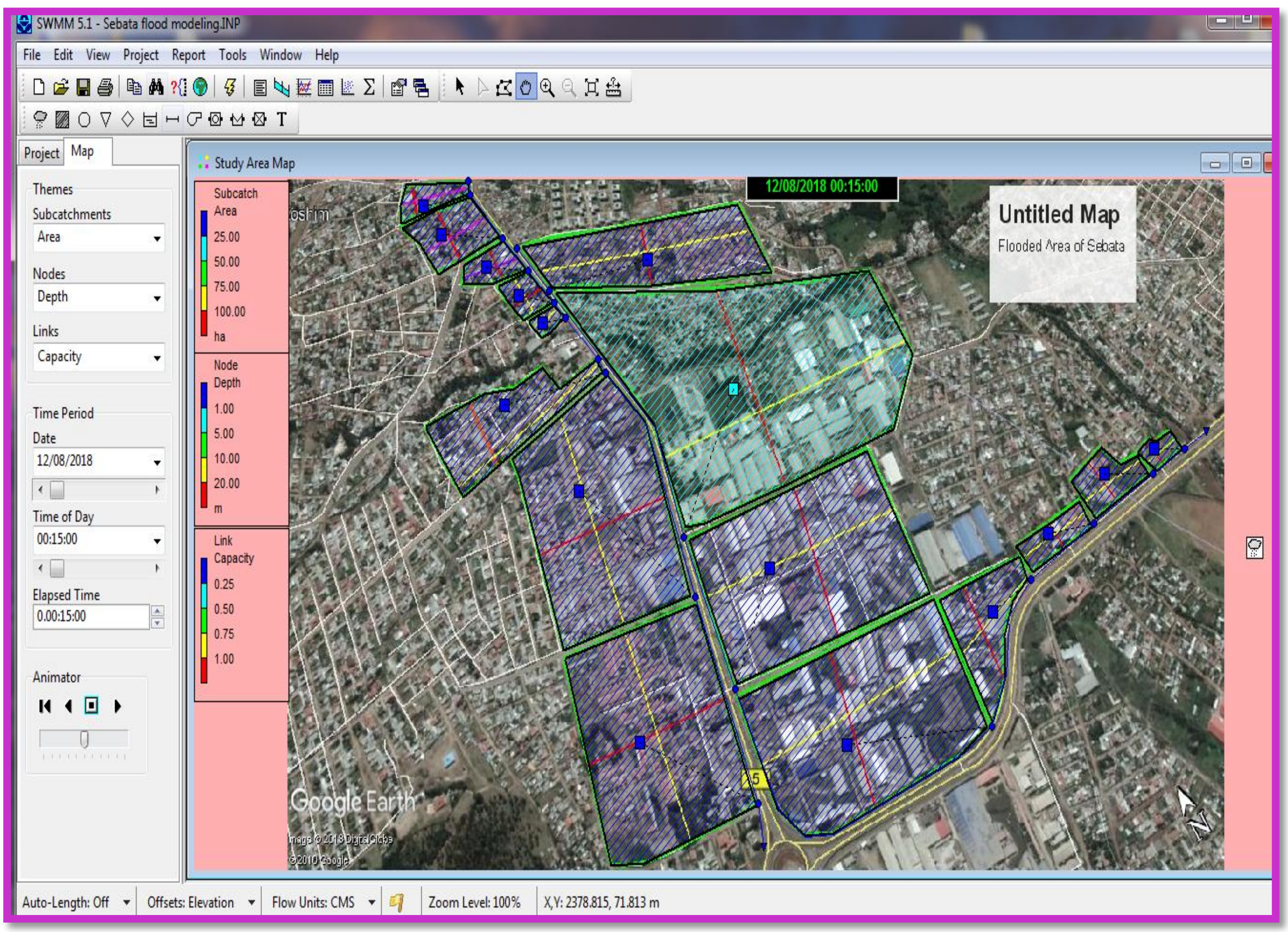


Figure 4-5: General Network of modeled map area

4.6.2 Simulation and water elevation profile along drainage system

Depending on the land use land cover of the area the junction or the manhole are modeled as rectangular shape having different dimension .It has been assumed that there are no energy losses in the in junction. The modeled junction is divided into two parts one starts from boundary of Addis Ababa and sebeta to Noke square and the second one is from Noke to jamo across the furi. In junction model includes boundary conditions to represent various types of water loads, as infiltration or fixed water levels.

The precipitation is introduced into the model by associating each sub-catchment to the rainfall time-series as format of intensity. The general network of junction modeling is show to identify where the flooded is occurred repeatedly from time to time. The following modeled junction figure show the water elevation profile along the main road started from between boundary of Addis Ababa to central of sebeta town.

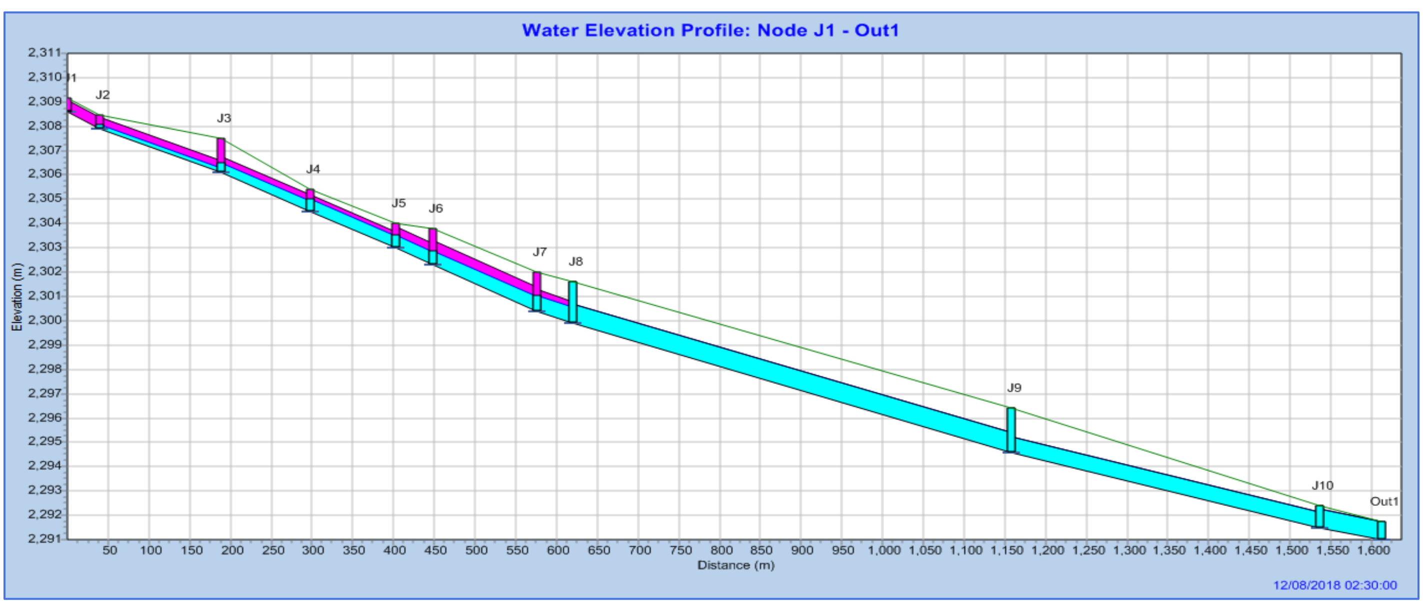


Figure 4-6: Water flow profile in the modeled Junction at station of Noke square

The water profile plot along junction is obtained for nodes from junction J1 to outlet1 is as shown in figure above. The simulation status report shows that sections between these junctions are surcharged (flooded). For example from the above figure junction J8, J9, J10 and at out1 is highly flooded having depth 1.7, 1.8 and 0.9 respectively.

