ADDIS ABABA UNIVERSITY

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Graduate Studies Program

School of Civil and Environmental Engineering

Water Supply and Environmental Engineering Chair

Impact of Flood in Urban Drainage System and Identifying Cause of Storm Water Flooding: - The Case of Gurd Shola Area, Addis Ababa, Ethiopia

By:

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Addis Ababa,

Ethiopia

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A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Master of Science in Water Supply and Environmental Engineering.

Advisor: Dr. Mebruk Mohammed

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LIST OF ABBREVIATIONS

AAU.......................... Addis Ababa University

DEM.......................... Digital elevation model

GIS............................ Digital elevation model

LULC........................ Land use Land covers

HRU.......................... Hydraulic response unit

UDS...........................Urban drainage system

Br...............................Birr

O&M.........................Operation and Maintenance

AACRA.................... Addis Ababa City Road Authority

AAWSA......………..Addis Ababa Water and Sewerage Authority

ABSTRACT

Disasters like flooding have changed dimensions of urban areas. The urban flooding in cities is mainly in the form of flash floods and water logging of streets due to high intensity short spell rainfall. But the levels of damage to these disasters have increased over time in the urban areas because of increased rainfall runoff volume. However, it is clearly evident that different level of exposure and different extents of flood hazard characteristics vary the urban flood risk nature from city to city. Addis Ababa is one of the fastest growing cities in Africa and urbanization is known to increase the amount of runoff generated from the urban catchment. Due to urbanization and lack of proper design and management, the city's' transport infrastructure has experienced frequent flooding.

The objective of this research is to identify the drainage condition of Gurd shola area, which is one of the villages found in in Addis Ababa with respect to the hydrology, hydraulic and operation and maintenance features. In this study, the impacts of important factors on flooding in urban drainage system of Gurd Shola area were evaluated using primary and secondary data collection systems. For the analysis of rainfall data and their probability distribution Gumbel and log Pearson's III distribution statistical methods were used. In order to see the impact, runoff coefficient for different time interval year 2004 and 2019 was used and also the rainfall intensities for different duration was analyzed for a period of 1988-2017.

The rational formula and Bentley Civil Storm software were used to compute the peak flood estimation for (T= 10 years) and to determine the hydrological peak flow respectively. The analysis from the frequency distribution indicates that Gumble Extreme Value distribution was to be a good fit. The finding of the study shows that, the flooding problem mainly arises due to improper cleaning and storm water management. Slops also should be clearly checked in order avoid unwanted storm water accumulation on the road surface.

Key words: Urban drainage, Storm water, hydraulic, hydrology, flooding

1. INTRODUCTION

1.1. Background

The hydrologic cycle, often called water cycle, is one of the main components of the planetary system regulating human, animal and plant life. Therefore, the stability of water cycle is critical for the sustainability of biological populations and ecosystem. In general, climate is characterized by meaningful seasonality assessed through temperature, precipitation, wind movement, isolation, etc. Generally, climate features a steady picture of the terrestrial system (Mekonnen H. Daba et al., 2018).

Drainage is an integral part of different areas or environment (e.g. urban, rural, forest, and agriculture etc.) which helps to remove unwanted water volume (Parkinson, 2003). Here, urban drainage includes the removal of unexpected water from urban areas (i.e., domestic and industrial wastewater) along with sewerage, grey-water, heavy rainfall, and storm water (Laskar, 1996). Inversely, most of the drainages in the rural areas are related to road drainage that is designed to shed water into roadside ditches. Improper land-use planning of cities, which increase the extent of impervious land, aggravates this problem by increasing the runoff intensity. Storm water drainage systems, designed for inadequate capacity, also increases the chances of urban flooding.(Kumar, 2018)

Therefore, implementing effective storm water management system is needed aiming to ensure storm water generated from developed catchments causes minimal nuisance, danger and damage to people, property and the environment. This requires the adoption of a multiple objective approach, considering issues such as ecosystem health, both aquatic and terrestrial; flooding and drainage control; public health and safety; economic considerations; recreational opportunities; social considerations and aesthetic values (Urban drainage manual, 2007)

All cities and towns in world have their own urban drainage system (UDS) while developed countries have well-designed UDS adaptive to climate change situation (i.e. heavy rainfall and flood), developing countries UDS is poor in quality and incapable to remove sudden extensive water flow (Bishop, 1968). However, strong floods also bring substantial risk to lives and livelihoods.

Flooding is the most frequent and damaging of all natural hazards. Since 1980, the reported direct economic losses are well in excess of $1.6 trillion in the period 1980–2015, and more than 225,000 people have lost their lives (Ewnetu, 2013).

Ethiopia is one of the country in which flooding is the main problem. Service life of infrastructure can be highly reduced by improper drainage system. It can be seen from rainy season which lasts from July to September where the highways are covered by surface water. This water accelerates the deterioration rate of the roads and results in economic loss. The flooding of the highways is the result of improper drainage system of the roads and poor integration of road and urban storm water drainage network (Ewnetu, 2013).

Despite the fact that, overall development of a nation, particularly in road sector, the practice of the construction of proper integrated drainage structures did not get due attention in our country. Therefore, the problems and achievements on the design, construction, and maintenance of surface road drainage systems need to be assessed to provide remedial measures for the better performance of the road infrastructure. Insufficient urban storm water drainage facility represent one of the most common sources of compliant from the citizens in many towns of Ethiopia and this problem is getting worse and worse with the ongoing high rate of urbanization in different parts of the country, especially in Addis Ababa (Adugna, 2015).

Thus, the focus of this study is to review and asses the drainage problem of the study area "Gurd Shola" using both primary and secondary data collection. ArcGIS 10.1 was used to delineate the area and prepare different spatial maps for the study. As well Bentley civil storm is used to calculate the hydrology and hydraulics characteristics of the drainage system. The study also incorporate in assessing the existing drainage system, identifying the major factors contributing to the flooding, investigating impacts of drainage system, and finally formulating strategies and providing solutions through which the identified problems shall be addressed.

1.2. Statement of the Problem

Climate change and urbanization are two phenomena that are now playing an important role in the development of infrastructure in urban areas. In many developing countries around the world, urban growth has taken place in such a way that resources to meet the demand for water and sanitation suffer from excessive pressure (UNDESA, 2013). According to (Barry and Fabian, 2000) urban drainage systems are closely related to weather phenomena. Drainage systems undergo problems or see increased numbers of problems when a weather event changes as a consequence of changes in the global mean temperature, resulting in urban flooding.

Flooding in urban storm sewer systems could cause loss of life and considerable damage as well as posing a threat to property and environment and public health. Many inner sub cities in Addis Ababa have been exposed to flooding for a number of reasons including poor maintenance of storm sewer systems and outmoded and limited capacity of storm systems with reference to examples of strong rain which cause blockages in pipe, electrical issues, sever traffic congestion, and numerous operational problems. The daily use of storm sewer systems has rapidly resulted in outdated systems because of large variations in urban land use, rising growth in population, and changing rainfall patterns. The issue of storm sewer modeling is now one of the most dynamic areas in hydraulics and hydrology study. This research tried to identify the main reason behind flooding in Gurd Shola area and showed the larger picture at country scale by assessing the hydraulic properties, hydrological characteristics of the drainage in line with operation & maintenance checked to identify the main contributing factor for the flooding problem. It is important to identify the various factors that influence the causes for flooding. The aforementioned scientific outlooks and direct assessment along the main road and Light rail way (LRW), there is a common flooding problem which creates a sever traffic congestion especially in rainy season from July to September. The flooding does also affect the asphalt pavement by eroding & creating a number of potholes and this will result in longer period impact even after a rain. Besides, the traffic congestion & car accidents, it hinders the movement of pedestrians as the flood flows over the walk way. Gurd Shola is one of the sites that have flooding problem in Addis. Addis Ababa City Road Authority (AACRA) is the responsible body for managing, repairing and maintaining the roads in the city. The authority is investing a lot of money for maintaining pothole damages caused by flooding and cleaning blocked drainages. However, the problem remains the same every year.

1.3. Objective of the study

1.3.1. General Objective

The general objective of this study is to identify the cause of flooding either due to hydraulic property or hydrological characteristics of the storm water to the specified area and find proper engineering solution.

1.3.2. Specific objectives

- ❖ To identify the possible hydraulic reasoning behind flooding in the stated area.
- ❖ To identify the possible hydolgical reasoning behind such flooding in the stated area.
- ❖ To identify the possible operation and maintenance reasoning for flooding in the study area.
- ❖ To identify which cause is significant (O & M, hydraulic, hydrological or all together) and find remidal engineering solution for the problem identifed.

1.4. Research Question

- ❖ Has roughness of conduit property play a role for the cause of flooding in Gurd Shola area?
- ❖ Is land use change a reason for flooding in the stated area?
- ❖ What will be the impact of operation and mantenance for flooding in the study area?
- ❖ Which one is the most important influencing factor for flooding in Gurd Shola area?

1.5. Significance of the study

The study is geographically bounded to Gurd Shola area yeka sub-city Addis Ababa Ethiopia. Study area is choosen due to the fact that a lot of settlemet has been there passing through the road, sensetivety due to roads from “Lamberet to Kotebe” is on construction and flooding is occurred in short period after the road is completed. The paper identify the possible cuse of the drainage problem of the mentioned study area and give engineering and scientific explanations for the cause and suggest for future solution. The study doesn’t include structural design.

1.6. Thesis outline

The thesis is divided in to five chapters as outlined below

Chapter 1 Introduction: this chapter deals with an introduction about hydrologic cycle what we called water cycle, urban drainage system, flooding and it's consquence to human life and also to the environment. The determination for this study was described in the statement of problem part and the general as well as specific objectives of the study were also covered.

Chapter 2 Literature Review: this chapter devoted to describe the relevant research works that have been done by previous researchers. The effects of different factors on the process have been discussed in conjuction with the materials and methodologys which were employed. Overall, this chapter is dedicated in appraising and highlighting previous study and providing theoretical framework for this study.

Chapter 3 Materials and Methods: presents the data acquisition and processing used in this project to achieve the objectives compared to the previous researches. All experiments in this study were designed explicitly. Details of each experiment work, including data collection and preparation, qualitative analysis.

Chapter 4 Results and Discussion : this chapter details the model processe studies for the data calibration and validation.

Chapter 5 Conclusion and Recommendations: draws conclusion and provides recommendation for future research investigations in this filed.

2. LITERATURE REVIEW

2.1. History of Urban Drainage System

The practice of urban drainage system has been traced back to some hundred years ago. The efficient conveyance of storm water from urbanized areas was motivated primarily by reasons of convenience and the reduction of flood damage potential. Such practices which were aimed to improve the quality of urban life have resulted in other problems, such as artificially induced flooding, increased erosion and environmental degradation originating from the pollution of receiving waters. As a result, attention has given to the comprehensive management of urban drainage systems including the implementation of storage and treatment facilities. The objective of such practice was to effectively utilize components of drainage systems for the betterment of urban life and to protect the environment in a cost-effective manner. To facilitate the effective management of the complex natural elements and engineering works, mathematical modeling is often employed to better understand system behavior and performance which in turn leads to better engineering and Management decisions. Generally, storm water management lies near the heart of basic landscape architecture and engineering. Professional ethics enforces every practitioner to integrate storm water and meaningfully with every community and ecosystem (Barry and Fabian, 2000). Essentially all site developments, of all kinds, involve impervious and compacted surfaces. The change in land cover increases runoff over the surface, dumps flood waters in to streams, reduces ground water recharge, diverts water from base flows, and turns oils from the streets to pollutants. That is urban storm water drainage system has started to prevent the environment and the human health from various flooding hazards by safely removing floods.

Natural hydrological processes would have prevailed; there might have been floods in extreme conditions, but these would not have been made worse by human alteration of the surface of the ground. Artificial drainage systems were developed as soon as humans attempted to control their environment. Archaeological evidence reveals that drainage was provided to the buildings of many ancient civilizations such as the Mesopotamians, the Minoans (Crete) and the Greeks (Athens). Historical accounts show that the objectives of the drainage systems were to collect rainwater, prevent flooding, and convey wastes. At the time, planning and design were limited, people used to able to find the systems that met their objectives after trial-and-error modifications. Despite the lack of optimization and the use of trial-and-error construction methods, numerous ancient urban drainage systems can be rated very successful (Elias, 2015).

2.2. Hydraulic impacts on urban drainage systems

The design and operation of an urban drainage system is closely associated with the rainfall characteristics of the local urban area, especially the intensity and amount of rainfall. The increasing global mean temperature has been a concern for several years, as the hydrological cycle intensifies accordingly, and a larger number of heavy precipitation (k.Berggren et al., 2008). When assessing the impact of climate change, especially precipitation changes, on a city through the urban drainage system, some problems need to be taken into account. Two of the main problems are (1) the type of input rainfall data used for model simulation to represent changes in the future and (2) how the urban drainage impacts should be measured to reflect and accurately describe the event and system characteristics.

2.3. Effectiveness of Hydraulic and Hydrologic parameters in storm sewer system

Flooding in urban storm sewer system could cause loss of life and considerable damage and also posing a threat to property and the environment and public health (S.TAshley and W.SAshley, 2008). City flooding during heavy precipitation is considered a natural phenomenon. Urban flooding can be simulated by a two-dimensional flow model depending on ground elevation, land use, and type of soil; all these parameters have a large impact on the degree of surface runoff (Lee.S et al., 2016).

Efficient drainage of the rain network has a strong connection with the length of drain and time of concentration of sub catchment affecting velocity and peak runoff discharges. Urbanization also impacts hydrology, which is typically characterized by raising the values of peak flooding and reducing the time lag thus causing an increase in runoff volume (Fread L Ogaden et al., 2011).

2.4. Existing Storm Water Drainage Condition of Addis Ababa

The pattern of urbanization and modernization in Ethiopia has increase along with urban infrastructure development. The combined effect of this results in higher rain drop intensity and consequently accelerated and concentrated runoff. Inadequate integration between road and urban storm water drainage infrastructure provision and poor management, significant proportion of the study area is exposed to flooding hazards/risks. This has resulted in negative impacts on urban storm water drainage provision and management. The major causes of flooding was found to be the blockage of urban storm water drainage lines along with inadequate/poor integration between road and urban storm water drainage infrastructures. (Adugna, 2011), recommended improvement in the integration of road and urban storm water drainage infrastructure and integrated solid waste management to prevent over flowing of flood as a result of blockage of drains.

2.5. How Urbanization Affects the Water Cycle

The water cycle, also known as the hydrological cycle, is the continuous exchange of water between land, water bodies, and the atmosphere. The world's total water resource estimated as 1.36 x 108 M ha-m. Of these global water resources, about 97.2% is salt water mainly in oceans and only 2.8% is available as fresh water at any time on the planet earth (Raghunath, 2006). Impervious surfaces associated with urbanization alter the natural amount of water that takes each route as topography of land changes by urbanization. In highly urbanized areas, over one-half of all rain becomes surface runoff, and deep infiltration is only a fraction. The increased surface runoff requires more infrastructures to minimize flooding. Scientific measures need to be considered in order to sustain the water cycle while urbanization is taking place (Raghunath, 2006).

2.6. Impact of Urbanization on Rainfall- Runoff Processes

Urbanization is an important index to reflect the development level of a country, but it is enhances the interaction between human society and the environment. The unbalance of the water conservancy facilities transformation and the rapid urban development resulted in considerable urban water problems. Urbanization increases the risk of flooding due to increased peak discharge and volume, and decreased time to peak that restricted the development of cities. In highly urbanized areas, over half of rainfall becomes surface runoff, and deep infiltration is only a small fraction of natural situation (Brun S.E and L.E, 2011). However, some researchers did not found significant changes in runoff coefficients in an urbanized catchment. Rainfall-runoff process is known to be related to complex factors in urban, such as land use/cover, river network morphology, construction of drainage system and water transfer. The complexity of underlying surface, the uncertainty of anthropogenic disturbance, and lack of high quality datasets for calibration and validation may limit research for the rainfall-runoff processes in an urban catchment (Guan Mingfu et al., 2015).

2.7. Causes and Consequences of Flooding

According to (Mulugeta, 2016) and (Sinafikish, 2013), floods are caused by many factors such as heavy rainfall, highly accelerated snowmelt, severe winds over water, unusual high tide, tsunamis, or failure of dams, levees, retention ponds, or other structures that retained the water. In other way, flooding can be exacerbated by increased amounts of impervious surface or hard ground cover that not allow the water to pass thorough as well as by other natural hazards such as wildfires, which reduce the supply or the amount of vegetation cover that can absorb rainfall.

(Mulugeta, 2016) indicated that floods can occur due to meteorological, partly meteorological or other causes, which can exacerbate the occurrence of flooding. Meteorological causes include snowmelt, rain, and combination of rain and ice melt. Coastal storm surges and estuarine interactions between stream flow and tidal conditions entail the partly meteorological causes. The remaining causes of floods can be attributed to other natural hazards such as earthquakes, landslides, Tsunamis and hurricanes or human-caused (technological) hazards such as dam breaks, fail levees, dykes, weirs and terraces. The cause of flooding can be described according to the water source, geography of receiving area, cause and the speed of onset. Water source-related floods can originate from the ocean (coastal floods), rivers (fluvial floods), from underground (groundwater floods) and from rain (pluvial floods). These major flood types will each be described in terms of its geography, cause, and onset speed.

