JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF HYDRAULIC AND WATER RESOURCES ENGINEERING

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Performance Assessment of Storm Water Drainage System

The case of Gelgel Beles Town, Ethiopia

By: Tikdem Morka

A research Submitted to School of Graduate Studies of Jimma University, Jimma Institute of Technology, and Faculty of Civil and Environmental Engineering, Hydrology and Hydraulic Engineering Chair in Partial Fulfillment of the Requirements for The Degree of Master of Science in Hydraulic Engineering.

November, 2021

Jimma, Ethiopia

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Main Advisor: Dr. Zeinu Ahmed
Co-Advisor: Mr. Sewmehon Sisay

November, 2021
Jimma, Ethiopia

DECLARATION

I declare that this thesis entitled with "Performance Assessment of Storm Water Drainage System: The case of Gelgel Beles Town, Ethiopia" is my work and that all sources of materials used in this thesis have been acknowledged by the complete reference. This thesis has been submitted in partial fulfillment of the requirement for the degree of Master of Science in hydraulics engineering at Jimma institute of technology. I confidently declare that I have not submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

____________________________ ____________________ ____________

Name of student Signature Date

APPROVAL SHEET

We certify that the thesis entitled "Performance Assessment of Storm Water Drainage System of Gelgel Beles Town" is the work of Tikdem Morka and we here by recommend for the examination by Jimma Institute of Technology in partial fulfillment of the requirements for degree of Masters of Science in Hydraulic Engineering.

Dr. Zeinu Ahmed (PhD) ____________________ ____________________

(Main Advisor) Signature Date

Mr. Sewmehon Sisay (MSc.) ____________________ ____________________

(Co-Advisor) Signature Date

As a member of Board of Examiners of the MSc. Thesis open Defense Examination, we certify that we have read, evaluated the Thesis prepared by Tikdem Morka and examined the candidate. We recommended that the Thesis could be accepted as fulfilling the Thesis requirements for the Degree of Masters of Science in Hydraulic Engineering.

Dr. ____________________________________ ____________________ ____________________

External Examiner Signature Date

Mr. ____________________________________ ____________________ ____________________

Internal Examiner Signature Date

Mr. ____________________________________ ____________________ ____________________

Chair holder Signature Date

Mr. ____________________________________ ____________________ ____________________

Chair Person Signature Date

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First and for most I thank my Almighty God, for through him I had my well-being and passed every hurdle in my study time and in my life at all. Secondly, I would like to express my sincere and deepest gratitude to my advisor Dr. Zeinu Ahmed (PhD) and co-advisor Mr. Sewmehone Sisay (MSc.) for all their limitless efforts in guiding me through my work. Lastly, I would like to express my humble gratitude to my family & my friends.

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The collected data from field survey was compiled in MS-Excel sheet and then made re-arrangement according to questionnaire survey and personal observations. Later, all data

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LIST OF ACRONYMS

Symbol	Description
BMP	Best Management Practice
CSA	Central Static Agency
DEM	Digital Elevation Model
ECDF	Empirical Cumulative Distribution Function
GOF	Goodness of Fit Test
Ha	Hectare
IDC	Intensity-Duration-Curve
IDF	Intensity-Duration-Frequency
MDL	Main Drainage Line
NMA	National Meteorological Service Agency
PD	Probability Distribution
PDS	Poor Drainage System
SCS	Soil Conservation Service
SDL	Sub Drainage Line
SUDS	Sustainability Urban Drainage System
Tc	Time of Concentration
Qp	Peak Discharge
UN	United Nation

ABSTRACT

Urbanization of an area invariably leads to increase in overall imperviousness of the area. Storm water drainage problem is one of the major challenges facing many countries in Ethiopia in general and Gelgel Beles town in particular. The objective of this study is to evaluate the current storm water drainage systems and associated problems. This research involves collection of both primary data collected from interview field surveying, while the secondary data for the study has been obtained from gelgel beles municipality office, gilgel beles town finance office, minster of metrological agency and from responsible organizations for further interpretation and analyses. The land use land cover image was processed for the years and 2020 by using Arc GIS.10.1 and Google earth pro then for each land use/land cover, annual storm water runoff volume was calculated. The Intensity Duration Frequency (IDF) curve was developed by Gumbel method to analyze rainfall and the consequent peak runoff for different return periods using a rational method. The existing storm drainage systems of Gelgel Beles town were: lack of well-connected drainage lines, solid and liquid wastes were directly disposed into the storm drainage system, which results in decreasing the efficiency of the system, unavailability of drainage systems at the proper place. Additionally, the awareness of the community towards such an issue was absent; the major percentage of drainage system performs severely degraded. Most of survey results obtained in three kebele can shows the majority of the drainage systems were inadequate to carry the design flood based on intensity with a return period it designed. The other challenges of storm water management were related to lack of city-wide drainage master plan, absence of hydrologic data considerations during designing drains, and weak enforcement on solid waste dumping into drains system. The Rainfall depth was calculated by different probability distribution methods and the value is 123.68mm, 133.64mm, 125.26mm, 151.21mm for Normal, Log Normal, Person Type III, Gumble (EVI) respectively and by ERA it was 102.45 mm for 100-year return period. The value for annual runoff volume in the study area was $10089.09m^3$*,* $2321.245m^3$*,* $2263.234m^3$*, and* $557.7444m^3$ *for Built-up area, Grass cover, Vegetation cover and bare land respectively. Finally, before the urban drainage becomes a permanent socio-economic nuisance and brings irreversible damage to the city; this study strongly recommends immediate implementation of best management practice that is supported by strong institutional setup, policy framework, and the public at large.*

Key Words*: Urbanization, Storm Water Drainage, Runoff, Drainage Capacity*

CHAPTER ONE
INTRODUCTION

1.1 Background

Urban storm water drainage facilities are part of the urban infrastructure elements and design of these facilities require due attention. Urbanization is one of the most important demographic trends of the twenty-first century. Majority of the population growth is concentrated in towns and cities. In context to developing countries, most the urban growth is unplanned, leading to rapid densification, and associated construction of buildings resulting in dramatic increase in impermeable areas due to paving and built-up area *(Bajracharya et al., 2015).*

As population grows, demand for housing and commercial amenities naturally follows. The urbanization adds roads, rooftops, parking lots, sidewalks, and other imperviousness to the landscape. In recent years, researchers have reported that imperviousness is an effective predictor of environmental degradation *(Moglen & Kim, 2007).* Land surface is covered by buildings and pavement; do not allow rain and snowmelt to soak into the ground. Instead, most developed areas rely on storm drains to carry large amounts of runoff from roofs and paved areas to nearby waterways. The level of economic also has implications to urban hydrology and storm water management in other ways. For instance, the increasing use of the car and other forms of road transport results in a significant increase in impervious areas for the road surfaces and areas for parking. In heavily developed cities, roads and other transport related impervious surfaces can constitute up to 70% of the total impervious urban areas

According to *Parkinson & Mark, (2005).* the increase in impermeable areas caused by urbanization has a number of important impacts on the hydrological response from a catchment related to deferent factor reduced infiltration, reduced surface (depression) storage capacity and decreased evapotranspiration.

As human settlements raised higher, they quickly began influencing the natural hydrological processes. Ditches dug, fields were under-drained, streams straightened and rivers embanked in order to quickly take water from the land to the sea *(*Abraha, *2018).* At this time, many watercourses running through towns and cities encased in large pipes under the ground are now no longer visible. In doing so, the natural water cycle has significantly disrupted landscapes and wildlife habitats have destroyed *(*A Graham *et al., 2012)*. These impacts are related to quality and quantity variables of the hydrologic cycle. As the process of urbanization accelerates, drains become increasingly overloaded and unable to cope with heavy rainfall.

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

The absence of adequate integration between road and urban storm water drainage net-work is also the other challenge in urban areas, because the run-off generated/produced within a particular urban area will not safely be discharged in to the final receiving system. Thus, this will be the source of environmental problems like over topping, erosion, pollution, barrier to traffic and other related problems *(Dagnachew, 2012).*

Different parts of the Ethiopian highlands receive between 600 and 2700 mm of rainfall annually *(*Liu *et al., 2008).* This heavy rain sometimes creates high flood in the overlaying area which causes loss of property. Gelgel Beles town is like other towns of Ethiopia have a lot of problems including inadequacy and poor-quality drainage infrastructure. The presence of Beles River in the town without proper River training structure at upstream and downstream river cross-section and the result of poor drainage line along roads in the town have result in seasonal floods and other environmental problems are most frequently occurring especially on downstream parts of the town. This has resulted in negative impacts on sustainable urban drainage system provision and management. Thus, there is a need of studying the storm water management in Gelgel Beles town to handle the yearly repeating urban storm water drainage problems with overloading the drainage system and the serious consequences on the environment.

1.2 Statement of the problems

Urbanization is one of the most important demographic trends of the twenty-first century. Majority of the population growth is concentrated in towns and cities. In context to developing countries, most the urban growth is unplanned, leading to rapid densification, and associated to construction of buildings resulting in dramatic increase in impermeable areas due to paving and built-up areas.

As population grows, demand for housing and commercial amenities naturally follows. In addition to this urbanization adds roads, rooftops, parking lots, sidewalks, and other imperviousness to the lands *(Moglen & Kim, 2007).* Impermeability increases with the increase of impervious surface in urban areas, this in turn increases the over land flow resulting in flooding and related environmental problems. Impermeability increases with the increase of impervious surface in urban areas, this in turn increases the over land flow resulting in flash flooding and related environmental problems. The pattern of urbanization and modernization in Ethiopia has meant to increase densification along with urban infrastructure development *(Belete, 2011).* It has led to deforestation, use of corrugated roofs, and paved surfaces. Due to this the problems of 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 Gelgel Beles *(Besha & Alemayehu, 2016).* This study aims will be to identify the major storm water drainage problems and to determine best management practices with the provision of recommended possible engineering solution.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study is to conduct performance assessment of storm water drainage system.

1.3.2 Specific Objective

The specific objectives of this study are: -

- ✓ To compare the recent IDF curve and the IDF curve developed by ERA for Gelgel beles town.
- ✓ To assess the hydraulic capacity of existing drainage system.
- ✓ To identify the operational problems of the existing drainage system in line with road.

1.4 Research Questions

- ✓ What is the difference between the recent IDF curve and the IDF curve developed by ERA for Gelgel beles town?
- ✓ What is the hydraulic capacity of the existing drainage system of the town?
- ✓ What are the operational problems of existing drainage systems of the Gelgel Beles town?

1.5 Scope of the Study

The study is limited to the Performance Assessment of existing storm water drainage structures and proposing mitigation measures. The main focus of this study includes: investigate the functionality of the existing storm water drainage systems, identify the impact of Beles river on the storm water drainage system of the study area, land use land cover change effects on the storm water runoff volume and identify the alternative effective storm water measures as well as proposing best management practice for the existing problem. Evaluating the whole catchment is not necessary to come up with solution for the current storm water problem. Therefore, some representative major flood prone areas are selected. The study is limited to some parts of Gelgel Beles town (Three Kebele; including G/Mariam village and the nearby villages (Kuter-2 and Edida) for runoff computation using rational method, but there is new settlement area which have no completely any kinds of drainage coverage, but most those areas are exposed to flash flooding due the lack of drainage provision is not included in this study. This research also does not include structural design of all types of drainage structures except proposing the type and size of required drainage structures.

1.6 Significance of the Research

The investigation of storm water drainage problems in Gelgel Beles town will contribute in solving the storm water drainage problems and sustain the drainage systems under the effect of urban expansion. The finding of this research will also provide valuable information that can be used as an input or reference for further studies. It also more important, that can envisage the outputs of the study will be key inputs in designing of sustainable drainage system for the future. The study is also very important for academicians and researchers who conduct similar researches on other storm water drainage structures, urban drainage, storm water management; local street drainage and land use/land cover effects on runoff. The result of this study will help in filling the gaps by identifying problems to sustainability, taking proper designing of storm water drainage system and proper functioning of drainage system under the growth of urban expansions.

1.7 Limitation of the Study

The limitation was problem was associated with getting adequate, reliable of secondary and primary data. There was no recorded data related with drainage system for scaled land use and land cover map of town and drainage network to compare with the existing once. For instance, the purpose of the study was cleared to the respondents; however, most people were not voluntary to give the correct information about the overall demographic data of the region and the town because most of people found in a position aren't come to power with education status. Regarding secondary data collections, the problems encountered include the following: -

- ✓ Some government offices were hided the required information.
- ✓ Some government offices were asked payment to give the asked information.
- ✓ Even those that were willing to give their data did not have complete information and the available data lacks quantity and quality.

1.8 Thesis Outline

This research paper includes five chapters. The ***first chapter*** is Outlines the statement of the problem, objectives of the study and research questions. The chapter also provides some background information on the problems of storm water drainage system in Gelgel Beles town in addition to by expansion of urbanization and inadequate storm water drainage for the town.

The ***second chapter*** briefly reviews related literature about storm water drainage system this included related to storm water management in the storm water management in developing countries, conventional and sustainable storm water management, best management practices and also drainage system of flooding and causes of flooding in the urban area.

The ***third chapter*** is deals with the location and general Gelgel Beles town faces of the study areas and it outlines the research methodology employed in this study. The approaches used for this study are included and discussed.

The ***fourth chapter*** focuses on review, result and discussions using appropriate approaches of minimize or avoiding storm water drainage problem and safe environment with in Gelgel Beles town.

The ***last chapter*** can summarize the entire study by outlining a brief conclusion, and forwarding some recommendations to the problem currently existed.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Introduction to Drainage

The removal of surface or subsurface water from a given area by natural or artificial means is called drainage. The term is commonly applied to the removal of excess water by canal, drains, ditches, culvert and other structures designed to collect and transport water either by gravity or by pumping. A drainage project may involve large-scale reclamation and protection of marshes, underwater lands or lands subject to frequent flooding. Such a project usually involves a system of drainage ditches and dikes, and often pumps are required to raise the water into the drainage network.

In cases of large-scale drainage, it is essential to improve the discharge capacity of natural channels to protect adjacent properties and to upgrade the ditches and channels that convey the runoff from farm drainage systems to improved channels. Such connecting drains commonly follow the natural surface drainage pattern of the area, intercepting the normal surface runoff that takes place during period of excessive rainfall. Small-scale drainage is often practiced by farmers and other landowners who wish to remove surface water from arable fields or to improve water-laden soils. Properly constructed drainage systems can also prevent erosion and gullying of land on slopes by catching the surface water before it reaches the slope. Another important purpose of drainage is to prevent excessive accumulation in the soil of soluble salts that might be detrimental to plant growth *(Mallick & El-Korchi, 2008).*

The essential principle of any type of land drainage is to provide an open, adequate and readily accessible channel through which the surface or subsurface water can flow. For this purpose, open ditches are sometimes used, but these are not always satisfactory because they may become choked with sediments and vegetation. Underground drains are usually employed, particularly on land that is to be plowed.

In draining comparatively flat land, common practice is to lay along one side of the plot a main drain to which a number of traverse laterals are connected. The laterals are often set parallel to the main drain, coming together to join it at the lower end of the field. Local conditions of soil and terrain govern the spacing of laterals and the depth at which they are placed *(Alaneme, et al., 2021).*

2.2 History of Urban Drainage Engineering

The use of drainage systems by humans has a long history dating back to the early third millennium B. C. during the Indus civilization. Not far behind were the Mesopotamians *(Leta, 2020).* The Minoan civilization on Crete, in the second millennium B.C. also had extensive drainage systems. Knossos, approximately five km from Herakleion, the modern capital of Crete, was one of the most ancient and most unique cities of the Aegean and of Europe. The drainage systems at Knossos were most interesting, consisting of two separate systems, one to collect the sewage and the other to collect rain water *(Getachew, 2011).*

Drainage of urban settlements has been practiced for more than five thousand years, but the recognition and understanding of drainage impacts on the environment and the need for mitigation of such impacts have emerged fairly recently. Urban drainage was first built to improve living conditions in urban settlements by preventing water ponding, flooding and draining marshes for new development. Historical records refer to early urban drainage structure skills flourished in ancient Rome and Pompeii *(Chocat et al., 2001).*

Urban drainage was firmly established as a vital public works system in the early parts of the twentieth century. Engineers continued to improve design concepts and methods. During the second half of the twentieth century regulatory elements were spread in the United States, Europe, and other locations addressing urban drainage issues. Computer modeling tools advanced the methods used to design and analyze urban drainage systems. Regulations, monitoring, computer modeling, and environmental concerns have altered the perspective of urban drainage from a public health and nuisance flooding concern during the first half of the twentieth century into a public health and nuisance flooding with additional concerns for ecosystem protection and urban sustainability *(Kaur et al., 2015).*

2.3 Advancement of Urban Drainage System

Historically, urban drainage systems have been viewed with various perspectives. During different time periods and in different locations, urban drainage has been considered a vital natural resource, a convenient cleansing mechanism, an efficient waste transport medium, a flooding concern, a nuisance wastewater, and a transmitter of disease *(Asfaw, 2016).*

In general, climate, topography, geology, scientific knowledge, engineering and construction capabilities, societal values, religious beliefs, and other factors have influenced the local perspective of urban drainage. For as long as humans have been constructing cities these factors have guided and constrained the development of urban drainage solutions *(Parkinson, 2003).*

2.4 Development of Modern Urban Drainage Practices

The beginning of modern urban drainage practices was initiated in European cities during the nineteenth century. One critical turning point in urban drainage occurred during the middle of the nineteenth century. During the first half of the nineteenth century sanitary wastes were discharged from buildings to privy vaults and cesspools *(Metcalf et al., 1991).* Most sewers were designed exclusively for storm water drainage. Sanitary wastes accumulated in privy vaults and cesspools and were periodically collected by scavengers and transported to a suitable disposal location. As the nineteenth century progressed the concept of urban drainage changed with the incorporation of water-carriage sanitary waste collection into the urban drainage systems. Sanitary connections to the sewers were made legal and new sewers were constructed to drain storm water and sanitary wastewater.

The public perspective of urban drainage changed during the nineteenth century from a neglected afterthought to a vital public works system. The public also shifted their stance regarding funding the construction and maintenance of sewer systems. The shift in public perspective was driven by many factors, but the most important was probably the scientific evidence accumulated during the second half of the century linking sanitary wastes and disease transmission *(Parkinson, 2003).* The perspective of urban drainage also changed from a design standpoint during the nineteenth century. Most sewers constructed before the nineteenth century were not planned or designed by an engineer using numerical calculations. Instead a trial-and-error process was executed, which in some cases eventually produced well-functioning systems *(Dagnachew, 2012).*

2.5 Current Urban Drainage Perspectives

Urban drainage in the early parts of the twentieth century was firmly established as a vital public works system. Engineers continued to improve design concepts and methods. During the second half of the twentieth century regulatory elements were promulgated in the United States, Europe, and other locations addressing urban drainage issue *(Burian & Edwards, 2002).*

Extensive monitoring efforts vastly improved the understanding of urban drainage quantity and quality characteristics. Computer modeling tools advanced the methods used to design and analyze urban drainage systems. Regulations, monitoring, computer modeling, and environmental concerns have altered the perspective of urban drainage from a public health and nuisance flooding concern during the first half of the twentieth century into a public health and nuisance flooding with additional concerns for ecosystem protection and urban sustainability *(Burian & Edwards, 2002).*

Methods to design and construct sustainable urban drainage systems are currently being researched and tested. Alternative development concepts (e.g., low-impact development) are influencing development practices to minimize the impacts of development on storm water drainage. In addition, alternative on-site wastewater management strategies are being touted as more sustainable than centralized wastewater management for some situations.

Communities are searching for innovative techniques to capture, detain, and use rainwater within the watershed instead of constructing massive drainage structures. Many communities are developing watershed wide storm water quality management plans to meet the dual objectives of flood prevention and water quality control. Urban drainage has indeed expanded significantly during the past few decades beyond a technical challenge to drain the urban area expeditiously to include the consideration of social, economic, political, environmental, and regulatory factors *(Abdu, 2019).*

2.6 Storm Water Management in Developing Countries

The increasing urbanization of the world's population is constantly creating new challenges for storm water management. Although rain is vital for both human beings and their environment (to replenish rivers, water points and groundwater, grow vegetation), rainfall events generate flows and volumes of water that can be difficult to control and that accumulate in the lowest parts of towns, flooding residential areas and creating pools of stagnant water under the factors influencing storm water management of town *(Larsen et al., 2013).*

Table 2: 1 Specific factors inhibiting modernization of urban drainage in developing country

Factors	Characteristics
Concern for the environment	Less familiar than conventional sanitary planning
Legal or clandestine urban development	No effective control
Runoff quality	Highly contaminated
Urban sediment and garbage	Large quantities transported in runoff
Climate	Increase risk of epidemics and construction costs
Engineering ‘know-how’	Shortage concerning modern approaches
Population and administrators relations	Lack of integration for seeking solutions

Sources: (Tucci, 2001)

2.7 Urban Storm Water Drainage Practice in Ethiopia Perspective

According to *(Dagnachew, 2012),* most watersheds in urban Ethiopian, receive significant amount of annual rainfall. The rainfall intensity is generally high, control of runoff at the source, flood protection, and safe disposal of the excess water or runoff through proper drainage facilities have become essential.

Drainage problems in urban Ethiopian include flooding, deterioration of roads, land degradation, sedimentation, and blockage of drainage facilities, water logging and the like. With urbanization, impermeability increases with increase in impervious surfaces (i.e., residential houses, commercial buildings, paved roads, parking lots, etc.) drainage pattern changes, overland flow gets faster and environmental problems such as land degradation, flooding increases.

Before the establishment of national urban planning institute there has been no formal working organization in the area of urban storm water drainage system. Even nowadays the attention towards urban storm water system is at its immature stage that is why most of the urban storm water drainage structures get blocked with solid waste of various types after huge money has been invested on them. In some areas they by themselves are source of environmental problem *(Belete, 2011).*

The primary aim of urban storm water drainage system in urban and rural area was to safely discharge the storm run-off out of the urban centers. The technologies in handling flooding problems due to poor urban storm water drainage system in Ethiopia, which have ever been practiced, are not in position to utilize flood or runoff for various uses, like treatment or sedimentation of runoff water, construction of detention ponds and other perforated structures for the water to be infiltrated in to the soil *(Dagnachew, 2012).*

2.8 General Indication of Storm Water Runoff

Population growth and urban development can create potentially severe problems in urban water management. One of the most important facilities in preserving and improving the urban water environment is an adequate and properly functioning storm water drainage system construction of houses, commercial buildings, parking lots, paved roads and streets increases the impervious cover in a watershed and reduces infiltration.

Also, with urbanization, the spatial pattern of flow in the watershed is altered and there is an increase in the hydraulic efficiency of flow through artificial channels, curbing, gutters and storm drainage and collection systems. Those factors can increase the volume and velocity of runoff and produce larger peak flood discharges from urbanized watersheds than occurred in the pre-urbanized condition. Many urban drainage systems constructed under one level of urbanization are now operating under a higher level of urbanization and have inadequate capacity *(Sarma et al., 2016).*

2.9 Urban Storm Water Management System

Storm water collection is a function of the minor storm drainage system which is accommodated through the use of roadside and median ditches, gutters, and drainage inlets. Storm water management is an increasingly important consideration in the design of urban drainage systems. Storm water management practices, when properly selected, designed, and implemented, can be utilized to mitigate the adverse hydrologic and hydraulic impacts caused by drainage facilities, thereby protecting downstream areas from increased flooding, erosion, and water quality degradation and existing downstream conveyance constraints, particularly in cases where the roadway drainage system *(Schmitt et al., 2004).*

Storm water management system is a tool for managing storm water runoff from rainfall. Naturally, this water flows from fields to stream from stream to rivers and so on. However, development has changed some of these natural flows and has led to overflowing concerns. As a result, storm water management system is required in order to deal with the overflows. Therefore, a sustainable storm water management on the street has a potential to bring street comfort through shading and reducing peak storm water runoff volumes *(Andy Graham, 2016).*

According to *Dagnachew(2012),* most watersheds in urban Ethiopian, receive significant amount of annual rainfall. The rainfall intensity is generally high, control of runoff at the source, flood protection, and safe disposal of the excess water or runoff through proper drainage facilities have become essential. Drainage problems in urban Ethiopian include flooding, deterioration of roads, land degradation, sedimentation, and blockage of drainage facilities, water logging and the like. With urbanization, impermeability increases with increase in impervious surfaces (i.e., residential houses, commercial buildings, paved roads, parking lots, etc.) drainage pattern changes, overland flow gets faster and environmental problems such as land degradation, flooding increases.