The second part of modeled junction area is from Noke square towards to Jamo town which consists of about junction 9 and one outlet2. Compared to from the previous modeled area, this area is highly flooded like Junction(12),Junction(13),Junction(14), Junction(15),Junction(16),Junction(17),Junction (18), Junction(19) and including outlet 2.

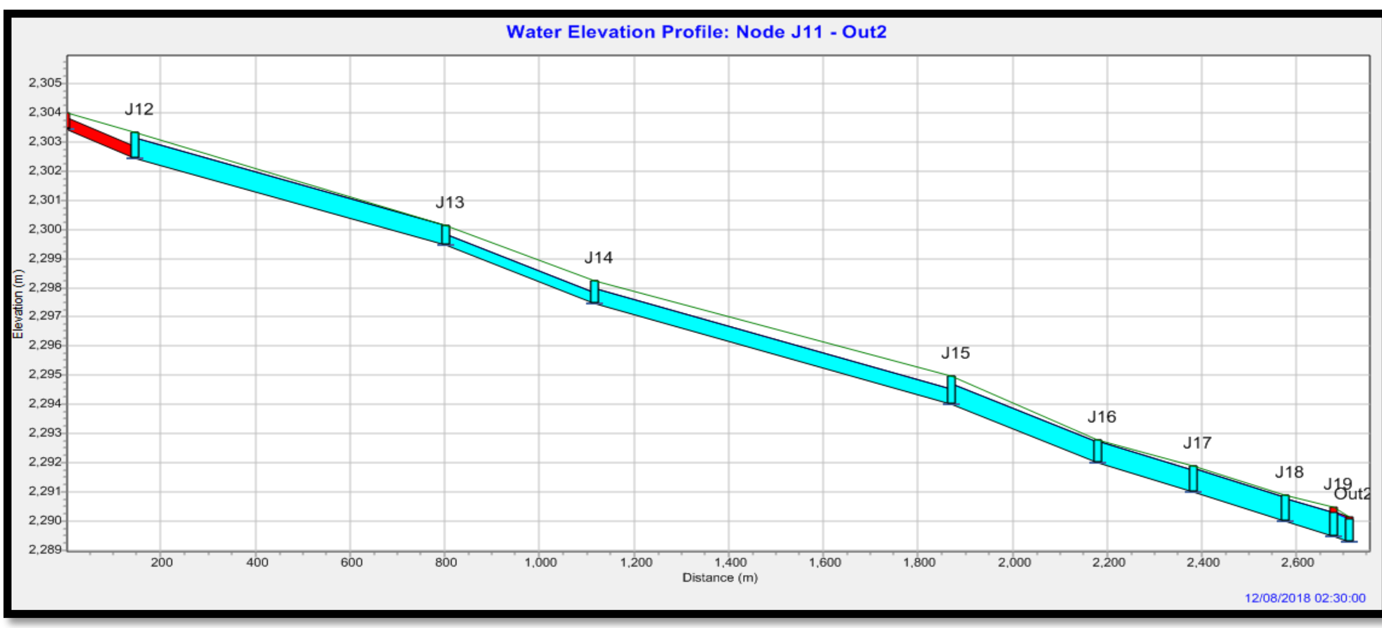


Figure 4-7: Water elevation flow profile in the modeled Junction at station from Noke square towards to Jamo.

4.6.3 SWMM Model Performance Evaluation

The performance of SWMM model software must be evaluated in order to minimize the degree of error, extent of its accuracy, consistency and adaptability. A forecast efficiency criterion is therefore necessary to judge the performance of the model.

Since SWMM software is both hydrological and hydraulics modeling, Assessing performance of its required subjective and/or objective estimates of the closeness of the simulated behavior of the model to observations or calculated value. Since the observed data of run off is not efficient for evaluation of performance model instead the data calculated used as observed one but for calibration and validation process we 15 days measured data is used. In this thesis work, the model performance in simulating calculated discharge has been evaluated during calibration and validation through using Nash and Sutcliffe efficiency criteria (NSE), coefficient of determination (R2). According to calculated and simulated value of discharge for return period of T5, NSE value is 0.9789, R2 value is 0.9999 and forT10 NSE value is 0.979 and R2 value is 0.9993. From the above criteria the value of NSE for both T5 and T10 is located between 0.9 and 1 indicate that the model performs very well as well as the value of R2 is located between range value of 0 to 1 which shows best model performance accordingly (Moriasi et al ,2007)

4.6.3.1 Continuity Error Model performance Evaluation

Surface runoff percent: As the model is run the value of surface runoff is about -0.64%.

Flow routing: In hydrology, routing is a technique used to predict the changes in shape of a hydrograph as water moves through a river channel or a reservoir.

As the model is show the value of flow routing is about 0.03% this implies the continuity error is very low and the model is good performance during run process.

4.6.4 Validation and calibration by SWMM and using measured value method

Calibration is the process whereby model parameter are adjusted to make the model output match with observed data. When simulated outputs like runoff are close to observed outputs, the model is said to be properly calibrated. Therefore SWMM parameters should typically be calibrated and validated against measurements to reach reliable results. However, some of the model parameters are quite straightforward to deduct from e.g. accurate spatial data and can be reasonably defined even without calibration. This included subcatchement runoff, depth of junction or node, flow rate of conduit and manning roughness value. However, if no runoff measurements required for calibration exist, literature values can be found for several of these parameters. Many parameter values are suggested e.g. in the

SWMM User's Manual (Rossman, 2010) .But from subcathment measurement of runoff for 15 days used as calibration and validation.

Validation is the process of representing that a given site specific data is capable of making accurate predictions. This was done by applying the calibrated data using a different data set out of the range of calibration without changing the parameter values. The data is said to be validated if its accuracy and predictive capability in the validation period have been proven to lie within acceptable limits (Reuben, 2007). If the resultant fit is acceptable then the data prediction as valid.