Climate change and increasing need for dwellings and industrial properties have a tendency to increase the risk of flooding, and many development activities which are situated in flood plains can increase the risk and impacts of flooding(Elliott and Leggett, 2002). It is generally accepted that many land use change practices or changes in land use patterns such as expansion of settlements including road construction, deforestation, and different practices in arable and grassland management have a great contribution to increase the frequency and severity of flooding. Land use and land cover changes have different effects on the local hydrological cycle depending on the nature of the land use cover that existed and that one which results after the changes(A.Wahren et al., 2009). According to (Sinafikish, 2013), land use is being dynamically shaped under the influence and interaction of two broad sets of forces human needs and environmental features and processes. Land use occurs as a result of natural process such as climatic variation, volcanic eruptions, change in river channels or the sea levels, etc. However, most of the land cover changes of the present and the recent past are due to human actions or intervention to using of the land for production or settlement. This is because of the different socio-economic drivers including demographic, social, economic, technological, market, political and institutional factors and their processes. There are two major aspects that connect land use and flooding. The first one is the location or existence of values and key components of the economy on flood plains provides economic benefits and at the same time creates risks for the society in terms of flood loss potential. Secondly, the development of land through different construction activities has consequences on the flow of water on the one hand, either by accelerating runoff through reducing the infiltration capacity of soils or obstructing the natural drainage system as well as sediment and pollutants on the other hand. In general, human alterations of the catchment area can significantly contribute to changes to all those processes that are the hydrological processes through large scale land use changes and land use practices In addition to this, with increasing human alteration and development of the catchment area, the runoff generation process is changed, especially through decreasing the infiltration capacity of the soil and the change of soil cover. This has led to a great concern over human beings which play a great role in increasing flood hazards through the alterations of the catchments(WMO, 2009). Likewise, (Tan, 2011), cited in (Sinafikish, 2013), clearly stated about the relationship between land use change and flooding: 'Catchment land use/land cover changes influence the condition for transformation of precipitation into runoff by expanding impervious surfaces which lead to decrease infiltration rate and consequently increase the amount and rate of runoff'.

The other important factor that causes flooding is the absence of land use policy. (WMO, 2007), cited in (Sinafikish, 2013), stated that, land use policies and regulations play an important role in catchment management and in reducing the risk due to flooding. But, due to the absence of such policy, there may be human intervention in the catchment that affects the hydrological process including illegal settlement and other restricted activities. Flooding has serious implications on the infrastructure, people and economy. That is, the adverse effects of floods often involve far reaching socio-economic and environmental consequences including loss of life and property; mass migration of people and animals; environmental degradation; and shortages of food, energy, water and other basic needs.

According to (Lucena. Vanessa et al., 2006), cited in (Sinafikish, 2013), flooding has both direct and indirect consequences. The direct impacts of flooding concerns when damages caused by the physical contact of floodwaters or when peoples or objects directly affected by the floodwater. In addition to this, as (Zein, 2010), stated that, the direct losses of flooding include fatalities, injuries homelessness, collapse of buildings and infrastructures, sedimentation, pollution and so on. While, indirect losses include diseases, psychological impact, short and long-term economic loss and so on. As shown in Figure 2.1, human casualties, economic loses; infrastructural damage and adverse environmental impacts are worth mentioning in this regard.

2.8. Flood Risk and type

Flooding, defined as the inundation of predominantly dry land, has occurred ever since water bodies existed on this planet. As societies around the world developed, human presence increasingly intersected with this phenomenon. Currently, the most densely populated and rapidly developing areas are located near rivers or on deltas at the coast. Combined with increasing sea levels and possible changes in rainfall intensity due to climate change, flooding has evolved into the most frequent and damaging natural hazard that people face today (Brenden Jongman et al., 2018) Some of flooding types are discussed in section below.

Pluvial Flooding

Pluvial flooding is flooding that occurs due to very local rainfall. Most cases of pluvial flooding can be observed in low-lying, flat polder areas and urban centers. Within cities, the occurrence of pluvial flooding heavily depends on two main things. The first element includes the amount of urbanization and the capacity of the soil to absorb rainfall (the degree of accommodation to handle local rainfall by either conveying the floodwater downstream with drainage and sewerage infrastructure or temporarily storing it in storage ponds or underground sewerage basins)

Coastal Flooding

A Coastal Flooding, as the name suggests, occurs in areas that lie on the coast of sea, ocean, or other large body of open water. It is typically the result of extreme tidal conditions caused by severe weather. Extreme water levels and flooding along the coast occur due to high tides, storm surges, high waves, or a combination of these. A storm surge is a rise in the sea surface caused by storms with low-pressure and strong winds, like extra tropical cyclones or tropical cyclones, such as hurricanes and typhoons. Coastal flooding is categorized in three levels:

- **Minor:** A slight amount of beach erosion will occur but no major damage is expected.
- **Moderate:** A fair amount of beach erosion will as well as damage to some homes and businesses.
- **Major:** serious threat to life and property. Large-scale beach erosion will occur, numerous roads will be damaged. Citizens should review safety precautions and prepare to evacuate if necessary.

Flash floods

Flash floods are fast-moving waters that sweep everything in their path. They are caused by heavy rainfall or rapid snow thaw. It happens when the ground cannot absorb the water as quickly as it falls. This type of flood usually subsides quickly, but while it lasts can be fast-moving and dangerous. Flash floods usually cover a relatively small area and occur with little to no notice, generally less than six hours. The rapid water torrents can move large objects such as cars, rocks, and trees.

River floods

River floods is one of the most common types of inland flood; occurring when a body of water exceeds its capacity. River flood is characterized by gradual riverbank overflows caused by extensive rainfall over an extended period of time. The areas covered by river floods depend on the size of the river and the amount of rainfall. River floods rarely result in loss of lives but can cause immense economic damage.

Urban floods

Urban floods occur when the drainage system in a city or town fails to absorb the water from heavy rain. The lack of natural drainage in an urban area can also contribute to flooding. Water flows out into the street, making driving very dangerous. Although water levels can be just a few inches deep, urban floods can cause significant structural damage.

Groundwater flood

As opposed to flash floods, groundwater flooding takes time to occur. As rain falls over an extended period the ground becomes saturated with water until it cannot absorb any more. When this happens, water rises above the ground's surface and causes flooding. This type of flooding can last for weeks or sometimes even months.

Drain and Sewer flooding

Sewer floods are not always attributed to the weather. As well as rainfall, they could occur as a result of a blockage or similar failure within the drainage system. Drain and sewer flooding may be internal (within a building or external).

2.9. Managing urban flood

The ultimate aim of integrated urban flood risk management is to minimize human loss and economic damages, while making use of the natural resources for the benefit and wellbeing of the people however it is realized that absolute flood security is in most cases utopian. Flood risks cannot be entirely avoided, thus they have to be managed. Consequently, flood management does not strive to eliminate flood risks but to mitigate them. This may be achieved either by reducing flood risks to an acceptable level or by retaining, sharing or transferring flood risks through respective measures. These measures should form part of an integrated risk management process. The basic steps of an integrated management process are:

- ❖ Risk assessment
- ❖ Planning and implementation of measures
- ❖ Evaluation and risk reassessment (WMO/GWP Associated Program on Flood Management, March 2008)

2.10. Storm water

Storm water (surface runoff) is the second major urban flow of concern to the drainage engineer. 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. Reliable data on the quantity and quality of existing and projected storm water flows is a prerequisite for cost-effective urban drainage design and analysis (Butler and Davies, 2004).

2.11. Operation and Maintenance (O&M)

In the past, operation and maintenance (O & M) of urban drainage systems has often been inadequate. The temptation has been to assume that if there were no immediate problems, there was no need to spend money. Yet, drainage systems corrode, erode, clog, collapse and ultimately deteriorate to the point of failure and beyond. Maintenance is needed to maintain the operational function of the system and to extend its working life. Emphasis has now changed from considering sewer networks as liabilities to recognizing them as valuable assets, with O & M needed to maintain a properly performing system.

The major O & M functions are:

- location and inspection
- cleaning and blockage clearance
- chemical dosing
- fabric rehabilitation – repair, renovation or replacement (Butler and Davies, 2004).

2.12. Urban Drainage Model and Selection Criteria

The purpose of models in urban drainage engineering is to represent a drainage system and its response to different conditions in order to answer questions about it, usually in the form 'What if ...?' In a sense, people have been modeling drainage systems all the time they have been using calculations to help them to build systems that would operate successfully. For example, the Rational Method is a simple model of the conversion of rainfall into runoff that can be used to look at the likely effects of different rainfall intensities.

There have always been two main uses for sewer system models: design (of new systems) and analysis (of existing systems). In design, the physical details of a proposed drainage system are determined so the system will behave satisfactorily when exposed to specific conditions. In simulation, the physical details of the system already exist, and the model-user is interested in how the system responds to particular conditions (in terms of flow-rate and depth, and the extent of surcharge and surface flooding (Butler and Davies, 2004).

Storm water modeling tools can be both stand-alone programs with their own graphical user interface or they can be integrated into other software, such as ArcGIS from ESRI, Autodesk's AutoCAD. (Lind,

2015) On table 2-1 a model comparison for some future is shown and for our study Bentley civil storm is selected, it is easy of interface, integration option with ArcGIS, AutoCAD and the circumstance that our study area is small doesn't acquire a more sophisticated software, the aim is to evaluate the existing drainage system, this study find it convenient using the model.

Table 2- 1: Existing storm water modeling tools comparison

Function	Software integration	PCSWMM	XPSWMM	Info Works ICM	MIKE URBAN (SWMM or MOUSE)	Civil Storm
Developer		CHI	XP Solution	DHI	INNOVYZE	Bentley
Combined Hydrologic and Hydraulic Model		Yes	Yes	Yes	Yes	Yes
Input Complexity		Medium/High	Medium/High	High	Medium/High	Medium
Import/Export Connection	GIS	Yes	Yes	Yes	yes	yes
	CAD	Yes	yes	yes	yes	yes
Water system	Storm water	Yes	Yes	Yes	Yes	Yes
	wastewater	Yes	Yes	Yes	Yes	No
	river system	Yes	Yes	Yes	Yes	No
Area of Use	water quality	Yes	Yes	Yes	yes	Yes
	swear system	Yes	No	Yes	Yes	No
	Long term predictions/Single Event	Both	Both	Both	No	No
	Simulation of 1D pipe flow	Yes	Yes	Yes	Yes	Yes

Source: (Lind, 2015) Storm water modeling tools: - a comparison and evaluation

2.13. Calibration and validation of hydrological models

Model calibration is the process of estimating model parameters by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. Model validation involves running a model using input parameters measured or determined during the calibration process (D. N. Moriasi et al., 2007).

After the model has been calibrated evaluation occurs. Hydrological models can be evaluated in many different ways, but it usually involves validation of the prediction performance under changed conditions and sensitivity and uncertainty analysis (Solomatine, 2011).

2.14. Model performance criteria measurements

The process of evaluating the performance of a hydrological forecasting model requires both graphical and numerical analyses of model errors between forecast data and observed data. In doing so model performance check is always a key issue for any hydrological modeling as there is not a single best statistical measure to check the performance of a model's outputs with observed data. There are three non-dimensional and one dimensional measure which are widely used to assess the model performance. These model performance measures are coefficient of determination (R2), Nash-Sutcliffe coefficient of Efficiency (NSE) (Nash and Sutcliffe 1970), Root Mean Square Error (RMSE) and percent of bias (PBAIS), (Suresh Sharma et al., 2015).

The selection and use of a specific performance criterion and the interpretation of the results are very difficult, since each criterion may place a different emphasis on different types of forecast and observed behaviors, and because the selection of an error measure is dependent on the situation, and not on whether one of the error measures was found to be superior on all criteria (Seok Hwan Hwang et al., 2012).As cited on (Seok Hwan Hwang et al., 2012) (Legates and and McCabe, 1999) Concluded that a more complete assessment to model performance should include at least one goodness-of- fit measure, such as the Nash and Sutcliffe Efficiency Coefficient(NSC)(Nash and Sutcliffe 1970), and one absolute error measure, e.g. root mean square error (RMSE).

The performance measures used in this study were the Nash–Sutcliffe efficiency (NSE), root mean square error (RMSE), and the coefficient of determination for linear regression (R2), some of the methods are viewed bellow.

2.14.1 Nash Sutcliffe model Efficiency coefficient

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). Nash-Sutcliffe efficiency indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE = 1, corresponds to a perfect match of the model to the observed data. NSE = 0, indicates that the model predictions are as accurate as the mean of the observed data, Inf < NSE < 0, indicates that the observed mean is a better predictor than the model. NSE was recommended for two major reasons: (1) it is recommended for use by ASCE (1993) and (Legates and and McCabe, 1999), and (2) it is very commonly used, which provides extensive information on reported values. (Servat and Dezetter, 1991) also found NSE to be the best objective function for reflecting the overall fit of a hydrograph.

2.14.2 RMSE (Root Mean Square Error)

The Root Mean Square Error (RMSE) (also called the root mean square deviation, RMSD) is one of the commonly used error index statistics (Singh et al., 2004). Although it is commonly accepted that the lower the RMSE the better the model performance (Singh et al., 2004). RMSE a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled. These individual differences are also called residuals, and the Root Mean Square Error serves to aggregate them into a single measure of predictive power. Root Mean Square Error measures how much error there is between two data sets. In other words, Root Mean Square Error compares a predicted value and an observed or known value.

2.14.3 R^2 (R-squared correlation)

R-squared correlation is an important statistical measure which in a regression model represents the proportion of the difference or variance in statistical terms for a dependent variable which can be explained by an independent variable or variables. In short, R-squared correlation determines how well data is fit the regression model or how well the modeled data is fit to observation data. The coefficient of determination, R2, is similar to the correlation coefficient, R. The correlation coefficient formula will tell you how strong of a linear relationship there is between two variables. R-Squared is the square of the correlation coefficient. For the calculation of R-squared you need to calculate Pearson correlation and then square it[1].

2.14.4 PBIAS (Percent bias)

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 1999). PBIAS was selected for recommendation for several reasons: (1) percent deviation of stream flow volume (Dv) was recommended by ASCE (1993), and

(2) PBIAS has the ability to clearly indicate poor model performance (Gupta et al., 1999). PBIAS values for stream flow tend to vary more, among different auto calibration methods, during dry years than during wet years (Gupta et al., 1999). This fact should be considered when attempting to do a split-sample evaluation, one for calibration and one for validation[1].

([1]https://agrimetsoft.com/)

3. MATERIAL AND METHODOLOGY

3.1. Study Area Description

Addis Ababa was established in late 19^{th} century by Emperor Menelik II and his wife Empress Taitu. Addis Ababa means 'New Flower' in English. Addis Ababa, the capital of Ethiopia, were the attempt of urban planning has begun when the Italian come back after 40 years of their defeated 1896 by Emperor Menelik. Urban planning attempts to prepare a master plan for the City of Addis Ababa were made: by architect Le Corbusier in 1936 and by architects Guidi and Valle in 1938. According to Mahiteme, 2007 the second attempt to prepare a master plan was inspired by the previous work of Le Corbusier and incorporate proposed housing development with residential segregation of natives and Europeans, waste management, road construction and a public transportation system (Yitbarek and Stark, 2018). Many of the major roads that still crisscross the city were built during the period of Italian occupation (PRUNIER and FICQUET, 2014).

Ethiopia is located between 4^0 and 15^0N latitude, 32^0 and 48^0E longitudes. The country has an area of 1,112,000 km^2. The country is naturally endowed with small to large streams that drain from the high plateau areas to the lowlands. Ethiopia has four main weather seasons. Kiremt or Meher (summer) - June, July and August are the summer season. There is heavy rain falls in these three months. Belg (autumn) - September, October and November are the spring season sometime known as the harvest season. Bega (winter) - December, January and February are the dry season with frost in morning especially in January. Tseday (spring) - March, April and May are the autumn season with occasional showers. May is the hottest month in Ethiopia.

Location

Addis Ababa lies 9°1′48″N latitude and 38°44′24″E longitude. The city is located at the heart of the country, at an altitude ranging from 2,100 meters at Akaki in the south to 3,000 meters at Entoto Hill in the North. Gurd Shola located in Yeka sub city which is one of the ten sub-cities of Addis Ababa. Specific study area was bounded from Lambert Menharia upper right, Elfora to the upper and lower left and Gurd Shola Ethio-telecom on lower right. A more detail of the study area is shown on the map here under and Google earth imagery is also presented.

Climate

Since Addis Ababa is located around the equator its temperature stays nearly constant month to month with no more than 10^0 change and a temperate climate due to its high altitude location in the subtropics. Accodring to Köppen climate classification the weather of Addis Ababa is warm and temperate having the average annual temperature 16.3 °C. Precipitation here averages 1143 mm.

Demography

Ethiopia is an ancient country with a very young population and the second-most populous country in Africa, has an estimated population of 94,352,139 million (Agency, 2013) . According to the CSA's 2017 population projection, the majority of Ethiopians reside in rural areas. However, Ethiopia's urban population more than doubled from 4.87 to 11.86 million between 1984 and 2007 and growing at a rate of 3.8% annually, is expected to triple by 2037 (Habitat, 2017) The level of urbanization in Ethiopia currently stands at 19%, low even by sub-Saharan African standards. However, the rate of urbanization is expected to accelerate at about 5% annually (Habitat, 2017). Most of the study area is covered with residential and commercial buildings.