Even nowadays the attention towards urban storm water system is at its immature stage that is why most of the urban storm water drainage structures get blocked with solid waste of various types after huge money has been invested on them. In some areas they by themselves are source of environmental problem *(Belete, 2011).* The primary aim of urban storm water drainage system in urban and rural area was to safely discharge the storm run-off out of the urban centers.

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Urban drainage systems are needed in proposed developed urban areas because of the interaction between human activity and the natural water circulation. The system can be represented as a network consisting of catchments and sub catchments, manhole, conduit and outlet *(Nie, 2004).*

2.10 Effect of Urbanization on Surface Water Flow

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

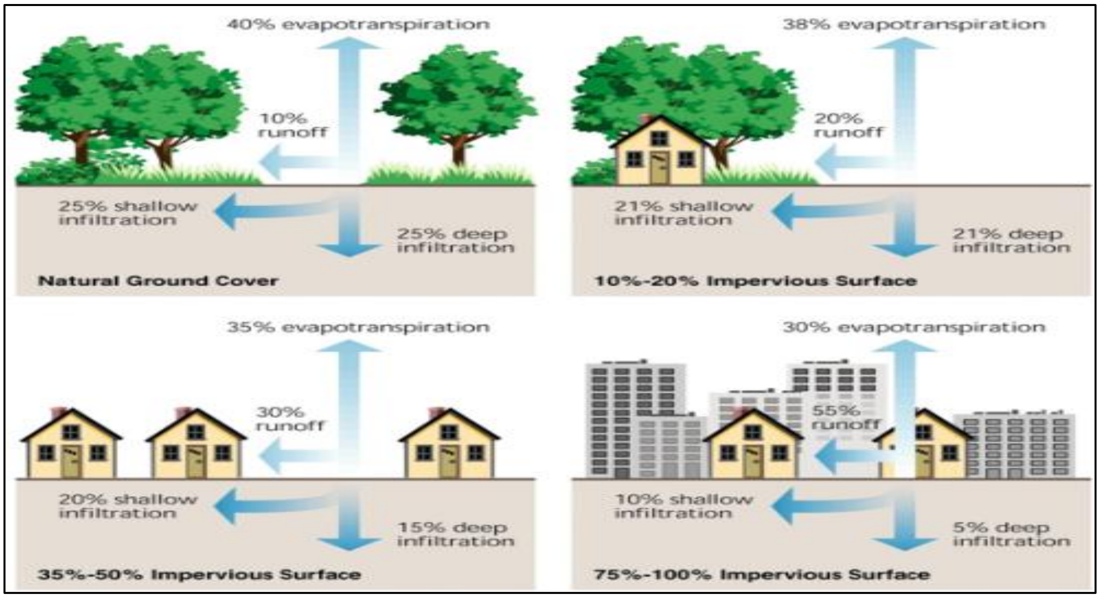

Figure: 2. 1 Influence of urbanization on water cycle (Sourced from CWP, 2015 Paper)

As result of urbanization, catchment area is rapidly changing from pervious areas to impervious areas. For example, forests are replaced with buildings and roads *(Tikkanen, 2013).* Due to this, increasing the storm water runoff, peak flow and time to peak increased Urbanization also causes increased pollutant and sediment delivery that contaminate lakes and streams due to the unfiltered and rapid transport of chemical, sand and nutrients *(Zakia et al., 2014).* The runoff coefficient is a measure of the amount of rainfall that is converted to runoff or storm runoff generation. As the percentage of watershed imperviousness increases, the runoff coefficient increases with urbanization.

2.10.1 Increase in Runoff

The volume of water available for runoff increases because of the increase in the impervious cover provided by roofs of buildings, streets, paved parking lots, lined drains which reduce the amount of infiltration. Before urbanization much of the rainfall is absorbed by the surrounding vegetation, soil and ground cover.

Rain falling on undisturbed land such as forests, grasslands, and wetlands is partly intercepted by vegetation, partly retained by surface depressions and puddles, and partly infiltrates into the ground but only a small fraction flow overland *(Manual, 2010).* The runoff coefficient is a measure of the amount of rainfall that is converted to runoff or storm runoff generation. As the percentage of watershed imperviousness increases, the runoff coefficient increases with urbanization *(Zinabie & Kebede, 2020).*

2.10.2 Decrease in Time of Concentration

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

2.10.3 Sustainability in Urban Drainage System (SUDS)

According to *(Leta, 2020).*the world's population has recently become predominantly urban, and the total world urban population is projected to double by 2050 years. Because of urbanization trend, the U.N. Habitat has reasoned that "the millennium ecosystem goals will be won or lost in cities. This reality has made different disciplines such as civil engineering, urban planning and architecture to focus on developing and testing new theories, strategies, and best practices to enhance the sustainability of cities. This reality has made different disciplines such as civil engineering, urban planning and architecture to focus on developing and testing new theories, strategies, and best practices to enhance the sustainability of cities.

The techniques of sustainable drainage systems are widely recommended and applied in many parts of the world, whereas the terminology varies in different regions, but with similar design philosophies. Despite the enrichment of the techniques and tools for SUDS, application of sustainable drainage remains a very challenging task in reality.

Many practical implementations of SUDS tend to underestimate their complexity and therefore the resulting performance is often not satisfactory, due to e.g. a lack of experience of SUDS operation and maintenance, ignorance of interaction with other water bodies, and institutional impediments and barriers towards SUDS practices *(Viaggi et al., 2014).*

The design of SUDS involves many different disciplines and multidimensional criteria. It is essential for stakeholders to comprehend the broad scope of sustainable design and consider the urban water cycle as a whole planning unit. Meanwhile, climate change and urbanization changes need to be incorporated into the design in order for SUDS to adapt to future changing condition *(Miguez et al., 2012).*

2.11 Emerging Challenges in Urban Drainage System

A number of emerging challenges can be identified in the current urban drainage practice. Most of these have been recognized for some time, but not fully addressed or implemented by the urban drainage community. Another challenge is imposed by climate change, which has strong implications for traditional hydrological design. The existing global circulation models provide data at large scales, but recent attempts to interpolate such data for small urban area were not successful. Among the impacts of climate change on urban drainage systems one could name higher frequencies of extreme events, more rainfall of higher intensity an area and raising out flow from sewers system *(Leta, 2020).*

Past design of urban drainage mostly relied on passive control of drainage systems by gravity flow (given by the systems architecture and assets) and in water quality issues, on responding to environmental problems caused outside of the authority of drainages managers futures improvements will a raise from elevating control of inputs to drainages systems and drainage operation to higher level concerning drainage flows ,real time control holds promise for a greater operational effectiveness *(Campisano et al., 2004).*

Dynamic regulation and operations offer distinct advantages, particularly when centrally operated and designed for global optimization. However, the progress achieved so far in terms of actual installations has been rather flows a promising path is offered by controlling the use of chemicals in urban areas and banning non-essentials use of dangerous chemicals. However, in spite of these concerns, the evidence from many locations around the world indicates a gradual improvement for the state of urban drainage *(Marsalek, 2005).*

2.11.1 Problem of Poor Drainage System

The practice of urban drainage in developing countries encounters more serious problems than those of developed countries, because urban development occurs under more difficult socioeconomic, technological and climatic conditions. Developing counties experience accelerated urbanization without adequate investment in infrastructure, and against a background of deficient public services for water treatment, collection and treatment of foul sewage, garbage collection, urban drainage, transport and health.

Urban concentrations have environmental consequences in the form of urban flooding and pollution of water courses, soil and air. Settlements are established in inappropriate areas such as those originally set aside for environmental preservation and on steep hillsides and areas liable to flooding *(Adane, 2019).*

2.11.2 Uncontrolled Urban Settlement

Impermeable surfaces and the construction of drains for rapid storm-water removal are the major causes of urban floods due to traditional urban settlement, pursued without regard for the environment. Such urbanization patterns make it difficult to control urban drainage, since it not only causes or aggravates local flooding but can also create problems downstream. The extent of impermeable cover is directly correlated with runoff coefficients and also with population density, so that an indirect method of evaluating the impact of urbanization on drainage is to relate population density with runoff coefficients. There is evidence world-wide that higher urban population density commonly results in greater storm-water generation, but many urban planners take no account of this important effect and neglect the wider costs of their storm-water control procedures. Urban planners in favor of greater density reason that urban infrastructures become economically viable; however *(Mascaró, 1987),* concluded that the cost of urban drainage per hectare was essentially constant irrespective of population density. On the other hand, urban planners frequently fail to take into account the fact that density increases supported by micro-drainage can result in flooding problems downstream, usually in narrow reaches, for which costs of straightening and canalization are ignored. Modern urban drainage calls for detention and infiltration areas, contrary to the philosophy of higher population density.

Many cities in developing countries have a density index which already causes critical drainage situations. Besides the problems of control in legal settlements, socio-economic problems lead to the invasion of public areas, forming slums with high population density and high rates of impermeable soil surface. This is the ‘occult’ city, in contrast to the ‘official’ city which is subject to legislation on the use and occupancy of land. The forms of land occupation, whether planned (the ‘official’ city) or unplanned (the ‘occult’ city), have significant effects on the hydrology and can lead to the failure of storm water management policies, if not considered seriously. In parts of the city that are already occupied the difficulty of controlling storm-water quantity is greater because: (a) the storm-drain network still serves to transmit runoff rapidly; (b) many rivers in urban rivers have been modified by straightening, or by burying them in conduits;

(c) city streets and buildings stand on the river banks; and (d) the levels of surface occupancy and impermeable areas are high.

The ideal concept is to regard urban drainage as preventive, incorporated into the urban plan for new development, following principles that conserve natural drainage, preserving strips of vegetation along river banks, minimizing impermeable surfaces, and making use of installations for infiltration and detention of runoff. In Gelgel Beles town, the adoption of such measures is being put into practice by means of management plans for urban drainage which set restrictions on the amounts of runoff from new building lots. Despite the problems typical of developing countries, many corrective solutions for modern urban drainage are also applicable, since they take advantage of spaces still available. It is a task requiring creativity and integration of engineering with urban planning.

2.11.3 Excess Sediment and Garbage

Urban areas in developing countries have significant proportions of exposed soil liable to erosion and giving rise to large quantities of sediment. Building sites, weather in areas where the city is expanding or within developed urban area, do not normally have controls for erosion prevention or for retaining sediment so that it does not the streets, storm drains and urban rivers. It is no exaggeration to say that 10 to 15% of urbanized area in developing countries contributes extensively to sediment production and transport *(Leta, 2020).*

The amount of garbage entering the drainage network is reduced corresponding to a production of 0.4 to 0.8% of total garbage produced *(Adane, 2019).* For developing countries, the rate of garbage accumulation in the streets is certainly higher, since in some parts of the cities the storm drain network is used for garbage disposal. With these high sediment and garbage loads, no modern solution to urban drainage is viable without special retention structures upstream or rigorous maintenance procedures with dredging or mechanical removal of the large volumes carried after every storm *(Adane, 2019).* This is a peculiar feature of developing countries which makes control works for storm runoff control even more expensive to implement.

2.11.4 Lack of Community Participation

Lack of community participation in the search for enduring solutions for urban drainage problems is one of the main obstacles preventing the success of modern storm runoff control measures, whether by structural or non-structural measures. In democratic countries, this community participation usually depends on two factors: (a) the desire and ability of people to organize themselves, and (b) the opening of channels of direct communication by the municipal administration. This forms a way by which municipal authorities can talk to city-dwellers, and vice versa. It can also develop into a kind of participatory or direct democracy for defining priorities in urban drainage works.

The level of technical information and environmental education increases for all concerned. Lack of community participation leads to the repetition of earlier errors in solving drainage problems, to the discredit of public action, and lack of concern with environmental questions. It can also bring about low investment in urban facilities.

Table 2: 2 socioeconomic factors in developing countries as compared with developed

Socioeconomic Factor	**Effect**	**Consequence**
Insufficient environmental education of most of the population	Lack of knowledge and care about the impact of trash on streets and in watercourses	Discharge of refuse, sediments and excreta onto streets and into watercourses
Social forces of the poorest segment of the population	Clandestine occupancy of urban preserved areas	Deforestation, exposure of bare soil, impervious
	Clandestine occupancy of urban risk areas	Landslides, production and direct discharge of sediments and refuse into watercourses
		Unacceptable exposure to major floods (life-risking floods)

Source*: (Tucci, 2001)*

One of the main obstructions preventing the success full control of storm runoff measures ether by structural or non-structural measures is the absence of community participation to providing solutions to urban drainage problem. Such participation simply depends on the desire and ability to organize themselves, strict compliance societal goals and providing medium of direct communication by the appropriate municipal administration *(Bekele, 2017).*

In most enveloping countries this has been a problem for sustainable storm water drainage management. Lack of community participation leads to the repetition of earlier errors in solving drainage problems, to the discredit of public action, and lack of concern with environmental questions *(Asfaw, 2016).* It can also bring about low investment in urban facilities.

Community participation in terms of sanitation provides members of the community for opportunity to contribute in the policy and decision-making process. In its contribution, the place of planning, implementation, monitoring and maintenance of drainage channels should be given its rightful place as regards to sustainability. Community participation in its approach is means of ensuring augmented social accountability with the involvement of citizens in decision making process *(Leta, 2020).*

2.11.5 Lack of Suitable Technology

For the environmental approach to be successful, a change of technical culture is required through training (capacity building at all levels, for district engineers and urban planners) and environmental education for the people *(Mukherjee)*. Academic institutions can play a big role to take on the task of spreading information in repeated seminars and technical-scientific meetings who work in the field of storm-water drainage to increase their knowledge regarding to the subject matter. As *(Mukherjee)*, said the trust that develops in such meetings between researchers and technicians opens up communication channels leading to collaboration between municipality and university in technical support services for modernizing urban drainage practice.

Table 2: 3 Lack of technology in developing countries as compared with developed countries

Factor	**Effect**	**Consequence**
Technical and economic insufficiency of public administration	Raw domestic sewage legally or illegally mixed to storm water drainage	Heavy contamination of storm water runoff
	Precarious public works cleaning services	More deposition of trash and refuse on the streets
	Precarious public works inspection services	More deposition of sediments on the streets due to uncontrolled production in building lots
	Technically outdated and ill-planned storm drainage systems	Drainage works aiming exclusively to rapid drainage of excess storm water

Source: (da Silveira, 1999)

2.12 The State-of-the-Art of Urban Drainage Systems

When rainfalls on to undeveloped land, most of the water will soak into the topsoil and slowly percolate through the soil to the nearest watercourses or groundwater. A small proportion of the rainfall usually 15 to 20 % becomes direct surface runoff that usually drains into watercourses slowly because the ground surface is rough *(Kuruppu et al., 2019).* So, for removing water quickly from soil surface adequate drainage system is required. A drainage system can be either natural or artificial. Many areas have some natural drainage which means the excess water flow to the lakes and rivers.

Natural drainage, however, is often inadequate and artificial drainage (surface & subsurface) is required for safely removal of water from road pavements and its surroundings *(Asfaw, 2016).*

Urban drainage systems can be thought of consisting of two main parts: the convenience-oriented, or the minor system, which contains the components that accommodate frequent, small runoff events; and, the emergency, or major system, which comprises the components that control infrequent but large runoff volume. Although many of the components are common to both of convenience and emergency systems, their relative importance in the two systems varies significantly *(Adane, 2019).*

2.13 Dual Drainage system

An important aspect of urban drainage models is the division of the model into a sewer system and the surface flow, also called dual drainage. Urban storm water drainage systems are composed of two distinct and mostly separate components, namely a surface and subsurface storm sewer network. The surface is the “major” system composed of street ditches and various channels designed to handle events of 25-100 year return frequency. The subsurface sewer network is the “minor” component, designed to carry the runoff from a storm of 2-10 years return frequency. The systems are linked curb inlets and manholes *(Hearn, 2013).* This consideration of distinct surface flow and its interaction with sewer flow is denoted as dual drainage modeling.

A. Minor Drainage system

The minor system in dual drainage consists of conduits or pipes that intercept and receive water from houses, parks and street and conduct them to the major systems such as channels or river *(Deriba, 2015).* The sewerage system can be categorized in this section.

B. Major Drainage system

The major system is defined as the surface (streets, parks) and all pre-existing river channels and manmade channels. The rivers and channels are meant to receive waters from the minor system and overland flow. Based on this criterion, the surface flow types are falls into this category *(Deriba, 2015).*

2.14 Methods for improving drainage system

Before the three decades ago, there has been no formal working organization in the area of urban storm water drainage system. Even now a day the attention towards urban storm water system is at its immature stage that is why most of the urban storm water drainage structures get blocked with solid waste of various types after huge amount of money has been invested on them. In some areas they by themselves are sources of environmental problems *(Adane, 2019).* The technologies in handling the environmental problems of urban storm water drainage in Ethiopia, which have been practiced, are not in a position to utilize the flood/runoff for various uses, like the treatment/sedimentation of runoff water, construction of detention ponds and other perforated structures for the water to be infiltrated in to the soil, rather the primary aim of urban storm water drainage system in the country is to safely discharge the storm/run-off out of the urban centers *(Belete, 2011).*

2.15 Operational and Maintenance Requirement for Drainage System

The design and construction of urban drainage systems is relatively straight forward, but subsequent operation and maintenance remain major challenges to urban authorities who are often in effective in dealing with the scale of the problem. Uncollected solid waste often finds sites way into surface drains and sewers; these drains, blocked with rubbish, then have less capacity than clean ones, and more likely to flooding during large storms. The operational problems caused by poor solid waste management are exacerbated by a lack of effective arrangements for drainage cleaning and maintenance. This tends to be related to a lack of resources, a power and inappropriate equipment for the case. But, to make matters worse, the department responsible for solid waste management is often separate from that responsible for cleaning and coordination between different urban authorities is genially very poor *(Leta, 2020).*

2.16 Best Management Practice in Storm Water Drainage Design

This section provides guidance on factors that should be considered when selecting BMPs for storm water drainage design. BMP selection involves many factors such as physical site characteristics, treatment objectives, aesthetics, safety, maintenance requirements, and cost.

Typically, there is not a single answer to the question of which BMPs should be selected for a site; there are usually multiple solutions ranging from standalone BMPs to treatment trains that combine multiple BMPs to achieve the water quality objectives. Factors that should be considered when selecting BMPs are the focus of this section *(Adane, 2019).*

i. Physical site characteristics

The first step in BMP selection is identification of physical characteristics of a site including topography, soils, contributing drainage area, groundwater, base flows, wetlands, existing drainage ways, and development conditions in the tributary watershed *(Liu et al., 2015).*

ii. Space limitations

Space limitations are frequently cited as feasibility issues for BMPs. In some cases, constraints due to space limitations arise because adequate spaces for BMPs are not considered early enough in the planning process *(Liu et al., 2015).* This is most common when a site plan for roads, structures, etc., is developed and BMPs are embraced into the remaining spaces.

iii. Best management processes (BMP)

The physical and chemical characteristics of storm water runoff change as urbanization occurs, requiring comprehensive planning and management to reduce adverse effects on receiving waters. As storm water flows across roads, rooftops, and other hard surfaces, pollutants are picked up and then discharged to streams and lakes *(Liu et al., 2015).* Additionally, the increased frequency, flow rate, duration, and volume of storm water discharges due to urbanization can result in the scouring of rivers and streams, degrading the physical integrity of aquatic habitats, stream function, and overall water quality.

Storm water drains traditionally lead to local creeks and waterways where the storm water is dispersed without treatment. Unmanaged storm water systems can result in pollutants such as oil, sediment, nutrients and rubbish entering waterways. Physical changes can also occur, such as waterway channel erosion, due to the reduced storm water infiltration which typically occurs with urbanization, and consequent increased velocity and extended duration of flow entering the natural water system. If storm water is left unmanaged, pollution and physical changes caused by storm water can cause considerable damage to the environment and, in particular, to waterways *(Deriba, 2015).*

2.17 Adoption activities to Decrease Runoff Generated from Watershed Area

The principle of runoff reduction starts by recognizing that developing or redeveloping land within a watershed inherently increases the imperviousness of the areas which increase runoff. Therefore, the volume, rate of runoff and the associated pollutant loads are outlines for various approaches to reduce or minimize this impact through planning and design techniques. The extent of impervious land covering the landscape is an important indicator of storm water quantity, quality and the health of urban watersheds. Impervious land coverage is a fundamental characteristic of the urban and suburban environment: rooftops, roadways, parking areas and other impenetrable surfaces cover a soil that, before development, allows rainwater to infiltrate *(Liu et al., 2015).*

2.17.1 Manage Watershed Impermeable Zone

Land use planning on the watershed scale is a powerful tool to manage the extent of impervious land coverage. This planning has two elements. First, identify open space and sensitive resource areas at the regional scale and target growth to areas that are best suited to development, and second, plan development that is compact to reduce overall land conversion to impervious surfaces and reliance on land-intensive streets and parking systems *(Adane, 2019).*

2.17.2 Minimize Directly Connected Impervious Areas

Impervious areas directly connected to the storm drain system are the greatest contributor to nonpoint source pollution. The first effort in site planning and design for storm water quality protection is to minimize the “directly connected impervious area. Any impervious surface that drains into a catch basin, area drain, or other conveyance structure is a “directly connected impervious area.” As storm water runoff flows across parking lots, roadways, and paved areas, the oils, sediments, metals and other pollutants are collected and concentrated. If this runoff is collected by a drainage system and carried directly along impervious gutters or in material or infiltration into the soil, it also increases in speed and volume, which may cause higher peak flows downstream, and may require larger capacity storm drain systems, increasing flood and erosion potential *(Liu et al., 2015).* Minimizing directly connected impervious areas can be achieved in two ways: (1) Limiting overall impervious land coverage, (2) Directing runoff from impervious areas to pervious areas for infiltration, retention/detention, or filtration.