Table 4.5: model Calibration of certain subcatchement's peak runoff

Calibration parameters for SWMM hydrology and hydraulic parameters					
Name of Subcatchement	Name of Parameter's	Meaning	Value range	Initial value	used values / sensitivity to peak flow
S1	N-Impervious	Manning's roughness coefficient for impervious area	0.011-0.015	0.012	0.015
	N-Pervious	Manning's roughness coefficient for pervious area	0.05-0.8	0.13	0.05
	Destore Impervious	Depth of depression storage on impervious area	0-3	1	3
	Destore pervious	Depth of depression storage on pervious area	3 _10	5	10
	Conduit roughness	Manning 's roughness coefficient of for conduit	0.011-0.024	0.014	0.055
S2	N-Impervious	Manning's roughness coefficient for impervious area	0.011-0.015	0.011	0.014
	N-Pervious	Manning's roughness coefficient for pervious area	0.05-0.8	0.056	0.8
	Destore Impervious	Depth of depression storage on impervious area	0-3	1.45	3
	Destore pervious	Depth of depression storage on pervious area	3 _10	2.9	10
	Conduit roughness	Manning 's roughness coefficient of for conduit	0.011-0.024	0.022	0.024

Table 4.6: Validation value of peak Run off for certain catchments

Validated value of peak runoff m3/se			
S.no	Name of subcatchement	Measured value of=8/15CdtanΘ/2√2gh^5/2	validated value peak run off m3/se
1	S1	0.24	0.220
2	S2	0.39	0.340
3	S3	0.10	0.120

4.6.4.1 Comparation of different model with SWMM.

The US EPA SWMM 5.1 model and GIS were applied to an urban catchment in Sebeta town and rational method is used for comparison of peak discharge. Calculations are presented in table 4-6: the total runoff from whole sub-catchments by SWMM is 20.68 m3/sec, whereas by rational method is 15.88 m3/sec.

Table 4.7: Comparation peak discharge by SWMM and rational method.

S. No	Name of Subcatchements	Discharge=0.0078 CIA	EPSWMM5.1 result of peak Discharge (Q) m3/s	Difference
1	S1	0.209868848	0.19	0.02
2	S2	0.516661696	0.43	0.09
3	S3	0.165678474	0.18	-0.01
4	S4	0.186232774	0.16	0.03
5	S5	0.077682337	0.06	0.02
6	S6	0.436940712	0.75	-0.31
7	S7	1.729835328	2.33	-0.60
8	S8	1.798066425	1.57	0.23
9	S9	0.960842571	1.28	-0.32
10	S10	4.64777352	4.95	-0.30
11	S11	2.185566474	2.62	-0.43
12	S12	1.960911225	2.31	-0.35
13	S13	0.531689886	0.60	-0.07
14	S14	0.16418688	0.11	0.05
15	S15	0.229735643	0.24	-0.01
16	S16	0.077000879	0.10	-0.02

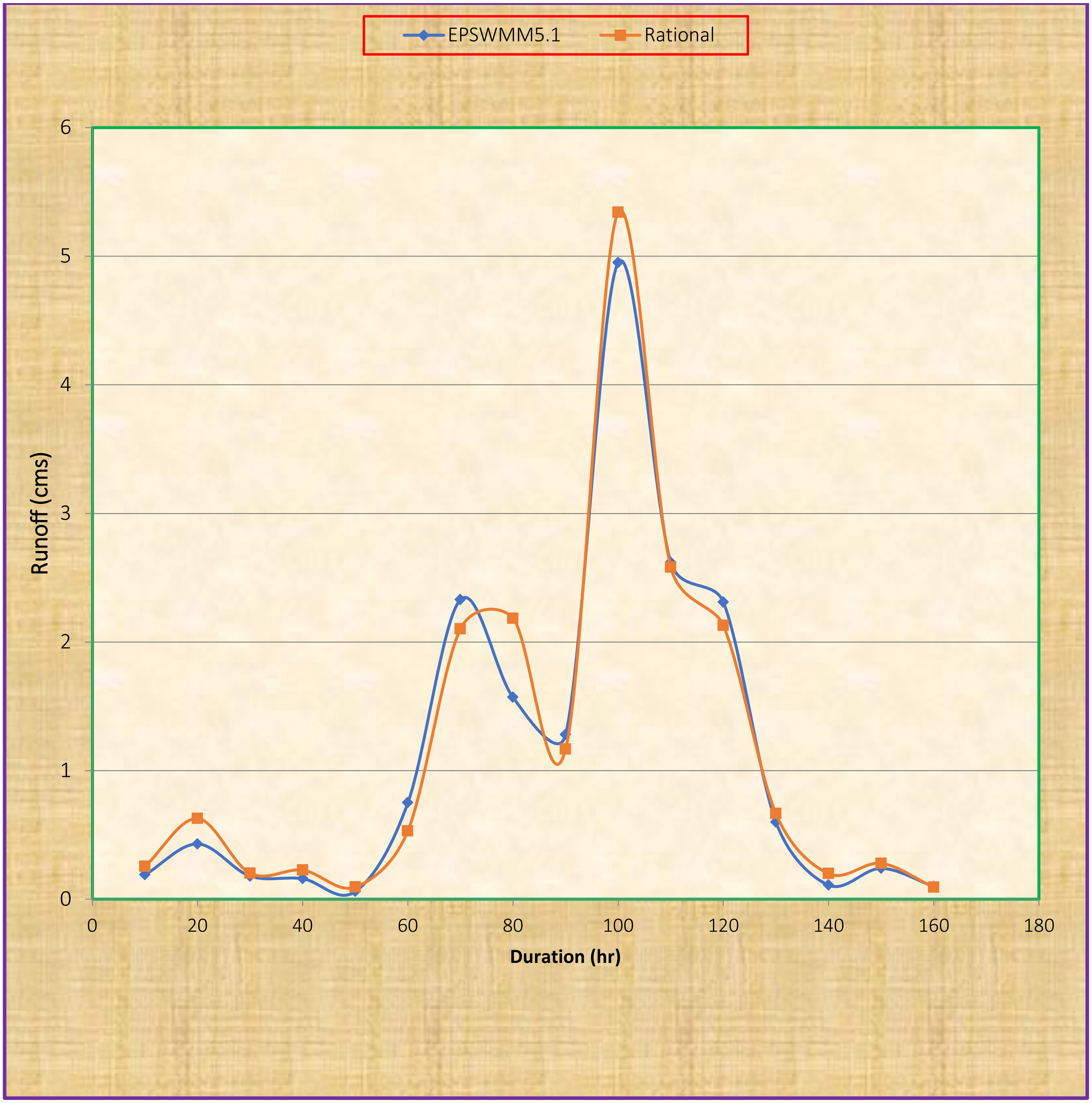
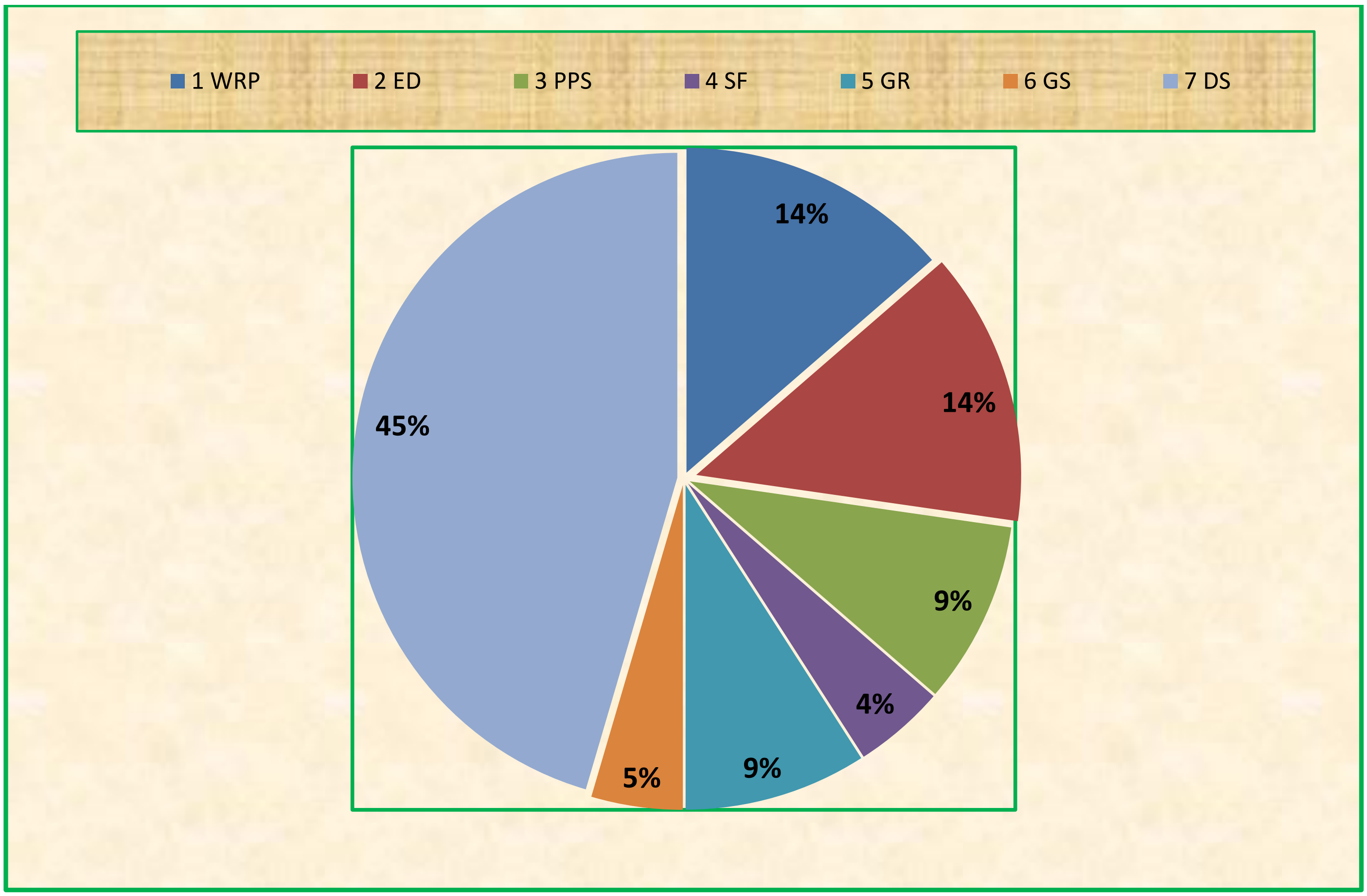