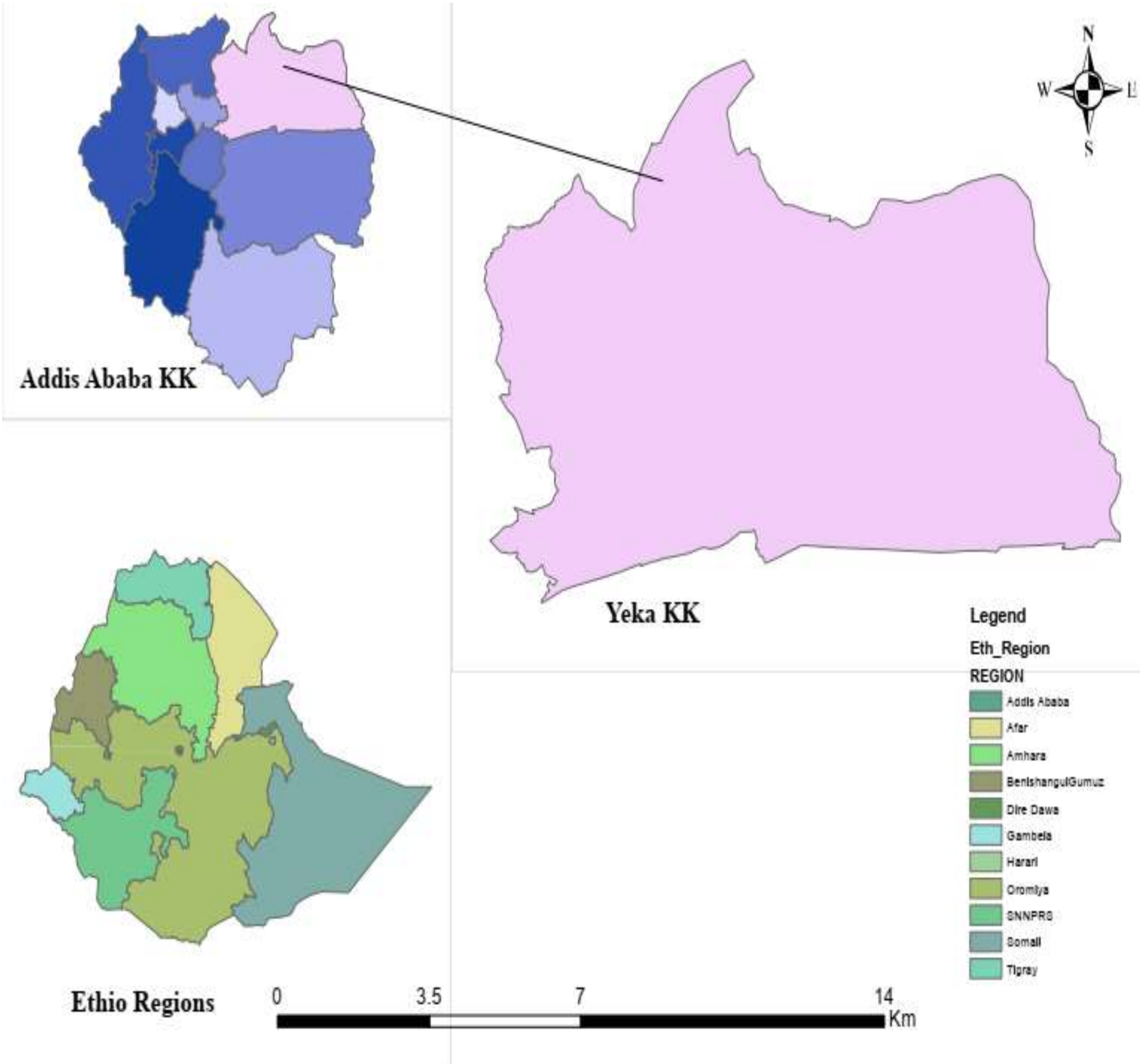

Figure 3. 1 Location map of the study area in the sub city scale

(Source: Ministry of water, irrigation and electric city)

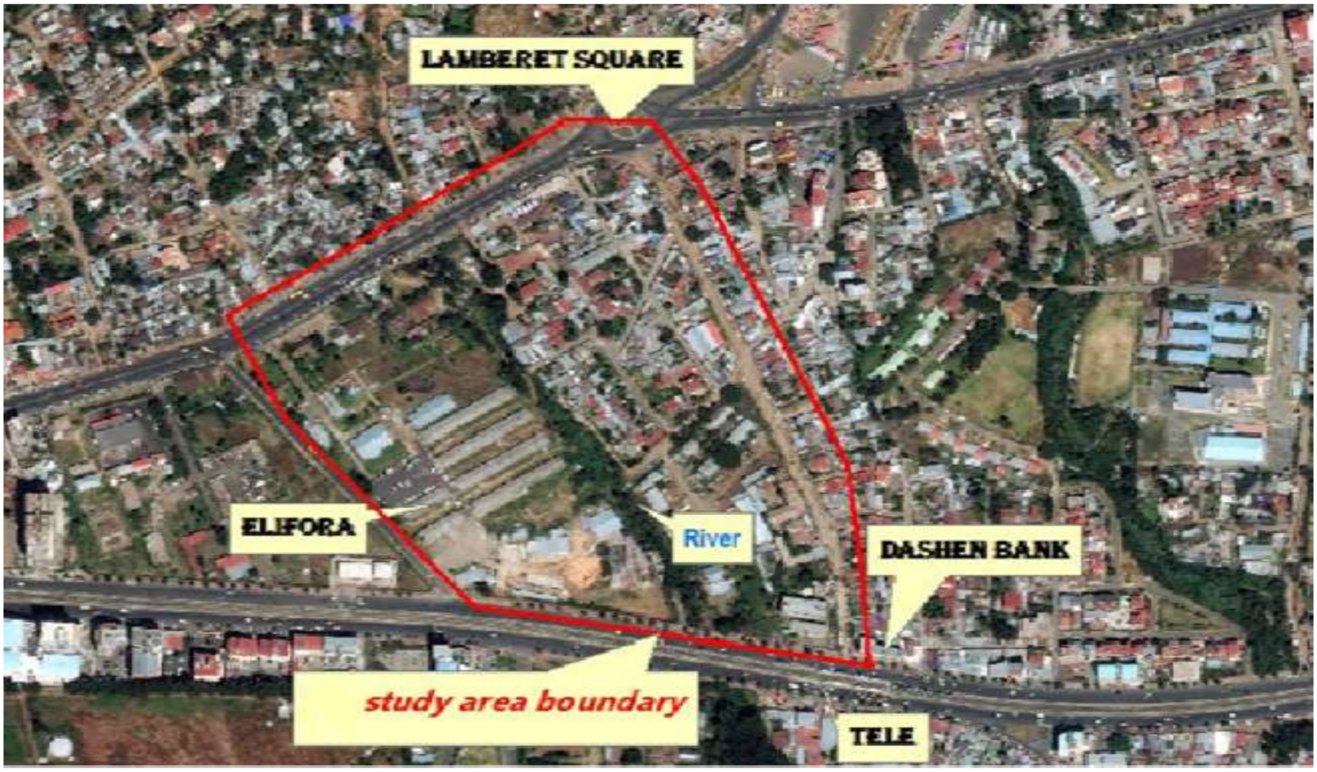

Figure 3. 2 Location map of the study area of specific boundary

(Source: Google Earth)

Addis Ababa has land use ranges from agricultural to high density commercial areas. The present land use and land cover of the study area covered with Commercial building, residential building, asphalt rode, bare land and LRT (light rail way transit system rout). The Current condition of the existing area has lot of changes from the time were the design time was planned. The construction of Commercial building, residential building, asphalt road and LRT (light rail way transit system rout) has a contributed for increasing the runoff of the area and contribute to the current drainage problem.

3.2. Data type and Collection

On this section the steps taken to construct this research discussed and the existing drainage systems assessed are discussed.

- **Primary data**

  Key informant interviews were conducted with officials of selected government offices like AACRA and AAWSA. In addition to interview with the design office, local residence and site observation were also made to see the major cause for the drainage problems like clogs, if there is regular operation and maintenance done and photographs were taken and presented.

- **Secondary data**

The secondary data was collected and organized by referring different literature reviews, published academic journals, reports, conference proceedings and text books on related to the objectives of the study.

3.2.1. Rainfall Data

Rain fall data was acquired from Addis Ababa meteorological agency. There are two metrological stations in Addis Ababa city, Bole International Airport Station and Addis Ababa Observatory Station. Considering the distance to the study area data was taken from Bole International Airport Station. Data close to 30 years of precipitation rainfall that is from 1988-2017 E.C was used on this thesis. The rain fall data was used for the development of the IDF curve. That is, depth per unit time (mm/h or in/h).

3.2.2. Land Use Land Cover Data

Digital elevation model (DEM) is the digital representation of the land surface elevation with respect to any reference datum. DEM is frequently used to refer to any digital representation of a topographic surface and is the simplest form of digital representation of topography. DEMs are used to determine terrain attributes such as elevation at any point, slope and aspect. On this thesis 12.5x12.5 DEM data[2] was used.

3.2.3. Site Survey

Observation is ethnological data collections methods in which the researchers visit or participate in location or group of people to better understand people, environment or other phenomena within the space. On this study informal observation and interviews have been conducted, when conducting observations, the learning curves are habits, patterns, behaviors, reactions, and general information about people in a particular environment to better understand what they do and, why they do it (Though; observations alone often won't tell us the "why"). Site visits will be conducted to get the first hand information of the area. Key Informant interview and site assessment were done with different stakeholders and people living near the study area.

[2]https://search.asf.alaska.edu/

The study used desk review of the previous study and previous drainage design manual documents of the study area. Data collections for different institutions are shown in Table 3.1.

Table 3- 1: Data source

Data type	Source (responsible bureaus)
Daily Rainfall (Excel data sheet)	National meteorological agency
Road network and Drainage design (AutoCAD file)/ partial document	Addis Ababa City Road Authority
DEM (GIS data) 12.5m X 12.5m	https://search.asf.alaska.edu/
LULC (GIS data)	Google earth and master plan of the town

Table 3- 2: Materials and Software used

Material	Purpose
Meter	For measuring the actual size of the drainage Manholes,
GPS recorded/Smart Phone	For taking GPS and taking site pictures
software's	
ArcMap 10.4	For Mapping (Geo referencing base map), For preparing land use land cover
Arc hydro 10.4	For natural catchment delineation
Google Earth Pro 7.1	Base map preparation (catchment preparation)
Bentley Civil storm	For hydrologic and hydraulic modelling

3.3. General Methodological Approaches

Urban flooding happens when capacity of drainage system is overloaded. It may also result from storm water drainage capacity inefficiency or from flood estimation problem. Therefore, what is important must be determining the hydraulic capacity of the conduit with the corresponding runoff entering to the conduit. This will help the study to identify the possible cause for flooding (hydraulic or hydrologic). The procedure to address the objectives has been shown here under.

3.3.1. Procedure to estimate the hydraulics capacity assessment

The storm water drainage network, hydraulic capacity inefficiency is one of the causes for flooding in urban area. The caring capacity of the conduit was determined using Manning's equation. Roughness coefficient, Area, slope, and diameter were the main inputs to the equation. The input parameters are discussed on the table below.

Table 3- 3: Hydraulic and hydrologic modeling elements impute data

Parameter	Description
	Sub catchment
Area	Delineated in GIS using 12.5m DEM and considering artificial barriers rivers etc.
Sub catchment width	Automatically calculated using GIS. A routine traced all the conduits lengths in a sub catchment area. Then the area is divided by the longest conduit length
Catchment slope	Calculated from the difference between the highest contour and the lowest contour for the rise and used the longest length developed for the width
Roughens coefficient (n)	Used general values from literature and design document
Runoff coefficient (c)	Self-computed from base map and from design document of the town
	Manhole
Depth	Found in design document of the town CAD data
Invert elevation	Estimated based on pipe slopes
	Conduits
Shape	Found in design document of the town cad data and site visit
Diameter	Found in design document of the town cad data and actual measurement
Roughness	Based on the standard published values for different pipe materials
Length	Scaled

(Source: Author, 2020)

3.3.2. Procedure to estimate the discharge percentage computation

With the rapid urbanization happening on cities, the nature of the natural hydrological cycle has been changing and it causes many adverse effects like urban flooding in urban areas. Due to the increasing population, urbanization will escalate rapidly and this will result the impervious lands to increase volume which contribute in more runoff generation. Urban storm water management systems are becoming crucial because of the urbanization and due to the consistent climate change on the globe. The other major factor for runoff generation is land use change, in urban areas land use has been found as a key factor in creating inadequacy in urban drainage to carry storm water runoff in catchments having a under sized designed conduit. The main focus of the study is to identify the urban flooding, so the runoff generation with different land use conditions was analyzed to check the possible hydraulic or hydrologic cause. The run of generation has been analyzed using rational method, this is because the catchment area is less than 50ha and the design also used the same method to calculate the runoff. So land use of the design period 2004 and existing condition scenarios 2019 are used to estimate the discharge.

The run off coefficient (C) is important for flood control channel construction and for possible flood zone hazard delineation. A high runoff coefficient (C) value may indicate flash flooding areas during storms as water moves fast overland on its way to a river channel or a valley floor. Runoff coefficient (C) used in the calculation for the 2004 land use condition was derived from design document of master plan of the town. For the existing land use condition 2019 it was computed using Google earth for the study area and site visit, each catchment were sub categorized and detail land use has been taken form ERA recommended land use table. The detailed land use coefficient has been shown on table 4.5 for each specific period.

Discharge percentages were calculated after estimating the rational method parameter to predict flooding.

The percentage calculation is shown below.

$$Q_{\%} = [{Q_{self} - Q_{design}}/{Q_{self}}]*100$$

Where: $Q_{\%}$, percentage discharge

Q_{self}, self-calculated discharge

Q_{design}, design discharge

3.3.3. Procedure to estimate the impact of O&M

Understanding maintenance and operational performances determines flooding impact. Maintenance programs for watercourse channels and culverts cleaning were assessed when these operations were performed in respect to the flooding event using interviews and personal observation. Engineers from

AACRA, AAWSA and local residents were interviewed. The basic questions asked while interviewing are shown on the annex part of this study. Finally after under going the above techniques the cause and the major contributor for flooding was concluded.

Table 3- 4: Summary of data collection methods and techniques

Specific Objectives	**Description**	**Type of data**	**Data source**	**Conceptual frame work**	**Data collection**	**Analysis**	**Result**
First Specific Objectives	To identify the possible hydraulic reasoning behind flooding in the stated area	Area, slop, roughness coefficient, diameter, Bentley Civil storm	AACRA, GIS, Books, Google earth	Determining the carrying capacity of the conduit and compare with the flow incoming to the system	Site measurement and reading	Peak runoff vs catchment flow	Summary of findings on the existing maximum flow
Second Specific Objectives	To identify the possible hydrological reasoning behind such flooding in the stated area	Run off coefficient (C), LULC (GIS data), DEM (GIS data), Rainfall (Excel data sheet), IDF curve, Spatial data, Arc hydro 10.4, Bentley Civil storm, Google Earth Pro 7.1, ArcMap 10.4	AACRA, National meteorological agency, Master plane of the city and google earth,	IDF curve generation, Statical tool calculation, peak runoff estimation	Reading, Scanning, copying and writing	Maximum Peak Flow and land use condition for year 2004 vs 2019	Flooding discharge percentage computed
Third Specific Objectives	To identify the possible operation and maintenance reasoning for flooding in the study area	O&M M schedule, Cleaning schedule, Books, Report, journals, researches, articles	AACRA, Site visit, interviews	Maintenance and cleaning of channels, manholes, culverts	Site visit, Interview	Hydraulic and hydrologic result vs O&M	Summary of findings on the existing situation of the O&M condition of the hydraulic system
Fourth Specific Objectives	What is the most influential cause for the study area to flood (O &M, hydraulic, hydrological or all together	Discharge computed, Hydraulic analysis, Books, Report, journals, Similar researches, articles	Result of the Bentley Civil storm software analysis,	Bentley Civil storm model result	-	Bentley Civil storm	Summary of Major factors that result for flooding on the study area

(Source: Author, 2020)

3.1. Schematic Diagram of the Data Analysis Schematic Diagram of the Data Analysis

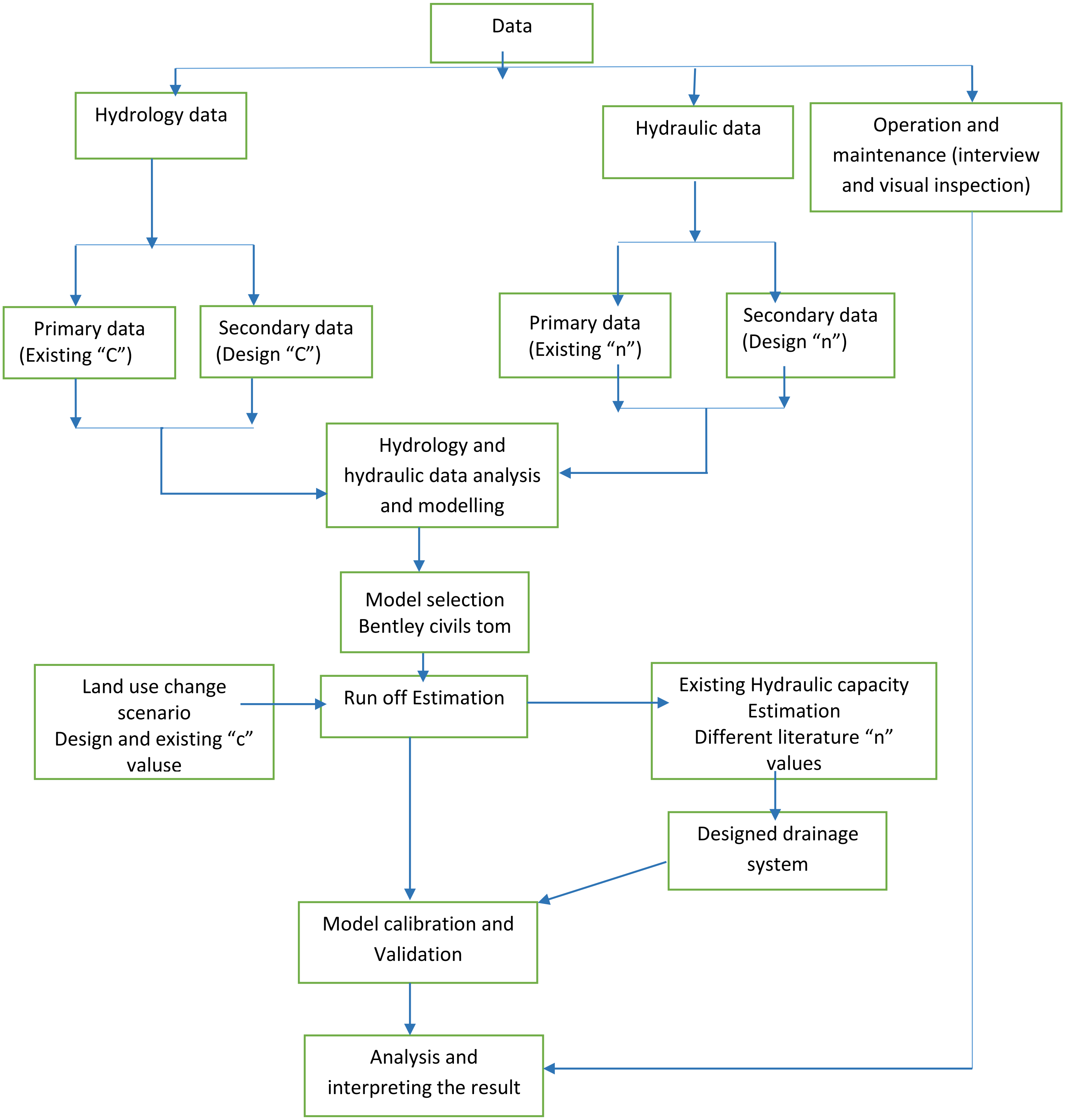

Figure 3. 3 Data analysis flow chart

As it shown on the above diagram, once the data have been collected, the next step is to compile it into a usable format. The main reason for analyzing the data is to draw all of the various pieces of collected information together, and to fit them into a comprehensive and accurate representation of the hydrologic and hydraulic characteristics of a particular site.