2.18 Maintenance and Sustainability of BMP

Maintenance should be considered early in the planning and design phase. Even when BMPs are thoughtfully designed and properly installed, they can become eyesores, breed mosquitoes, and cease to function if not properly maintained. BMPs can be more effectively maintained when they are designed to allow easy access for inspection and maintenance and to take into consideration factors such as property ownership, easements, visibility from easily accessible points, slope, vehicle access, and other factors. For example, fully consider how and with what equipment BMPs will be maintained in the future *(Adane, 2019).*

2.19 Model Selection Criteria for Designing Storm Drainage System

There are various computer-based modeling tools for modeling storm water quantity and quality. By considering their availability, user friendly there are different model used for simulation of runoff quantity and quality, primarily from urban areas. Some of them are (Civil Storm, Bentley, SWMM, PCSWMM and XPSWMM) *(Lind, 2015).*

2.20 Design of storm Drainage System

When applied to urban areas, storm duration is often assumed as the time of concentration of the whole catchment, a value equal to 60% of its lag time, according to the Soil Conservation Service (SCS). The lag time (T) is a function of the slope (Y), length (L) and retention capacities of the catchment (S) are easily calculable parameters using GIS tools *(Adane, 2019).*

2.20.1 Land Use/Land Cover

Land use/land cover (LU/LC) changes are affected by human intervention and natural phenomen a such as agriculture, population growth, consumption, patterns, urbanization, economic develop ment etc. As a consequence, timely and precise information about (LULC) change detection of the area of interest is extremely important for understanding relationships and interactions between human and natural resources for better decision making. Information on land use/land cover and possibilities for their optimal use is essential for the selection, planning and implementation of land use schemes to meet the increasing demands for basic human needs and welfare *(Prawasi & Hooda, 2005).*

CHAPTER THREE
MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Gelgel Beles town is located in Benishangul-Gumuz Regional state, Metekel Zone, Mandura Woreda, at a distance of 550 km from Addis Ababa and 376 km from the regional capital, Asosa. Gelgel Beles town astronomical location is 10°50" and 11°50" North latitude and 36°10´and 36°30" East longitude. The town is founded on a relatively flat area adjacent to the Gelgel Beles River. The general elevation of the surroundings of the town is in the range of 1030m a.s.l. towards the south and south east the land get relatively mountainous as it ascends to the G/Mariam town. The study area has shown a rapid growth especially since 1995. The woreda has a total area of 110,000ha. But Gelgel Beles town is one of the cities which included in this wored, it has an area of 1120ha based on the newly proposed master plan for town. Its topographical feature is encompassed of 55% flat land, 5% hilly, 5% gorges and 35% of the area is undulated land *(GBTA, 2019).*

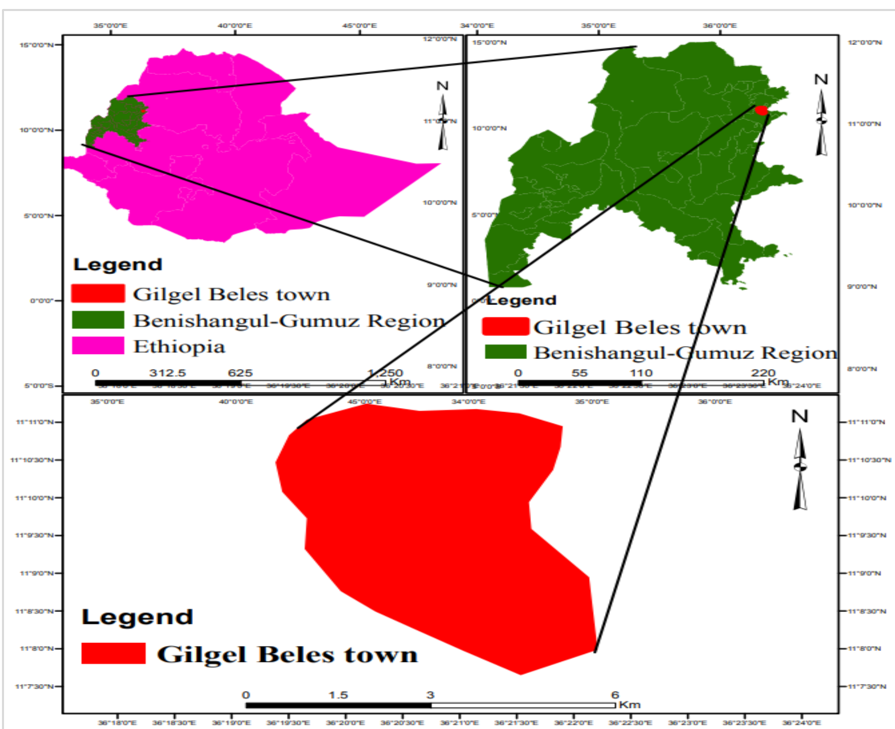

Figure: 3. 1 Location map of the study area

3.2 Climate and Hydrology

The maximum air temperatures were amounting to 35oC and minimum temperature amounting 21oC. The months of maximum temperature are from February to May while in December & January minimum temperature is recorded *(GBTMC, 2019).*

In general, as per to the Ethiopian temperature zoning the town of the study area having an average elevation of 1030 m.a.s.l belongs to the Kola Zone.

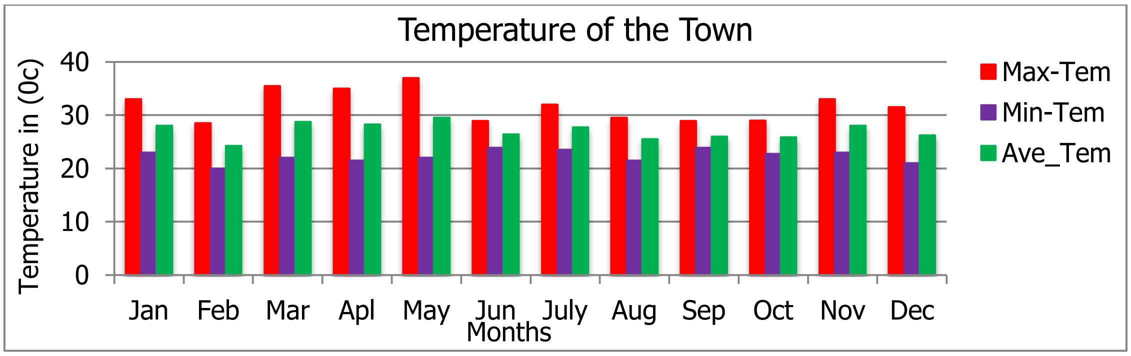

Figure: 3. 2 Maximum, average and low temperature of Gelgel Beles town

3.3 Rainfall of Gelgel Beles Town

Precipitation is the most commonly measured meteorological data. Rainfall records of one station are used to analyze daily maximum rainfall. The patterns of the seasonality of rainfall in the study area are determined by analyzing long term maximum daily rainfall data for this study. Based on Gelgel Beles meteorological gauging center, the long-term annual rainfall amount is computed for a period of 1989-2020. The maximum annual rainfall observed in a year 1992 with an amount of 115.5mm and the minimum value observed in a year 1994 with a value of 23 mm.

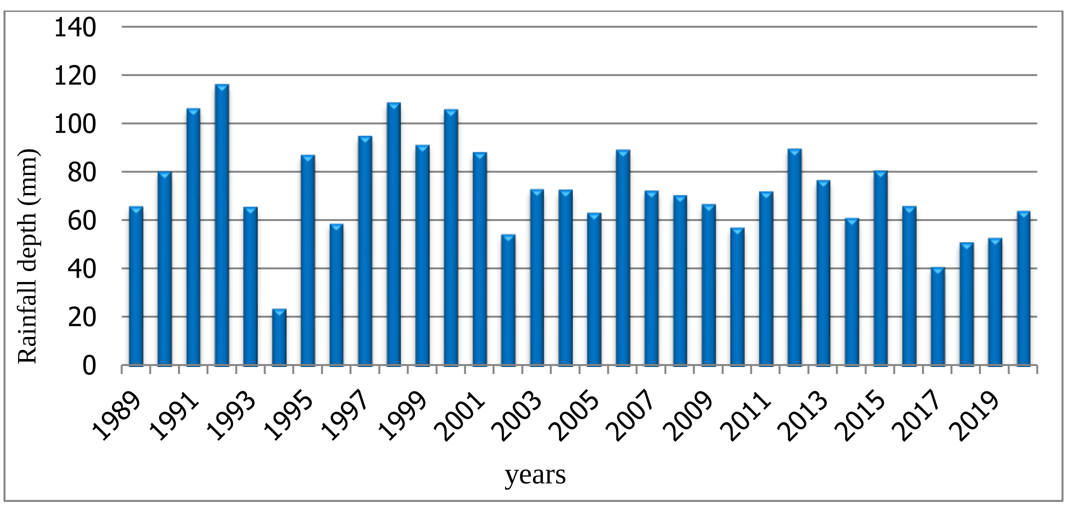

Figure: 3. 3 Annual Maximum 24hr Rainfall (mm) of Gelgel Beles town from (NMA)

3.4 Land Use of the Town

Effective land management helps to associate supply of land with demand for different functions such as housing, commerce and investment like. Land is the largest economic resource of the town; land use pattern is characterized by random development which mainly geared towards horizontal and vertical expansion. Particularly, most areas in the town are not well kept and utilized as per the acceptable standard. Entire area of the town is 1120ha based on the new master plan layout, but the Lulc is done for area of 336ha, because this area currently occupied by population. The town has structural plan. But the use of land is not well planned and there is poor land management in town for different condition.

3.5 Population

The base population for the projection was obtained from the 2009 population and housing Census of Gelgel Beles town including G/Mariam village and the nearby villages (Kuter-2 and Edida) which are settled along the road. Accordingly, the data of zone health office, town municipality and Keble administration offices the total population size of the study area in the year 2009 E.C is 29,244. But since a construction of Ethiopian renaissance dam was begin; the population of the town is ultimately increased rapidly from time to time *(GB, CSA, 2009).*

According to 2009-year census, the gender composition the female population of study area is slightly higher than the number of male populations. Accordingly, the female population is 55.63% (16,268) whereas the male population is 44.37 % (12,976). But currently the population of the town was expected to be twice of the 2009 years (Gelgel Beles town municipality).

Table: 3. 1 Growth rates as established by CSA for Populations of Gelgel Beles town

Years	1995-2000	2000-2005	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
Urban growth rate%	3.35	3.51	3.69	3.88	4.06	4.2	4.5

Hence to assure its progress a potable, reliable and adequate water supply and sanitation system must be established. Provision of water supply and sanitation system for such a town would certainly and substantially contribute to the sustainability of the ongoing improved urban development in particular and the healthy economic activity of the region in general.

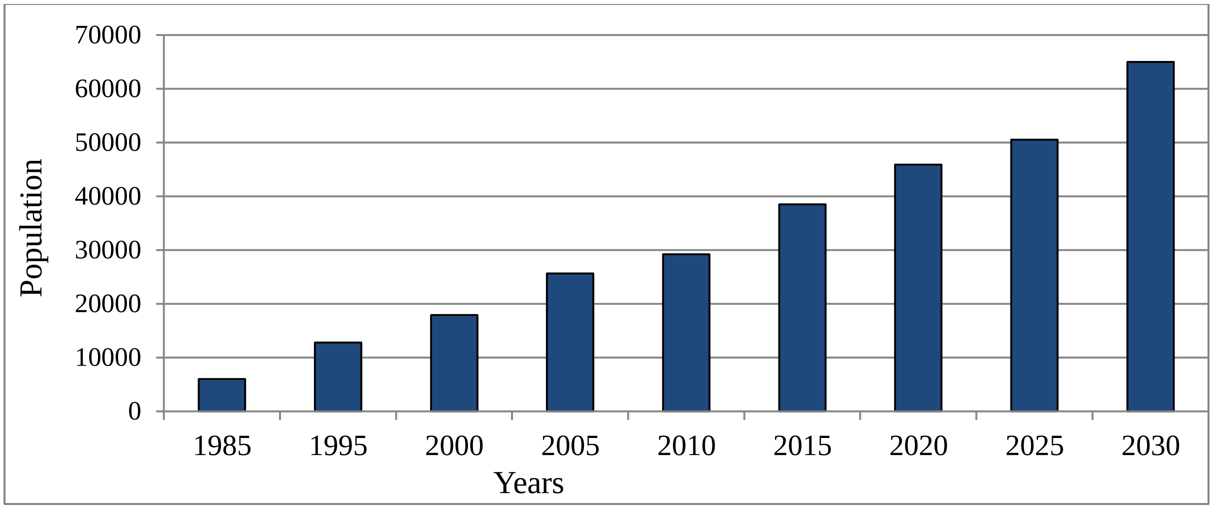

Figure: 3. 4 Projected Populations Gelgel beles town (1989-2030)

Therefore, accuracy in population projection is one of the important parameters, which greatly influences system unit capacity. Knowing the base population of a town along with some indications on future growth trend would enable to design a reliable and sustainable urban infrastructure in the town.

3.6 Data Collection

3.6.1 Data Types and Sources

This part comprises of the types and sources of data which have been used in this study. Accordingly, the qualitative as well as quantitative types of data were part of this study. The data source for this research work were collected both from primary and secondary sources.

3.6.2 Primary data sources

Field survey/observation, interview and questionnaires were the primary data sources which were employed in this study with the help of a base map and check list. About 90% of this study was dependent on primary data sources.

3.6.3 Secondary data sources

Secondary data was the other type of data collection method using existing records, master plan, and other proceedings and reports. It is only 10% of this study which was dependent on secondary data sources. Such data sources are meteorological data (rainfall data) from National Meteorological Service Agency of Ethiopia, contour map; Digital Elevation

Model (DEM), Land Use and Land Cover Data, geological, Soil Data, other findings/literatures and reports were secondary data sources which were used for this particular research. This was important to get the best information on the over-looked causes of poor drainage challenges and unconstructed storm water drainage as result of improper urbanization. Other secondary sources of information that was used include books, journals and manuals.

Table: 3. 2 Data collected and their sources

Types of Data	Sources of Data
Meteorological data	National Meteorological Service Agency Addis Ababa Ethiopia, Hydrology department
LULC Maps	From USGS 30*30 for satellite data of land sate for different time of period interval.
DEM (30mx30m resolution)	https://earthexplore.usgs.gov/
Base map	Gelgel Beles town municipality office
Topographic Maps	Ethiopian Mapping Authority Addis Ababa, Ethiopia
Valuation of existing drainage	Will be collected from field by using video and camera

3.6.4 Sampling Techniques

Purposive sampling technique was involved in this study. Evaluating the whole catchment is not necessarily important to come up with solution for storm water drainage problem. Therefore, some representative major flood prone areas with their impact to Beles river stream and the area where the problem is most encountered are selected. This study conducted on three woreda. These three woreda (G/Mariam kebele, kuter-2 kebele & Edida kebele) are located around Beles river stream and all their storm drainages outlet is to Beles river stream. All of them are incorporated under this study because of their influence to Beles river stream and all of the kebeles have been facing high flooding problems and storm water related disease during summer season.

3.7 Different Types Materials used in Research

There are different types of software used in this study. These are in given below. All this software is used in this study.

Table: 3. 3 Software and their uses in the study Area

Software	Their uses
ARC-GIS	For LULC map delineation, to fixing drainage outlet, stream network delineation of a town by input data for DEM
GPS	Used to collect (X and Y) coordinate for each drainage line
Digital camera	To take photo graph of the existing storm water drain age system.
Easy Fit 5.6	To test goodness of fit for rainfall data
Spreadsheet 2016	To plot graph and chart and calculation
Tape meter	To measure the existing storm water drainage line, width and diameter which helps to evaluate the capacity of drainage system

3.8 Data Analysis and Presentation

For accomplishing the objectives of the study and to answering the research questions, the collected raw data was edited, coded, classified, and tabulated in order to make it ready for analysis. Then different methods of data analysis, such as descriptive analysis (Summarizing sample information), inferential statistics to generalize the result obtained based on comparatively, causality relationship was used in this study. Firstly, the quantitative data were arranged, organized and then codified. Secondly, data analyzed using software and different tools such as Microsoft excel, EasyFit5.6 and Arc-GIS were employed to facilitate the process of data analysis. The qualitative data types were condensed, narrated and interpreted so as to make them meaningful information.

3.9 Methods of Data Analysis

Evaluating urban storm water drainage system is challenging and hence needs an ample methodology. Two types of methodologies were used to perform this research. The descriptive type was used to describe challenges and factors which impaired the performance of storm water drainage system and the condition of the Gilgel Beles town catchment area. Whereas, the exploratory type was particularly used to explore the existing condition and coverage of urban storm water drainage facilities which have been used by the sub-cities and best management practices for the existing drainage problems.

The general objective of this study were focuses on identifying/assessing the main cause of urban drainage problems as result uncontrolled urban settlement in Gelgel Beles town to make sustainable and to put engineering solution to the problems.

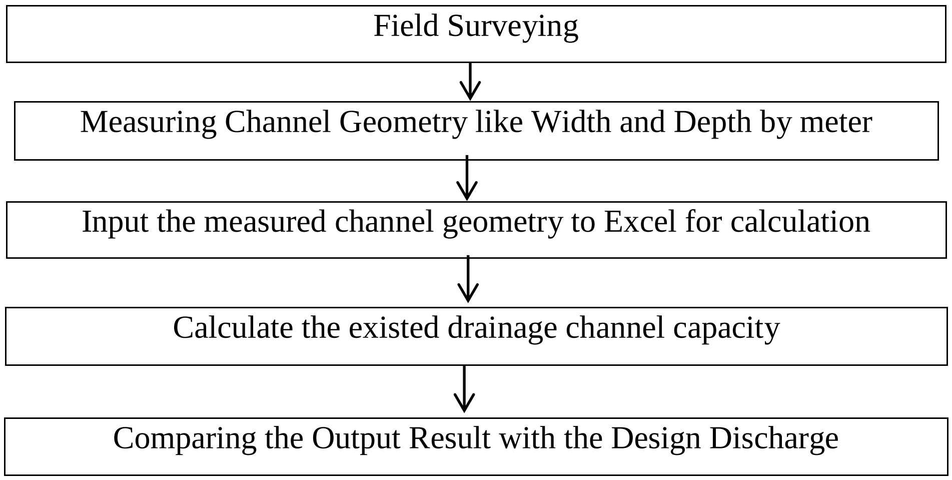

Figure: 3. 5 Performance assessments in case of functionality for existed drainage system

3.10 Rain Fall Data

Rainfall data for Gelgel Beles town can be obtained from National metrological service agency (NMA). Some of the data are obtained from the new constructed Gelgel Beles gauging stations. But even the stations are newly constructed it has some of missed data within ten years; therefore the data are not complete enough to use for frequency analysis. Consequently, this study used rainfall data from the *(NMA, 2020)*, and 10 year data from Gelgel Beles gauging stations for (from 1989 to 2020) of daily rain fall depth record. Therefore the data at this station is used to develop intensity-duration-curve (IDF) for rain fall analysis.

Table: 3. 4 Annual maximum 24hr rainfall (mm) at Gilgel Beles meteorological office

Year	1989	1990	2000	2010	2020
0	-	79.8	105.5	56.6	63.5
1	-	105.8	87.7	71.5	
2	-	115.8	53.8	89.2	
3	-	65.2	72.4	76.1	
4	-	23	72.2	60.5	
5	-	86.7	62.6	80.1	
6	-	58.2	88.7	65.4	
7	-	94.4	71.8	40.3	
8	-	108.2	70	50.5	
9	65.3	90.8	66.2	52.3	

The thesis focuses on the identifying of the real problem in the urban drainage on storm water management in Gelgel Beles town to make sustainable and to put best engineering solution to the problem. The objectives of this study should fit its fixed criteria through:-

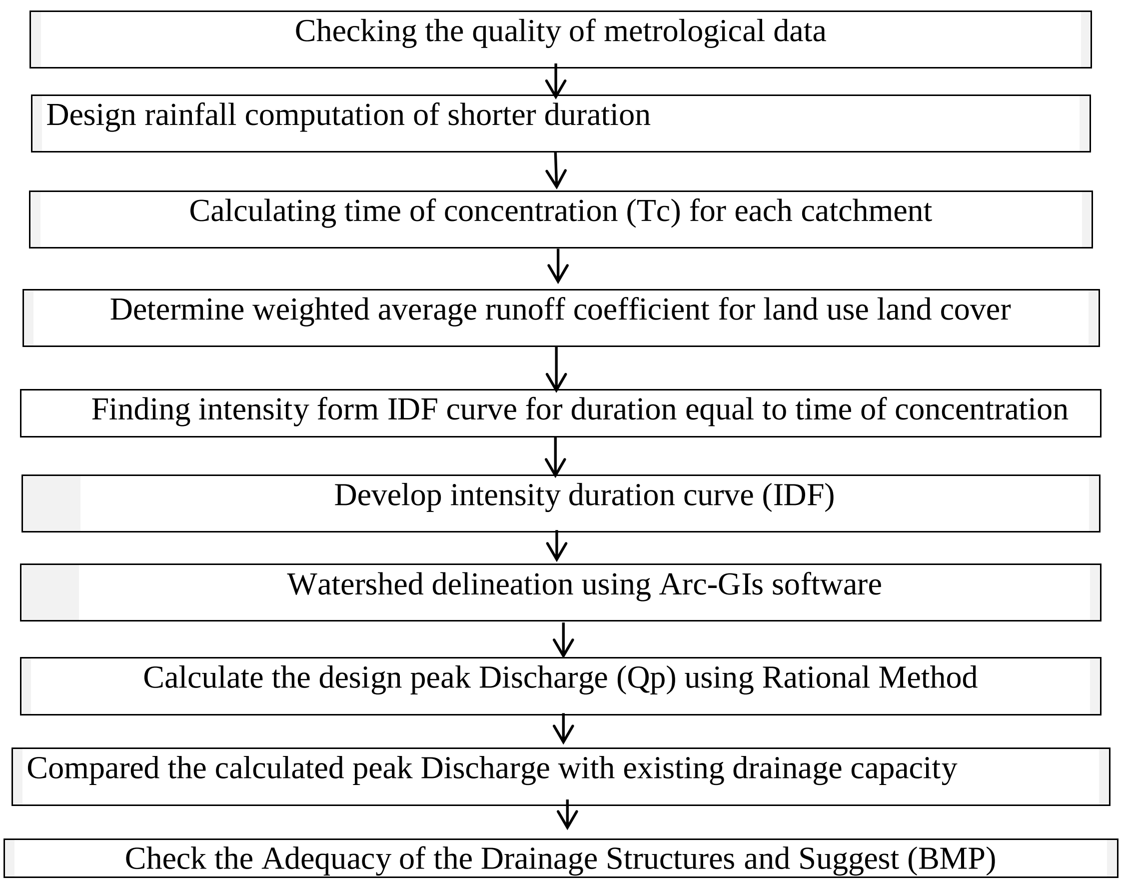

Figure: 3. 6 Evaluate adequacy of Existing Storm water drainage system

3.11 Hydraulic and Hydrological Analysis

3.11.1 Meteorological data Availability

In any kind of hydrological study rainfall data analysis is very crucial because of its spatial and temporal variability matters. In Ethiopia, the source of meteorological data is the national meteorological service agency (NMA). Gelgel Beles town astronomical location is 10°50" and 11°50" North latitude and 36°10´ 36°30" East longitude.

The town is founded on a relatively flat area adjacent to the Beles River. The general elevation of the surroundings of the town is in the range of 1030m a.s.l. towards the south and south east.

In order to apply flood estimation models for peak discharge computation using available rainfall data, the rainfall depth-duration-frequency relationship is required. Available rainfall data on the stations has been collected and analyzed using four methods of distribution analysis namely Normal, Log normal, Log Pearson-III and Gumbel's methods. Due to the rain gage station in the study area is one the outlier test is appropriate to check the quality of the data.

3.11.2 Rainfall Data Screening

Rainfall data obtained from the national meteorological agency of Ethiopia (NMA) at Addis Ababa Ethiopia, hydrology department center have been evaluated and screened to make sure that available rainfall data is fit for the purpose it is required. Rough rainfall data screening in the study area was first done by visual inspection of daily rainfall data.

Consistency and continuity of rainfall data series are very important for obtaining reliable results from such studies. However, these rainfall data series very often contain gaps or missing values due to various reasons such as the absence of observers, problems with measuring devices, loss of records etc. The use of a rainfall data series with missing values may critically influence the statistical power and accuracy of a study. By estimating and filling the missing rainfall data, a series could be made longer to make the water related study more reliable. In this study normal ratio method have been proposed and adopted in filling missing data with a view to obtaining a continuous and lengthy rainfall data series.

3.11.3 Filling in Missing Rainfall Data

When undertaking an analysis of precipitation data from gauges where daily observations are made, it is often to find days when no observations are recorded at one or more gauges. These missing days may be isolated occurrences or extended over long periods. In order to compute precipitation totals and averages, one must estimate the missing values. A number of methods have been proposed for estimate missing rainfall data. The station average method is the simplest method.

The normal-ratio method is conceptually simple; it differs from the station-average method of that the average annual rainfall is used in deriving weights. If the total annual rainfall at any of the N region gauges differs from the annual rainfall at the point of interest by more than 10%, the normal-ratio method is preferable. For this study normal-ratio method is used for filling the missing rainfall data.

If for example rainfall data at day 1 is missed from station Z having mean annual rainfall of Nz and there are three surrounding stations with mean annual rainfall of N1, N2, and N3 then the missing data Pz can be estimated *(Yilma, 2005).*

$$Pz = \frac{1}{3} \left[P1 * \frac{Nz}{N1} + P2 * \frac{Nz}{N2} + P3 * \frac{Nz}{N3} \right] \qquad (3.1)$$

Where:

Pz - missing rainfall data (daily, monthly or yearly)

P1, P2 and P3 – rainfall data at nearest different station (daily, monthly or yearly)

Nz - mean annual rainfall at missed station

N1, N2, and N3- mean annual rainfall at different nearest station

3.11.4 Data Consistency Test

If the conditions relevant to the recording of rain gauge stations have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. The most common method of checking for inconsistency of a record is the double-mass curve analysis *(Garg, 1980).*

The daily heaviest rainfall data from Gilgel Beles meteorological station from 1989 to 2020 are taken for analysis in this study. Hence, 32 years of daily heaviest rainfall data are available. These data should be checked for its consistency of higher and lower outlier testes.