Figure 4-8: Manual comparing of EPSWMM 5.1 Verses Rational method for peak discharge

4.7 Storm water management scenarios

The storm water management like wet retention pond, extension detention, permeable pavement system, sand filter, green roof, grass swale and road side ditches are the main point that responsible for sustainable urban storm water management by any means. As I surveyed about 5 days the whole study area of Sebeta the storm management scenario is accountable for managing the runoff about less than 45% while side road ditches responsible about greater than 50%. As I consult the local community about storm water management techniques they have no knowledge about it. But the said there highly flood Around the Noke Square including Weleta and furi kebale that extended along the main road to alamgena.



DS=drainage system GR=Green roof

WRP= Wet retention pond EDB= Extended Detention basin

PPS=Permeable pavement systems GS=Grass Swale

SF=Sand filter

Figure 4-9: Storm water management techniques pie chart

4.7.1 The performance of best management practice for rainfall runoff

The best management practice like bio retention cell, rain garden; green roof, infiltration trench, permeable trench and vegetative swale have their own effective on rainfall runoff analysis. As mention in the previous section, the model simulation is without introduction of best management practice and the value of peak runoff is high and when introduction of best management is the value of peak runoff is became decrease which shows the best management practice is one of the parameter SWMM software. The following table 4.5 shows the effect of best management practice on peak runoff.

Table 4.5: Comparing of peak runoff with and without best management practice

Without best management practice							With best management practice			
No	Name of subcatchement	Total precipitation (mm)	Total infiltration(mm)	Total runoff(mm)	Peak runoff (CMS)	Coefficient of runoff	Total infiltration(mm)	Total runoff(mm)	Peak runoff (CMS)	Coefficient of runoff
1	S1	198.93	8.92	135.6	0.19	0.85	9.5	125.89	0.1	0.85
2	S2	198.93	8.92	132.33	0.43	0.833	9.3	111.53	0.33	0.833
3	S3	198.92	8.92	131.59	0.18	0.828	9	108.45	0.1	0.828
4	S4	198.92	8.53	136.8	0.16	0.861	8.68	99.34	0.089	0.861
5	S5	198.92	10.67	133.03	0.06	0.837	11.98	110.215	0	0.837
6	S6	198.93	9.5	133.55	0.75	0.84	9.67	112.93	0.125	0.84
7	S7	198.93	9.5	135.01	2.33	0.85	9.99	89.45	1.56	0.85
8	S8	198.93	8.92	128.82	1.57	0.811	9.145	78.98	1.256	0.811
9	S9	198.92	11.77	132.6	1.28	0.834	13.56	69.78	0.99	0.834
10	S10	198.92	6.59	136.04	4.95	0.856	7.59	100.56	3.54	0.856
11	S11	198.93	4.65	139.45	2.62	0.877	5.89	79.39	1.53	0.877
12	S12	198.93	4.65	138.68	2.31	0.873	5.68	109.35	1.32	0.873
13	S13	198.93	4.65	140.43	0.6	0.884	5.55	103.56	0.34	0.884
14	S14	198.92	19.02	118.62	0.11	0.746	24.512	93.19	0.1	0.746
15	S15	198.92	9.7	138.2	0.24	0.87	11.23	93.167	0.111	0.87
16	S16	198.93	8.53	0. 62	0.1	0.885	9.321	88.45	0.0	0.885

5. CONCLUSION AND RECCOMENDATION

5.1 CONCLUSION

This study sustainable urban storm water management and drainage system modeling in small urban catchment of Sebeta town by using SWMM and rational method for hydrologic analysis and for modeling of drainage structure manning equation is the main keys for this study as well as for analysis of hydraulic purpose. The model operates on a yearly time step and allows the catchment area to be subdivided into sub catchments. The objective of this study was to sustainable urban storm water and modeling drainage system from sub catchment SWMM model and to take and recommend appropriate effect of flood reduction measures around high flood producing areas. Arc GIS, and Google earth interface was used to prepare and process a geospatial data required running the model. More calibration process of SWMM model using manual and rational because of weakness of SWMM model for calibration and validation.

The flooding risk is very high due to the drainage system is undersized to cope with the current rainfall rates, but also is very limited to face the upcoming predicted rainfall. The most affected areas are the main line and ring road drainage system, although other singular spots are also likely to be affected by flooding. The rainfall data which were collected from NMAS was checked and evaluated using R^2 and generated the IDF curve of study area. As IDF curve of study area is developed it is compared with ERA's prevesiouly. First the meteorological missed data due to misreading and fail of the gauging instruments were filled by arithmetic and rational method. The filled data consistence was checked by developing double mass curve. And as additional detection of data error is outlier's methods, where it is used G-B test system. The value of XH (higher outliers) and XL (lower outliers) is 128.8mm and 23.3mm which is shows no low outliers and high outliers were detected.