3.2. Data Analysis

3.2.1. Rainfall Data

The required data for rain fall analysis is the daily rainfall which is collected daily in the meteorological agencies. It is recommended that the period of record should be at least 10 years. Where the site being studied is on the same stream and near gauging station, peak discharges can be adjusted to the site by drainage area ratios using drainage area to some power. For this method to be valid, the gage data used must be homogeneous, i.e., no significant changes in the characteristics of the drainage basin or climatologically patterns have occurred over the period of record.

Addis Ababa, the study area daily rainfall data can be collected from the Addis Ababa Observatory Station and Bole International Airport Station. This are the two stations in which rain fall data is recorded in Addis Ababa. The Bole International Airport Station is taken due location near to the study area. The data includes daily rainfall precipitation of 30 consecutive years from the year 1988 to 2017 GC. These rainfall data are records of rainfall depth in 24hr duration.

3.2.1.1. Frequency Analysis

The magnitude of an extreme event is inversely related to its frequency of occurrence, very severe events occurring less frequently than more moderate events. The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distribution (Ven Te Chow et al., 1997). Please refer annex part of frequency analysis.

While thinking of urban drainage design the first steps is determination of the rainfall event or events to be used. The most common approach is to use a design storm or event that involves a relationship between rainfall intensity (depth), duration, and the frequency or return period appropriate for the facility and site location. Historical rainfall data were available in 24 hr. duration and reduction is done by developing IDF curve.

3.2.1.2. Fitting the Probability Distribution

Historical data are used to drive sample, then the sample is used to estimate a population which will be used in making projections of the magnitude and frequency of rainfall (Ven Te Chow et al., 1997). Hence, for reliable estimates for extreme hydrological event, long term data series is required.

Extracted annual maximum rainfall data series for durations of 24 hours arranged in descending order of magnitude were fitted against Gumbel (Extreme Value Distribution Type I) and Log Pearson Type III distributions using the frequency analysis technique. They are used to predict the design flood for a river at some site. The two distribution methods were suggested by ERA design manual.

These were achieved by plotting the maximum annual rainfall data to the probability distribution function, the reduced variate (YT) for the case of Gumble and the frequency factor (KT) for Log Pearson Type III and R-squared value test was carried out for all the stations and respective durations. The method of fitting the annual maximum rainfall data to the Gumbel and Log Pearson probability distributions are shown below.

A) Gumble (Extreme Value Distribution Type I or double-exponential distribution of extreme value)

The study of extreme hydrologic events involves the selection of a sequence of the largest or smallest observations from sets of data. In this study Gumbles distribution methods has been applied for frequency analysis and the equations for Gumbles distribution return period T is given as.

$X_T = \overline{X} + \partial_x K$, where ∂_x = Standard deviation of the Sample Size

K= Frequency Factor, which is expressed as, $K = \frac{Y_t - \overline{Y_n}}{Snx}$

In which Y_t, Reduced Variate, $Y_t = \left\lfloor L_n . L_{n.}\left(\frac{T}{T-1}\right)\right\rfloor$

The value of Yn and Sn are selected from Gumbles extreme value distribution considered depending on the sample size.

This can be evaluated on excel sheet as follows

- Compute Annual extreme values using =max (Yo) function, where Yo represents all record of 24-hour daily rainfall data
- Computing sample parameters like minimum, Average, standard deviation and coefficient of skewness Using equations

$$YT = -\ln [\ln (T/T-1)] \text{ and } XT = X \text{ (mean)} + KTS$$

Where, XT is event magnitude of the record, X (mean) and S are the mean and standard deviation of sample data. YT is the reduced variate of a given return period T and Sn is the reduced mean and standard deviation as a function of sample size n, respectively. Their values are read from the tables (Subramanya, 1997).The result is tabulated for different return period.

B) Log Pearson Type III

It is three-parameter gamma distribution with a logarithmic transform of the variable. Mean, standard deviation, and coefficient of skew are the three necessary parameters that are essential to describe the distribution.

Evaluating using this method on excel sheet as follows, given return period and; maximum annual rainfall data

- Transform the data to log
- Calculate sample parameters of log data i.e. Y(average), Sy, coefficient of skewness
- Using return period and coefficient of skewness read K value from table
- Calculate YT= Y(average)+KSY
- Calculate XT = 10^YT

The above two distribution methods should be checked for goodness of fit (GOF) tests, GOF function. These tests show how well the selected distribution fits to data. There are three most commonly used GOF tests. These tests are the Anderson-Darling, the Kolmogorov-Smirnov, and the Chi Squared tests. In all three tests a parameter or statistic unique to each method is calculated for the required distribution types and these distributions are ranked based on their parameter values.

3.2.1.3. Goodness of Fit Test

The goodness of fit (GOF) tests measure the compatibility of a random sample with a theoretical probability distribution function. The tests show how well the selected distribution fits to data. There are four most commonly used GOF tests. These tests are Kolmogorov-Smirnov, Anderson-Darling, Chi-Squared and R^2 tests. In all four tests, parameter or statistic unique to each method is calculated for the required distribution types and these distributions are ranked based on their parameter values.

Kolmogorov-Smirnov Test

This test is used to decide if a sample comes from a population with a specific distribution. The Kolmogorov-Smirnov (K-S) test is based on the empirical distribution function (ECDF). Assume that we have a random sample y_1, y_2 ..., y_n from some continuous distribution with CDF F(y). The empirical CDF is denoted by

$$\mathbf{Fn}(\mathbf{y}) = \frac{1}{n}.[Number\ of\ observation\ \leq y]$$

The Kolmogorov-Smirnov statistic (D) is based on the largest vertical difference between F(x) and Fn(x). It is defined as

$$\boldsymbol{D_n} = sup_x|F_n(y) - F(y)|$$

Anderson-Darling Test

The Anderson-Darling procedure is a general test to compare the fit of an observed cumulative distribution function to an expected cumulative distribution function. This test gives more weight to the tails than the Kolmogorov-Smirnov test. The Anderson-Darling test is an alternative to the chi-square and Kolmogorov-Smirnov goodness-of-fit tests.

The Anderson-Darling statistic (A2) is defined as

$$A^2=-N-S$$

Where

$$S = \sum_{i-1}^{N} \frac{(2i-1)}{N} [\ln F(Y_i) + \ln(1 - F(Y_{N+1-i}))]$$

F is the cumulative distribution function of the specified distribution. Y_i are the ordered data.

Chi-Squared Test

The Chi-Squared test is used to determine if a sample comes from a population with a specific distribution. This test is applied to binned data, so the value of the test statistic depends on how the data is binned. For the chi-square goodness-of-fit computation, the data are divided into k bins and the test statistic is defined as

$$X^2 = \sum_{i-1}^{k} (O_i - E_i)^2 | Ei)$$

Where Oi is the observed frequency for bin i, and E_i is the expected frequency for bin i calculated by

$$E_i = N(F(Y_u) - F(Y_i)$$

Where F is the cumulative distribution function for the distribution being tested, Y_u is the upper limit for class I, Y_i is the lower limit for class I, and N is the sample size.

3.2.1.4. Design Rainfall of Shorter Duration

The rainfall depths obtained from gauging station are of 24hr duration depth. Design and analysis of drainage structures require rainfall intensity duration relationship of shorter duration. Because rainfall data of shorter duration is unavailable appropriate IDF derivation for shorter duration is required. Ethiopian Road Authority Drainage Design Manual 2003 suggests the following equation.

$$R_{Rt} = \frac{t}{24} \frac{(b+24)^n}{(b+t)^n}$$

Where:

RRt = Rainfall depth ratio (Rt: R24)

Rt = Rainfall depth in a given duration t

R24 = 24hr rainfall depth

Coefficients b = 0.3 and n = 0.78 - 1.09 suggested by ERA manual results are tabulated for rainfall durations 10, 20, 30 … 180 minutes.

3.2.1.5. Developing Intensity Duration Curve

One of the first steps in many hydrologic design projects, such as in urban drainage design, is the determination of the rainfall event or events to be used. The above approaches are methods to develop the IDF curve. An IDF is a plot of average rainfall intensity

I.e. Average rainfall intensity in that duration = rainfall depth /duration, the duration is in minuets (S.K Garg, 2005)

IDF curve comparison with ERA has been done and shown on the annex part of the study. ERA IDF curve has higher value which is due to the range of rainfall data taken were higher than that of IDF curve of the study area.

3.3. Model development and approaches

From section 2.7 of literature review the simulation software package selected for this study was the Bentley civil storm vi8 software. Bentley civil storm has capabilities and is used internationally for storm water, sanitary sewer, and watershed modeling.

3.4. Hydraulic Modeling

Bentley civil storm hydrologic and hydraulic model was used in this research which was developed by Bentley systems. They are developed for the analysis of complex storm water systems. Engineers can analyze these systems using built-in hydraulic and hydrology tools and a variety of wet-weather calibration methods. The tool is intended for calculating hydraulic capacity, water surface profiles for steady, gradually varied flow in natural or man-made channels. The hydraulic capacity of the storm water network was evaluated with Manning's equation.

The information necessary to build the hydraulic model is related to the details of the storm water drainage infrastructure. Master plans of the study area and Google earth were used for network layout.

The hydraulic structures exists in the study area were manholes, inverts and conduits. Inconsistencies of the data were updated using extensive field works.

- Manhole Inverts

DEM 12.5*12.5 was used to estimate Ground elevations and invert elevations were calculated based on man hole depth and ground elevation.

- Conduits

The parameters for channel are invert start, invert stop elevation, length and manning's roughness coefficient (n) and material type. All our cross sections are circular and the material is concrete, the existing cross section measured using tape meter and the roughness coefficient is 0.013 as recommended by ERA manual for concert surface.

- Outfall

While modeling drainage system deadly nodes within the drainage system were modeled as outfalls, they represent outfall discharges into rivers. The invert elevations and ground elevations are principal input parameters for outfall. In this thesis model there are four outfall points which discharges to the river.

3.5. Peak Discharge Estimation

Hydrology deals with estimating flood magnitudes as the result of precipitation. In the design of highway drainage structures, floods are usually considered in terms of peak runoff or discharge in cubic meters per second (m^3/s) and hydrographs as discharge per time.(ERA, 2002)

While estimate peak rate of runoff, volume of runoff, and time distribution, error will result in a structure that is either undersized and causes more drainage problems or oversized and costs more than necessary. On the other hand, it must be realized that any hydrologic analysis is only an approximation. The peak flood can be calculated from the data availability.

According to ERA design manual 2002 there are two methods of calculating the peak discharges, rational method and SCS method. The rational method Provides peak runoff rates for small urban and rural catchment areas, less than 50 hectares, but is best suited to urban storm drain systems and rural ditches. It shall be used with caution, if the time of concentration exceeds 30 minutes. Rainfall is a necessary input. This study has used this method due to the size of catchment area less than 50 hectares and also the previous design has used same approach.

While the U.S. Soil Conservation Service (SCS) has developed a synthetic unit hydrograph procedure that has been used widely for developing rural and urban hydrographs. The unit hydrograph used by the SCS method is based upon an analysis of a large number of natural unit hydrographs from a broad cross section of geographic locations and hydrologic regions.

- Catchment Delineation for Study Area

A catchment area for urban draining is determined from road network (master plan), topographic maps, and field surveys. For large catchment areas with the different land use land change it is a must to divide the area into sub-catchment areas, sub-catchments are hydrologic units of land whose topology and drainage system elements direct surface runoff to a single discharge point (Elias, 2015)
The watershed delineation was done based on the boundary condition i.e. (artificial barrier, rivers, gorges etc...). The natural Watershed delineation was done using Arc Swat 10.4 using DEM as input. Finally the artificial catchment was over laid on the natural catchment and the contributing boundary of the study area was digitized using ArcGIS 10.4 keeping the boundary condition.

- Runoff Calculation

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 a duration equal to the time of concentration (the time required for water to flow from the most remote point of the basin to the location being analyzed), (ERA, 2002).The rational formula is expressed as:

$$Q = 0.00278\ CIA$$

Q = maximum rate of runoff, m^3/s

C = runoff coefficient representing a ratio of runoff to rainfall (Tables 5-3 through 5-5 on Annex-B attached)

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

A = catchment area tributary to the design location, ha

Assumptions inherent in the rational formula are as follows:

- The first step in applying the Rational Method is 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.
- Peak flow occurs when the entire watershed is contributing to the flow.
- Rainfall intensity is the same over the entire drainage area.
- Rainfall intensity is uniform over time duration equal to the time of concentration, Tc. The time of concentration is the time required for water to travel from the hydraulically most remote point of the basin to the point of interest.
- Frequency of the computed peak flow is the same as that of the rainfall intensity, i.e., the 25-year rainfall intensity is assumed to produce the 25-year peak flow.
- Coefficient of runoff is the same for all storms of all recurrence probabilities. Because of these inherent assumptions, the Rational formula should only be applied to drainage areas smaller than up to 50 ha (ERA, 2002).

❖ Run off Coefficient (C)

The runoff coefficient is the most important variable in the rational method of rainfall to runoff transformation. The study area constitutes different land use types ranging from gravel road, residential houses, commercial buildings and asphalt road. Each catchment area was carefully assessed using Google map and individual C values were obtained.

Table 3- 5: ERA recommended runoff coefficient values for different land use

Type of Drainage Area	**Runoff Coefficient C**
Business: Downtown areas	0.7-0.95
Neighborhood areas	0.5-0.7
Residential: Single-family	0.3-0.5
Multi units, detached	0.4-0.6
Multi units, attached	0.6-0.75
Suburban	0.25-0.4
Residential (0.5 hectares lots or more)	0.3-0.45

Apartment dwelling areas	0.5-0.7
Industrial: Light areas	0.5-0.8
Heavy areas	0.6-0.9
Parks, cemeteries	0.1-0.25
Playgrounds	0.2-0.4
Railroad yard areas	0.2-0.4
Unimproved areas	0.1-0.3

Source: ERA Manual 2013

❖ Rainfall Intensity (“I”)

The rainfall intensity (“I”) is determined using two input parameters: Intensity-Duration-Frequency (IDF) curves and Time of Concentration (“Tc”).

• IDF Curves

Refer to the IDF curves used on section 4.1.3 of this thesis.

• Time of Concentration

The time of concentration is the time for a drop of water to flow from the remotest point in the watershed to the point of interest. Many empirical equations are available for calculating time of concentration for a watershed. Among them the Manning Kinematic equation for sheet flow and Manning Equation for flow in a channel were used.

Travel time (Tt) is the ratio of flow length to flow velocity.

$$T_t = \frac{L}{3600V}$$

Where, Tt is travel time (hr), L is flow length (Ft) and V is average velocity (ft/s). 3600 is conversion factor from second to hours.

3.6. Model calibration and validation

All rainfall-runoff models are so a simplifications of the real-world systems under investigation. The model components are aggregated descriptions of real world hydrologic processes. One consequence of this is that the model parameters often do not represent directly measurable entities, but must be estimated using measurements of the system.

To calibrate a model, values of the model parameters are selected so that the model simulates the hydrological behavior of the catchment as closely as possible.

According to the purpose or objective of the research work there are different calibration and validation methods to be used. This study has used two areas Ayeretena and Sebeta which has similar clime condition which helps to cross check the model for validation and calibration.

Table 3- 6: Calibration and validation data

Total number rainfall recorded	**Data used for simulation (Years)**	**Data used for calibration (Years) (Ayeretena)**	**Data used for validation in (Years) (Sebeta)**
30 years	1988-2006	1988-2018	2014-2017

4. RESULT AND DISCUSSION

As it has been clearly stated, the main objectives of this study is to assess the hydrology, hydraulic and O&M problem and find out of all the cases which will be the major contributor for flooding or altogether. On this chapter the results and the analysis were summarized and discussed to address the specific objectives supported by literature review, journals and other studies. Findings are presented as follows in the following sub topics below.

4.1. Rainfall analysis and result

According to (P. M. Younger et al., 2009) rainfall is the core element of the hydrological cycle that drives energy circulation in the atmosphere. The process and result of obtaining design discharge from rainfall analysis are described below.

4.1.1 Data gap filling

The rain fall data received from the meteorological agency was complete which was achieved due to the location that the meteorological agency station is found in the heart of the city helps to control and capture the data on time.

4.1.2 Statistical tools and parameters

Different statistical tools were used for the analysis of both rainfall data and their probability distributions. In any statistical analysis, different statistical methods such as the Gumbel distributions and log Pearson's III distributions are applied. In this research the two methods were used and the analysis result is shown below (see table 4-1).

Table 4- 1: Summary of goodness of fit test

Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared		R2	
	Statistic	Rank	Statistic	Rank	Statistic	Rank	Statistic	Rank
Gumble Extreme Value	0.12305	1	0.32167	1	2.3361	1	0.9984	1
Log-Pearson 3	0.12862	2	0.34655	2	2.2677	2	0.9814	2

In order to identify which distribution fits to the theoretical probability distribution, GOF test conducted using Easy Fit 5.6 professional software and Gumble Extreme Value fits for the statistical value for all the three different test methods is lesser and for case of r^2 it is found larger than that of the Log-Pearson 3 values as tabulated above. That is, Gumble Extreme Value method have proved to be good fit when checked with all the four tests of statically tools parameters . Then further analysis of the research is carried out with Gumble Extreme Value result.