A. Test for Higher Outlier

Higher outlier: $YH = [\, Y_{ave} + Kn * \delta n - 1]$ .... (3.2)

Where:

Y_{ave} = Mean of data in log unity

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

$\delta n - 1$ = Standard devotion

Higher outlier test = 10^{YH}……………………………………………………………..……… (3.3)

B. Test for Lower Outlier

$YL = [\ Y_{ave}- (Kn * \delta n - 1)]$ … … … … … … … … . … (3.4)

Lower outlier = 10^{YL}…………………………………………...…………………..…. (3.4.1)

3.11.5 Checking Data Reliability

Relative standard Relative standard less than 10% the data series could be regarded as reliable adequate *(Subramanya, 2008).*

Where:

N= Number of data

Y_{ave} = Mean of data

$\delta n - 1$ = Standard devotion

Standard error of mean $(\delta n - 1) = \frac{\delta n - 1}{\sqrt{n}}$ … . … … … … (3.5)

Relative Standard error = $\frac{\delta n}{Yave} * 100$ …. . . . (3.6)

3.12 Design Rainfall Analysis

3.12.1 Estimation of Average Depth of Rainfall

Hydrological studies require extensive analysis of meteorological, hydrological and spatial data to represent the actual processes taking place in the environment and estimation of quantities out of it. The size of an extreme event is inversely related to its frequency of occurrence. As result of this most of hydrological problems require knowledge of the average depth of rainfall over a significant area such as a basin. The rain catchment at one station in a basin may be different from that of other stations in the same basin.

A. Area Rainfall

Area rainfall requires a method of estimating aerial average rainfall over a basin by using Arithmetic average method to be used for this research by judgment consideration of quality and nature of the data, and the importance and required precision of the result rainfall data used.

Therefore, arithmetic mean method is appropriate for the study area and were used for estimation annual runoff volume in 25 year is the sum of average depth of rainfall over a Gelgel Beles town catchment it is found in appendixes.

B. Return Period

Subsequently, rational method is used to relate or compare the results. It is the average time interval between the occurrence of storms and floods of a given magnitude. Return period, also called recurrence interval is a term commonly used in hydrology. The historical rainfall data available is a 24hr duration rainfall flood frequency analysis is utilized to determine the magnitude of flood with a particular probability of exceedances from a statistical of record flood. Any probability distribution can be used as the model but the reliability of the distribution is checked by the goodness of fit tests. Among many methods, Gumbel methods were used for this research.

3.13 Design Rain Fall Computation of Shorter Duration

After checking the consistency of the data for higher and lower outlier, the data should be arranged for further analysis. These rainfall analyses and processing is aimed at determination of appropriate intensity-duration frequency relationship. Probability distributions are basic concepts in statistics. The results of statistical experiments and their probabilities of occurrence are linked by probability distributions.

Extreme rainfall depth for study area for different return periods was determined using probability models including Normal (N), Log-normal (LN), Log-Pearson type III (LP3) and Gumbel (EVI) probability method of analysis *(Subramanya, 2008).*

A. Normal distribution

The normal distribution is the most useful continuous distribution of all the distributions. In the normal distribution, the maximum value of expected rainfall (XT) corresponding to any return period (T) can be calculated using Eq. (3):

$$\mathrm{XT} = \mathrm{Xave} * (1 + \mathrm{Cv} * \mathrm{KT}) \quad \ldots (3.7)$$

$$Z = W - \frac{2.515517 + 0.802853w + 0.0110328w^2}{1 + 1.432788w + 0.189269w^2 0.001308w^3} \quad \ldots (3.7.1)$$

$$w = [ln\{\frac{1}{p2}\}]\ {}^{1}/_{2} \quad for\ (0 < p \leq 0.50) \quad \ldots (3.7.2)$$

Coefficient KT is calculated as

$$KT = \left[Z + (Z^2 - 1)K + \frac{1}{3}(Z^3 - 6Z)K^2 - (Z^2 - 1)K^3 + ZK^4 + \frac{1}{3}K^5\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (3.7.3)$$

Where

'XT' is the maximum value of expected rainfall, is the mean.

'Cv'' is the coefficient of variation.

Z= standard normal variant.

'P' is the exceedance probability (P=1/T).

B. Log-normal distribution

The log-normal distribution is a distribution of random variables with a normally distributed logarithm. The lognormal distribution model includes a random variable Y, and Log(Y) is normally distributed. The log-normal distribution assumes that Y=ln(X); therefore, the maximum value of expected rainfall (XT) corresponding to any return period (T) can be calculated using:

$$XT = \exp(YT) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (3.8)$$

$$XT = YT * (1 + Cvy * KT) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \ldots\ldots . (3.8.1)$$

Where

Y_T and C_{vy}, are the mean and coefficient of variation of respectively.

'K_T' is the frequency factor which is the same as the standard normal variant.

C. Log-Pearson type-III distribution

The log-Pearson type-III distribution has been widely and frequently used in hydrology and for hydrologic frequency analyses. In the log-Pearson type-III distribution, the maximum value of expected rainfall (X_T) corresponding to any return period (T) can be calculated using Eq. (3.14):

$$YT = \operatorname{antlog}(Y) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \ldots . . (3.9)$$

$$\text{Log}\ (Y) = Yave + Kt * \delta n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (3.9.1)$$

$$KT = \frac{2}{Cs}\left[\left\{\left(Z - \frac{Cs}{6}\right)\frac{Cs}{6} + 1\right\}^3 - 1\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \ldots\ldots . \ldots (3.9.2)$$

Where, Y_{ave},'δn' and 'Cs' are the mean, standard deviation and coefficient of skewness of rainfall data, respectively, and 'KT' is the frequency factor.

Then R-squared value test was carried to obtain best fitted distribution methods

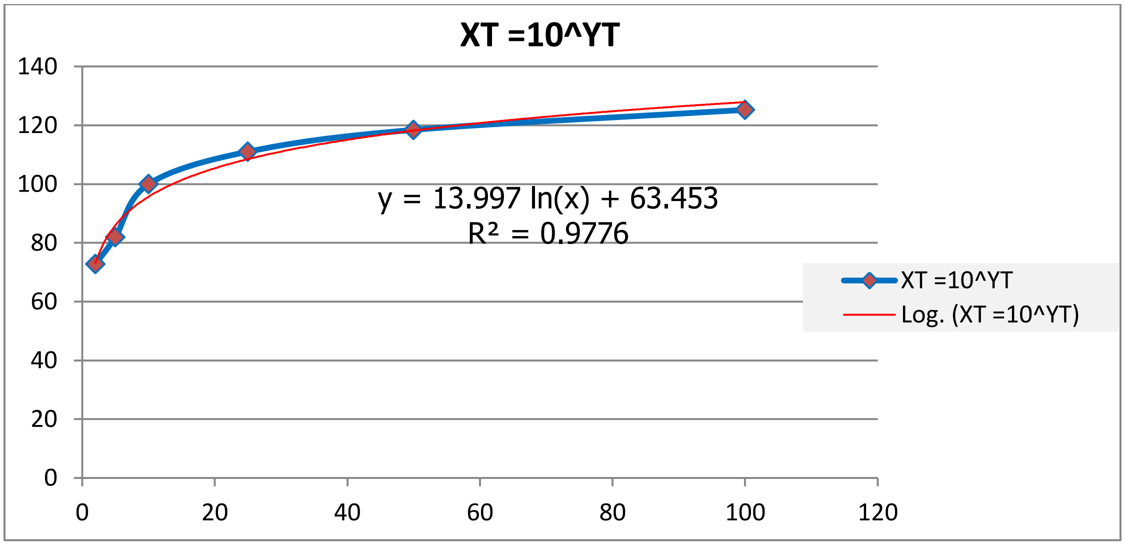

Figure: 3. 7 Fitting distribution test by Log Pearson Type III

D. Gumbel (EV I) distribution

The Gumbel distribution named in honor of Emil Gumbel, and also known as the Extreme Value Type I (EV I) distribution, is a continuous probability distribution. This distribution can be applied to model maximum or minimum values of a random variable using Eq. (3.10):

$$XT = (Xmean * (Kt * \delta n - 1) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.10)$$

$$KT = \frac{\sqrt{6}}{\pi}[0.5772 + \ln\{\ln\frac{T}{T-1})\}] \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.10.1)$$

Where: $X_{mean,}$ is the mean, ‘δn’ standard deviation and ‘KT’ is the frequency factor, which depends on the return period (T) and probability distribution R^2 can be obtain as:

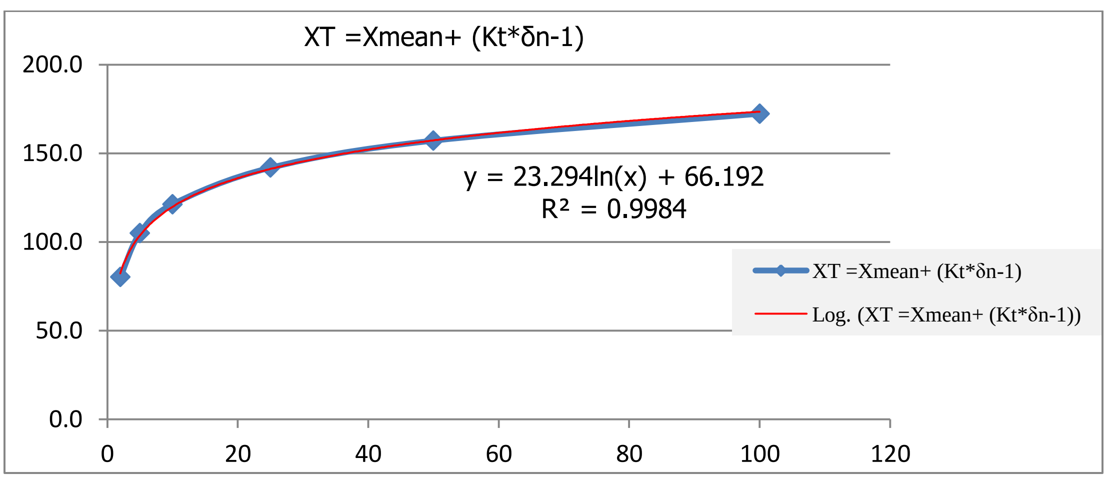

Figure: 3. 8 Fitting distribution test by Gumbel-Extreme Value Distribution for (log fit)

3.14 Goodness of Fit Test

The goodness of fit (GOF) tests measures the compatibility of a random sample with a theoretical probability distribution 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.

1. Kolmogorov-Smirnov Test

This test is used to decide if a sample comes from a hypothesized continuous distribution. It is based on the empirical cumulative distribution function (ECDF). Assume that we have a random sample Y1, Y2, Yn,……….Xn, from some continuous distribution with CDF F(x). The empirical CDF is denoted by

$$\mathrm{En} = \frac{\mathrm{ni}}{\mathrm{N}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.10.2)$$

Where

"ni" is number of points less than Yi

Yi+1 is ordered from smallest to largest value

Test Statistic: The Kolmogorov-Smirnov test statistic is defined as

$$D = max\left[F(Yi) - \left(\frac{i-1}{N}\right), \frac{i}{N} - F(Fi)\right] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.10.3)$$

Where F is the theoretical cumulative distribution of the distribution being tested, which must be a continuous distribution. The hypothesis regarding the distributional from is rejected if the test statistic, D, is greater than the critical value obtained from a table.

2. 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 statistic ($A2$) is defined as

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1) * \left[lnF(Xi) + \ln\left(1 - F\left(X_{n-i+1)}\right)\right)\right] \dots\dots\dots\dots\dots\dots\dots\dots (3.10.4)$$

The hypothesis regarding the distributional form is rejected at the chosen significance level (alpha) if the test statistic, A^2 is greater than the critical value obtained from a table. When comparing different distribution, lower statistics means better fit.

3. **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. Although there is no optimal choice for the number of bins (k), there are several formulas which can be used to calculate this number based on the sample size (N). For example, Easy Fit employs the following empirical formula:

$$K = [1 + \log_2 * N] \dots \dots \dots (3.11)$$

The data can be grouped into intervals of equal probability or equal width. The first approach is generally more acceptable since it handles peaked data much better. The Chi-Squared statistic is defined as,

$$X^2 = \sum_{i=1}^{k} \frac{(Oi - Ei)^2}{Ei} \dots \dots \dots (3.11.1)$$

Where $Oi$is the observed frequency for bin, Ei

$$E_{i} = (F(_{X2}) - F(_{X1}) \dots \dots \dots (3.11.2)$$

Where F is the CDF of the probability distribution being tested, and x_1, x_2 are the limits for bin i. When comparing different distribution, lower statistics means better fit. Easy Fit 5.6 Professional software is used for testing goodness of the recommended Normal (N), Log-normal (LN), Log-Pearson type III (LP3) and Gumbel (EVI) method.

3.15 Development of Intensity- Duration- Frequency Curve (IDF Curve)

Rain fall of a place can be completely defined if the intensities, durations and frequencies of the various storms occurring at that place are known. Whenever an intense rain occurs, its magnitude and duration is generally known from meteorological readings. This available data can be used to determine the frequencies of the various rains. Such frequency data for storms of various durations can be represented by Intensity-Duration frequency (IDF) curves. An IDF curve is a plot of average rainfall intensity (rainfall depth is averaged over the duration *(Garg, 2005).*

However, when short time duration rainfall data is not available intensity of a short time rainfall long time rainfall would be calculated using reduction formula. 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 *(ERA, 2013)*, suggests the following equation for calculation of shorter duration rainfall from 24hour duration rainfall:

$$R_{Rt} = \frac{t(b+24)^n}{24(b+t)^n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.12)$$

Where

RRt = Rainfall depth ratio Rt: R24

Rt= Rainfall depth in a given duration t (hours)

R24 = 24hr rainfall depth

Coefficients n = 0.92, b = 0.3, based on studies of large gauges in east Africa *(* Waikar and Undegaonkar Namita, *2015).*

The methods employed to develop IDF curve for the shorter duration events using the above equations are as follows. Using the trend line equation obtained from Gumbel method of frequency analysis, i.e. y = 0.7088x +90.405 (See Index-Figure 23) where y is 24-hour rainfall depth (R24) of a return period x under consideration, R24 is calculated for 2, 5, 10, 25, 50 and 100 year return period. Rearranging the above equation gives

$$R_t = \frac{t(b+24)^n}{24(b+t)^n} * R_{24} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.12.1)$$

$I_t = \frac{Rt}{t} \ldots..$ Substituting in the above equation gives (mm/hr)

$R_t = \frac{R_{24}(b+24)^n}{24(b+t)^n}$, where, I_t (mm/hr), t (hours), R24 (mm)

Using b = 0.3 and n = 0.92 as suggested by ERA 2013 manual results are tabulated (Appendix) for rainfall durations 5, 10, 15, 20, 30 … 180 minutes. The resulting table is graphed for each return period. That is IDF curve is developed using reduction formula.

3.16 Hydrological Model

Typically, the hydrologic component of the model is responsible for runoff generation and flow routing from the drainage sub-catchment to the receiving drainage system (culverts, ditches, storm water mains). For this study, the Rational Method is used for runoff generation with the flow routing component captured in the time of concentration calculations completed for each sub catchment.

3.17 Run off Determination Using Rational Method

3.17.1 Rational Method

Runoff estimation can be performed by either statistical methods or deterministic methods. Statistical methods are based on historical gauging records to estimate the probability of occurrence of a given event. Runoff from a given site may be subject to changes by urbanization and drainage improvements. Statistical methods have no parameter to account for these changes and that is their limitation. Unlike statistical methods deterministic methods are based on a cause-effect consideration of the rainfall runoff processes. Rational formula is recommended for drainage area less than 50h *(* ERA*, 2013).*

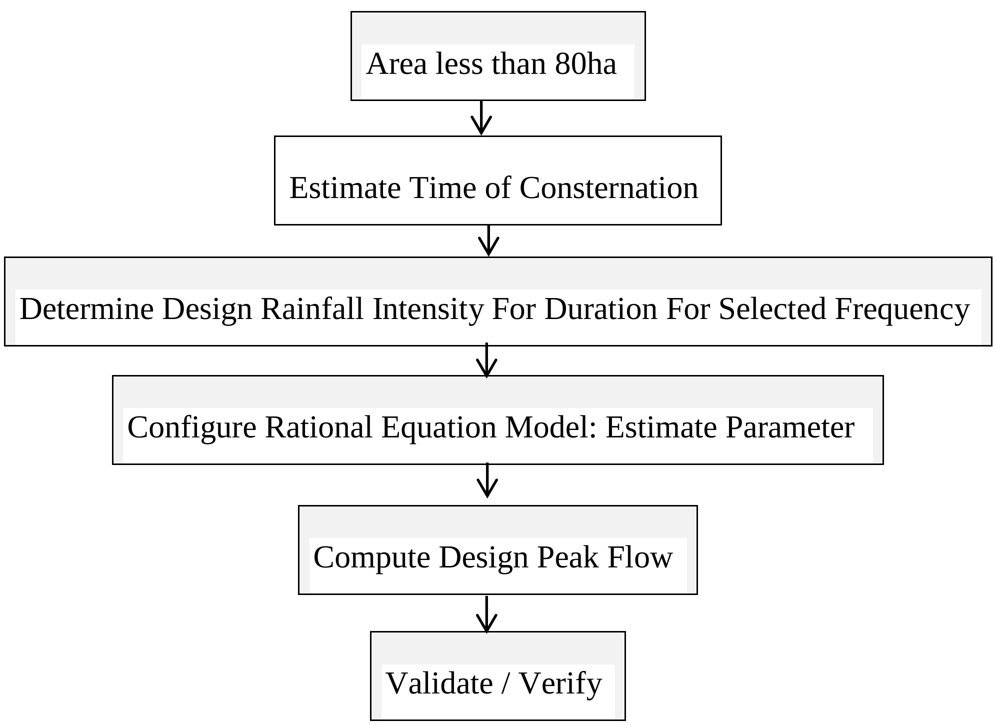

Figure: 3. 9 Step in developing and applying rational method

This method is used in this research for peak discharge determination from smaller catchments area less 80 ha as recommended by ERA drainage design manual. The equation of rational formula is function of catchment area, runoff coefficient and time of concentration. The equation is expressed as:

$$Q = [\,0.278\ C * i * A\,] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.13)$$

Where

Qp =Peak runoff in m^3/s

C = Runoff coefficient

i = Rainfall intensity in $\mathrm{mm/hr}$ and A = Catchment area in $(km)^2$

The design rainfall intensity is the intensity of a constant intensity design storm with the specified design return period and duration equal to the time of concentration of the drainage area. Once the design return period and duration are determined, the design rainfall intensity can be determined from an appropriate intensity-duration-frequency graph or equation for the location of the drainage area. If IDF curves are not available for the catchment and a maximum precipitation P, (cm) occurs during a storm period of tR hours, then the design intensity I (= ic) can be obtained from *(* H.M *Raghunath 2008).*

$$i_c = \frac{P}{tR}\left[\frac{tR+1}{tC+1}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.13.1)$$

However, for this study an IDF curve is developed and the design intensity can be read for corresponding time of concentration and return period. Some limitations in using rational formula are:

- ✓ The peak probability to happen (return period) is equal to the rainfall intensity
- ✓ The runoff coefficient C is constant during the rain storm
- ✓ The concentration time is approached
- ✓ The area limitation of 80 ha

3.17.2 Determination of Run off Coefficient (C)

The runoff coefficient is the fraction of rainfall striking the drainage area that becomes runoff from that drainage area. Runoff coefficients determined constant, dependent on the nature of the drainage area surface. An impervious surface like a concrete parking lot will have a runoff coefficient of nearly one. A very tight clay soil will also have a relatively high runoff coefficient, while a sandy soil would have more infiltration and a lower runoff coefficient. In addition to the nature of the surface and the soil, the slope of the drainage area has an effect on the runoff coefficient. A greater slope leads to a higher runoff coefficient. The runoff coefficient is the most important variable in the rational method of rainfall to runoff transformation. A weightage method is employed to obtain the representative runoff coefficient i.e. the individual areas multiplied by their specific runoff coefficient and their values added together and divided by the cumulative area *(* Zewdu, *2015).*

Equation below is used to determine weighted average runoff coefficient values for each catchment area under rational method using land use map of Landsat 2020 to classify land use land cover for Gelgel Beles town. A weightage method is employed to obtain the representative runoff coefficient i.e. the individual areas multiplied by their specific runoff coefficient and their values added together and divided by the cumulative area *(* Ven Te Chow, *2012).*

$$C_w = \sum\left(\frac{Ai*Ci\ldots\ldots+An*Cn}{\sum At}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.14)$$

Where:

Cw = weighted C;

Ci = runoff coefficient for each catchment area

At = total catchments area

The runoff coefficient, ‘C’, is a statistical composite of several aspects, including the effects of rainfall intensity, catchment characteristics, infiltration (and other losses) and channel storage. The runoff coefficient must account for the future development of the catchment as depicted in the planning scheme or zoning maps for the relevant local government, but should not be less than the value determined for the catchment under existing conditions.

3.17.3 Rainfall Intensity (i)

The design rainfall intensity is the intensity of a constant intensity design storm with the specified design return period and duration equal to the time of concentration of the drainage area. Once the design return period and duration are determined, the design rainfall intensity can be determined from an appropriate intensity-duration-frequency graph or equation for the location of the drainage area *(* ERA, *2002).*

3.17.4 Drainage Area (A)

The drainage area, A, is often determined from a map which includes the drainage area of interest. It may be necessary to first determine the boundaries of the drainage area using a contour map. Once the boundaries are known, the area can be determined using the map scale. However, for large catchment areas Gelgel Beles town is necessary to divide the area into sub catchment areas to account for common outlet of the town by over laying the natural drainage system and master plan of the town using Arc GIS.

3.17.5 Time of Concentration (T_c)

Tc is the time of concentration, the time required for rain falling at the farthest point of the catchment to flow to the measuring point of the river. Thus, after time tc from the commencement of rain, the whole of the catchment is taken to be contributing to the flow. The value of i, the mean intensity, assumed that the rate of rainfall is constant during tc, and that all the measured rainfall over the catchment area contributes to the peak flow. The peak flow Qp occurs after the period (Tc).

There are a number of methods that can be used to estimate time of concentration (tc), some of which are intended to calculate the flow velocity within individual segments of the flow path (e.g. shallow concentrated flow, sheet and open channel flow, etc.) the time of concentration can be calculated as the sum of the travel times within the various consecutive flow segments.

A. Open Channel Flow

Water moves through a catchment area as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type that occurs is a function of the conveyance system and is best determined by field inspection. Travel time is the ratio of flow length to flow velocity:

$$Tt = \frac{L}{3600V} \quad \ldots (3.15)$$

Where:

T_t = travel time, hr.

L = flow length, m

V = average velocity, m/s

3600 = conversion factor from seconds to hours. When the channel section and roughness coefficient (Manning's n) are available, then the velocity can be computed using the manning equation:

$$V = \frac{1}{n}\left(R^{2/3} * S^{1/2}\right) \quad \ldots (3.15.1)$$

Where:

V= average velocity, m/s.

R= hydraulic radius, m (equal to A/P_w).

A = cross sectional flow area, m^2

Pw = wetted perimeter, m

S = slope of the hydraulic grade line, m/m and n = manning's roughness coefficient m/m

B. Sheet Flow Time

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

$$T_t = \left[\frac{0.091(n*L)^{0.8}}{(P2)^{0.5}(S^{0.4})} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.16)$$

Where:

Tt = travel time in (hr.)

n = Manning's roughness coefficient.

L = sheet flow length (m)

P_2 = 2-year, 24-hour rainfall in (mm).

S = slope of land surface (m/m) which based on topographic maps of the area.

The time of concentration is the sum of sheet and channel flow. In order to calculate the Time of Concentration (Tc) parameter, the sub-catchment slope, length and roughness coefficient need to be determined. The slope was estimated using the contour. The length was estimated by tracing the drainage flow path from the furthest point in the sub-catchment to the discharge point. The roughness coefficient was estimated based on ditch material type.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Evaluation of LULC Changes Effect on the Storm Water Runoff Volume

The land use land cover image processed for the years 2020 by using ArcGIS.10.1 and Google earth pro for each land use and land cover, annual storm water runoff volume was calculated and digital change detection were evaluated for area which currently occupied by population.