The meteorological data was collected from Ethiopian meteorological agency (EMA) for the years (1990-2016) and the dimension of each ditches, depth and remark of flood are collected by own survey at least 20 days from the study area.

The model performance evolution during yearly flood occurrences calibration and validation period at the whole catchments indicated that R^2=0.992, NSE=0.701 respectively.

The study area covers 112 ha which is subdivided into 16sub catchments, including junction 19 and having conduit 19. The physical catchments of study area is covers the whole catchments more commercial and business land use system where as forest cover and agriculture is the least land use system.

From storm water management scenario drainage system cover more area about 45% but this drainage is not properly functioned or disconnected while another urban storm water sustainable like Wet retention pond=14%, Permeable pavement systems=9%, Sand filter=4% Green roof= 9%and Grass Swale=5% as own survey over all the catchments.

As modeling storm water management model show over the catchment the drainage system like junction J8-J19 is high over flooded due to less capacity to compensate this flood.

Therefore sustainable storm water management and modeling drainage system go parallel to each other for aesthetic of urban areas.

5.2 RECCOMENDATION

- ✓ The whole ditches of along the main road and across the block is opened it should close in order to avoid any damages.
- ✓ When the drainage system is designed the slope of ditches should be more considered.
- ✓ The cross section of drainage should be completely updated according to ERA new manual standard.
- ✓ The drainage system line of study area not properly separated for urban storm water and for waste water therefore it should be need proper arrangement.
- ✓ From the conceptual model of drainage network there is missed element like orifices and weir it should be considered during design of urban drainage system.
- ✓ Urban drainage systems cannot be designed in isolation from the communities that they serve. For example, where communities construct houses on drainage pathways and floodplains, it may be necessary to relocate some of the houses for the construction of drains. So, drainage system and community serve should be isolated.
- ✓ I recommended the meteorological station to focused on record of pruned flood area occurs as written documentation with time series event.
- ✓ As the urban area survey it has less storm water management system therefore the ERA should consider it while design drainage system.
- ✓ Around the main road the drainage system the open drainage system should be closed for any safety.
- ✓ The existing community should treat or maintain drainage system safety or ERA should have rehabilitated it.
- ✓ This study depends on, the secondary data collected from different organizations and agencies as its input and simulation of the final model result. But the primary data is better for representativeness of these data and for better result.

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APPENDIXES

A.TABLES

Station Name: Addis Ababa Bole

Table –A-1: Monthly Total Rainfall(mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually Pcp
1990	3	161	60	145	25	48	194	294	143	46	2	0	1122
1991	0	30	134	15	8	108	279	288	123	4	2	0	991
1992	15	28	35	59	55	82	255	223	157	64	2	0	975
1993	12	52	12	168	92	157	210	292	190	24	0	0	1208
1994	0	0	53	70	29	112	242	199	99	1	11	0	817
1995	0	81	73	133	96	77	166	257	97	0	0	29	1010
1996	21	16	134	96	125	290	346	313	211	0	0	0	1553
1997	29	0	22	67	45	128	257	161	95	59	15	0	877
1998	67	40	44	100	198	112	271	237	173	139	0	0	1380
1999	4	0	35	18	31	105	294	271	63	127	0	0	947
2000	0	0	18	88	95	102	193	222	158	20	8	0	902
2001	0	10	174	15	117	166	289	207	113	11	0	0	1103
2002	31	26	79	37	50	116	214	234	73	1	0	33	891
2003	5	34	49	112	18	111	204	238	130	5	0	33	939
2004	26	12	32	113	7	115	241	230	122	50	1	0	948
2005	55	14	42	116	165	159	174	248	78	26	7	0	1084
2006	2	37	108	94	38	115	313	331	133	36	0	0	1206
2007	10	21	61	87	134	158	191	305	131	37	0	0	1136
2008	0	0	0	34	75	73	295	259	193	22	53	0	1005
2009	41	0	12	46	52	78	238	270	86	42	2	80	947
2010	0	115	76	160	95	107	320	139	105	0	14	16	1146
2011	3	14	28	31	86	148	183	297	141	0	12	0	943
2012	0	0	35	75	59	73	229	282	177	1	0	20	949
2013	0	0	64	114	79	101	158	270	127	45	3	0	961
2014	0	42	30	34	62	42	180	254	95	35	0	0	772
2015	0	0	21	138	124	104	163	227	132	18	3	0	930
2016	124	19	51	138	124	104	163	227	132	18	3	0	1103
Mean	**17**	**28**	**55**	**85**	**77**	**114**	**232**	**251**	**129**	**31**	**5**	**8**	1031

Station Name: Addis Ababa Observatory

Table –A-2 : Monthly Total Rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annually Pcp
1990	1	156	59	106	20	89	219	269	184	16	6	0	**1125**
1991	0	75	107	35	57	191	249	263	126	3	0	50	**1155**
1992	20	34	20	41	52	109	249	295	209	70	0	3	**1101**
1993	11	67	16	158	97	208	274	427	243	62	0	5	**1568**
1994	0	0	82	82	63	123	309	225	142	1	15	0	**1043**
1995	0	69	42	174	68	103	190	315	136	0	0	48	**1146**
1996	28	5	107	128	122	259	266	339	294	0	0	0	**1549**
1997	39	0	25	51	39	104	273	194	114	62	50	2	**952**
1998	55	21	49	49	154	124	285	260	214	127	0	0	**1338**
1999	3	0	29	16	24	120	273	305	88	75	0	0	**934**
2000	0	0	18	50	110	145	245	306	251	46	21	0	**1191**
2001	0	12	211	25	168	216	428	246	132	14	0	0	**1452**
2002	15	21	90	56	63	173	257	216	109	0	0	17	**1016**
2003	11	53	63	99	20	152	292	233	193	1	2	55	**1173**
2004	25	20	50	140	30	142	239	273	164	77	0	0	**1159**
2005	46	52	83	161	134	180	246	315	163	38	4	0	**1421**
2006	1	11	141	79	75	150	356	244	239	54	0	8	**1358**
2007	51	19	60	74	120	169	262	381	148	25	0	0	**1309**
2008	0	13	0	49	94	89	277	361	257	88	79	23	**1331**
2009	21	3	28	81	59	83	350	388	113	46	4	65	**1241**
2010	3	80	56	98	74	271	314	206	238	2	26	15	**1381**
2011	14	13	44	23	66	182	181	341	146	0	42	0	**1052**
2012	0	0	16	71	50	69	324	298	216	2	0	10	**1057**
2013	4	0	47	92	85	153	228	353	201	58	22	0	**1244**
2014	2	47	62	26	94	67	220	262	265	35	2	0	**1081**
2015	0	0	27	140	109	230	217	310	149	0	8	0	**1189**
2016	60	12	48	137	133	187	183	300	142	16	4	2	**1222**
Mean	**15**	**29**	**58**	**83**	**81**	**151**	**267**	**293**	**181**	**34**	**11**	**11**	**1214**