Table 4- 2: Design point rainfall using Log person III and Gumbel Methods

Design Point Rainfall and return period		
Return Period(T)	**Design point Rainfall (Log Person-III)**	**Design point Rainfall Gumbel Method (Chosen for further analysis)**
2	34.52	43.60
5	49.99	55.82
10	58.77	63.92
25	66.65	74.14
50	73.87	81.73
100	80.04	89.26

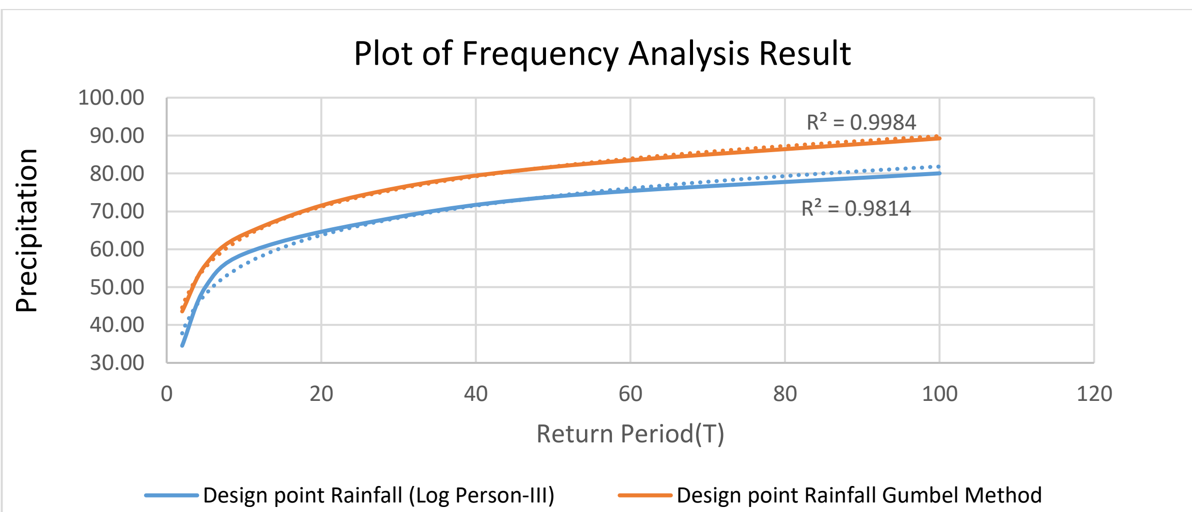

Figure 4- 1: R^2 for Gumbel and Log-person III

4.1.3 Intensity – Duration – Frequency Curves

The result of IDF curve from steps shown in section 3.5.1.4 is as follows. The reasonable length of record for frequency analysis should be more than 30 years. However, a record of up to 20 years can be used as sample data set for frequency analysis if data for longer record is not available. The IDF curve is developed from 24-hour rainfall data of 30 years i.e. 1988 to 2017 GC, obtained from Ethiopian Meteorological Agency rainfall gauge located around Bole, Addis Ababa.

Intensity (mm/hr), I_t=R_t/t. Where I_t (mm/hr)

$$I_t = \frac{(R_{24}(b+24)^n}{24(b+t)^n}$$

Using b = 0.3 and n = 0.92 as suggested by ERA manual results are tabulated for rainfall durations 5, 10, 15… 180 minutes. The resulting table is graphed for each return period.

Table 4- 3 : IDF Curve

Return Period (T)	2	5	10	25	50	100
t (minute)	Intensity in (mm/hr.)					
5	82.63	105.79	121.14	140.51	154.90	169.17
10	68.95	88.28	101.09	117.25	129.25	141.16
15	59.28	75.89	86.91	100.80	111.12	121.36
20	52.06	66.66	76.33	88.53	97.59	106.59
25	46.47	59.49	68.12	79.01	87.10	95.13
30	41.99	53.76	61.57	71.41	78.72	85.97
35	38.34	49.08	56.20	65.19	71.86	78.48
40	35.28	45.17	51.73	60.00	66.14	72.24
45	32.70	41.86	47.94	55.60	61.30	66.94
50	30.48	39.02	44.69	51.83	57.14	62.40
55	28.55	36.56	41.86	48.56	53.53	58.46
60	26.87	34.40	39.39	45.68	50.36	55.00
65	25.37	32.49	37.20	43.15	47.56	51.95
70	24.04	30.78	35.25	40.89	45.07	49.22
75	22.85	29.26	33.50	38.86	42.84	46.78
80	21.78	27.88	31.93	37.03	40.82	44.58
85	20.80	26.63	30.50	35.37	39.00	42.59
90	19.92	25.50	29.20	33.86	37.33	40.77
95	19.10	24.46	28.01	32.48	35.81	39.11
100	18.36	23.50	26.91	31.22	34.41	37.58

105	17.67	22.62	25.90	30.05	33.12	36.17
110	17.03	21.81	24.97	28.96	31.93	34.87
115	16.44	21.05	24.11	27.96	30.82	33.66
120	15.89	20.35	23.30	27.03	29.79	32.54
125	15.38	19.69	22.55	26.16	28.83	31.49
130	14.90	19.08	21.85	25.34	27.94	30.51
135	14.45	18.51	21.19	24.58	27.10	29.59
140	14.03	17.97	20.57	23.86	26.31	28.73
145	13.64	17.46	19.99	23.19	25.56	27.92
150	13.26	16.98	19.44	22.55	24.86	27.15
155	12.91	16.53	18.93	21.95	24.20	26.43
160	12.58	16.10	18.44	21.39	23.57	25.75
165	12.26	15.70	17.97	20.85	22.98	25.10
170	11.96	15.31	17.53	20.34	22.42	24.48
175	11.67	14.95	17.11	19.85	21.88	23.90
180	11.40	14.60	16.72	19.39	21.37	23.34

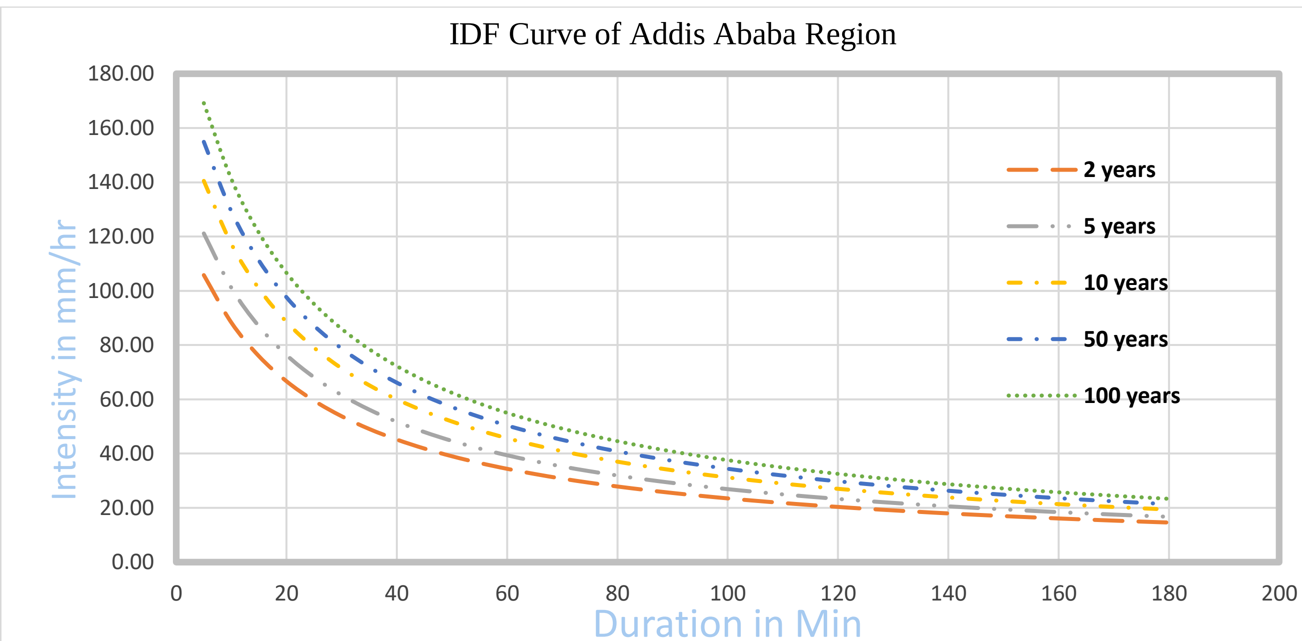

Figure 4- 2: IDF Curve

The corresponding changes in IDF statistics show that the extreme precipitation quantiles typically used for design of urban drainage systems can increase up to 30% by the end of this century. Those changes mean that sewer surcharge or flooding would occur about twice more frequently than in the present climate (if no other environmental or management changes are accounted for). This would have a significant impact on future urban water management and planning. (P. Willems a, 2011)

4.2. Peak Runoff Estimations

In this study, the runoff water generated from the drainage basin as it is mentioned on the methodology part were based on urban storm water drainage design manual of our country recommended by Ethiopian Road Authority drainage manual 2003. The manual recommends that area less than 50 ha will be computed with rational method.

The peak runoff was simulated using rational method in Bentley civil storm. The study area was divided in 68 sub-catchments for modeling with Bentley civil storm Vi8 software. The model result obtained is indicated in table 4.4.

Table 4- 4: 10 years Maximum peak flow and land use condition for year 2004 and 2019

	Land use change comparison for the year 2004 and 2019					change in Q(m^3/s)
	Land use change scenario 2004			land use change scenario 2019		
Label	Selected Area in (ha)	Runoff Coefficient (Rational) (C)	Flow (Maximum) (m^3/s)	Runoff Coefficient (Rational) (C)	Flow (Maximum) (m^3/s)	
			A		B	C=B-A
Cat-1	0.029	0.600	0.001059	0.825	0.001456	0.000397
Cat-10	1.058	0.600	0.000726	0.825	0.000999	0.000273
Cat-11	0.04	0.600	0.000479	0.825	0.000659	0.00018
Cat-12	0.612	0.600	0.000444	0.825	0.000610	0.000166
Cat-13	0.378	0.600	0.000389	0.825	0.000535	0.000146
Cat-14	0.018	0.600	0.000359	0.825	0.000494	0.000135
Cat-15	0.012	0.600	0.000374	0.825	0.000514	0.00014
Cat-16	0.012	0.600	0.000413	0.825	0.000568	0.000155
Cat-17	0.014	0.600	0.000448	0.825	0.000616	0.000168
Cat-18	0.02	0.600	0.00045	0.825	0.000619	0.000169
Cat-19	0.013	0.600	0.000938	0.825	0.001289	0.000351
Cat-2	0.012	0.500	0.031862	0.825	0.052572	0.02071
Cat-20	0.011	0.600	0.001343	0.825	0.001846	0.000503
Cat-21	0.01	0.600	0.001069	0.825	0.001470	0.000401
Cat-22	0.01	0.600	0.001987	0.825	0.002732	0.000745
Cat-23	0.011	0.600	0.001244	0.825	0.001711	0.000467
Cat-24	0.012	0.600	0.001198	0.825	0.001647	0.000449
Cat-25	0.012	0.600	0.000938	0.825	0.001289	0.000351
Cat-26	0.026	0.600	0.000871	0.825	0.001198	0.000327
Cat-27	0.037	0.600	0.001057	0.825	0.001454	0.000397
Cat-28	0.03	0.600	0.000536	0.825	0.000737	0.000201
Cat-29	0.055	0.600	0.001201	0.825	0.001651	0.00045
Cat-3	0.034	0.600	0.001447	0.600	0.001447	0

Cat-30	0.033	0.600	0.001544	0.825	0.002122	0.000578
Cat-31	0.026	0.825	0.005884	0.825	0.005884	0
Cat-32	0.024	0.825	0.00282	0.825	0.002820	0
Cat-33	0.029	0.825	0.002937	0.825	0.002937	0
Cat-34	0.015	0.825	0.005114	0.825	0.005114	0
Cat-35	0.033	0.825	0.005559	0.825	0.005559	0
Cat-36	0.043	0.825	0.005103	0.825	0.005103	0
Cat-37	0.118	0.825	0.003988	0.825	0.003988	0
Cat-38	0.057	0.825	0.002778	0.825	0.002778	0
Cat-39	0.059	0.825	0.005639	0.825	0.005639	0
Cat-4	0.103	0.500	0.018434	0.500	0.018434	0
Cat-40	0.112	0.825	0.001213	0.825	0.001213	0
Cat-41	0.103	0.825	0.000377	0.825	0.000377	0
Cat-42	0.08	0.825	0.000627	0.825	0.000627	0
Cat-43	0.056	0.825	0.001253	0.825	0.001253	0
Cat-44	0.113	0.825	0.00182	0.825	0.001820	0
Cat-45	0.024	0.825	0.002772	0.825	0.002772	0
Cat-46	0.008	0.825	0.003241	0.825	0.003241	0
Cat-47	0.013	0.825	0.001955	0.825	0.001955	0
Cat-48	0.025	0.825	0.003456	0.825	0.003456	0
Cat-49	0.037	0.825	0.00314	0.825	0.003140	0
Cat-5	0.056	0.500	0.011397	0.500	0.011397	0
Cat-50	0.065	0.825	0.003571	0.825	0.003571	0
Cat-51	0.039	0.825	0.00383	0.825	0.003830	0
Cat-52	0.07	0.825	0.003635	0.825	0.003635	0
Cat-53	0.063	0.825	0.004228	0.825	0.004228	0
Cat-54	0.072	0.825	0.00544	0.825	0.005440	0
Cat-55	0.077	0.825	0.004123	0.825	0.004123	0
Cat-56	0.073	0.825	0.002957	0.825	0.002957	0
Cat-57	0.085	0.825	0.002358	0.825	0.002358	0
Cat-58	0.109	0.825	0.003384	0.825	0.003384	0
Cat-59	0.083	0.500	0.049066	0.852	0.083609	0.034543
Cat-6	0.06	0.825	0.000885	0.825	0.000885	0
Cat-60	0.047	0.500	0.026696	0.825	0.044048	0.017352
Cat-61	0.068	0.500	0.056214	0.500	0.056214	0
Cat-62	1.629	0.500	0.010443	0.825	0.017230	0.006787
Cat-63	0.886	0.500	0.014177	0.825	0.023392	0.009215
Cat-64	1.866	0.500	0.01127	0.825	0.018596	0.007326
Cat-65	0.347	0.500	0.017531	0.500	0.028927	0
Cat-66	0.471	0.600	0.003287	0.600	0.003287	0
Cat-67	0.374	0.500	0.008605	0.500	0.008605	0
Cat-68	0.582	0.825	0.001737	0.825	0.001737	0
Cat-7	0.091	0.600	0.000451	0.825	0.000620	0.000169
Cat-8	0.286	0.600	0.000448	0.825	0.000616	0.000168
Cat-9	0.035	0.600	0.000493	0.825	0.000678	0.000185
Total			**0.3767**		**0.4903**	

Note: discharge change in the table is caused by type of land use. For example impermeable man-made surfaces- concrete and tarmac can cause rivers in urban drainage basins to have a higher discharge due to higher amounts of surface runoff.

Urban development is considered to be a source of pollution for water resources, while increasing flooding and threatening both people's safety and the integrity of infrastructure on a broader scale. Urbanization also reduces infiltration, base flow and lag times, as well as increasing storm water flow volumes, peak discharge, frequency of floods and surface runoff.

Land use change assessment has been conducted on the study area to see the contribution to flooding. Percentage calculation was carried out with the change in land use scenarios using Bentley civil storm modeling tools. From the table 4.4 the result of Q-max (maximum flow) for the year 2004 and 2019 adding up all catchment flow result is 0.3767 and 0.4903 m3/s respectively. The land use change has clearly shows the increase in peak run off generation which may be the cause for flooding but to conclude the major contributor, Hydraulic capacity of the system also has to be checked carefully.

In the aerial imageries shown below, one can easily see the change in the land use of this particular study area for the peak run off analysis land use condition year 2004 and 2019.

(a) 2019 (b) 2004

Figure 4- 3: Areal imagery of the study area in 2004 and 2019

(Source: - Google earth)

On methodology part it has been noted that the runoff coefficient is the most crucial part in the rational methods. Areal imagery of the two scenarios year 2004 design period and 2019 were presented to show the change of runoff coefficient through time. The gravel roads were changed to asphalt, bare land changed to residential and commercial buildings and drainage swear systems were also constructed. Table 4.4 the positive increment in Q (m3/s) shows that land use change for scenario 2019 is higher in runoff than that of design period land use change scenario 2004.