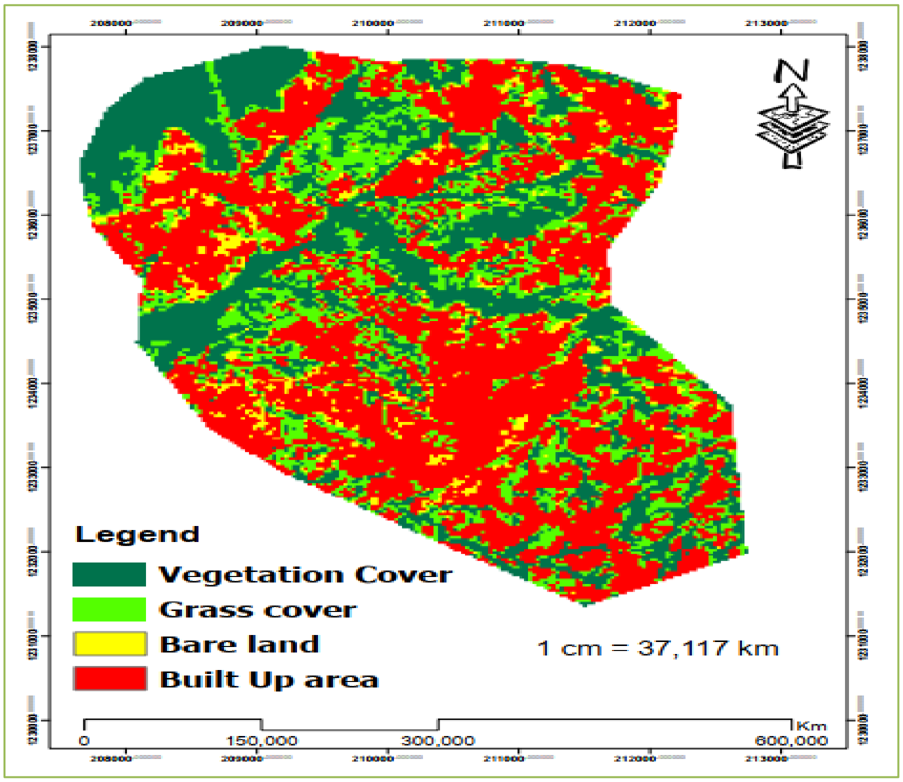

Figure 4. 1: Land use land cover maps of Gelgel Beles town catchment in year of (2020)

Table 4. 1: Estimated annual runoff from land use land cover map of year (2020)

Lulc Map of town	*Runoff coefficient*	*Areal rainfall (m)*	*Area(m^2)*	*Volume runoff (m^3)*
Built -up area	0.75	0.0774	173800	10089.09
Vegetation cover	0.35	0.0774	83545	2263.234
Grass cover	0.45	0.0774	66645	2321.245
Bare land	0.6	0.0774	12010	557.7444

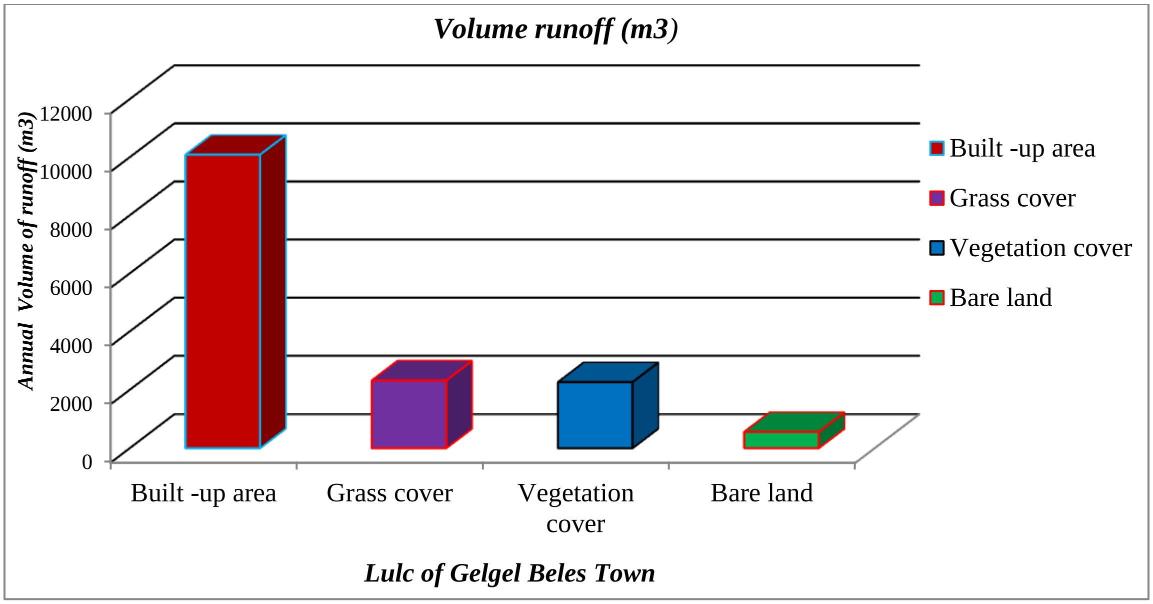

Figure 4. 2: Annual runoff generated at study area in year of (2020)

The results indicate that annual runoff volume of Built -up area in the study area has maximum volume (10089.09) m^3, Grass cover was the second in generating maximum runoff (2321.245m^3) of the total annual runoff volume. The Vegetation cover has decreased from year to year which accounts for 2263.234m^3). The Bare Land area has increased from time to time as result of unplanned urbanization and cutting of tree for housing and wood purpose and it generate annual runoff volume that accounts (557.7444m^3).

Generally With urban expansion and development, more of the natural landform will be converted into impervious surface. This significant shift from some classes to others was also observed. Drivers of the observed changes might be climatic factors such as rainfall and drought to socioeconomic factors and also the city is in the stage of rapid urbanization and with it, a rapid increase in built-up spaces.

4.2 Hydrologic Analyses of Existed Drainage System

For all hydrologic analyses, the following factors shall be evaluated and included when they will have a significant effect on the final results: Drainage basin characteristics including: size, shape, slope, land use, geology, soil type, surface infiltration and Stream channel characteristics aggradation, degradation, and debris and meteorological characteristics such as precipitation amounts and type rainfall intensity (areal and point) over the catchment.

4.3 Peak discharge calculated using Rational Formula

The discharge calculated by this method for area less than 0.8km^2. The parameters involved in this calculation were run-off coefficient from Land use composition of the study area (the runoff coefficient is determined for land use and land cover of year 2020); rainfall intensity reading from time concentration and return is specified for IDF curve which developed for Gelgel Beles town. The calculated rainfall intensity is indicated in appendix. Return period is fixed based long time strategic plane. The recurrence design frequency 25 years for a long-range strategy plan for the entire urban area, therefore, this research used 25 years' design storm frequency for urban area *(* ERA*, 2013).* Using the daily maximum rainfall from metrological agency, 24-hour design rainfall was calculated using Gumbel distribution methods. The values are compared with Ethiopian Roads Authority recommended values and the maximum was taken, as it is recommended by ERA. The rainfall of ERA is attached on the appendix part.

Land use composition of the in Gelgel Beles town the total area was 1120ha. But the Lulc is done for area currently occupied by population. The runoff coefficient taking the average land use land cover in 2020 using the above formula was 0.586 in equation (3.14) and to used overall the catchment because due to improper land use map of Gelgel Beles town.

A. **Time of concentration**

☑ Sheet flow Time: -Sheet flow is flow over plan surfaces. It usually occurs in the headwater of the streams (usually for the first 100 m run), but from topographic map obtained 100 m Sheet flow, natural range and short grass slope of 0.055 m/m, and length of 100 m and Manning's roughness coefficient is 0.0125. The 2-year, 24-hour rainfall depth is calculated to be 69.03 mm.

Hence, from equation travel time for sheet flow is determined as: $Tt= [0.091(nL)^{0.8}/ (P2)^{0.5} S^{0.4}]$ $= [0.091(0.0125*100)^{0.8}/ (69.03)^{0.5} 0.055^{0.4}]$ = **Tt_1= 0.166hr.**

☑ For shallow concentrated flow, unpaved watershed slope is approximated S1=0.01 and length from topography map is 562m. $V=4.9178(0.055)^{0.5}$ for unpaved watershed. $V=4.9178(0.055)^{0.5}$ = 0.483127m/sec. Finally, travel-time is determined as:

☑ The estimation of shallow concentrated flow (Time of concentration Tt2) for given catchment unpaved watershed is **Tt_2 = 0.323hr.**

☑ For channel flow, natural stream channel, winding with weeds and pools, Slope is 0.013m/m, and Length is 562m. Rectangular channel for main cachement-1 (MDL-1): 1V:1H, Width (B_1) =1.25m, Depth (y_1) =0.55m, S_1=0.01, Manning's n channel (n=0.0125), Area of channel (A1) =0.69m^2, Perimeter of channel=2.35m and V channel= 8.23m/s. The time is equal to **Tt_3 = 0.019hr.**

The time of concentration is the sum of Tt values for the various consecutive flow segments: $Tc=Tt_1+Tt_2+Tt_3$ = 0.166hr +0.323hr +0.019hr = **0.508hr**

Table 4. 2: Result of peak discharge using rational method

Location Kebele	Main-Line ID	Area (ha)	Total Tc (hr)	IDF(for 25 year frequency)(mm/hr)	Runoff Coefficient	Discharge (m^3/s)
G/Mariam	MDL-1	13.16	0.508	122.43	0.586	2.63
	MDL-2	10.49	1.486	58.50	0.586	1.00
	MDL-3	10.26	0.882	91.60	0.586	1.53
	MDL-4	9.23	0.342	146.50	0.586	2.20
	MDL-5	8.39	1.012	81.20	0.586	1.11
	MDL-6	7.69	0.773	100.20	0.586	1.26
	MDL-7	7.10	0.509	121.40	0.586	1.40
	MDL-8	6.59	0.563	116.70	0.586	1.25
	MDL-9	6.15	1.039	77.30	0.586	0.77
	MDL-10	5.77	0.712	102.40	0.586	0.96
	MDL-1	5.43	0.698	108.50	0.586	0.96
Kuter-2						
	MDL-2	5.13	0.758	105.50	0.586	0.88
	MDL-3	4.86	0.901	90.82	0.586	0.72
	MDL-4	4.62	0.483	126.50	0.586	0.95
	MDL-5	4.40	1.012	80.60	0.586	0.58
	MDL-6	4.20	0.487	126.50	0.586	0.86
	MDL-7	4.01	0.916	88.00	0.586	0.58
	MDL-8	3.85	1.237	77.70	0.586	0.49
	MDL-1	3.69	0.515	121.40	0.586	0.73
	MDL-2	3.55	0.39	137.00	0.586	0.79
Edida			6			
	MDL-3	3.42	0.329	151.07	0.586	0.84
	MDL-4	3.30	0.971	85.50	0.586	0.46
	MDL-5	3.18	1.139	72.50	0.586	0.38

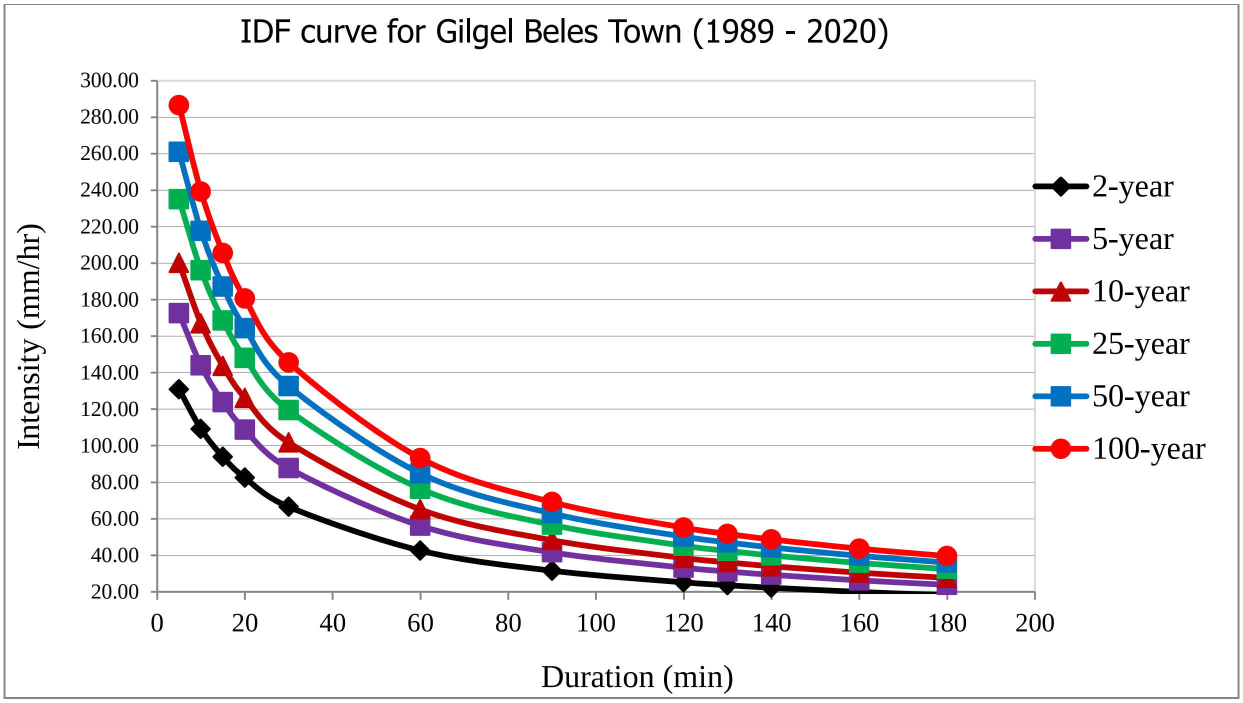

Figure 4. 3: Intensity duration-frequency curve for Gelgel Beles town

Table 4. 3: Result of peak discharge using rational method

Location Kebele	Main-Line ID	Area (ha)	Total Tc (hr)	IDF(for 25 year frequency)(mm/hr)	Runoff Coefficient	Discharge (m^3/s)
G/Mariam	MDL-1	13.16	0.508	122.43	0.586	***2.63***
	MDL-2	10.49	1.486	58.50	0.586	***1.00***
	MDL-3	10.26	0.882	91.60	0.586	***1.53***
	MDL-4	9.23	0.342	146.50	0.586	***2.20***
	MDL-5	8.39	1.012	81.20	0.586	***1.11***
	MDL-6	7.69	0.773	100.20	0.586	***1.26***
	MDL-7	7.10	0.509	121.40	0.586	***1.40***
	MDL-8	6.59	0.563	116.70	0.586	***1.25***
	MDL-9	6.15	1.039	77.30	0.586	***0.77***
	MDL-10	5.77	0.712	102.40	0.586	***0.96***
	MDL-1	5.43	0.698	108.50	0.586	***0.96***
	MDL-2	5.13	0.758	105.50	0.586	***0.88***
	MDL-3	4.86	0.901	90.82	0.586	***0.72***

Kuter-2	MDL-4	4.62	0.483	126.50	0.586	***0.95***
	MDL-5	4.40	1.012	80.60	0.586	***0.58***
	MDL-6	4.20	0.487	126.50	0.586	***0.86***
	MDL-7	4.01	0.916	88.00	0.586	***0.58***
	MDL-8	3.85	1.237	77.70	0.586	***0.49***
	MDL-1	3.69	0.515	121.40	0.586	***0.73***
	MDL-2	3.55	0.396	137.00	0.586	***0.79***
	MDL-3	3.42	0.329	151.07	0.586	***0.84***
Edida	MDL-4	3.30	0.971	85.50	0.586	***0.46***
	MDL-5	3.18	1.139	72.50	0.586	***0.38***

4.4 Hydraulic capacity and design of the Existing Drainage Systems

The land use type and drainage network of the study area was the key point for the result of area, runoff coefficient, rainfall intensity and length of the catchment in order to determine hydraulic capacity. The shape of cross-sectional existing condition of all main storm water drainage type in Gelgel Beles town was rectangular channel, but in case of sub line (trapezoidal, rectangular and circular) are constructed as result topographic condition of the area and the manning coefficient is the roughness of the material found at (appendix) part. Manning’s roughness coefficient for concrete pipe is (n = 0.013). So that the amount of discharge conveyed in the existing drainage system could be determined by the manning equation.

Table 4. 4: Existing capacity of main draining catchment of Gelgel Beles town

Location Kebele	Main-Line ID	B (m)	Y (m)	P (m)	n (m/m)	S (m/m)	A (m2)	R (m)	V (m/s)	Q m^3/s
G/Mariam	*MDL-1*	0.75	0.30	1.35	0.013	0.055	0.23	0.17	0.17	1.28
	MDL-2	1.25	0.43	2.10	0.013	0.010	0.53	0.25	0.17	1.70
	MDL-3	1.25	0.43	2.10	0.013	0.014	0.53	0.25	0.20	2.01
	MDL-4	0.65	0.43	1.50	0.013	0.043	0.28	0.18	0.19	1.48
	MDL-5	1.25	0.43	2.10	0.013	0.011	0.53	0.25	0.18	1.78
	MDL-6	1.25	0.43	2.10	0.013	0.019	0.53	0.25	0.24	2.34
	MDL-7	0.70	0.55	1.79	0.013	0.047	0.38	0.21	0.26	2.36
	MDL-8	0.70	0.80	2.29	0.013	0.036	0.56	0.24	0.30	3.29
	MDL-9	0.72	1.38	3.47	0.013	0.011	0.99	0.29	0.23	3.60
	MDL-10	0.72	1.38	3.47	0.013	0.021	0.99	0.29	0.31	4.97
	MDL-1	1.25	0.43	2.10	0.013	0.020	0.53	0.25	0.24	2.40
	MDL-2	1.25	0.43	2.10	0.013	0.020	0.53	0.25	0.24	2.40
	MDL-3	1.25	0.43	2.10	0.013	0.020	0.53	0.25	0.24	2.40
Kuter-2										
	MDL-4	0.65	0.43	1.50	0.013	0.040	0.28	0.18	0.18	1.43
	MDL-5	1.25	0.43	2.10	0.013	0.011	0.53	0.25	0.18	1.78
	MDL-6	0.75	0.43	1.60	0.013	0.033	0.32	0.20	0.19	1.58
	MDL-7	0.72	0.43	1.57	0.013	0.012	0.31	0.19	0.11	0.90
	MDL-8	0.72	0.43	1.57	0.013	0.010	0.31	0.19	0.10	0.82
Edida	*MDL-1*	0.77	0.43	1.82	0.013	0.040	0.33	0.18	0.17	1.67
	MDL-2	0.75	0.43	1.60	0.013	0.040	0.32	0.20	0.21	1.74
	MDL-3	0.75	0.43	1.60	0.013	0.040	0.32	0.20	0.21	1.74
	MDL-4	1.25	0.43	2.10	0.013	0.010	0.53	0.25	0.17	1.70
	MDL-5	0.72	0.50	1.71	0.013	0.010	0.36	0.21	0.12	1.00

Table 4. 5: Existing Sub-catchment line flow to main drainage catchment of the study area

Location	No	Direction	Trapezoidal			Rectangular		Circular						
	Sub-Line ID	Flow to	Bt (m)	Yt (m)	T (m)	Br (m)	Yr (m)	Dc (m)	n	A (m2)	P (m)	S %	V (m/s)	Q (m3/s)
G/Mariam Kebele	SDL-1	MDL-1				0.65	1.00		0.016	0.65	2.65	2.50	1.81	1.17
	SDL-2	MDL-1				0.40	0.60		0.016	0.24	1.60	2.00	1.00	0.24
	SDL-3	MDL-2	0.45	0.70	0.75				0.025	0.81	2.43	1.10	1.26	1.01
	SDL-4	MDL-3						0.60	0.013	0.79	3.14	2.90	4.20	2.05
	SDL-5	MDL-4	0.45	0.35	0.45				0.025	0.18	1.17	5.20	2.21	0.19
	SDL-6	MDL-5	0.50	0.70	0.80				0.025	0.45	1.93	2.30	1.44	0.65
	SDL-7	MDL-6				0.30	0.40		0.06	0.12	1.10	5.30	1.31	0.16
	SDL-8	MDL-7				0.45	0.60		0.016	0.27	1.65	6.50	1.91	0.52
	SDL-9	MDL-8				0.20	0.40		0.016	0.08	1.00	1.20	0.69	0.06
	SDL-10	MDL-9	0.70	0.80	1.00				0.025	0.75	2.37	1.60	1.74	1.11
	SDL-11	MDL-10	0.40	0.80	1.00				0.025	0.52	2.08	2.80	1.67	0.87
	SDL-12	MDL-3						0.80	0.013	0.50	2.51	2.00	1.73	0.87
	SDL-13	MDL-4				0.70	0.70		0.016	0.49	2.10	2.00	1.68	0.82
	SDL-14	MDL-10				1.25	0.55		0.016	0.69	2.35	5.50	3.23	2.22
Kuter-2 Kebele	SDL-1	MDL-1	0.50	0.30	0.70				0.025	0.24	1.35	5.00	1.77	0.42
	SDL-2	MDL-2	0.40	0.20	0.50				0.025	0.09	0.81	6.80	1.50	0.14
	SDL-3	MDL-3						0.80	0.013	0.50	2.51	1.90	4.14	2.71
	SDL-4	MDL-1				0.60	0.40		0.016	0.24	1.40	1.00	3.91	2.19
	SDL-5	MDL-4				0.70	0.30		0.016	0.21	1.30	4.00	5.45	2.13
	SDL-6	MDL-5				0.60	0.50		0.016	0.30	1.60	2.00	2.14	2.87
	SDL-7	MDL-6				1.30	0.50		0.016	0.65	2.30	2.10	2.19	2.52
	SDL-8	MDL-7						0.80	0.013	0.50	2.51	1.90	4.14	2.71
	SDL-9	MDL-8				1.55	0.55		0.016	0.69	2.35	1.40	1.63	1.13
	SDL-10	MDL-2						0.80	0.013	0.50	2.51	1.90	4.14	2.71
	SDL-11	MDL-8	0.70	0.80	1.00				0.025	0.75	2.37	1.60	1.74	1.12
Edida Kebele	SDL-1	MDL-1				1.30	0.50		0.016	0.65	2.30	2.10	2.19	2.52
	SDL-2	MDL-2				0.40	0.60		0.016	0.24	1.60	2.00	1.02	0.24
	SDL-3	MDL-1						0.80	0.013	0.50	2.51	1.90	4.14	2.71

	SDL-4	MDL-2				0.60	0.50		0.016	0.30	1.60	2.00	2.14	2.87
	SDL-5	MDL-3				1.25	0.40		0.016	0.50	2.05	1.00		2.59
	SDL-6	MDL-4						0.60	0.013	0.79	3.14	2.90	4.20	2.05
	SDL-7	MDL-5	0.70	0.80	1.00				0.025	0.75	2.37	1.60	1.74	1.12
	SDL-8	MDL-3				0.70	0.30		0.016	0.21	1.30	4.00	5.45	2.13
	SDL-9	MDL-5						0.80	0.013	0.50	2.51	1.90	4.14	2.71

Table 4. 6: Existing and Rational method of discharge resulted

Location Kebele	Main-Line ID	Existing condition Discharge(m^3/s)	Rational method Discharged(m^3/s)
G/Mariam	*MDL-1*	1.28	2.63
	MDL-2	1.70	1.00
	MDL-3	2.01	1.53
	MDL-4	1.48	2.20
	MDL-5	1.78	1.11
	MDL-6	2.34	1.26
	MDL-7	2.36	1.40
	MDL-8	3.29	1.25
	MDL-9	3.60	0.77
	MDL-10	4.97	0.96
Kuter-2	*MDL-1*	2.40	0.96
	MDL-2	2.40	0.88
	MDL-3	2.40	0.72
	MDL-4	1.43	0.95
	MDL-5	1.78	0.58
	MDL-6	1.58	0.86
	MDL-7	0.90	0.58
	MDL-8	0.82	0.49
Edida	*MDL-1*	1.67	0.73
	MDL-2	1.74	0.79
	MDL-3	1.74	0.84
	MDL-4	1.70	0.46
	MDL-5	1.00	0.38

Based on the hydraulic calculation the existing drainage structure capacity were checked and presented in (Table 4.4) to compare the peak discharge for each existing catchment by used empirical equations (rational method) as described in the methodology part.