Station Name: Sebeta

Table-A-3: Monthly Total Rain fall (mm)

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	**Annually Pcp**
1990	0	158	19	116	34	74	246	221	138	24	3	0	**1032**
1991	3	24	110	29	22	102	208	244	121	16	0	0	**877**
1992	41	51	46	41	71	93	329	380	252	120	12	7	**1443**
1993	25	136	39	414	338	216	526	1089	296	52	0	0	**3131**
1994	0	0	136	102	147	220	428	317	114	0	16	0	**1479**
1995	0	72	98	120	228	69	530	558	114	7	0	19	**1814**
1996	26	0	111	63	281	341	405	433	131	0	0	0	**1790**
1997	30	0	33	54	12	274	197	197	51	0	62	0	**909**
1998	70	3	15	30	102	130	215	217	106	49	0	36	**972**
1999	0	23	48	14	57	98	218	221	77	102	1	1	**861**
2000	0	0	3	76	37	96	174	183	216	27	21	25	**858**
2001	0	4	158	11	156	119	273	164	66	21	0	0	**971**
2002	25	47	100	32	31	155	173	251	113	1	0	21	**949**
2003	3	6	52	76	14	123	275	327	118	1	0	39	**1035**
2004	17	15	46	123	19	137	262	190	166	56	0	0	**1031**
2005	50	25	61	135	193	92	157	162	70	3	9	0	**957**
2006	0	14	53	84	52	81	288	273	185	13	0	0	**1043**
2007	24	28	32	100	68	125	84	243	128	4	0	0	**835**
2008	0	0	1	22	57	135	239	313	201	42	84	0	**1093**
2009	31	2	3	58	52	47	158	199	36	20	2	21	**627**
2010	0	33	72	94	78	110	297	169	79	6	8	20	**967**
2011	9	14	27	35	73	150	155	217	76	37	15	0	**806**
2012	0	0	20	217	76	130	203	176	162	8	0	13	**1005**
2013	0	7	87	97	93	127	188	257	130	37	33	0	**1055**
2014	0	36	20	28	122	72	159	237	130	38	3	0	**845**
2015	0	0	15	35	130	106	163	224	61	0	14	0	**748**
2016	47	34	23	150	131	136	236	226	87	6	3	3	**1080**
Mean	**15**	**27**	**53**	**87**	**99**	**132**	**251**	**285**	**127**	**26**	**11**	**8**	**1119**

Station Name: Tulu Bolo

Table-A-4: Monthly Total Rainfall(mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annually Pcp
1990	0	28	18	102	29	150	247	200	37	0	0	0	810
1991	9	7	71	11	129	191	192	167	4	0	0	0	781
1992	14	34	62	37	43	337	442	635	66	8	5	3	1686
1993	12	26	14	114	194	549	440	564	326	19	0	0	2258
1994	0	0	87	47	69	284	339	317	233	0	3	0	1379
1995	0	8	43	50	45	135	90	222	0	3	0	15	610
1996	18	3	40	66	88	226	244	338	191	0	4	0	1217
1997	0	0	36	61	42	203	343	113	79	63	37	0	977
1998	0	18	0	90	155	317	344	341	114	69	0	0	1448
1999	16	0	56	0	79	270	357	449	140	6	0	0	1372
2000	0	0	2	161	132	222	321	227	114	6	26	5	1216
2001	0	3	98	36	92	187	224	160	36	7	0	0	843
2002	46	9	42	61	43	225	237	241	77	0	0	41	1022
2003	40	12	49	94	24	127	315	219	92	0	0	8	979
2004	53	0	11	93	45	271	331	185	164	0	2	5	1159
2005	26	0	54	181	165	208	181	203	84	18	6	0	1126
2006	0	13	106	63	91	198	261	138	162	6	0	0	1039
2007	7	13	41	49	122	258	206	200	147	13	0	0	1056
2008	0	0	7	48	124	234	281	306	91	47	0	0	1139
2009	41	0	16	9	67	59	264	212	90	13	0	112	883
2010	0	104	82	82	186	290	349	157	108	0	10	34	1403
2011	3	18	53	15	76	189	111	237	152	0	0	0	854
2012	0	0	91	98	107	213	23	253	122	0	0	0	907
2013	0	0	34	72	129	252	412	454	217	112	0	2	1684
2014	0	32	54	22	78	95	311	334	80	14	0	0	1019
2015	0	2	64	96	128	114	207	210	93	0	6	0	920
2016	22	11	62	100	158	99	241	148	100	24	5	0	969
Mean	**11**	**13**	**48**	**69**	**98**	**219**	**271**	**268**	**115**	**16**	**4**	**8**	**1139**

Station Name: Wolkomi

Table –A-5: Monthly Total Rain fall(mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually Pcp
1990	0	154	61	30	39	186	130	258	119	10	2	6	**996**
1991	2	68	95	10	68	111	212	208	105	0	0	22	**901**
1992	42	72	103	88	67	97	202	278	80	41	0	8	**1078**
1993	39	74	44	76	158	111	203	521	208	81	0	0	**1515**
1994	0	0	48	50	67	164	290	283	237	1	11	0	**1151**
1995	0	46	31	135	67	95	208	249	129	0	0	14	**974**
1996	69	4	165	67	158	168	293	211	129	7	4	9	**1284**
1997	38	0	18	79	36	138	277	208	121	45	47	0	**1007**
1998	50	40	37	51	87	222	241	220	138	70	2	0	**1159**
1999	5	0	8	27	62	128	197	176	84	107	0	0	**793**
2000	0	0	38	67	126	159	186	202	146	55	27	9	**1015**
2001	1	9	115	27	110	162	268	211	58	15	0	0	**975**
2002	38	17	44	32	35	196	224	176	45	2	0	98	**906**
2003	22	0	104	130	15	178	316	185	62	0	2	2	**1016**
2004	49	2	23	173	22	114	249	199	164	10	0	0	**1007**
2005	63	0	82	127	111	152	264	118	77	3	3	0	**999**
2006	0	25	87	70	68	139	189	111	113	17	0	0	**820**
2007	30	29	29	111	93	167	219	190	85	21	0	0	**976**
2008	20	0	42	25	29	101	133	200	112	72	21	8	**764**
2009	46	0	10	45	54	71	117	207	55	16	3	21	**643**
2010	20	30	85	72	85	143	254	195	102	0	9	25	**1019**
2011	3	2	29	103	95	135	184	148	26	0	10	0	**737**
2012	0	0	0	64	96	115	188	116	65	2	0	7	**651**
2013	11	2	72	69	206	137	79	198	119	26	5	0	**924**
2014	0	47	29	59	89	68	156	239	111	47	12	0	**856**
2015	0	0	21	120	119	111	169	119	108	0	4	0	**771**
2016	48	5	41	237	91	117	309	85	74	14	4	0	**1025**
Mean	**22**	**23**	**54**	**79**	**83**	**136**	**213**	**204**	**106**	**25**	**6**	**9**	**961**