4.3. Discharge percentage computation

On the pervious section 4.2, the total runoff calculations for each catchment were done and the total flow was estimated. Hence, on this section of the study the percentage difference between the design discharges and the three scenarios i.e. design, 2004 and 2019 discharge will be calculated.
The percentage calculation is shown below.

$$Q_{\%} = [{Q_{self} - Q_{design}}/{Q_{self}}]*100$$

Where: $Q_{\%}$, percentage discharge

Q_{self}, self-calculated discharge

Q_{design}, design discharge

Table 4- 5: 100 years discharge computation design year for 2004 and 2019

Label	Outflow element	Runoff Method	Area (Ha)	Runoff Coefficient Design (C)	Runoff Coefficient (2004) (C)	Runoff Coefficient (2019) (C)	Flow Maximum (Q M^3/s) Design	Flow Maximum (Q M^3/s) (2004)	Flow (Maximum) (m^3/s) (2019)
Cat-1	MH-19	Rational	0.029	0.6	0.6	0.825	0.001333	0.001333	0.001833
Cat-10	MH-45	Rational	0.020	0.6	0.6	0.825	0.000914	0.000914	0.001257
Cat-11	MH-23	Rational	0.013	0.6	0.6	0.825	0.000603	0.000603	0.000830
Cat-12	MH-24	Rational	0.012	0.6	0.6	0.825	0.000559	0.000559	0.000768
Cat-13	MH-28	Rational	0.011	0.6	0.6	0.825	0.000489	0.000489	0.000673
Cat-14	MH-36	Rational	0.010	0.6	0.6	0.825	0.000452	0.000452	0.000622
Cat-15	MH-42	Rational	0.010	0.6	0.6	0.825	0.000471	0.000471	0.000647
Cat-16	MH-43	Rational	0.011	0.6	0.6	0.825	0.000520	0.000520	0.000715
Cat-17	MH-43	Rational	0.012	0.6	0.6	0.825	0.000564	0.000564	0.000776
Cat-18	MH-41	Rational	0.012	0.6	0.6	0.825	0.000567	0.000567	0.000779
Cat-19	MH-6	Rational	0.026	0.6	0.6	0.825	0.001180	0.001180	0.001623
Cat-2	MH-31	Rational	1.058	0.6	0.5	0.825	0.048136	0.040114	0.066187

Cat-20	MH-35	Rational	0.037	0.6	0.6	0.825	0.001690	0.001690	0.002324
Cat-21	MH-38	Rational	0.030	0.6	0.6	0.825	0.001346	0.001346	0.001851
Cat-22	MH-47	Rational	0.055	0.6	0.6	0.825	0.002501	0.002501	0.003439
Cat-23	MH-52	Rational	0.034	0.6	0.6	0.825	0.001566	0.001566	0.002154
Cat-24	MH-30	Rational	0.033	0.6	0.6	0.825	0.001508	0.001508	0.002073
Cat-25	MH-89	Rational	0.026	0.6	0.6	0.825	0.001180	0.001180	0.001623
Cat-26	MH-79	Rational	0.024	0.6	0.6	0.825	0.001097	0.001097	0.001509
Cat-27	MH-67	Rational	0.029	0.6	0.6	0.825	0.001331	0.001331	0.001830
Cat-28	MH-67	Rational	0.015	0.6	0.6	0.825	0.000674	0.000674	0.000927
Cat-29	MH-57	Rational	0.033	0.6	0.6	0.825	0.001512	0.001512	0.002079
Cat-3	MH-107	Rational	0.040	0.6	0.6	0.6	0.001822	0.001822	0.001822
Cat-30	MH-58	Rational	0.043	0.6	0.6	0.825	0.001943	0.001943	0.002672
Cat-31	MH-75	Rational	0.118	0.6	0.825	0.825	0.005388	0.007408	0.007408
Cat-32	MH-90	Rational	0.057	0.6	0.825	0.825	0.002582	0.003550	0.003550
Cat-33	MH-54	Rational	0.059	0.6	0.825	0.825	0.002689	0.003697	0.003697
Cat-34	MH-62	Rational	0.103	0.6	0.825	0.825	0.004683	0.006439	0.006439
Cat-35	MH-3	Rational	0.112	0.6	0.825	0.825	0.005090	0.006999	0.006999
Cat-36	MH-104	Rational	0.103	0.6	0.825	0.825	0.004672	0.006424	0.006424
Cat-37	MH-80	Rational	0.080	0.6	0.825	0.825	0.003651	0.005021	0.005021
Cat-38	MH-80	Rational	0.056	0.6	0.825	0.825	0.002544	0.003498	0.003498
Cat-39	MH-83	Rational	0.113	0.6	0.825	0.825	0.005164	0.007100	0.007100
Cat-4	MH-112	Rational	0.612	0.6	0.5	0.5	0.027850	0.023208	0.023208
Cat-40	MH-83	Rational	0.024	0.6	0.825	0.825	0.001111	0.001528	0.001528
Cat-41	MH-84	Rational	0.008	0.6	0.825	0.825	0.000345	0.000474	0.000474
Cat-42	MH-87	Rational	0.013	0.6	0.825	0.825	0.000574	0.000790	0.000790
Cat-43	MH-88	Rational	0.025	0.6	0.825	0.825	0.001147	0.001577	0.001577
Cat-44	MH-97	Rational	0.037	0.6	0.825	0.825	0.001666	0.002291	0.002291
Cat-45	MH-98	Rational	0.056	0.6	0.825	0.825	0.002538	0.003490	0.003490
Cat-46	MH-100	Rational	0.065	0.6	0.825	0.825	0.002967	0.004080	0.004080
Cat-47	MH-33	Rational	0.039	0.6	0.825	0.825	0.001790	0.002461	0.002461
Cat-48	MH-34	Rational	0.070	0.6	0.825	0.825	0.003164	0.004351	0.004351
Cat-49	MH-105	Rational	0.063	0.6	0.825	0.825	0.002875	0.003954	0.003954
Cat-5	MH-107	Rational	0.378	0.6	0.5	0.5	0.017219	0.014349	0.014349
Cat-50	MH-93	Rational	0.072	0.6	0.825	0.825	0.003270	0.004496	0.004496
Cat-51	MH-92	Rational	0.077	0.6	0.825	0.825	0.003507	0.004822	0.004822
Cat-52	MH-1	Rational	0.073	0.6	0.825	0.825	0.003328	0.004576	0.004576
Cat-53	MH-95	Rational	0.085	0.6	0.825	0.825	0.003872	0.005323	0.005323
Cat-54	MH-58	Rational	0.109	0.6	0.825	0.825	0.004981	0.006849	0.006849
Cat-55	MH-78	Rational	0.083	0.6	0.825	0.825	0.003775	0.005191	0.005191
Cat-56	MH-48	Rational	0.060	0.6	0.825	0.825	0.002708	0.003723	0.003723
Cat-57	MH-8	Rational	0.047	0.6	0.825	0.825	0.002159	0.002969	0.002969
Cat-58	MH-53	Rational	0.068	0.6	0.825	0.825	0.003099	0.004261	0.004261
Cat-59	MH-51	Rational	1.629	0.6	0.5	0.852	0.074129	0.061774	0.105263

Cat-6	MH-46	Rational	0.018	0.6	0.825	0.825	0.000811	0.001115	0.001115
Cat-60	MH-53	Rational	0.886	0.6	0.5	0.825	0.040332	0.033610	0.055456
Cat-61	MH-69	Rational	1.866	0.6	0.5	0.5	0.084928	0.070774	0.070774
Cat-62	MH-8	Rational	0.347	0.6	0.5	0.825	0.015777	0.013147	0.021693
Cat-63	MH-106	Rational	0.471	0.6	0.5	0.825	0.021418	0.017849	0.029450
Cat-64	MH-82	Rational	0.374	0.6	0.5	0.825	0.017027	0.014189	0.023412
Cat-65	MH-108	Rational	0.582	0.6	0.5	0.5	0.026486	0.022072	0.036419
Cat-66	MH-108	Rational	0.091	0.6	0.6	0.6	0.004139	0.004139	0.004139
Cat-67	MH-108	Rational	0.286	0.6	0.5	0.5	0.013001	0.010834	0.010834
Cat-68	O-4	Rational	0.035	0.6	0.825	0.825	0.001590	0.002187	0.002187
Cat-7	MH-46	Rational	0.012	0.6	0.6	0.825	0.000568	0.000568	0.000781
Cat-8	MH-44	Rational	0.012	0.6	0.6	0.825	0.000564	0.000564	0.000776
Cat-9	MH-45	Rational	0.014	0.6	0.6	0.825	0.000621	0.000621	0.000854

As it can be seen from the above table the land use parameter taken for the design phase (Runoff Coefficient Design (C)) were constant 0.6. This has resulted wrong estimation of the land use value, the self-analyzed computation applies artificial catchment delineation i.e. the boundary condition, artificial barriers, the current land use conditions and existing gullies and rivers in the study area.

The percentage computation for the design phase flow maximum (Q M^3/s) Design) and 2004 self-computed (flow maximum (Q M^3/s) (2004)) result has shown a 6.63 % drop in run off, this is due to the wrong estimation of land use condition for the design phase flow maximum (Q M^3/s) design. While the discharge computation for 2019 and 2004 self-computed result has shown a 23.38 % increment of run off. This occurred because of the impervious surfaces has intensely changed like gravel roads are changed to asphalt, commercial buildings are constructed, this changes the runoff coefficient (C) while on the design the runoff coefficient was assumed a constant.

4.4. Hydraulics Capacity Assessment

In hydraulic review, the main focus was the hydraulic capacity of the conduits drain, which is controlled by its dimension, invert level, and gradient. Insufficient hydraulic capacity was one of the major factors causing buildup of surface water and flash flood during a storm event. The storm water drainage network hydraulic capacity inefficiency is one of the cause for flooding in urban area.(Butler and Davies, 2010). The discharge capacity of the earth drain was then determined using Manning's method using primary data input i.e. Roughness coefficient, Area, slope, and diameter. Accordingly, the peak rate of runoff with respect to roughness coefficient change and hydraulic capacities of the conduit constructed were computed and the obtained result are presented in table 4.6

Figure 4- 4: Areal imagery of the study area 2004 and 2019

Table 4- 6: Capacity Assessment – 10-Year Storm

Label	Section Type	Diameter (cm)	Area (m2)	Slope	Hydraulic capacity (m³/s)	Peak runoff rate(m³/s)	Deference
Conduit_3	Circle	90	0.006362	0.113104	0.012747	0.000678	0.012069
Conduit_4	Circle	90	0.006362	0.035542	0.213934	0.213934	0
Conduit_5	Circle	90	0.006362	0.048732	0.00146	0.00146	0
Conduit_6	Circle	90	0.006362	0.0397	0.001466	0.001466	0
Conduit_7	Circle	90	0.006362	0.053744	0.001457	0.001457	0
Conduit_8	Circle	90	0.006362	0.102283	0.001458	0.001458	0
Conduit_9	Circle	90	0.006362	0.032337	0.701914	0.701914	0
Conduit_10	Circle	90	0.006362	0.050962	0.001465	0.001465	0
Conduit_11	Circle	120	0.01131	-0.006401	0.237531	0.237531	0
Conduit_12	Circle	90	0.006362	0.054737	0.001455	0.001455	0
Conduit_13	Circle	90	0.006362	0.066262	0.008791	0.008791	0
Conduit_14	Circle	90	0.006362	0.051518	0.001456	0.001456	0
Conduit_15	Circle	90	0.006362	0.102001	0.012747	0.012747	0
Conduit_16	Circle	90	0.006362	0.05997	0.001459	0.001459	0
Conduit_17	Circle	90	0.006362	0.041309	0.001462	0.001462	0
Conduit_18	Circle	90	0.006362	0.041127	0.009401	0.009401	0

Conduit_19	Circle	90	0.006362	0.050862	0.203955	0.203955	0
Conduit_20	Circle	90	0.006362	0.081708	0.001469	0.052572	-0.051103
Conduit_21	Circle	90	0.006362	0.078342	0.164326	0.164326	0
Conduit_23	Circle	90	0.006362	0.049858	0.164128	0.001846	0.162282
Conduit_24	Circle	90	0.006362	0.061581	0.009935	0.000494	0.009441
Conduit_25	Circle	90	0.006362	0.040316	0.001456	0.001456	0
Conduit_26	Circle	90	0.006362	0.034241	0.182019	0.182019	0
Conduit_27	Circle	90	0.006362	0.039815	0.001458	0.001458	0
Conduit_28	Circle	90	0.006362	0.117147	0.084714	0.084714	0
Conduit_29	Circle	90	0.006362	0.040461	0.012747	0.012747	0
Conduit_30	Circle	90	0.006362	0.042302	0.010944	0.000568	0.010376
Conduit_31	Circle	90	0.006362	0.058424	0.008006	0.000678	0.007328
Conduit_32	Circle	90	0.006362	0.040686	0.012128	0.000619	0.011509
Conduit_33	Circle	90	0.006362	0.05241	0.00739	0.000619	0.006771
Conduit_34	Circle	90	0.006362	0.033482	0.185494	0.00147	0.184024
Conduit_35	Circle	90	0.006362	0.107475	0.009683	0.000659	0.009024
Conduit_36	Circle	120	0.01131	-0.00738	0.007891	0.007891	0
Conduit_37	Circle	90	0.006362	0.046611	0.082227	0.083609	-0.001382
Conduit_38	Circle	120	0.01131	-0.012003	0.008819	0.019588	-0.010769
Conduit_39	Circle	90	0.006362	0.071606	0.200021	0.200021	0
Conduit_40	Circle	90	0.006362	0.072506	0.001459	0.001459	0
Conduit_41	Circle	120	0.01131	0.003825	0.236783	0.004261	0.232522
Conduit_43	Circle	90	0.006362	0.033939	0.186775	0.186775	0
Conduit_44	Circle	90	0.006362	0.045727	0.173563	0.00147	0.172093
Conduit_45	Circle	90	0.006362	0.051681	0.206994	0.002122	0.204872
Conduit_46	Circle	90	0.006362	0.052783	0.01043	0.000514	0.009916
Conduit_47	Circle	90	0.006362	0.030512	0.188415	0.001711	0.186704
Conduit_48	Circle	120	0.01131	-0.00747	0.005184	0.002957	0.002227
Conduit_49	Circle	90	0.006362	0.033347	0.083713	0.083713	0
Conduit_51	Circle	90	0.006362	-0.017564	0.008925	0.008925	0
Conduit_52	Circle	90	0.006362	0	0.084511	0.084511	0
Conduit_53	Circle	90	0.006362	0.073116	0.009487	0.009487	0
Conduit_54	Circle	90	0.006362	0	0.076711	0.076711	0
Conduit_55	Circle	90	0.006362	0.027311	0.215753	0.001651	0.214102
Conduit_56	Circle	90	0.006362	0.051108	0.076711	0.044048	0.032663
Conduit_57	Circle	120	0.01131	0.039711	0.041606	0.041606	0
Conduit_58	Circle	90	0.006362	0.006189	0.084217	0.084217	0
Conduit_59	Circle	90	0.006362	0.028209	0.158705	0.070774	0.087931
Conduit_60	Circle	90	0.006362	0.012243	0.159263	0.159263	0
Conduit_63	Circle	90	0.006362	0	0.160412	0.160412	0
Conduit_64	Circle	90	0.006362	0.065644	0.005884	0.001505	0.004379
Conduit_65	Circle	90	0.006362	0.035579	0.214378	0.214378	0
Conduit_66	Circle	90	0.006362	0	0.159835	0.159835	0
Conduit_67	Circle	90	0.006362	0.069229	0.08252	0.08252	0
Conduit_68	Circle	120	0.01131	-0.007028	0.000929	0.004123	-0.003194
Conduit_69	Circle	90	0.006362	0.001823	0.212814	0.002191	0.210623
Conduit_70	Circle	90	0.006362	-0.020281	0.009945	0.009945	0

Conduit_71	Circle	120	0.01131	-0.008053	0.238363	0.238363	0
Conduit_75	Circle	120	0.01131	-0.004351	0.004216	0.004216	0
Conduit_78	Circle	90	0.006362	0.018677	0.2149	0.001289	0.213611
Conduit_80	Circle	120	0.01131	-0.014112	0.004222	0.004222	0
Conduit_83	Circle	120	0.01131	-0.005684	0.004224	0.004224	0
Conduit_85	Circle	90	0.006362	0.008493	0.161782	0.161782	0
Conduit_86	Circle	90	0.006362	-0.020438	0.220319	0.001289	0.21903
Conduit_91	Circle	120	0.01131	0.032555	0.003155	0.003155	0
Conduit_93	Circle	90	0.006362	-0.007172	0.161071	0.161071	0
Conduit_95	Circle	90	0.006362	0.067175	0	0.001456	-0.001456
Conduit_96	Circle	90	0.006362	0.053700	0	0	0
Conduit_99	Circle	90	0.006362	0.032890	0.083099	0.083099	0
Conduit_104	Circle	90	0.006362	0.027649	0.030742	0.030742	0
Conduit_111	Circle	90	0.006362	0.040793	0	0.001447	-0.001447
Conduit_114	Circle	90	0.006362	0.053728	0.00506	0.011397	-0.006337
Conduit -1	Circle	120	0.01131	0.049017	0.049139	0.006849	0.04229
Conduit -2	Circle	90	0.006362	0.038993	0	0.002122	-0.002122

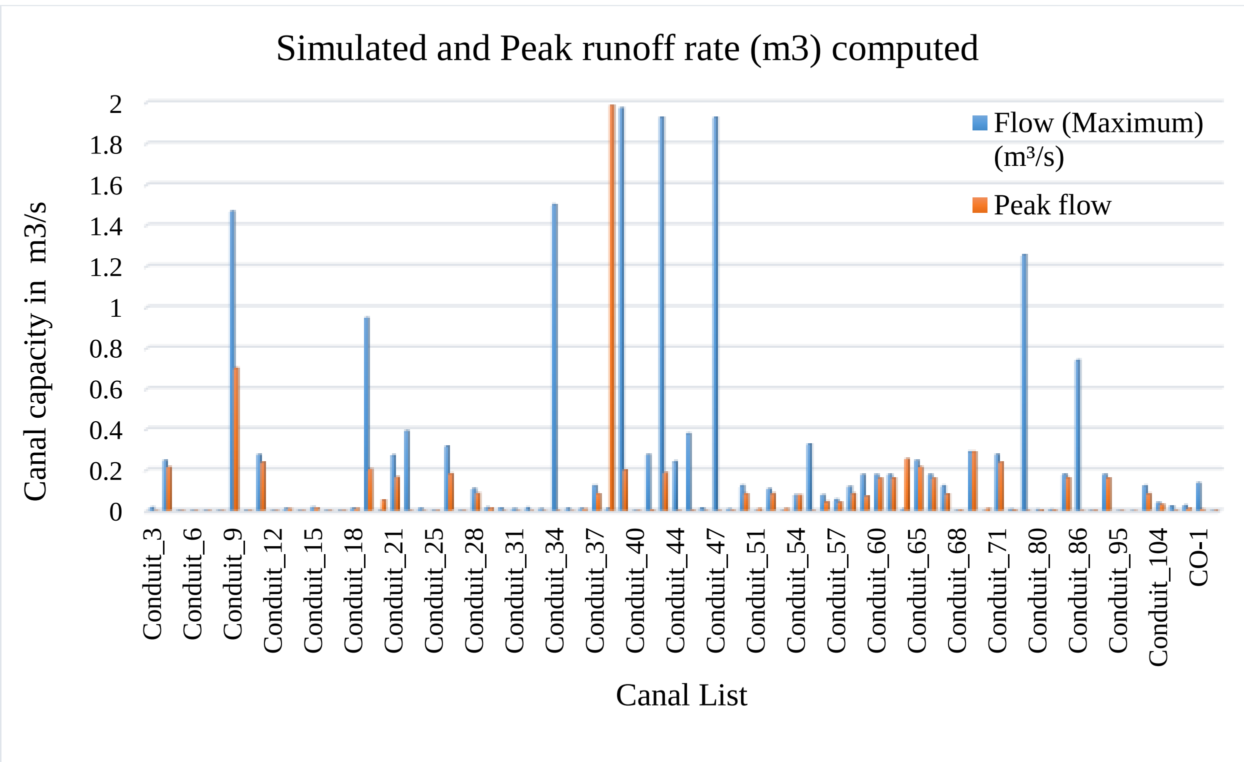

Figure 4- 5: Simulated and Peak runoff rate (m3) computed storm capacities.