The existing main storm drainage system has adequate capacity to carry the design flood but due improper connection and poor waste management almost all of the drain systems are un-factional. In addition to this the design storm of current rainfall data, the designed capacity was able to meet the runoff inflow without significant risk for surcharge or flooding. But there was flooding problem due to clogging of the drainage line by different waste material.

4.5 Rainfall Frequency Analysis

The rainfall frequency analysis is done using Normal, log normal, Log Pearson-III and Gumbel's methods as recommended by ERA manual 2013. The result is tabulated in (Table 4. 7)

Table 4. 7: Yearly Extreme series frequency analysis

Return Period	Extreme Rainfall depth (mm)			
	Normal	Lognormal	Log Pearson type -III	Gumbel
2	73.13	71.74	72.76	69.03
5	91.27	89.69	81.97	91.03
10	100.97	101.07	99.98	105.60
25	111.17	114.58	111.03	124.00
50	118.79	125.84	118.45	137.65
100	123.68	133.64	125.26	151.21

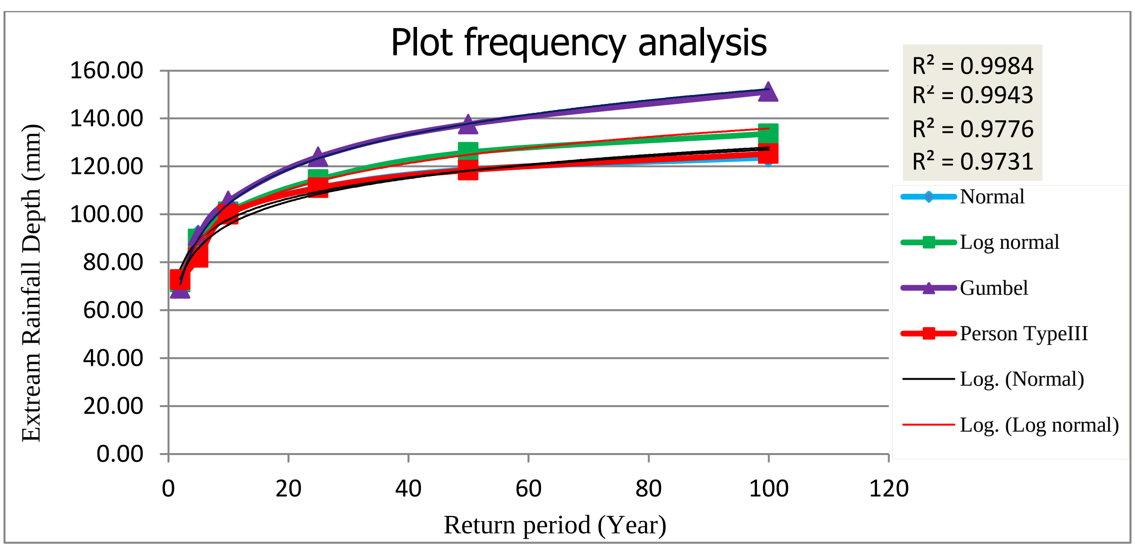

Figure 4. 4: Plot of frequency analysis result

In order to identify which distribution fits to the theoretical probability distribution, goodness of fit test (GOF) conducted using Easy Fit 5.6 professional software and the Gumbel distribution fits for the statistical value for all the three different test methods is lesser than that of the normal, log normal, and log Pearson-III values as tabulated in (Table 4.8).

That is, Gumbel's method have proved to be good fit in all the three tests compared to the normal, log normal, and log Pearson-III method. Accordingly, the Gumbel's method is chosen for further analysis. The statistics for all methods are calculated in (Table 4.8) below.

Table 4. 8: Goodness of Fit for Normal, Log normal, Pearson-type III and Gumbel's methods

Distribution	Kolmogorov-Smirnov		Anderson Darling		Chi-Squared	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
Gumbel	0.05695	1	0.24700	1	1.1240	1
Normal	0.06925	2	0.37496	4	1.3617	2
Log - Pearson III	0.06937	3	0.34186	2	1.3618	3
Log-normal	0.07316	4	0.34187	3	1.3619	4

Table 4. 9: Gumbel's Methods daily heaviest rainfall analysis for Gelgel Beles town

RT	Xave	$(\delta n - 1)$	Yn	Sn	YT	KT	$XT = X_{ave} + (KT * \delta n - 1)$
	71.083	20.94	0.538	1.1193			
2					0.367	-0.153	69.03
5					1.500	0.859	91.03
10					2.250	1.530	105.60
25					3.199	2.377	124.00
50					3.902	3.005	137.65
100					4.600	3.629	151.21

From frequency analysis Gumbel's methods have better R^2 =0.9984 values and gives satisfactory results for the three statics. Therefore, both methods show that the Gumbel's methods distribution fits with the rainfall data used for this study. Accordingly, the Gumbel's methods are chosen for further analysis.

4.6 Intensity – Duration – Frequency Curves

IDF curves are obtained through frequency analysis of rainfall observations. The IDF curve is developed from 24-hour rainfall data of 32 years (i.e. 1989 to 2020), obtained from Ethiopian meteorological agency. Data from rainfall measurements, for every year of record, determine the annual maximum rainfall intensity for specific durations (or the annual maximum rainfall depth over the specific durations). Common durations for design applications are: 5-min, 10-min, 15-min, 30-min, 1-hr, 2-hr, 6-hr, 12-hr, and 24-hr of shorter duration were used.

The IDF curve developed by ERA under rainfall region A2 and the new developed by different distribution method checked by the goodness of fit tests and Gumbel method were fit

Table 4. 10: Extreme RF (mm) for Gelgel Beles town Vs ERA rainfall depth for -A_2.

Return period (Year) VS Rainfall Depth(mm)						
PD	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
Normal	73.13	91.27	100.97	111.17	118.79	123.68
Log-normal	71.74	89.69	101.07	114.58	125.84	133.64
Person Type III	72.76	81.97	99.98	111.03	118.45	125.26
Gumbel (EVI)	69.03	91.03	105.6	124	137.65	151.21
ERA (XT)	**51.92**	**65.52**	**74.45**	**85.7**	**94.07**	**102.45**

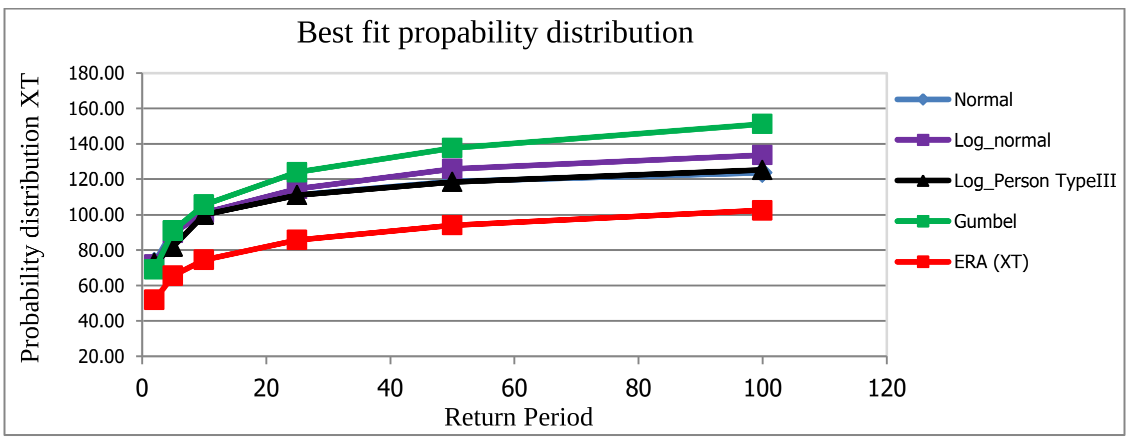

Figure 4. 5: Graph best fit frequency distributions function Compare with ERA distribution

Table 4. 11: Regions having similar flood frequency relationships

Return Period	24 hr Rainfall Depth(mm)Vs Frequency(Yr)							
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	200-Year	500-Year
RR-A1	50.30	66.02	76.28	89.13	98.63	108.06	117.48	130.00
RR-A2	**51.92**	**65.52**	**74.45**	**85.70**	**94.07**	**102.45**	**110.91**	**122.27**
RR-A3	47.54	59.61	67.66	77.92	85.62	93.34	101.13	111.58
RR-A4	50.39	63.83	72.28	82.55	89.97	97.20	104.32	113.63
RR-B1	58.87	71.26	79.29	89.35	96.84	104.37	112.02	122.41
RR-B2	55.26	69.95	79.68	92.03	101.29	110.61	120.07	132.87
RR-C	56.52	71.04	80.54	92.52	101.48	110.50	119.66	132.06
RR-D	56.23	76.84	90.37	107.46	120.23	133.05	146.00	163.44

Note: RR- Rainfall Region

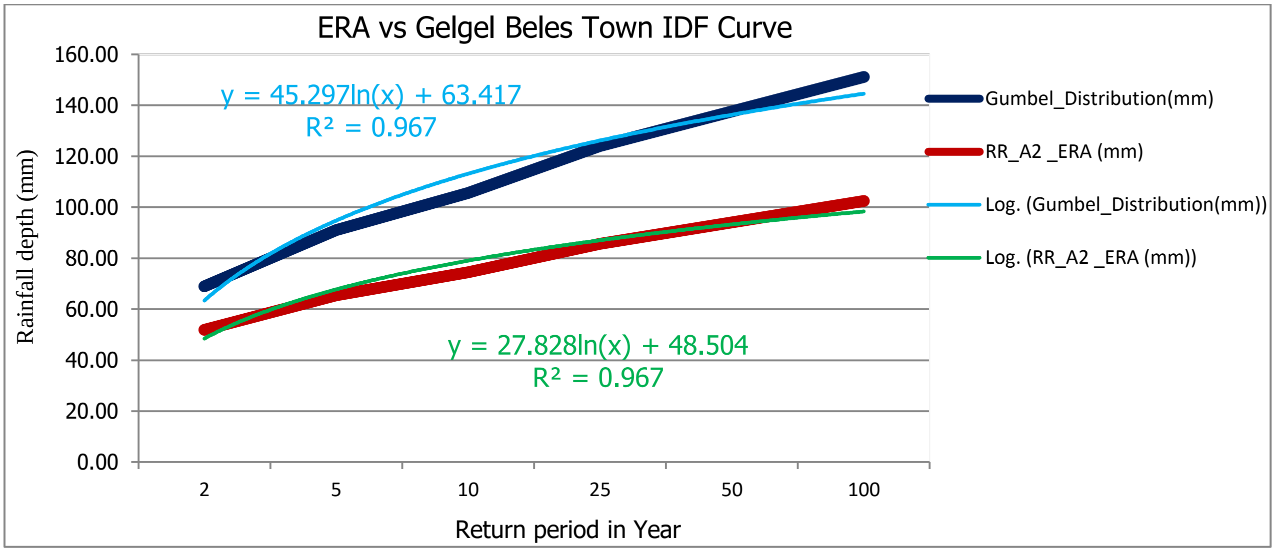

Figure 4. 6: Compared of Gelgel Beles town IDF Curve with ERA

From (Figure 4.4) the IDF curve developed by ERA under rainfall region A2, has R^2 = 0.967 and the new IDF Curve developed for Gelgel Beles town by different distribution method checked by the goodness of fit tests that has R^2= 0.967 more suitable than ERA IDF curve. Therefore from result tested used the new IDF curve developed by Gumbel probability distribution where that best fit for IDF Curve of Gelgel Beles town drainage systems sustainable management of study area.

Appropriate reduction equation as described in the methodology section has been applied. For this thesis calculated IDF curve for specific study area (Gelgel Beles town) is not applicable, so, it is difficult to comparison of the result found from this study and IDF curve developed by ERA for different rainfall region. Gelgel Beles town is actually found in region of A2. But the data ranges are different to develop IDF curves for the study area because of the data for this study is currently compared with ERA was used to develop IDF curve for the station. The data obtained for production of IDF curve is the result of calculations using reduction formula and it is tabulated in (Table 4.12). Even though data ranges of this analysis and the authorities are not the same, the IDF curve developed by ERA is presented in (Figure 4.8) for comparison.

Table 4. 12: IDF developing for different duration for given return periods by Gumbel

Duration(mint)	T(year)	2-year	5-year	10-year	25-year	50-year	100-year
	R 24 =	**69.03**	**91.03**	**105.6**	**124**	**137.65**	**151.21**
5		130.83	172.52	200.13	235.01	260.87	286.57
10		109.17	143.96	167.00	196.10	217.69	239.13
15		93.85	123.76	143.57	168.59	187.15	205.59
20		82.43	108.70	126.10	148.07	164.37	180.56
30		66.49	87.68	101.71	119.43	132.58	145.64
60		42.54	56.09	65.07	76.41	84.82	93.17
90		31.53	41.58	48.23	56.64	62.87	69.07
120		25.16	33.18	38.50	45.20	50.18	55.12
130		23.60	31.12	36.10	42.39	47.05	51.69
140		22.22	29.30	33.99	39.91	44.31	48.67
160		19.91	26.26	30.46	35.77	39.70	43.62
180		18.05	23.81	27.62	32.43	36.00	39.55

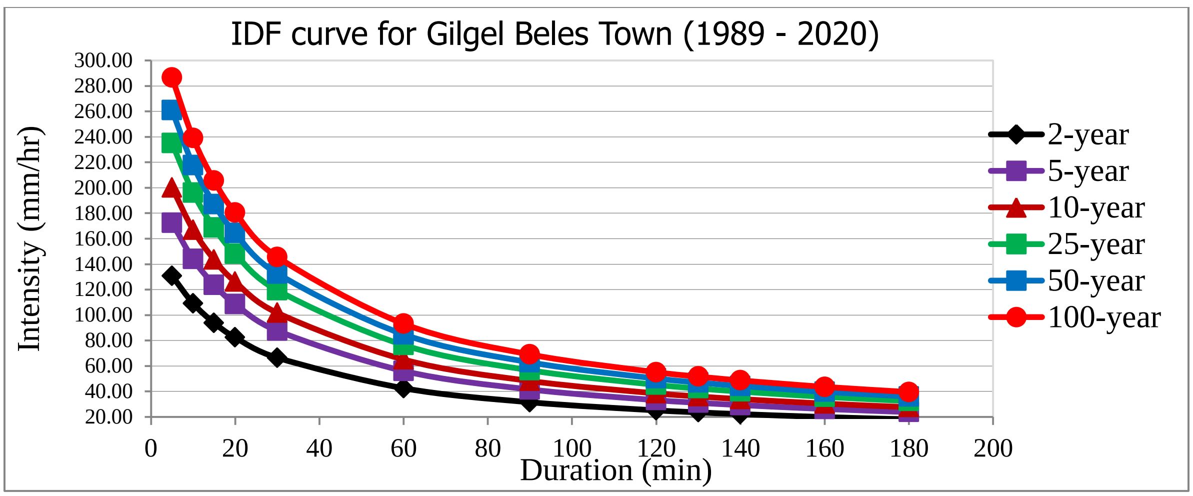

Figure 4. 7: IDF curve developed for Gelgel Beles town (1989-2020)

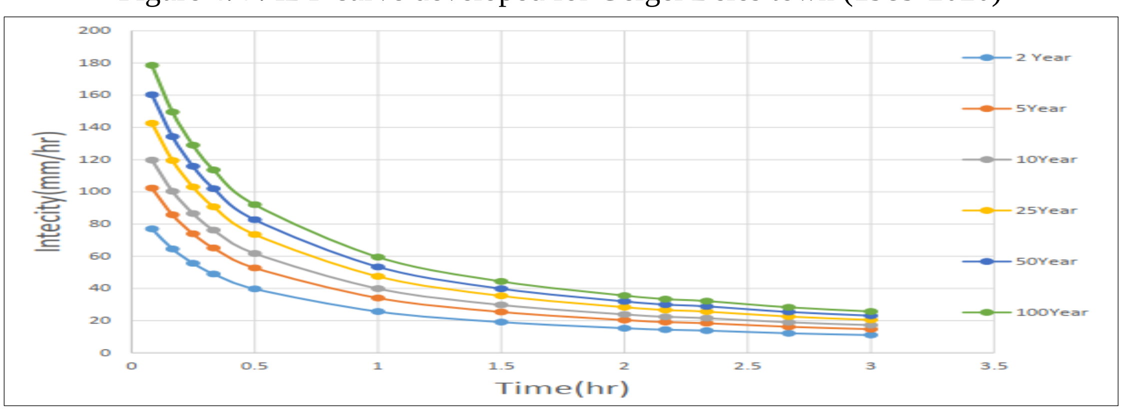

Figure 4. 8: IDF Curve developed for Rainfall Region A2 by ERA

Table 4. 13: Comparison of ERA IDF results with IDF develop by this study for station

T(min)	10		30		60		90		120	
ARI (yrs)	This study IDF (mm/hr)	ERA IDF (mm/hr)	This study IDF (mm/hr)	ERA IDF (mm/hr)	This study IDF (mm/hr)	ERA IDF (mm/hr)	This study IDF (mm/hr)	ERA IDF (mm/hr)	This study IDF (mm/hr)	ERA IDF (mm/hr)
2	109.17	72.58	66.5	40.32	42.54	26.74	31.53	20.11	25.16	18.75
5	143.96	104.42	87.6	55.88	56.09	37.52	41.58	28.61	33.18	24.33
10	167	122.19	101.7	62.22	65.07	40.29	48.23	35.55	38.5	24.16
25	196.1	158.91	119.4	77.2	76.41	49.9	56.64	38.33	45.2	33.85
50	217.69	171.76	132.5	84.48	84.82	54.4	62.87	39.56	50.18	36.55
100	239.13	188.32	145.6	92.54	93.17	59.51	69.07	45.7	55.12	38.71

The comparison results has large difference this is because the rainfall data used for developing IDF curve for Gelgel Beles town is from 1989 to 2020 and the other reason is ERA develop IDF curve for (2001) for different station. So, the rainfall intensity for study area at 10 years of 5-minute duration is 200.13 mm/hr and for 180-minute duration 27.62 mm/hr and the rainfall intensity of 25 years of 5-minute duration 235.01 mm/hr and for 180-minute duration 32.43 mm/h which is too much larger than ERA developed for A2 station. It would be said that the use of IDF curve developed in this study is safe with regard to design purposes but it could be uneconomical when it compared to ERA.

4.7 Questionnaire preparation

To collect baseline information about UDS of Gelgel Beles town, we communicated with community living in the town and a critical review was conducted very carefully on the available literatures both in published and unpublished sources. Then a reconnaissance empirical field survey was conducted to observe current drainage situation of Gelgel Beles town. Based on gathered experiences from reconnaissance survey, a semi-structured questionnaire was designed.

4.7.1 Questionnaire survey and data collection

Simple random sampling method was followed to conduct questionnaire survey in the study area. From each ward, 100 persons were randomly selected to survey questionnaire. A total of 300 questionnaires were surveyed amongst 300 respondents in the study area. Further, several research tools were used to collect field level data and experience of city dwellers namely; direct field observation, oral interviews, and group discussions. In addition, interviews and group discussions were also arranged with the concerned people to collect original data.

Table 4. 14: Location area of surveyed respondents in Gelgel Beles town

No	A sample is taken from	Respondent's number	Percentage (%)
1	G/Mariam Kebele	100	33.33
2	Kuter-2 Kebele	100	33.33
3	Edida Kebele	100	33.33
Total		300	100%

4.7.2 Data analysis for questionnaire survey

The collected data from field survey was compiled in MS-Excel sheet and then made re-arrangement according to questionnaire survey and personal observations. Later, all data was analyzed by using MS-Excel sheet (version: 2019) for creating required graphs and statistical analysis (e.g., average mean, standard deviation, & simple correlation).

Table 4. 15: Respondent's response on shape types of drainage system of study area

Types of Drainage Existed	G/Mariam Kebele	Kuter-2 Kebele	Edida Kebele
Trapezoidal	123	102	75
Rectangular	117	93	90
Circular	120	108	72
No drainage coverage area	75	96	129

4.7.3 Respondent Response on Quality of present drainage system and problems

Infrastructure development and quality of present drainage system was not similar in of Gelgel Beles town. But it is important for sustainable environment and development to ensure safe life of city dwellers. Majority number of the existing drains within the study area are unclosed drainage system (i.e., 68%) while 32% are closed drainage system (Table 4 16). This indicates the more probability of pollution and public health risks associated with present drainage system.

Table 4. 16: Respondent Response on types of drainage system in study area

Types Drainage system	G/Mariam Kebele	Kuter-2 Kebele	Edida Kebele
Closed	96	60	24
Unclosed	204	240	276
Total	300	300	300

4.7.4 Present status and facilities of drainage system in Gelgel Beles town

The current status of constructed UDS in Gelgel Beles town is not at satisfactory level. The collected and observed data from field is presented in (Table 4.17). Here, four satisfactory levels were identified to determine the condition of existing drainage services within the study area based on performances and strength of drains. It was found that most of the drains condition were bad type (i.e., 44%), followed by 23% Worst, 22% bad, 21.3% good and 12% very good drainage condition respectively.

Table 4. 17; Present status and facilities of drainage system in study area

Types Drainage system	G/Mariam Kebele	Kuter-2 Kebele	Edida Kebele
Good	48	84	60
Very Good	24	36	48
Bad	132	120	144
Worst	96	60	48
Total	300	300	300

4.7.5 Respondent Response on Major Causes of Poor Drainage System

The method of analysis adopted to draw conclusion and recommendations are frequency, percentage and descriptive method. Based on respondent response, the main causes of poor drainage system in Gelgel Beles town was shown in (Table 4.18) below.

Table 4. 18: Respondent response on the Causes of Poor Drainage System in Study Area

Causes of Poor Drainage System	Yes	No	I don't know
Inadequate of maintenance by the government	189	33	78
Disposal of solid waste into the gutter by the individual	231	21	48
The drainage systems are not wide enough in the area	183	42	75
Government negligence	156	84	60
The drainage systems are not well integrated with road	186	33	81
Poor monitoring and evaluation of site for construction	234	27	39
Use of sub-standard material for construction	246	21	33
Lack of communication during the construction	231	*36*	33
Low level of technical how to construct drainage system	189	93	48
Poor funding from government for constructing new	198	63	39

The method of analysis adopted to draw conclusion and recommendations are frequency, percentage and descriptive method. The main causes of poor drainage system in Gelgel Beles town was shown in (Table 4.18) above. The use of substandard materials have the highest percentage of (82%) and was ranked as first most causes of poor drainage system, followed by poor monitoring and evaluation of site for construction and inadequate of maintenance by the government and individual with percentage (78%). Disposal of solid waste into the gutter by the individual was ranked third with percentage (77%). Poor funding from the contractor during the construction and government negligence was ranked least by percentage (63% and 52%) respectively.

4.7.6 Respondent Response on Effect of Poor Drainage System

Environmental and infrastructural implication due to poor drainage system like other problems, PDS has also created environmental and infrastructural complication in Gelgel Beles town. As shown in (Table 4.19), there is high environmental problem due to PDS at study area.

Table 4. 19: Respondent response on the Effect of Poor Drainage System in study area

Effect of Poor Drainage System In Urban Area	Yes	No	I don't know
It may lead to flash flooding of houses	255	18	29
It improve excess of soil erosion	144	66	120
Destruction of living homes	63	99	48
It can lead to distortion of aesthetic environment	165	33	72
It cause health problems	228	36	36
It can lead to water pollution and bad smell at the area	228	48	24
Destruction of infrastructural facilities such as road, gutter and houses	234	51	15
It can lead to deposition of debris into the gutter	240	30	30

From (Table 4.19) indicates the effect of poor drainage system in Gelgel Beles town. The table shows that poor drainage system may lead to house flooding and cause health problems with highest percentage of (*85*%) and (*80*%) respectively. Destruction of infrastructural facilities such as road, gutter and it cause health problems of by percentage (*78*% and *76*%) respectively. Distortion of aesthetic environment and It improve excess of soil erosion were ranked third with percentage of (*55*% and *48*%) respectively. In such a way, the existing PDS plays an extensive adverse effect on the overall environment and development of the study area as well as threat for its sustainability. The expected effects of climate change necessitate a change in the approach used to plan and design drainage infrastructure. The planning and designing of new drainage infrastructure should incorporate development features and sustainable UDS that provide multiple benefits.