Table-A-6: Values of Intensity calculation for study area

TC(min)	It (mm/hrs)					
	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
15	100.12	147.39	188.19	232.38	250.33	268.14
30	88.89	125.98	167.11	182.11	199.24	224.29
45	75.56	116.45	160.65	161.98	170.38	208.72
60	66.89	100.18	161.47	150.74	157.62	164.44
75	54.67	77.58	149.50	123.43	129.32	135.17
90	44.56	64.97	191.26	88.25	103.43	118.58
105	36.45	45.78	138.07	58.35	69.01	83.63
120	18.32	30.89	135.57	39.29	45.53	49.75
135	13.09	19.39	23.56	28.82	32.73	36.61
150	12.16	18.01	21.88	26.78	30.41	34.01
165	11.38	16.85	20.47	25.05	28.45	31.82
180	10.71	15.86	19.27	23.58	26.77	29.94
195	10.13	14.99	18.22	22.29	25.31	28.31
210	9.61	14.24	17.30	21.17	24.04	26.89
225	9.16	13.57	16.49	20.17	22.91	25.62
240	8.76	12.97	15.76	19.28	21.90	24.49
255	8.39	12.43	15.10	18.48	20.99	23.47
270	8.07	11.94	14.51	17.76	20.16	22.55
285	7.77	11.50	13.97	17.10	19.42	21.72
300	7.49	11.10	13.48	16.50	18.73	20.95
315	7.24	10.72	13.03	15.94	18.10	20.25
330	7.01	10.38	12.61	15.43	17.52	19.60
345	6.79	10.06	12.23	14.96	16.99	19.00
360	6.60	9.77	11.87	14.52	16.49	18.44
375	6.41	9.49	11.53	14.11	16.03	17.93
390	6.24	9.24	11.22	13.73	15.59	17.44
405	6.07	9.00	10.93	13.37	15.19	16.99
420	5.92	8.77	10.66	13.04	14.80	16.56
435	5.78	8.56	10.40	12.72	14.45	16.16
450	5.64	8.36	10.15	12.42	14.11	15.78
465	5.51	8.17	9.92	12.14	13.79	15.42
480	5.39	7.99	9.70	11.87	13.48	15.08
495	5.28	7.82	9.50	11.62	13.20	14.76
505	5.21	7.71	9.37	11.46	13.01	14.56
520	5.10	7.55	9.18	11.23	12.75	14.26
535	5.00	7.40	9.00	11.01	12.50	13.98
550	4.90	7.26	8.82	10.80	12.26	13.71
565	4.81	7.13	8.66	10.59	12.03	13.46
580	4.72	7.00	8.50	10.40	11.81	13.21
595	4.64	6.87	8.35	10.22	11.60	12.98
610	4.56	6.75	8.21	10.04	11.40	12.75
618	4.52	6.69	8.13	9.95	11.30	12.64

Table –A-7: Inverted elevation of each Junction and Dimension of conduit

No	Name of Junction	Elevation of Junction	Max Depth of Junction	Inverted Elevation of Junction
1	J1	2308	0.55	2307.45
2	J2	2310	1.40	2308.6
3	J3	2308	0.55	2307.45
4	J4	2304	0.90	2303.1
5	J5	2298	0.40	2297.6
6	J6	2298	0.90	2297.1
7	J7	2296	0.80	2295.2
8	J8	2296	0.30	2295.7
9	J9	2300	0.60	2299.4
10	J10	2300	0.70	2299.3
11	J11	2304	0.55	2303.45
12	J12	2298	0.66	2297.34
13	J13	2298	0.70	2297.3
14	J14	2296	0.80	2295.2
15	J15	2268	0.40	2267.6
16	J16	2264	0.30	2263.7
17	J17	2264	0.50	2263.5
18	J18	2264	0.50	2263.5
19	J19	2264	0.30	2263.7

NO	Name of Conduit	Depth of conduit(m)	Width of conduit (m)	Length of Conduit (m)
1	C1	0.50	0.6	40.11
2	C2	0.50	0.6	148.12
3	C3	0.68	0.55	109.86
4	C4	0.68	0.55	104.85
5	C5	0.90	0.95	45.32
6	C6	1.00	0.95	127.36
7	C7	0.90	0.95	44.06
8	C8	0.80	0.83	538
9	C9	0.65	0.6	378.87
10	C10	0.75	0.9	75.61
11	C11	0.40	1	146.56
12	C12	0.70	0.78	656.75
13	C13	0.38	0.8	312.72
14	C14	0.52	0.7	754.4
15	C15	0.70	1.16	308.98
16	C16	0.76	0.9	201.94
17	C17	0.82	0.68	195.4
18	C18	0.80	0.6	101.74
19	C19	0.85	0.65	32.94

Table -A-8: Outlier Test (Testing outliers of maximum daily rainfall data (data screening))

No	Year	Maximum Daily Precipitation (mm) Sebeta town	Log y	y-Y	(y-Y)^2	(y-Y)^3
1	1990	40	1.60	-0.05	0.00	0.00
2	1991	52.4	1.72	0.06	0.00	0.00
3	1992	55.6	1.75	0.09	0.01	0.00
4	1993	116.3	2.07	0.41	0.17	0.07
5	1994	55.4	1.74	0.09	0.01	0.00
6	1995	151.4	2.18	0.53	0.28	0.14
7	1996	50.2	1.70	0.05	0.00	0.00
8	1997	50.9	1.71	0.05	0.00	0.00
9	1998	35.3	1.55	-0.11	0.01	0.00
10	1999	23.3	1.37	-0.29	0.08	-0.02
11	2000	38.1	1.58	-0.07	0.01	0.00
12	2001	33.1	1.52	-0.14	0.02	0.00
13	2002	58.6	1.77	0.11	0.01	0.00
14	2003	58.2	1.76	0.11	0.01	0.00
15	2004	60.2	1.78	0.12	0.02	0.00
16	2005	52.1	1.72	0.06	0.00	0.00
17	2006	46.1	1.66	0.01	0.00	0.00
18	2007	28.8	1.46	-0.20	0.04	-0.01
19	2008	38.8	1.59	-0.07	0.00	0.00
20	2009	52.1	1.72	0.06	0.00	0.00
21	2010	30.2	1.48	-0.17	0.03	-0.01
22	2011	29.5	1.47	-0.19	0.03	-0.01
23	2012	35.3	1.55	-0.11	0.01	0.00
24	2013	33.6	1.53	-0.13	0.02	0.00
25	2014	35.1	1.55	-0.11	0.01	0.00
26	2015	43.6	1.64	-0.02	0.00	0.00
27	2016	34.3	1.54	-0.12	0.01	0.00

Table-A-8: Values of Manning coefficient

Type of Channel and Description	Minimum	Normal	Maximum
EXCAVATED OR DREDGED			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense Weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Backhoe-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2 Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
NATURAL STREAMS			
1 Minor streams (top width at flood stage < 30 m)			
a. Streams on Plain			
1. Clean, straight, full stage, no rims or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8 Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravel, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
2 Flood Plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050

Type of Channel and Description	Minimum	Normal	Maximum
b. Cultivated area			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of spouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
3 Major Streams (top width at flood stage > 30 m). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
a. Regular section with no boulders or brush	0.025	--	0.060
b. Irregular and rough section	0.035	--	0.100
4 Various Open Channel Surfaces			
a. Concrete	0.012-	0.020	
b. Gravel bottom with:			
Concrete	0.020		
Mortared stone	0.023		
Riprap	0.033		
c. Natural Stream Channels			
Clean, straight stream	0.030		
Clean, winding stream	0.040		
Winding with weeds and pools	0.050		
With heavy brush and timber	0.100		
d. Flood Plains			
Pasture	0.035		
Field Crops	0.040		
Light Brush and Weeds	0.050		
Dense Brush	0.070		
Dense Trees	0.100		