As it can be seen on table 4.6 and figure 4.5, calculation were done by deducting the hydraulic capacity (m³/s) with peak runoff rate (m³/s). The result shows that except some minor conduits the hydraulic design is capable of carrying the peak runoff.

Table 4- 7 : Measured Maximum Peak Flow with changing roughness coefficient

Manning's n	Flow (Maximum) (m^3/s)	Manning's n	Flow (Maximum) (m^3/s)	Manning's n	Flow (Maximum) (m^3/s)
0.012	0.017749	0.013	0.016383	0.016	0.013312
0.012	0.017117	0.013	0.0158	0.016	0.012838
0.012	0.01421	0.013	0.013117	0.016	0.010657
0.012	0.007966	0.013	0.007353	0.016	0.005974
0.012	0.009327	0.013	0.00861	0.016	0.006995
0.012	0.008419	0.013	0.007771	0.016	0.006314
0.012	0.009795	0.013	0.009042	0.016	0.007346
0.012	0.013513	0.013	0.012474	0.016	0.010135
0.012	0.007598	0.013	0.007014	0.016	0.005698
0.012	0.009538	0.013	0.008805	0.016	0.007154
0.012	0.00728	0.013	0.00672	0.016	0.00546
0.012	0.009885	0.013	0.009125	0.016	0.007414
0.012	0.010876	0.013	0.01004	0.016	0.008157
0.012	0.00959	0.013	0.008852	0.016	0.007193
0.012	0.013494	0.013	0.012456	0.016	0.010121
0.012	0.010347	0.013	0.009551	0.016	0.00776
0.012	0.008588	0.013	0.007927	0.016	0.006441
0.012	0.008569	0.013	0.00791	0.016	0.006426
0.012	0.009529	0.013	0.008796	0.016	0.007147
0.012	0.012078	0.013	0.011149	0.016	0.009058
0.012	0.011826	0.013	0.010916	0.016	0.00887
0.012	0.003349	0.013	0.003091	0.016	0.002512
0.012	0.009434	0.013	0.008709	0.016	0.007076
0.012	0.010485	0.013	0.009679	0.016	0.007864
0.012	0.008484	0.013	0.007831	0.016	0.006363
0.012	0.007818	0.013	0.007217	0.016	0.005864
0.012	0.008431	0.013	0.007782	0.016	0.006323
0.012	0.014462	0.013	0.013349	0.016	0.010846
0.012	0.008499	0.013	0.007845	0.016	0.006374
0.012	0.00869	0.013	0.008022	0.016	0.006518
0.012	0.010213	0.013	0.009427	0.016	0.00766
0.012	0.008523	0.013	0.007867	0.016	0.006392
0.012	0.009673	0.013	0.008929	0.016	0.007255
0.012	0.007731	0.013	0.007137	0.016	0.005798
0.012	0.013852	0.013	0.012786	0.016	0.010389
0.012	0.007817	0.013	0.007216	0.016	0.005863
0.012	0.009122	0.013	0.00842	0.016	0.006842
0.012	0.009969	0.013	0.009202	0.016	0.007477
0.012	0.011306	0.013	0.010437	0.016	0.00848
0.012	0.011377	0.013	0.010502	0.016	0.008533

0.012	0.005628	0.013	0.005195	0.016	0.004221
0.012	0.003898	0.013	0.003598	0.016	0.002923
0.012	0.007784	0.013	0.007185	0.016	0.005838
0.012	0.009035	0.013	0.00834	0.016	0.006776
0.012	0.009605	0.013	0.008866	0.016	0.007204
0.012	0.009707	0.013	0.008961	0.016	0.00728
0.012	0.00738	0.013	0.006813	0.016	0.005535
0.012	0.007865	0.013	0.00726	0.016	0.005899
0.012	0.007716	0.013	0.007122	0.016	0.005787
0.012	0.0056	0.013	0.005169	0.016	0.0042
0.012	0.011425	0.013	0.010546	0.016	0.008569
0.012	0.006983	0.013	0.006445	0.016	0.005237
0.012	0.009552	0.013	0.008817	0.016	0.007164
0.012	0.00842	0.013	0.007772	0.016	0.006315
0.012	0.007159	0.013	0.006608	0.016	0.005369
0.012	0.007097	0.013	0.006551	0.016	0.005322
0.012	0.004675	0.013	0.004315	0.016	0.003506
0.012	0.003577	0.013	0.003302	0.016	0.002683
0.012	0.003116	0.013	0.002876	0.016	0.002337
0.012	0.010825	0.013	0.009993	0.016	0.008119
0.012	0.00797	0.013	0.007357	0.016	0.005977
0.012	0.011117	0.013	0.010262	0.016	0.008338
0.012	0.007629	0.013	0.007042	0.016	0.005721
0.012	0.001804	0.013	0.001665	0.016	0.001353
0.012	0.006017	0.013	0.005554	0.016	0.004513
0.012	0.008166	0.013	0.007538	0.016	0.006124
0.012	0.003579	0.013	0.003303	0.016	0.002684
0.012	0.004947	0.013	0.004567	0.016	0.003711
0.012	0.010526	0.013	0.009716	0.016	0.007894
0.012	0.006002	0.013	0.005541	0.016	0.004502
0.012	0.009454	0.013	0.008726	0.016	0.00709
0.012	0.010716	0.013	0.009892	0.016	0.008037
0.012	0.005774	0.013	0.00533	0.016	0.004331
0.012	0.003087	0.013	0.00285	0.016	0.002315
0.012	0.01081	0.013	0.009978	0.016	0.008107
0.012	0.014047	0.013	0.012966	0.016	0.010535
0.012	0.013513	0.013	0.012474	0.016	0.010135
0.012	0.00686	0.013	0.006333	0.016	0.005145
0.012	0.011295	0.013	0.010426	0.016	0.008471
0.012	0.003894	0.013	0.003594	0.016	0.00292
0.012	0.00604	0.013	0.005576	0.016	0.00453
0.012	0.011774	0.013	0.010869	0.016	0.008831
0.012	0.011757	0.013	0.010853	0.016	0.008818
0.012	0.013154	0.013	0.012142	0.016	0.009865
0.012	0.008371	0.013	0.007727	0.016	0.006278
0.012	0.016418	0.013	0.015155	0.016	0.012314

0.012	0.013826	0.013	0.012763	0.016	0.01037
0.012	0.003578	0.013	0.003303	0.016	0.002684
0.012	0.00551	0.013	0.005086	0.016	0.004133
0.012	0.010951	0.013	0.010109	0.016	0.008213
0.012	0.009791	0.013	0.009038	0.016	0.007343
0.012	0.011138	0.013	0.010282	0.016	0.008354
0.012	0.005278	0.013	0.004872	0.016	0.003958
0.012	0.007663	0.013	0.007073	0.016	0.005747
0.012	0.005858	0.013	0.005407	0.016	0.004393
0.012	0.013022	0.013	0.012021	0.016	0.009767
0.012	0.014674	0.013	0.013545	0.016	0.011005
0.012	0.007978	0.013	0.007365	0.016	0.005984
0.012	0.007026	0.013	0.006485	0.016	0.005269
0.012	0.003135	0.013	0.002894	0.016	0.002352
0.012	0.003946	0.013	0.003642	0.016	0.002959
0.012	0.008978	0.013	0.008287	0.016	0.006733
0.012	0.00809	0.013	0.007468	0.016	0.006068
0.012	0.008534	0.013	0.007877	0.016	0.0064
0.012	0.009794	0.013	0.00904	0.016	0.007345
0.012	0.010274	0.013	0.009484	0.016	0.007706
0.012	0.007882	0.013	0.007276	0.016	0.005912
0.012	0.020146	0.013	0.018596	0.016	0.01511
0.012	0.008343	0.013	0.007702	0.016	0.006258
0.012	0.00978	0.013	0.009028	0.016	0.007335
0.012	0.012602	0.013	0.011633	0.016	0.009452
Max	**1.006094**		**0.928705**		**0.754572**

Roughness is critical factor in the assessment of channel/conduit hydraulic capacity. Past experience has shown that conduit capacity has failed not because of inadequate design to handle unanticipated water flows, but because of inadequate cleaning and maintenance which eventually blocked water passage through the conduit.

Thus, on the above table 4.7, the study shows the change of roughness coefficient on the hydraulic system, this is important because when there was no proper clearing and maintenance program, debris will accumulate and passage of storm water will be a problem. To see this change, the study has taken variable roughness coefficient and model analysis was presented. Therefore, the result on the table 4.7 shows that when the roughness coefficient increase, this happen due to erosion of the concrete pipe, debris accommodation and sediment, hence the flow will decrease that lead the drainage system design to fail and cause flooding.

4.5. Model calibration and validation result

The table 4.8 presents Nash Sutcliffe, Root Mean Square Error and R-squared values and peak flows for calibration, validation and simulation periods. The RMSE is a perfect match between observed and predicted values when it equals 0 (zero) and in our case it is less than 0.1% RMSE and it indicate a good model prediction. Referring literatures, a model will indicates a perfect match between observed and predicted values when NSE and R2 = 1, Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance.

Table 4- 8 : Measured Maximum Peak Flow with changing roughness coefficient

Statistical measures			
Description	Nash Sutcliffe	Root Mean Square Error:	R-squared correlation (R2)
Validation (Ayeretena)	0.51	0.034	1
Calibration (Sebeta)	0.228	0.074	0.999
Acceptable range	0-1	< 0.1	0-1

4.6. Design problem

One of the most important factors in designing sustainable storm water drainage systems is the physical storage volume that needs to provide to achieve flood control and minimize the flooding impact of urban storm water runoff. This section begins on storm water drainage by investigating the performance of previous drainage design systems and compared with the current conditions of the drainage system using the design standards. As it can be seen from the two tables above; Table 4.6 and 4.7, some of the canals couldn’t accommodate the incoming flood which indicates the hydraulic design of some canals are unable to carry the incoming flow.

4.7. Maintenance and cleaning/ Management Problem

As stated on the methodology part, interview points were prepared to assess the O&M problem. Most of the interviewees agreed that the drainage problem happens on the rain season and the sewage and solid wastes management was not given good attention, moreover the People living in front of the main road dispose their solid waste to the drainage channel.

From all the questions interviewed, the crucial question asked was how frequently the maintenance /cleaning trend of the storm water drainage system is done in study area. Majority of the interviewees noticed that cleaning of the drainage system were done once a year before the rain season begin and agreed there was no regular maintenance of drainage to the streets, manholes and conduits.

The field observation justifies that side manholes was full of garbage and sediment which impede the normal flow of water in the channel. Even some manholes are completely closed which couldn't allow the incoming storm water to enter to drainage system. The drainage collected form residential catchment areas are not properly collected and connected to the main drainage system, the over flow will directly exposed to the road surface which contribute to runoff.

Besides the runoff generated from the blockage, poor cleaning and maintenance has increased the roughness of the pipe, which result increasing of the runoff generated and flooding to occur.

Figure 4- 6: Existing blocked drainage manholes

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The flood hazards problems are getting worse in the coming years due to the massive construction of houses, buildings and roads and less attention to river side drainage and catchments. Moreover, the city isn't showing enough concern about population settlements residing along the stream and the ecological, environmental, social and economic impacts of flood variability. It is also common to see flood on the newly constructed roads of Addis Ababa especially on the rainy season. As part of the problem Gurd Shola area is chosen because flooding happens soon after the project completion. Flood causes the disturbance of ecology and enormous impacts on environment, health risks, social disturbance, economy and financial disorder, loss of city infrastructure, and transportation systems, psychological frustration of the current and future risks. This Investigation has demonstrated that identify the cause of flooding either due to hydraulic property or hydrological characteristics of the storm water to the specified area is an effective method to prevent the area before flooding.

The effects of various hydraulic property or hydrological characteristics were simulated using Bentley civil storm model for the study area catchment based on the characteristics of the sub-catchment and storm sewer conduits. Percentage change of peak flow was computed based on design and self-computed runoff coefficient using rational method for 10 year return period of rainfall. The hydraulic capacities of the storm sewer were assessed taking different roughness value to assess external factors cleaning and maintenance. The results showed that the runoff had increased due to change in runoff coefficient of the study area and also most of the storm sewer networks in the study area had sufficient capacity to transport the runoff coming from the catchment.

Over all, the study showed that proper cleaning and maintenance had to be done to prevent flood events that often disrupt the catchment area which is the main contributor for flooding in the study area.

5.2 Recommendation

Based on the finding of this study, identifying impact of flooding problem is found to be interesting. It is recommended to continue scientific investigations to refine and advance to minimize the vulnerability of flooding. Specifically, further studies are recommended in the following.

- In this study for urban drainage system, natural catchment delineation were used, for further future work it is preferred to use artificial catchment delineation system,
- To conduct and design similar analysis investigation at large area.
- To assess the influence of other parameters on urban flood formation.
- To evaluate more model analysis and identify the one that is more efficient.
- To identify impact flooding from other area

The following issue are recommended to minimize the vulnerability of flooding around Gurd Shola area, Majority of the Addis Ababa city drainage system has huge problem when it comes to regular operation and cleaning. In order to improve the problems that has been hindering the drainage systems in this study area, periodical cleaning and maintenance should be done.

Natural catchment delineation was the first task undertaken while considering the drainage system, but urban drainage system sometimes wouldn't allow the pathway of the natural delineation. This is because there are different boundary conditions which should be observed like road, streams, gorges and new drainage system which brings change on the design of the urban drainage system and lesson can be taken from this case study.

As-built drawing and design analysis for the road and drainage system of the study area is not available. For such kind of studies to be complete (even for future maintenance and repair) responsible bodies must record such significant data.

Natural hydrological phenomena show due to increased impervious area precipitation responds quickly reducing the time to peak flow and producing higher peak flows in the drainage channels. Therefore, the design and construction (road as well as drainage) need to be revised as urbanization is highly growing in the city. Slope also should be clearly checked in order to avoid unwanted storm water accumulation on the road surface, which will be the potential cause for flooding.

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Appendix: Interview questions

Office interview

1. What is your name and position in this organization? ________________________________
2. Are there any site specific local drainage guidelines? __________________________________
3. What are the physical factors considered during the design of urban drainage design?

____

4. What is the overall situation of the storm water drainage system of the study area?

____

5. What is flooding situation of the storm water in study area?

____

6. What is sewage and solid waste management system in study area?

____

7. What is the maintenance /cleaning trend of the storm water drainage system in study area?

____

8. What is the cause of flooding in the study area? __________________________________

Informant interview

1. For how many years did you live in this area?

☐ < 1 year ☐ 2 – 5years ☐ > 5years

2. How frequent did you see cleaning and maintenance of the drainage system?

☐ Every week ☐ Every month ☐ Once in a year

Other____

3. Are there a flooding problems so far in the study area more on rainy season?

☐ Yes ☐ No

4. What do you think is the possible cause of the study area to flood?

☐ Heavy Rain ☐ Heavy load ☐ Lack of drainage

other____

5. What do you think should be done to minimize flooding for the future?

____

ANNEX

No	Year	Maximum_Daily Rainfall	Decending Order	Rank	Logarithmic Value/Yo/
1	1988	**35.80**	**71.20**	**1**	**1.852479994**
2	1989	**48.40**	**64.70**	**2**	**1.810904281**
3	1990	**37.00**	**64.70**	**3**	**1.810904281**
4	1991	**59.60**	**61.70**	**4**	**1.790285164**
5	1992	**44.30**	**60.50**	**5**	**1.781755375**
6	1993	**40.60**	**60.10**	**6**	**1.778874472**
7	1994	**38.20**	**59.60**	**7**	**1.77524626**
8	1995	**64.70**	**54.40**	**8**	**1.7355989**
9	1996	**52.00**	**52.00**	**9**	**1.716003344**
10	1997	**37.30**	**51.20**	**10**	**1.709269961**
11	1998	**60.10**	**49.10**	**11**	**1.691081492**
12	1999	**37.80**	**48.40**	**12**	**1.684845362**
13	2000	**47.00**	**47.00**	**13**	**1.672097858**
14	2001	**32.40**	**44.50**	**14**	**1.648360011**
15	2002	**28.60**	**44.30**	**15**	**1.646403726**
16	2003	**34.60**	**42.60**	**16**	**1.629409599**
17	2004	**29.00**	**40.60**	**17**	**1.608526034**
18	2005	**44.50**	**38.20**	**18**	**1.582063363**
19	2006	**61.70**	**38.10**	**19**	**1.580924976**
20	2007	**71.20**	**37.80**	**20**	**1.5774918**

21	2008	**37.20**	**37.30**	**21**	**1.571708832**
22	2009	**51.20**	**37.20**	**22**	**1.57054294**
23	2010	**54.40**	**37.00**	**23**	**1.568201724**
24	2011	**38.10**	**35.80**	**24**	**1.553883027**
25	2012	**64.70**	**34.60**	**25**	**1.539076099**
26	2013	**42.60**	**33.00**	**26**	**1.51851394**
27	2014	**27.20**	**32.40**	**27**	**1.51054501**
28	2015	**60.50**	**29.00**	**28**	**1.462397998**
29	2016	**33.00**	**28.60**	**29**	**1.456366033**
30	2017	**49.10**	**27.20**	**30**	**1.434568904**
		Minimum	**27.2**		
	Average	**45.42666667**		**Minimum**	**1.434568904**
	STDEV.P	**11.99816467**		**Average**	**1.642277692**
				STDEV.P	**0.114342571**
				Coficient of Skness	**0.056364156**

Testing for Outliers

The highest recorded value from meteorological station is (71.2 mm) is less than the higher outlier (86.166mm). therefore, no higher outlierdate will be eliminated.