4.8 Results from Field Observation and measurement

4.8.1 Coverage of the Drainage System in the Study Area

This section on storm water drainage begins by examining the performance of current drainage systems, coverage of the drainage system and evaluating the current conditions of the drainage system. This section gives information about how much percentages of the area is with and without storm water drainage system.

Table 4. 20: Coverage of drainage system in the study area

Coverage of Drainage System in the Study Area			
	G/Mariam kebele	kuter-2 kebele	Edida kebele
Total Area(ha)	428.95ha	368.69ha	322.35ha
Area with Drainage (ha)	55.15ha	42.74ha	29.89ha
Area without Drainage (ha)	373.8ha	325.95ha	292.46ha

Table 4. 21: Area covered with and without drainage in G/Mariam kebele

G/Mariam kebele	Area (ha)	Area in %
Area with Drainage (ha)	55.15	22.86%
Area without Drainage (ha)	373.8	77.14%

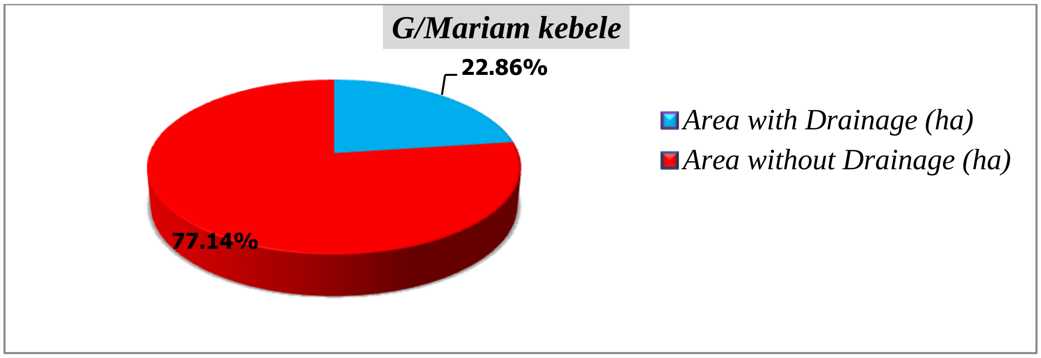

Figure 4. 9: Area covered with and without drainage in G/Mariam kebele

Table 4. 22: Area covered with and without drainage in kuter-2 kebele

kuter-2 kebele	Area(ha)	Area in %
Area with Drainage (ha)	42.74	23.10%
Area without Drainage (ha)	325.95	76.90%

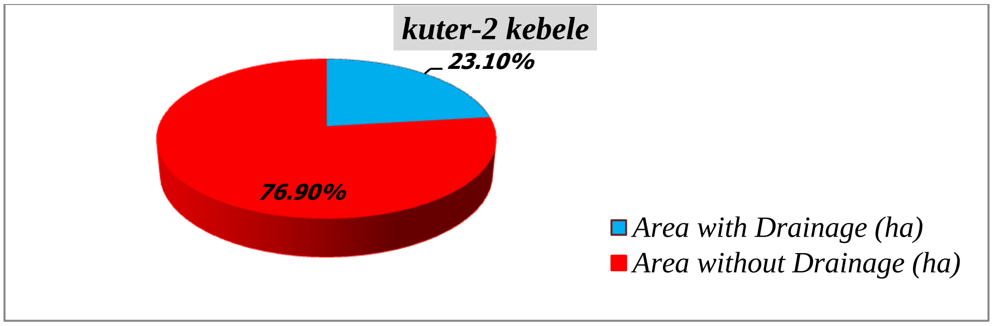

Figure 4. 10: Area covered with and without drainage in kuter-2 kebele

Table 4. 23: Area covered with and without drainage in Edida kebele

Edida kebele	Area(ha)	Area in %
Area with Drainage (ha)	29.89	19.28%
Area without Drainage (ha)	292.46	80.72%

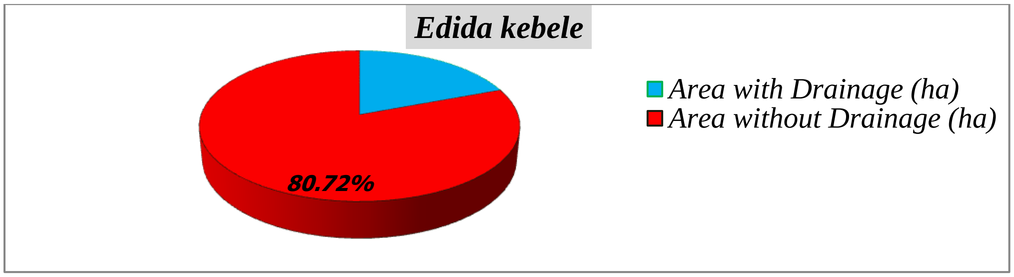

Figure 4. 11: Area covered with and without drainage in Edida kebele

Table 4. 24: Gelgel Beles town Urban Storm Water Drainage Condition

Drainage Pavement	Drainage Shape Type	Existing Condition	Percentage (%)	Percentage from Total (%)
Masonry, Earthen and Concrete	Rectangular	Good	18%	53%
		Bad	21%	
		Worst	14%	
	Trapezoidal	Good	8%	34%
		Bad	11%	
		Worst	15%	
	Circular	Good	7%	13%
		Bad	3%	
		Worst	3%	

Table 4. 25: Existing capacity of main draining catchment of Gelgel Beles town

Location Kebele	Main-Line ID	B (m)	Y (m)	P (m)	n (m/m)	S (m/m)	A (m2)	R (m)	V (m/s)	Q m^3/s
G/Mariam	*MDL-1*	0.75	0.30	1.35	0.013	0.055	0.23	0.17	0.17	1.28
	MDL-2	1.25	0.43	2.10	0.013	0.010	0.53	0.25	0.17	1.70
	MDL-3	1.25	0.43	2.10	0.013	0.014	0.53	0.25	0.20	2.01
	MDL-4	0.65	0.43	1.50	0.013	0.043	0.28	0.18	0.19	1.48
	MDL-5	1.25	0.43	2.10	0.013	0.011	0.53	0.25	0.18	1.78
	MDL-6	1.25	0.43	2.10	0.013	0.019	0.53	0.25	0.24	2.34
	MDL-7	0.70	0.55	1.79	0.013	0.047	0.38	0.21	0.26	2.36
	MDL-8	0.70	0.80	2.29	0.013	0.036	0.56	0.24	0.30	3.29
	MDL-9	0.72	1.38	3.47	0.013	0.011	0.99	0.29	0.23	3.60
	MDL-10	0.72	1.38	3.47	0.013	0.021	0.99	0.29	0.31	4.97
Kuter-2	*MDL-1*	1.25	0.43	2.10	0.013	0.020	0.53	0.25	0.24	2.40
	MDL-2	1.25	0.43	2.10	0.013	0.020	0.53	0.25	0.24	2.40
	MDL-3	1.25	0.43	2.10	0.013	0.020	0.53	0.25	0.24	2.40
	MDL-4	0.65	0.43	1.50	0.013	0.040	0.28	0.18	0.18	1.43
	MDL-5	1.25	0.43	2.10	0.013	0.011	0.53	0.25	0.18	1.78
	MDL-6	0.75	0.43	1.60	0.013	0.033	0.32	0.20	0.19	1.58
	MDL-7	0.72	0.43	1.57	0.013	0.012	0.31	0.19	0.11	0.90
	MDL-8	0.72	0.43	1.57	0.013	0.010	0.31	0.19	0.10	0.82
Edida	*MDL-1*	0.77	0.43	1.82	0.013	0.040	0.33	0.18	0.17	1.67
	MDL-2	0.75	0.43	1.60	0.013	0.040	0.32	0.20	0.21	1.74
	MDL-3	0.75	0.43	1.60	0.013	0.040	0.32	0.20	0.21	1.74
	MDL-4	1.25	0.43	2.10	0.013	0.010	0.53	0.25	0.17	1.70
	MDL-5	0.72	0.50	1.71	0.013	0.010	0.36	0.21	0.12	1.00

Table 4. 26: Existing Sub-catchment line flow to main drainage catchment of Gelgel Beles town

Location	No	Direction	Trapezoidal			Rectangular		Circular						
	Sub-Line ID	Flow to	Bt (m)	Yt (m)	T (m)	Br (m)	Yr (m)	Dc (m)	n	A (m2)	P (m)	S %	V (m/s)	Q (m3/s)
G/Mariam Kebele	SDL-1	MDL-1				0.65	1.00		0.016	0.65	2.65	2.50	1.81	1.17
	SDL-2	MDL-1				0.40	0.60		0.016	0.24	1.60	2.00	1.00	0.24
	SDL-3	MDL-2	0.45	0.70	0.75				0.025	0.81	2.43	1.10	1.26	1.01
	SDL-4	MDL-3						0.60	0.013	0.79	3.14	2.90	4.20	2.05
	SDL-5	MDL-4	0.45	0.35	0.45				0.025	0.18	1.17	5.20	2.21	0.19
	SDL-6	MDL-5	0.50	0.70	0.80				0.025	0.45	1.93	2.30	1.44	0.65
	SDL-7	MDL-6				0.30	0.40		0.06	0.12	1.10	5.30	1.31	0.16
	SDL-8	MDL-7				0.45	0.60		0.016	0.27	1.65	6.50	1.91	0.52
	SDL-9	MDL-8				0.20	0.40		0.016	0.08	1.00	1.20	0.69	0.06
	SDL-10	MDL-9	0.70	0.80	1.00				0.025	0.75	2.37	1.60	1.74	1.11
	SDL-11	MDL-10	0.40	0.80	1.00				0.025	0.52	2.08	2.80	1.67	0.87
	SDL-12	MDL-3						0.80	0.013	0.50	2.51	2.00	1.73	0.87
	SDL-13	MDL-4				0.70	0.70		0.016	0.49	2.10	2.00	1.68	0.82
	SDL-14	MDL-10				1.25	0.55		0.016	0.69	2.35	5.50	3.23	2.22
Kuter-2 Kebele	SDL-1	MDL-1	0.50	0.30	0.70				0.025	0.24	1.35	5.00	1.77	0.42
	SDL-2	MDL-2	0.40	0.20	0.50				0.025	0.09	0.81	6.80	1.50	0.14
	SDL-3	MDL-3						0.80	0.013	0.50	2.51	1.90	4.14	2.71
	SDL-4	MDL-1				0.60	0.40		0.016	0.24	1.40	1.00	3.91	2.19
	SDL-5	MDL-4				0.70	0.30		0.016	0.21	1.30	4.00	5.45	2.13
	SDL-6	MDL-5				0.60	0.50		0.016	0.30	1.60	2.00	2.14	2.87
	SDL-7	MDL-6				1.30	0.50		0.016	0.65	2.30	2.10	2.19	2.52
	SDL-8	MDL-7						0.80	0.013	0.50	2.51	1.90	4.14	2.71
	SDL-9	MDL-8				1.55	0.55		0.016	0.69	2.35	1.40	1.63	1.13
	SDL-10	MDL-2						0.80	0.013	0.50	2.51	1.90	4.14	2.71
	SDL-11	MDL-8	0.70	0.80	1.00				0.025	0.75	2.37	1.60	1.74	1.12
Edida Kebele	SDL-1	MDL-1				1.30	0.50		0.016	0.65	2.30	2.10	2.19	2.52
	SDL-2	MDL-2				0.40	0.60		0.016	0.24	1.60	2.00	1.02	0.24
	SDL-3	MDL-1						0.80	0.013	0.50	2.51	1.90	4.14	2.71

	SDL-4	MDL-2				0.60	0.50		0.016	0.30	1.60	2.00	2.14	2.87
	SDL-5	MDL-3				1.25	0.40		0.016	0.50	2.05	1.00		2.59
	SDL-6	MDL-4						0.60	0.013	0.79	3.14	2.90	4.20	2.05
	SDL-7	MDL-5	0.70	0.80	1.00				0.025	0.75	2.37	1.60	1.74	1.12
	SDL-8	MDL-3				0.70	0.30		0.016	0.21	1.30	4.00	5.45	2.13
	SDL-9	MDL-5						0.80	0.013	0.50	2.51	1.90	4.14	2.71

4.9 Current Situation of Existing Drainage System in the Study Area

From the result of a field survey and visit, drainage service in the town was inadequate in terms of quality and coverage. Currently, the storm water drainage management of the town is not efficient as a result of managing problems. Drainage systems are not well connected; are do not as have the capacity to carry large amounts of water, hence resulting in overflowing. In some areas, drainage systems were not provided, and almost all the drainage structures in the town, especially the open ditches are filled with a dry waste. Especially the great problem in the study area was lack of waste management techniques (like manholes and trash bin). In the case of Gelgel Beles town, the existed manholes were out of service and have been clogged with waste and blocked due to lack of clearance. Additionally, at different places, they were not constructed. From the total drains about almost all of the drainage lines is severely degraded and very little in coverage. This is due to inadequate attention to these drainage systems, misuse of the systems and there is no proper schedule for maintenance and clearance to maintain damaged drains before they became out of use.

Figure 4. 12: Current Situation of Existing Drainage System in the Study Area

The connection does not fit the criteria of sustainable and efficient drainage network, since there is no connection between minor and major drainage structure. The town's drainage network is almost all in a poor condition. In addition to this there is the destruction of some drainage structures along the road side due to improper alignment between road and drainage system. The destruction lessens the capacity of the drainage channel and lets the road to be flooded during rainy days. Most of the drainage structures are suddenly detached from the major drainage due to design problem and excess runoff generation over it

4.9.1 Performance Assessment of existing drainage system of the study area

Urban storm water drainages are designed based on different criteria so that they can give better services regarding to safely removing (neither siltation nor scouring) the urban runoff in to the water ways. Apart from field visits and survey reveals that there are different challenges which makes the process of disposing runoff through drainage channel in to water ways made difficulties in this area.

4.9.2 Effects of poor drainage system in line with road network

Road users were in consensus when it came to the effects of the poor drainage system on the road. Majority reported that the causes and effects of poor drainage on the road are water leaves debris on the road surface during the rains there by hindering free movements of vehicles on the road. It also washed away the asphalts during the rainy season, therefore totally making it impossible the passage of the road.

A significant proportion reported that runoffs on the road block and cracking the through the road and leave debris on the road after the rains; this debris would then hinder movement along the road and therefore inconvenience travelers.

The major causes of flooding as the blockage of urban storm water drainage lines along with inadequate/poor integration between road and urban storm water drainage infrastructures. In addition, with urbanization, impermeability increases with the increase in impervious surfaces (i.e. residential houses, commercial buildings, paved roads, etc.), drainage pattern changes, the overland flow gets faster flooding and environmental problems like land degradation increases. It is a crucial problem facing the existing and future road infrastructure. This suggests that it is important to perform operations such as maintenance and cleaning regularly to prevent over flooding of the water on the road.

4.9.3 Dumping of solid and liquid wastes in to storm water drainages

Dumping solid waste materials in to drainages and streams is the other challenge of storm water drainage system. Urban litter (alternatively called trash, debris, junk, floatables, gross pollutants, rubbish or solid waste) has become a major problem in this area. Typically, it consists of manufactured materials such as bottles, cans, plastic and paper wrappings, newspapers, shopping bags, cigarette packets and remains of chat. As a result of damping these solid wastes in to drains the drainage system has been clogged and causes flooding over streets and walk ways. As a result the runoff that is generated in that sub basin over flows with higher velocity which erodes the ditches as well as the road and walk ways. Most of the drainage lines in town accommodate as waste disposal and blocked by liquid and solid wastes.

Figure 4. 13: Dumping of solid and liquid wastes in to storm water drainages

Storm water management in urban area generally calls for participation of all stakeholders that include government, community and scholars. There should be enforcement by law for any waste dumping in open ditch. Different community outreach programs need to be designed so as to raise community awareness in sharing responsibility in their locality. The community should be responsible in keeping cleanness of all open ditches in the town by avoiding dumping of wastes in to it while municipality is responsible in temporal cleaning of the wastes occurred due erosion and some different natural cases, otherwise it will be very difficult to ensure environmental health and related hazards.

4.9.4 Destructed and detached, drainage structure

Majority of infrastructure development in Gelgel Beles town have less concern to the drainage system as result of unplanned and indiscriminate urbanization.

For example, housing construction, water supply lines and telephone line installation and expansion have been damaging drainage lines. The connection does not fit the criteria of sustainable and efficient drainage network, since there is no proper connection between minor and major drainage structure.

In addition to this there is the destruction of some drainage structures along the road side due to improper alignment between road and drainage system. The destruction lessens the capacity of the drainage channel and lets the road to be flooded during rainy days. Most of the drainage structures are suddenly detached from the major drainage due to poor design problem and most of the time after the construction they didn't care enough to maintain what they damage.

Figure 4. 14: Destructed and detached, drainage structure

4.9.5 Absence of regular clearance of drainage system

Concerning drainage infrastructure provision the main problems associated are like poor coordination and integration among stakeholders. Due to lack of f clearance storm water drainage lines they have become out of services. Sediment load, solid wastes blocked most of the drainage system. Urban litter (alternatively called trash, debris, junk, floatables, gross pollutants, rubbish or solid waste) has become a major problem through the town. It typically consists of manufactured materials such as bottles, cans, plastic and paper wrappings, newspapers, shopping bags, cigarette packets and remains of chat.

The major causes of inadequacy of present drainage systems in Gelgel Beles town is a result of inadequacy due to poor design, poor construction & absence of regular clearance for existed drainage channels. Sediment load, solid wastes blocked most of the drainage system.

So without scheduled clearance the service life of those ditches could be out of their life span. So, lack of proper maintenance are the prime causes of blockage in drainage system that will result that will result flash flooding at on the area.

Figure 4. 15: Absence of regular clearance of drainage system

4.10 Over all Challenges of Drainage Problems Gelgel Beles Town

The identified challenges can be grouped as planning, design and construction, monitoring and evaluation, collaboration and regulatory challenges, as discussed (Table 4.18) above.

4.10.1 Planning Challenges

The process of drains planning is not led by a master plan, as Gelgel Beles town has no city-wide storm water network master plan. Consequently, drains planning are based on traditional and fragmented approaches. The option of integrating other sustainable storm water management systems (e.g. rainwater harvesting, retention and detention based solutions) is absent. Moreover, Gelgel Beles town has no integrated planning approaches from the context of storm water management. For example, integrating storm water management with urban land-use planning, GI development and other landscape plans is absent at any level. The components of urban water (water supply, waste water & storm water) managed separately by separate institutions. Landscape and urban planning instruments therefore don't offer possibilities to integrate storm water management concerns and to promote sustainable storm water management on a range of spatial scales.

4.10.2 Design and Construction Challenges

Based on field survey and questionnaires response, the design of drains in Gelgel Beles town is carried out through segmental or fragmented approaches resulting in flash flooding. It was found that drains are usually designed without hydraulic and hydrologic analysis.

Most of the drains were found to be older. The largest parts of the drains especially in the older parts of the city were old and found filled with solid and liquid waste resulting in flash flooding. Moreover, the respondents' reported that the designers are less experienced to design drains due to inadequate exposure to such practices.

4.10.3 Monitoring and Evaluation Challenges

Drains are commonly provided by Benishangule gumuze regional government, but regarding monitoring and evaluation the city has no responsible institution to solve the problems. This shows that the city focuses only on provision than on the management of the provided drains and associated facilities. Moreover, no monitoring and evaluation on the hydraulic performance and need of storm water management facilities. Responsive measures are taken mainly based on complaints. It was also investigated that the number of studies in Gelgel Beles town related to storm water was not done which become a challenge to know the status and operation condition of drains.

4.10.4 Teamwork Challenges

The present study focus on performance assessment of storm water drainage system of Gelgel Beles town at three kebele, (G/Mariam Kebele, Kuter-2 Kebele and Edida Kebele) which are assumed to work with the city's storm water have no collaboration, creating redundancy of activities and resources, no clear roles and responsibilities, and no defined activity performed by each of the kebele administration regarding storm water management. Subsequently, sustainability in storm water management is unlikely due to the absence of monitoring and evaluation. These kebele administrations have no integrated plans.

4.10.5 Regulatory Challenges

The present study shown that demolished of construction materials were dumped inside drains and on flood plains, reducing the hydraulic capacity of drains & river through obstruction and silting up. Besides, liquid waste problems, dumping of wastes from repairing and throw directly into drains, blocking the hydraulic capacity of drains. The absence of legal instruments (or policies) to manage storm water at household, institutions and commercial levels represent additional storm water management challenge. Every one collects & conveys storm water from own compound to anywhere else without borders.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

According to the result of this thesis the existing drainage system has extensive defects and requires immediate rehabilitation or reconstruction, and also maintaining major drainage works. There is inadequate and low coverage of drainage system coupled with poor physical condition and ineffectiveness of drainage system development in the town. The current conditions of hydraulic calculation are performed and evaluated by collected the data of existing storm water drainage structure using field survey. The width and depth of channel are measured data based on the geometry of the channel by using tape meter measurement and slope from topographic map of town, then by using the measured values the existing condition of the drainage channel was computed and the design capacity of the drainage catchments of the town was calculated by taking the intensity for 25 year return period from the IDF and was determined by rational formula. The existing main storm drainage system has adequate capacity to carry the design flood but due improper connection and poor waste management almost all of the drain systems are un-factional. In addition to this the design storm of current rainfall data, the designed capacity was able to meet the runoff inflow without significant risk for surcharge or flooding. The design capacity of the drainage channel was determined for hydraulic and hydrologic case to estimate the total peak runoff to the town generated by main and sub drainage catchment respectively. This peak discharge is estimated based on the present existing land use land cover condition. The future land use land cover condition determines whether this discharge size increase, decrease or remain as it is. Therefore, any design modification for the drainage system or the road must consider the future land use land cover situation. After analyzing the results, the following conclusions were drawn:

From the analysis made it is concluded that limitation in hydrologic and hydraulic design studies along most economic channel section selection, construction and waste disposal and management potentially corroborated the inadequacy of the storm drainage canals. Road and urban drainage infrastructure provision are indispensable in an urban center for safe and easy reachability from one area to another and to protect flood damage on urban infrastructure and utilities as a result of pavement or imperviousness.

The integration of road and urban drainage lines have critically surveyed for the three kebele and found that there is inadequate integration between road and urban drainage lines. Most of the construction sites including housing construction, water supply lines, electric lines and telephone lines installation do not consider the effect of such infrastructure and utility development on the general environment.

As result of this existing capacity of main draining catchment of town of G/Mariam Kebele (*MDL-2, MDL-3, MDL-5, MDL-6, MDL-8, MDL-9 and MDL-10*) and Existing capacity of main draining catchment the town at Kuter-2 and Edida Kebele at (*MDL-1, MDL-2, MDL-3, MDL-4, MDL-5, MDL-6, MDL-7 and MDL-8*) are mostly safe in case of capacity to deliver the incoming runoff water but as result of poor design and construction problem they become over flooded during rainfall occurred. Almost 80% the main and sub catchment line in the town are filled with solid waste and the use of poor quality during construction of system highly made the main and sub line to be easily detached other.

The existing urban drainage lines or infrastructure could not accommodate or safely discharge in to the final receiving system. Generally, the performances of these storm water drainages were not satisfactory. Therefore, it is recognized that its capacity has shown lower results which needs some adjustment or improvement to give the best service, and needs a serious of regular maintenance and also provide drainage networking for the areas without drainage systems for its complete service.

5.2 Recommendation

In order to improve the problems that has been hindering the drainage systems in this study area, the following recommendations are made for better and sustainable urban storm water drainage system.