Table-A-9: Link discharge calculation by manning equation

No	Name of conduit	W (m)	L (m)	A (m2)=LW	d (m)	P(m) =B+2h	R=A/P	S	$R^{2/3}$	$S^{1/2}$	$R^{2/3}*S^{1/2}$	(V)=1/n $R^{2/3}S^{1/2}$	Discharge (Q)= AV
1	C1	0.6	40.11	0.3	0.5	1.6	0.19	0.017	0.328	0.132	0.043	2.164	0.65
2	C2	0.6	148.12	0.3	0.5	1.6	0.19	0.012	0.328	0.110	0.036	1.806	0.54
3	C3	0.55	109.86	0.374	0.68	1.91	0.20	0.015	0.337	0.121	0.041	2.035	0.76
4	C4	0.55	104.85	0.374	0.68	1.91	0.20	0.014	0.337	0.120	0.040	2.017	0.75
5	C5	0.95	45.32	0.855	0.9	2.75	0.31	0.015	0.459	0.124	0.057	2.852	2.44
6	C6	0.95	127.36	0.95	1	2.95	0.32	0.015	0.470	0.122	0.057	2.869	2.73
7	C7	0.95	44.06	0.855	0.9	2.75	0.31	0.011	0.459	0.107	0.049	2.444	2.09
8	C8	0.83	538	0.664	0.8	2.43	0.27	0.010	0.421	0.099	0.042	2.090	1.39
9	C9	0.6	378.87	0.39	0.65	1.9	0.21	0.008	0.348	0.090	0.031	1.574	0.61
10	C10	0.9	75.61	0.675	0.75	2.4	0.28	0.007	0.429	0.081	0.035	1.745	1.18
11	C11	1	146.56	0.4	0.4	1.8	0.22	0.007	0.367	0.083	0.030	1.515	0.61
12	C12	0.78	656.75	0.546	0.7	2.18	0.25	0.005	0.397	0.068	0.027	1.343	0.73
13	C13	0.8	312.72	0.304	0.38	1.56	0.19	0.006	0.336	0.080	0.027	1.344	0.41
14	C14	0.7	754.4	0.364	0.52	1.74	0.21	0.005	0.352	0.068	0.024	1.192	0.43
15	C15	1.16	308.98	0.812	0.7	2.56	0.32	0.006	0.465	0.080	0.037	1.871	1.52
16	C16	0.9	201.9	0.684	0.76	2.42	0.28	0.005	0.431	0.070	0.030	1.515	1.04
17	C17	0.68	195.4	0.5576	0.82	2.32	0.24	0.005	0.387	0.072	0.028	1.383	0.77
18	C18	0.6	101.74	0.48	0.8	2.2	0.22	0.005	0.362	0.070	0.025	1.270	0.61
19	C19	0.65	32.94	0.5525	0.85	2.35	0.24	0.006	0.381	0.078	0.030	1.484	0.82

B-FIGURES

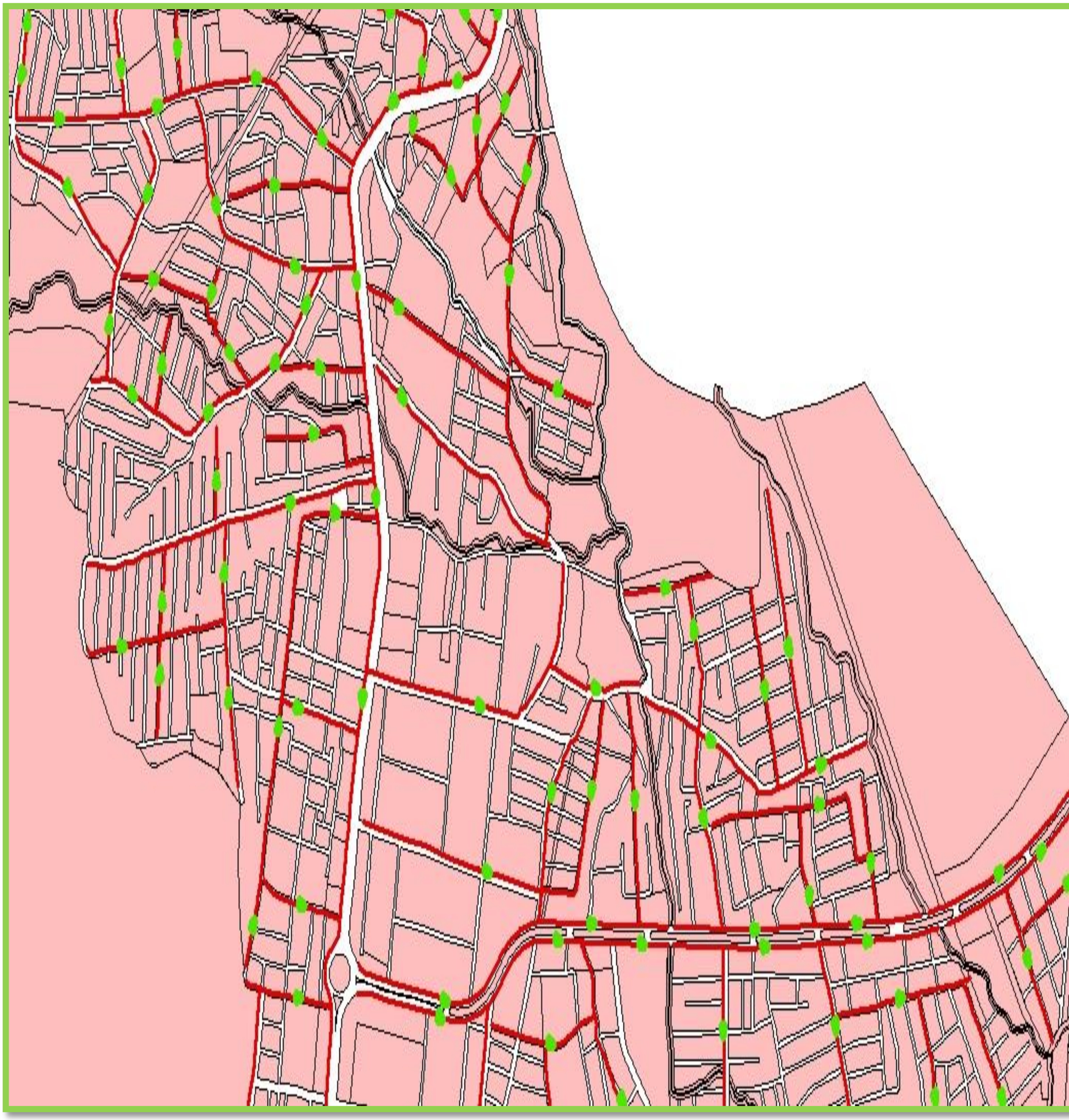

Figure –B-1: Direction of flow along drainage line