Determine the threshold value for high outliers Test for Higher outlier

yH = y + Knsy

Where

yH is the high outlier threshold in log units

Kn= from table for sample size N (Vente Chow, 1998)

sy=standard devotion

Higher outlier test=10YH

N= **30**

Kn= ***2.563***

1.9353377

86.16635068

Determine **<u>the threshold value for high outliers Test for Lower outlier</u>**

where yL is the low outlier threshold in log units

Kn= from table for sample size N (Vente Chow, 1998)

sy=standard devotion

yL **1.349217684**

Lower outlier=10yL **22.34692048**

The Lowest recorded value from meteorological station is (27.2mm) is Greater than the Lower outlier (22.34mm). therefore, no Lower outlierdate will be eliminated.

Design Rain fall Computation of shorter duration

A: Log Pearson Type III distributions analysis.

YT = Yavg + KT*Sy

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

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

Sy = Standard deviation [mm]

Yearly Extreme Series and Frequency Analysis Calculations Log-Pearson Type III distribution

Design Point Rainfall

Return Period (T)	Appling Log Pearson type III distribution,24 hours' rainfall design				
	X mean	KT	δn − 1	YT =Yavg + KT*Sy	YT=10^YT
2	1.642277692	-0.91	0.114342571	1.53811161	34.52324499
5		0.49		1.698854396	49.98669184
10		1.11		1.769152208	58.76952873
25		1.59		1.823830825	66.65470725
50		1.98		1.868470165	73.87035138
100		2.28		1.903298912	80.03849464

Return P		2	5	10	25	50	100
Coefficient of Skewness	0.06						
K_T		-0.91	0.49	1.11	1.59	1.98	2.28

Yearly Extreme Series and Frequency Analysis Calculations Gumbel Method

Return Period (T)			Design Point Rainfall				
	X_{Mean}	SD	Yn	sn	YT	KT	XT=X-+ KT∗ Sy
2	45.42666667	11.99816467	0.5362	1.1124	0.36651	-0.152541	43.596450
5					1.49994	0.866361	55.821409
10					2.25037	1.540963	63.915395
25					3.19853	2.393325	74.142169
50					3.90194	3.025655	81.728974
100					4.60015	3.653316	89.259759

IDF Curve table compared with ERA

t (minute)	ERA	Self	ERA	Self	ERA	Self	ERA	Self	ERA	Self	ERA	Self
5	98.40	82.63	124.17	105.79	141.10	121.14	178.28	140.51	162.42	154.90	194.16	169.17
10	82.11	68.95	103.62	88.28	117.74	101.09	148.77	117.25	135.53	129.25	162.02	141.16
15	70.59	59.28	89.08	75.89	101.22	86.91	127.90	100.80	116.52	111.12	139.29	121.36
20	62.00	52.06	78.24	66.66	88.90	76.33	112.33	88.53	102.34	97.59	122.34	106.59
25	55.33	46.47	69.83	59.49	79.34	68.12	100.25	79.01	91.33	87.10	109.19	95.13
30	50.01	41.99	63.11	53.76	71.71	61.57	90.61	71.41	82.54	78.72	98.68	85.97
35	45.65	38.34	57.61	49.08	65.46	56.20	82.71	65.19	75.35	71.86	90.08	78.48
40	42.02	35.28	53.02	45.17	60.25	51.73	76.13	60.00	69.35	66.14	82.91	72.24
45	38.94	32.70	49.14	41.86	55.84	47.94	70.55	55.60	64.27	61.30	76.84	66.94
50	36.30	30.48	45.80	39.02	52.05	44.69	65.76	51.83	59.91	57.14	71.62	62.40
55	34.00	28.55	42.91	36.56	48.76	41.86	61.61	48.56	56.13	53.53	67.10	58.46
60	31.99	26.87	40.37	34.40	45.88	39.39	57.97	45.68	52.81	50.36	63.13	55.00
65	30.22	25.37	38.13	32.49	43.33	37.20	54.75	43.15	49.87	47.56	59.62	51.95
70	28.63	24.04	36.13	30.78	41.06	35.25	51.88	40.89	47.26	45.07	56.50	49.22

75	27.21	22.85	34.34	29.26	39.02	33.50	49.31	38.86	44.92	42.84	53.70	46.78
80	25.93	21.78	32.73	27.88	37.19	31.93	46.99	37.03	42.81	40.82	51.17	44.58
85	24.77	20.80	31.26	26.63	35.52	30.50	44.88	35.37	40.89	39.00	48.88	42.59
90	23.72	19.92	29.93	25.50	34.01	29.20	42.97	33.86	39.15	37.33	46.80	40.77
95	22.75	19.10	28.71	24.46	32.62	28.01	41.22	32.48	37.55	35.81	44.89	39.11
100	21.86	18.36	27.59	23.50	31.35	26.91	39.61	31.22	36.08	34.41	43.13	37.58
105	21.04	17.67	26.55	22.62	30.17	25.90	38.12	30.05	34.73	33.12	41.52	36.17
110	20.28	17.03	25.60	21.81	29.09	24.97	36.75	28.96	33.48	31.93	40.02	34.87
115	19.58	16.44	24.71	21.05	28.08	24.11	35.48	27.96	32.32	30.82	38.64	33.66
120	18.93	15.89	23.89	20.35	27.14	23.30	34.29	27.03	31.24	29.79	37.35	32.54
125	18.32	15.38	23.12	19.69	26.27	22.55	33.19	26.16	30.24	28.83	36.15	31.49
130	17.75	14.90	22.40	19.08	25.45	21.85	32.16	25.34	29.29	27.94	35.02	30.51
135	17.21	14.45	21.72	18.51	24.68	21.19	31.19	24.58	28.41	27.10	33.97	29.59
140	16.71	14.03	21.09	17.97	23.96	20.57	30.28	23.86	27.58	26.31	32.98	28.73
145	16.24	13.64	20.49	17.46	23.29	19.99	29.42	23.19	26.80	25.56	32.04	27.92
150	15.79	13.26	19.93	16.98	22.65	19.44	28.62	22.55	26.07	24.86	31.17	27.15
155	15.37	12.91	19.40	16.53	22.04	18.93	27.85	21.95	25.38	24.20	30.34	26.43
160	14.98	12.58	18.90	16.10	21.47	18.44	27.13	21.39	24.72	23.57	29.55	25.75
165	14.60	12.26	18.42	15.70	20.93	17.97	26.45	20.85	24.10	22.98	28.81	25.10
170	14.24	11.96	17.97	15.31	20.42	17.53	25.80	20.34	23.51	22.42	28.10	24.48
175	13.90	11.67	17.54	14.95	19.93	17.11	25.19	19.85	22.95	21.88	27.43	23.90
180	13.58	11.40	17.14	14.60	19.47	16.72	24.60	19.39	22.41	21.37	26.79	23.34

Peak runoff estimation

Label	2019 Model result Flow (Maximum) (m^3/s)	Contributing catchment	Peak flow	Difference
Conduit_3	0.012747	Cat-19	0.000678	0.012069
Conduit_4	0.213934	equal to its capacity	0.213934	0
Conduit_5	0.00146	equal to its capacity	0.00146	0
Conduit_6	0.001466	equal to its capacity	0.001466	0
Conduit_7	0.001457	equal to its capacity	0.001457	0
Conduit_8	0.001458	equal to its capacity	0.001458	0
Conduit_9	0.701914	equal to its capacity	0.701914	0
Conduit_10	0.001465	equal to its capacity	0.001465	0
Conduit_11	0.237531	equal to its capacity	0.237531	0
Conduit_12	0.001455	equal to its capacity	0.001455	0
Conduit_13	0.008791	equal to its capacity	0.008791	0
Conduit_14	0.001456	equal to its capacity	0.001456	0
Conduit_15	0.012747	equal to its capacity	0.012747	0
Conduit_16	0.001459	equal to its capacity	0.001459	0
Conduit_17	0.001462	equal to its capacity	0.001462	0
Conduit_18	0.009401	equal to its capacity	0.009401	0
Conduit_19	0.203955	equal to its capacity	0.203955	0
Conduit_20	0.001469	Cat-2	0.052572	-0.051103
Conduit_21	0.164326	equal to its capacity	0.164326	0
Conduit_23	0.164128	Cat-20	0.001846	0.162282

Conduit_24	0.009935	Cat-14	0.000494	0.009441
Conduit_25	0.001456	equal to its capacity	0.001456	0
Conduit_26	0.182019	equal to its capacity	0.182019	0
Conduit_27	0.001458	equal to its capacity	0.001458	0
Conduit_28	0.084714	equal to its capacity	0.084714	0
Conduit_29	0.012747	equal to its capacity	0.012747	0
Conduit_30	0.010944	Cat-16	0.000568	0.010376
Conduit_31	0.008006	Cat-9	0.000678	0.007328
Conduit_32	0.012128	Cat-18	0.000619	0.011509
Conduit_33	0.00739	Cat-8	0.000619	0.006771
Conduit_34	0.185494	Cat-21	0.00147	0.184024
Conduit_35	0.009683	Cat-11	0.000659	0.009024
Conduit_36	0.007891	equal to its capacity	0.007891	0
Conduit_37	0.082227	Cat-59	0.083609	-0.001382
Conduit_38	0.008819	Cat-57	0.019588	-0.010769
		Cat-62		0
Conduit_39	0.200021	equal to its capacity	0.200021	0
Conduit_40	0.001459	equal to its capacity	0.001459	0
Conduit_41	0.236783	Cat-58	0.004261	0.232522
Conduit_43	0.186775	equal to its capacity	0.186775	0
Conduit_44	0.173563	Cat-21	0.00147	0.172093
Conduit_45	0.206994	Cat-30	0.002122	0.204872
Conduit_46	0.01043	Cat-15	0.000514	0.009916
Conduit_47	0.188415	Cat-23	0.001711	0.186704
Conduit_48	0.005184	Cat-56	0.002957	0.002227
Conduit_49	0.083713	equal to its capacity	0.083713	0
Conduit_51	0.008925	equal to its capacity	0.008925	0
Conduit_52	0.084511	equal to its capacity	0.084511	0

Conduit_53	0.009487	equal to its capacity	0.009487	0
Conduit_54	0.076711	equal to its capacity	0.076711	0
Conduit_55	0.215753	Cat-29	0.001651	0.214102
Conduit_56	0.076711	Cat-60	0.044048	0.032663
Conduit_57	0.041606	equal to its capacity	0.041606	0
Conduit_58	0.084217	equal to its capacity	0.084217	0
Conduit_59	0.158705	Cat-61	0.070774	0.087931
Conduit_60	0.159263	equal to its capacity	0.159263	0
Conduit_63	0.160412	equal to its capacity	0.160412	0
Conduit_64	0.005884	Cat-6	0.001505	0.004379
		Cat-7		0
Conduit_65	0.214378	equal to its capacity	0.214378	0
Conduit_66	0.159835	equal to its capacity	0.159835	0
Conduit_67	0.08252	equal to its capacity	0.08252	0
Conduit_68	0.000929	Cat-55	0.004123	-0.003194
Conduit_69	0.212814	Cat-27	0.002191	0.210623
		Cat-28		0
Conduit_70	0.009945	equal to its capacity	0.009945	0
Conduit_71	0.238363	equal to its capacity	0.238363	0
Conduit_75	0.004216	equal to its capacity	0.004216	0
Conduit_78	0.2149	Cat-25	0.001289	0.213611
Conduit_80	0.004222	equal to its capacity	0.004222	0
Conduit_83	0.004224	equal to its capacity	0.004224	0
Conduit_85	0.161782	equal to its capacity	0.161782	0
Conduit_86	0.220319	Cat-25	0.001289	0.21903
Conduit_91	0.003155	equal to its capacity	0.003155	0
Conduit_93	0.161071	equal to its capacity	0.161071	0
Conduit_95	0	Cat-1	0.001456	-0.001456

Conduit_96	0	equal to its capacity	0	0
Conduit_99	0.083099	equal to its capacity	0.083099	0
Conduit_104	0.030742	equal to its capacity	0.030742	0
Conduit_111	0	Cat-3	0.001447	-0.001447
Conduit_112	0.00506	Cat-5	0.011397	-0.006337
Conduit_1	0.049139	Cat-54	0.006849	0.04229
Conduit_2	0	Cat-30	0.002122	-0.002122

ERA recommended Runoff coefficient (C) for various selected land uses

Table 5-4 Recommended Runoff Coefficient C for Various Selected Land Uses

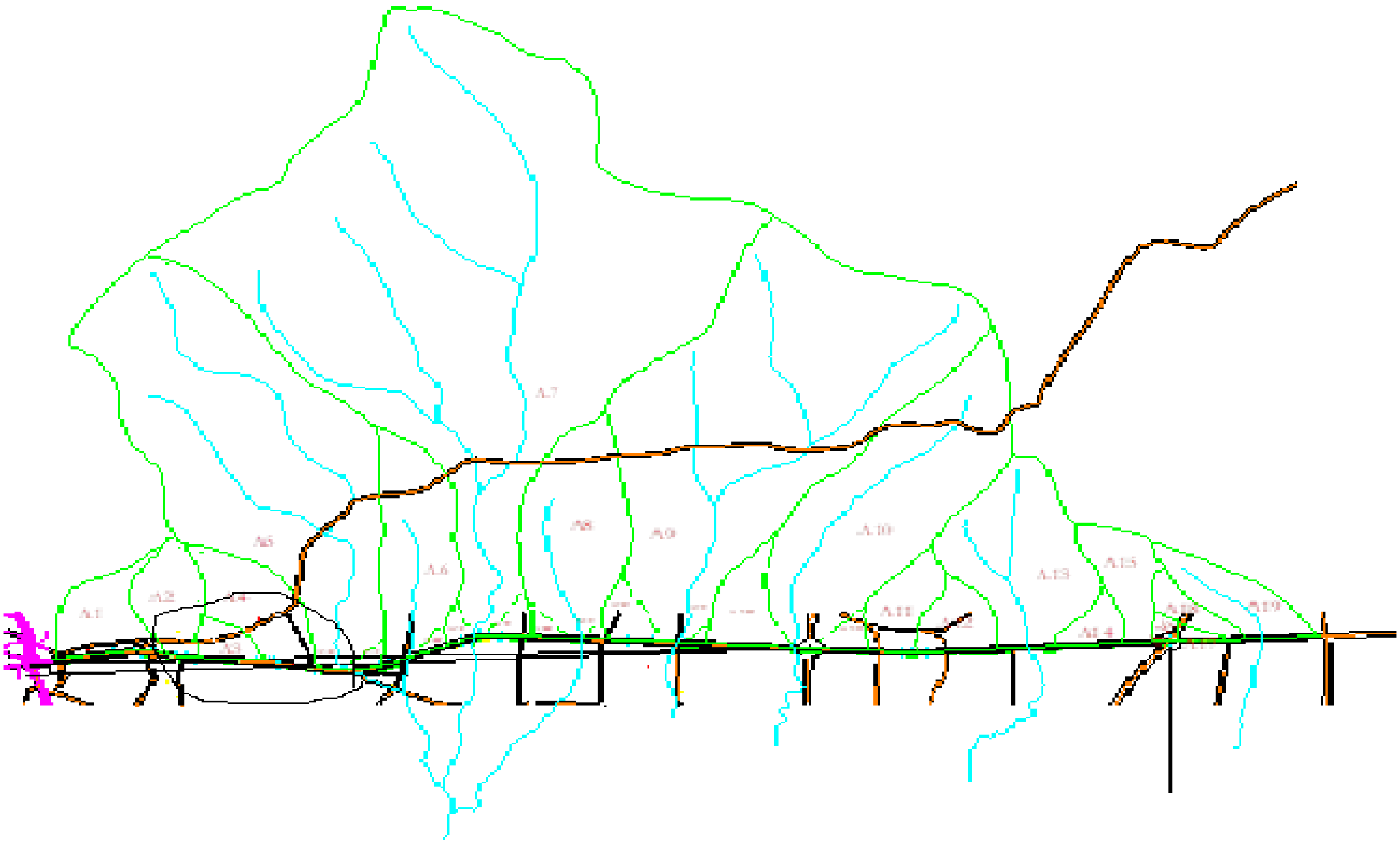
Description of Area		Runoff Coefficients
Business: Downtown areas		0.70-0.95
Neighborhood areas		0.50-0.70
Residential:	Single-family areas	0.30-0.50
	Multi units, detached	0.40-0.60
	Multi units, attached	0.60-0.75
	Suburban	0.25-0.40
Residential (0.5 hectare lots or more)		0.30-0.45
Apartment dwelling areas		0.50-0.70
Industrial:	Light areas	0.50-0.80
	Heavy areas	0.60-0.90
Parks, cemeteries		0.10-0.25
Playgrounds		0.20-0.40
Railroad yard areas		0.20-0.40
Unimproved areas		0.10-0.30

Source: Hydrology, Federal Highway Administration, HEC No. 19, 1984

Table 5-5 Coefficients for Composite Runoff Analysis

Surface		Runoff Coefficients
Street :	Asphalt	0.70-0.95
	Concrete	0.80-0.95
Drives and walks		0.75-0.85
Roofs		0.75-0.95

The design natural catchment delineation



Detailed Conduit and Catchment Map