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 organizations must record such significant data. Regulating hydrologic and hydraulic investigation for future modification situations is very important to safeguard safe drainage structures function for the long-term perspective. The expected change in the future rainfall patterns and the need for more urban areas are challenging the Gelgel Beles town.

Provision of proper connections or integrations between the road network and drainage network is required with regular maintenance and redesign.

Applicable design method which depends on the catchment area, variability of climate, future settlement of people, expansion of urbanization and other factors shall be taken into account during the detail design of the drainage facilities so as the structures capacity shall accommodate the design flood that will help in controlling un collected urbanization pattern. Future expansion plan of the city should be done by take in to account identified locations for storm water management, like flood control locations to apply the techniques by designing the detention and retention basins. Supervision of drainage canals during construction should be required to avoid challenges are associated with planning, design and construction, monitoring and evaluation, and regulatory issues. As seen from hydrologic and hydraulic calculation for the storm drainage line the result of peak discharge using rational method at G/Mariam Kebele at (MDL-1 and MDL-4) has no enough size to uphold the incoming flood. So, therefore to avoid this problem should be BMP recommended.

The existing ditches are opened ditches which may cause access difficulties and using usable areas, to control this problem they are proposed to be covered by concrete covers. Finally, for community creates awareness concerned the effects of disposing solid materials in to drainage facility by the municipality and other concerned body. For every individual, develop your plot with deep or wide drainage system. The environment remains our most valued legacy and possession which we must all strive to protect jealously.

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APPENDICES

Annex A: Annual maximum 24hr rainfall (mm) from Gilgel Beles meteorological center

No	Year	Max RF (mm)	Descending Order	Rank	Log (y)	New Mean (X)	Log (X)
1	1989	65.3	115.8	1	2.064	115.8	2.064
2	1990	79.8	108.2	2	2.034	108.2	2.034
3	1991	105.8	105.8	3	2.024	105.8	2.024
4	1992	115.8	105.5	4	2.023	105.5	2.023
5	1993	65.2	94.4	5	1.975	94.4	1.975
6	1994	23	90.8	6	1.958	90.8	1.958
7	1995	86.7	89.2	7	1.95	89.2	1.95
8	1996	58.2	88.7	8	1.948	88.7	1.948
9	1997	94.4	87.7	9	1.943	87.7	1.943
10	1998	108.2	86.7	10	1.938	86.7	1.938
11	1999	90.8	80.1	11	1.904	80.1	1.904
12	2000	105.5	79.8	12	1.902	79.8	1.902
13	2001	87.7	76.1	13	1.881	76.1	1.881
14	2002	53.8	72.4	14	1.86	72.4	1.86
15	2003	72.4	72.2	15	1.859	72.2	1.859
16	2004	72.2	71.8	16	1.856	71.8	1.856
17	2005	62.6	71.5	17	1.854	71.5	1.854
18	2006	88.7	70	18	1.845	70	1.845
19	2007	71.8	66.2	19	1.821	66.2	1.821
20	2008	70	65.4	20	1.816	65.4	1.816
21	2009	66.2	65.3	21	1.815	65.3	1.815
22	2010	56.6	65.2	22	1.814	65.2	1.814
23	2011	71.5	62.6	23	1.797	62.6	1.797
24	2012	89.2	60.5	24	1.782	60.5	1.782
25	2013	76.1	58.2	25	1.765	58.2	1.765
26	2014	60.5	56.6	26	1.753	56.6	1.753
27	2015	80.1	53.8	27	1.731	53.8	1.731
28	2016	65.4	52.3	28	1.719	52.3	1.719
29	2017	40.3	50.5	29	1.703	50.5	1.703
30	2018	50.5	40.3	30	1.605	40.3	1.605
31	2019	52.3	39	31	1.591	39	1.591
32	2020	63.5	23	32	1.114		
Mean			**72.36**		**1.833**	**74.28**	**1.856**
St dev			**21.72**		**0.172**	**19.231**	**0.116**
Skewness			**-0.254**		**-2.285**	**0.303**	**-0.326**

A. **Test for Higher outlier**

For data N=32, δn - 1=0.1724, X_{ave} = 1.833 and Kn=2.591

Higher outlier test YH= Yave + (Kn x $\delta n - 1$) = 1.833 + (2.591*0.1724) =2.279

Higher outlier test =10^{YH} = $10^{2.279}$ =190.23mm

The highest recorded value from meteorological station is (115.8mm) which was less than the higher outlier test (190.23mm). Therefore, no higher outlier data eliminated.

B. **Test for Lower outlier**

For data N=32, δn - 1=0.1724, X_{ave} = 1.833 and Kn=2.591

For lower outlier Y_L = $Y_{ave-(\partial n-1*Kn)}$ = 1.833 + (0.1724 x 2.591) =1.386

Lower outlier = 10^{YL} = Lower outlier = $10^{1.386}$ = 24.34mm

The lower recorded value from meteorological station is (23mm) which was less than the lower outlier test (24.34 mm). Therefore, the lowest value from recorded data (23mm) was excluded from the hydrological analysis.

C. **Checking Data Reliability**

For data size N = 32, mean (Xave) = 72.36 and standard deviation (∂n - 1) = 19.23

Standard error of mean (∂n - 1) = $\frac{21.72}{\sqrt{32}}$ =3.84

Relative Standard error = $\frac{3.84}{72.36}$x100 =5.31% < 10% hence the data series could be regarded as reliable and adequate.

D. **Precipitation gauge network**

The optimal number of rain gauge stations *N* required for a desired accuracy (or maximum error in per cent, ε) in the estimation of the mean rainfall. The optimal number of rain gauge stations N is calculated and standard deviation (δn -1) = 19.231, the depth of areal rainfall at Gilgel Beles meteorological gauge center is 0.07m for 32 years. CV is calculated to evaluate the variability of the rainfall. A higher value of CV is the indicator of larger variability, and vice versa which is computed as:

$$\mathbf{Cv = \frac{\delta}{\mu} x100}$$

Where CV is the coefficient of variation; σ is standard deviation and μ is the mean precipitation. According to (Addisu et al., 2015), CV is used to classify the degree of variability of rainfall events as less (CV< 20), moderate (20 < CV <30), and high (CV >30).

So, CV the coefficient of variation of the rainfall values at the existing m stations (in percent) is calculated as: $C_V = \frac{19.231}{74.28}$ x100 = 25.9 < 30. So, degree of variability of rainfall event is moderate. So, finally, to get the value of ε = 10% form design manual, the value of N is the number of rain gauge stations.

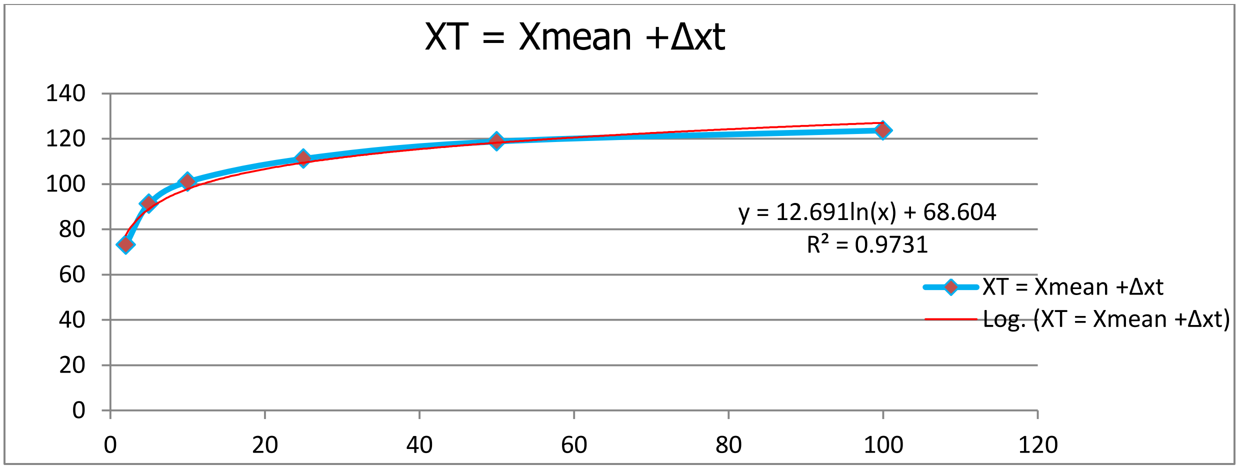
N = $[\frac{Cv}{\epsilon}]^2 = [\frac{25.9}{10}]^2$ = 6.71. So, the area needs additional 5 gaging station.

Annex B: Outlier test Kn value

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

Annex C: Yearly Extreme Series and Frequency Analysis Calculations using Normal Distribution

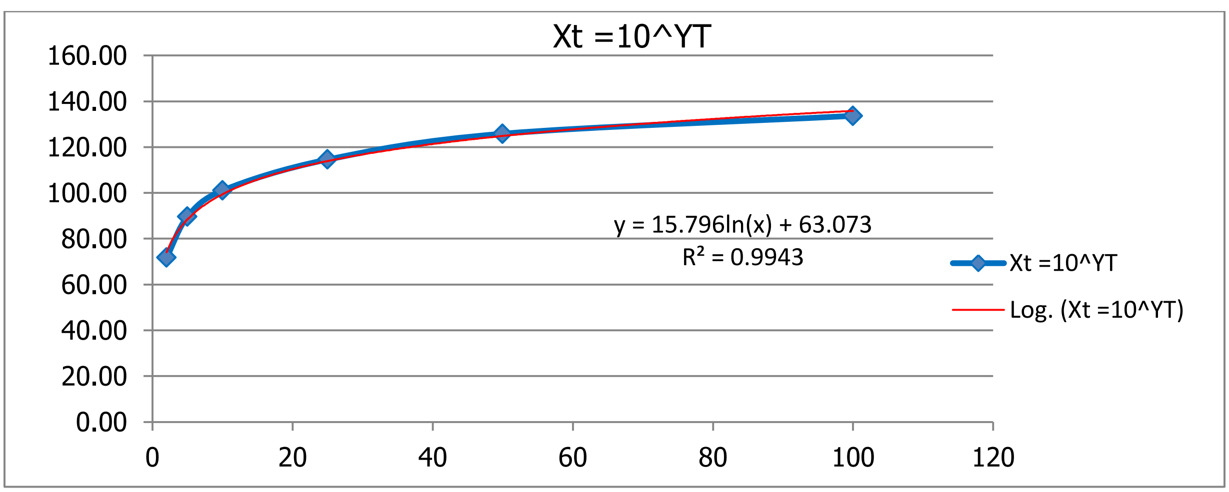
RT	[μ]	[∂n]	$P = \frac{1}{T}$	W	K_T =Z	ΔXT	[XT = μ + ΔXT]
	73.1281	**21.725**					
2			0.5	1.177	0.1^-5	0.9016	73.12812281
5			0.2	1.794	0.835	10.7602	91.27145096
10			0.1	2.146	1.282	27.1883	100.973143
25			0.04	2.537	1.751	36.0954	111.1695259
50			0.02	2.797	2.102	41.6569	118.7888917
100			0.01	3.035	2.327	46.5123	123.6765574



Annex D: Fitting distribution test by Normal Distribution Type

Annex E Yearly Extreme Series and Frequency Analysis Calculations using Log-Normal Distribution

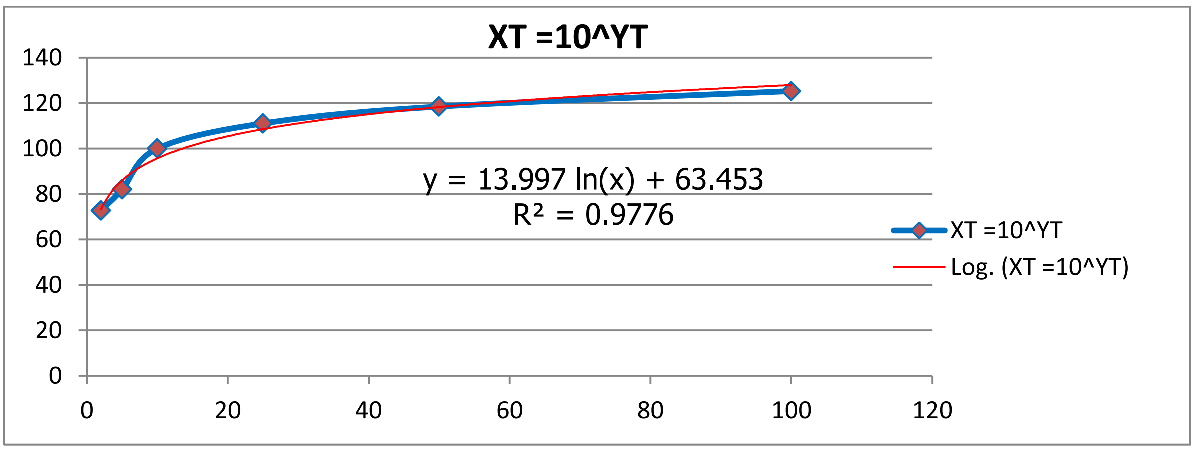
	R_T	Z	K	K_T	[YT = Yave + (Kt ∗ δn − 1)]	Xt =10^^{YT}
Y_{ave} =	2	-1E-07	-0.054	-1E-07	1.8558	71.74
1.85579	5	0.835	-0.054	0.835	1.9528	89.69
$\delta n - 1$	10	1.282	-0.054	1.282	2.0046	101.07
= 0.11611	25	1.751	-0.054	1.751	2.0591	114.58
Skewness	50	2.102	-0.054	2.102	2.0998	125.84
= - 0.326	100	2.327	-0.054	2.327	2.1259	133.64



Annex F Fitting distribution test by Log- Normal Distribution Type

Annex G: Yearly Extreme Series and Frequency Analysis Calculations Log Pearson type III Distribution

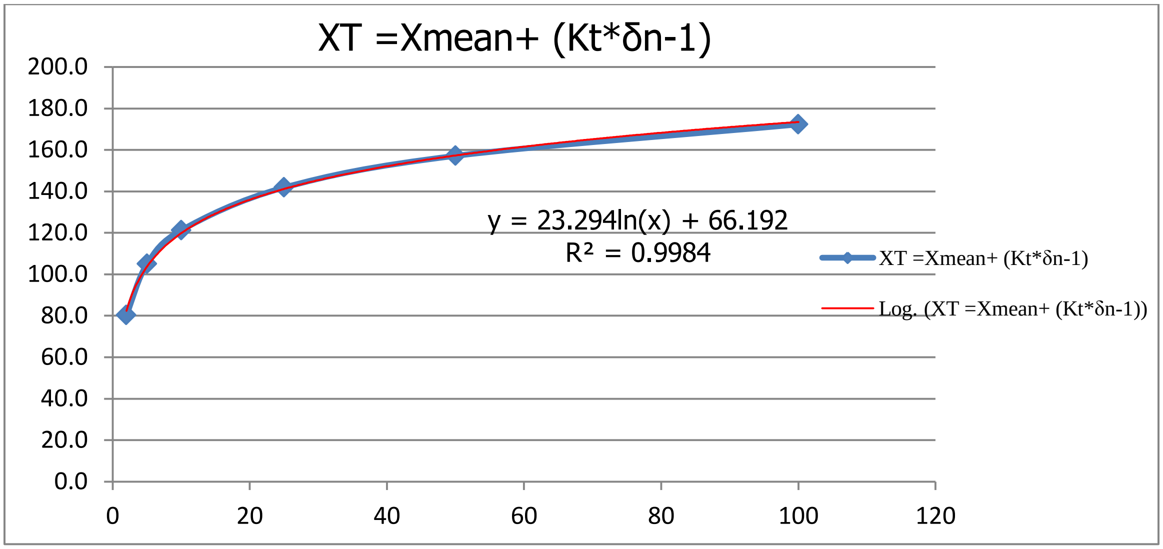
	RT	$P = \frac{1}{T}$	K_t	$YT = X_{ave} + (Kt + \delta n - 1)$	$X_T = 10^{\wedge YT}$
$\mathbf{Y_{ave}} = 1.856$	**2**	0.5	0.0526	1.862	72.76
	5	0.2	0.4984	1.914	81.97
$\boldsymbol{\delta n - 1} = 0.116$	**10**	0.1	1.2414	1.999	99.98
	25	0.04	1.6334	2.045	111.03
Skewness = 0.326	**50**	0.02	1.8754	2.074	118.45
	100	0.01	2.0845	2.098	125.26



Annex H Fitting distribution test by Log Pearson type III Distribution

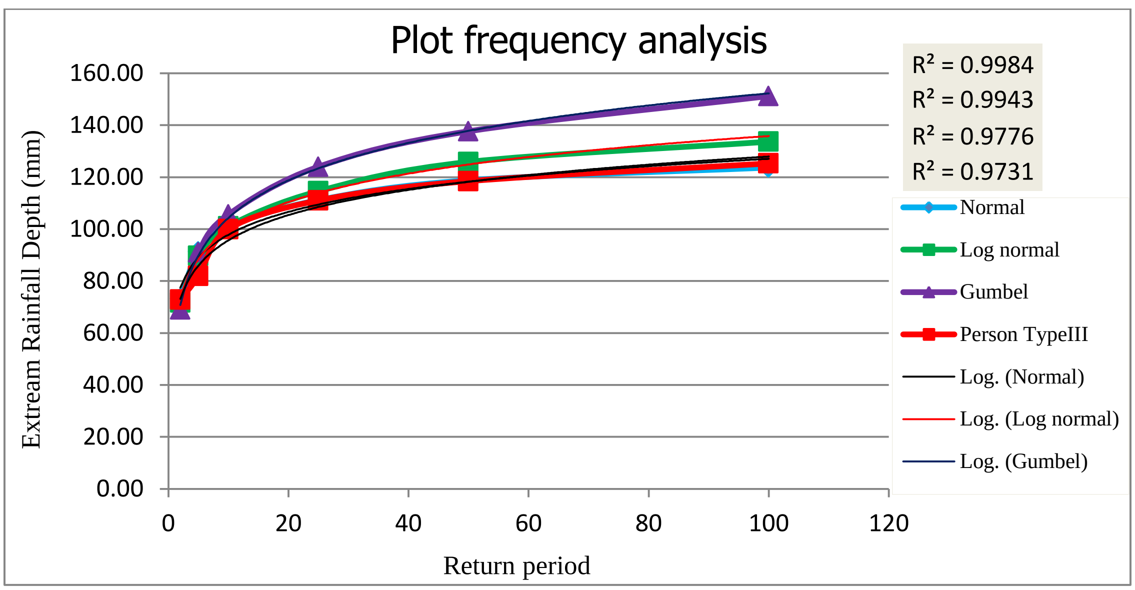
Annex I: Yearly Extreme Series and Frequency Analysis Calculations using Gumbel Method

RT	**Xave**	$(\boldsymbol{\delta n - 1})$	Yn	Sn	YT	KT	$XT = X_{ave} + (KT * \delta n - 1)$
	71.083	20.94	0.538	1.1193			
2					0.367	-0.153	69.03
5					1.500	0.859	91.03
10					2.250	1.530	105.60
25					3.199	2.377	124.00
50					3.902	3.005	137.65
100					4.600	3.629	151.21



Annex J: Fitting distribution test by Gumbel Method of Distribution Type

Frequency analysis between return period Vs precipitation having the trend line equation, R^2 gives a value of 0.9984. The value R^2 = 0.9984, shows that the pattern of the scatter is narrow and that Gumbel method of distribution type is suitable for predicting expected rainfall analysis for the study area.



Annex K: Plot of frequency analysis

Annex L: Meteorology station in Ethiopia (Years of record through 2010)

Meteorological Region	Station	Years of Record	Meteorological Region	Station	Years of Record
A1	Axum	17	**B1**	Bedele	39
	Mekele	46		Gore	56
	Maychew	32		Nekempte	40
A2	Gondar	56		Jima	54
	Debre Tabor	15	**B2**	Arba Minch	23
	Bahir Dar	45		Sodo	49
	Debre Markos	55		Awasa	36
	Fitche	44	**C**	Kombolcha	57
	Addis Ababa	57		Woldiya	29
	Debre Zeit	55		Sirinka	27
A3	Nazareth	46	**D1**	Gode	33
	Kulumsa	43		Kebri Dihar	40
	Robe/Bale	29	**D2**	Kibre Mengist	33
A4	Metehara	24		Negele	51
	Dire Dawa	58		Moyale	29
	Mieso	42		Yabelo	34

(Source: ERA, 20)

Annex L: Reduced mean yn in Gumbel's extreme value distribution, N size

N	0	1	2	3	4	5	6	7	8	9
10	0.4952	0.4996	0.5035	0.5070	0.5100	0.5128	0.5157	0.5181	0.5202	0.5220
20	0.5236	0.5252	0.5268	0.5283	0.5296	0.5309	0.5320	0.5332	0.5343	0.5353
30	0.5362	0.5371	0.5380	0.5388	0.5396	0.5402	0.5410	0.5418	0.5424	0.5430
40	0.5436	0.5442	0.5448	0.5453	0.5458	0.5463	0.5468	0.5473	0.5477	0.5481
50	0.5485	0.5489	0.5493	0.5497	0.5501	0.5504	0.5508	0.5511	0.5515	0.5518
60	0.5521	0.5524	0.5527	0.5530	0.5533	0.5535	0.5538	0.5540	0.5543	0.5545
70	0.5548	0.5550	0.5552	0.5555	0.5557	0.5559	0.5561	0.5563	0.5565	0.5567
80	0.5569	0.5570	0.5572	0.5574	0.5576	0.5578	0.5580	0.5581	0.5583	0.5585
90	0.5586	0.5587	0.5589	0.5591	0.5592	0.5593	0.5595	0.5596	0.5598	0.5599
100	0.5600									

Annex N: Coefficient of skewness KT value for person type III distribution (positive skew)

Coef. of skew, Cs	Return Period T in years						
	2	**10**	**25**	**50**	**100**	**200**	**1000**
3	-0.396	1.180	2.278	3.152	4.051	4.970	7.250
2.5	-0.360	1.250	2.262	3.048	3.845	4.652	6.60
2.2	-0.330	1.284	2.240	2.970	2.705	4.444	6.200
2	-0.307	1.302	2.219	2.912	3.605	4.298	5.910
1.8	-0.282	1.318	2.193	2.848	3.499	4.147	5.660
1.6	-0.254	1.329	2.163	2.780	3.388	3.99	5.390
1.4	-0.225	1.337	2.128	2.706	3.271	3.828	5.110
1.2	-0.195	1.340	2.087	2.626	3.149	3.661	4.820
1	-0.164	1.340	2.043	2.542	3.022	3.489	4.540
0.9	-0.148	1.339	2.018	2.498	2.957	3.401	4.395
0.8	-0.132	1.336	1.998	2.453	2.891	3.312	4.250
0.7	-0.116	1.333	1.967	2.407	2.824	3.223	4.105
0.6	-0.099	1.328	1.939	2.359	2.755	3.132	3.960
0.5	-0.083	1.323	1.910	2.311	2.686	3.041	3.815
0.4	-0.066	1.317	1.880	2.261	2.615	2.949	3.670
0.3	-0.050	1.309	1.849	2.211	2.544	2.856	3.525
0.1	-0.017	1.292	1.785	2.107	2.400	2.670	3.235
0	0.000	1.282	1.751	2.054	2.326	2.576	3.090
-0.1	0.017	1.270	1.716	2.000	2.252	2.482	2.950
-0.2	0.033	1.258	1.680	1.945	2.178	2.388	2.810
-0.3	0.050	1.245	1.643	1.890	2.104	2.294	2.675
-0.4	0.066	1.231	1.606	1.834	2.029	2.201	2.54
-0.5	0.083	1.216	1.567	1.777	1.955	2.108	2.400
-0.6	0.099	1.200	1.528	1.720	1.880	2.016	2.275
-0.7	0.116	1.183	1.488	1.663	1.806	1.926	2.150
-0.8	0.132	1.166	1.448	1.606	1.733	1.837	2.035
-0.9	0.148	1.147	1.407	1.549	1.660	1.749	1.910
-1	0.164	1.128	1.366	1.492	1.588	1.664	1.880
-1.4	0.225	1.041	1.198	1.270	1.318	1.351	1.465
-2.2	0.330	0.844	0.888	0.900	0.905	0.907	0.910
-3	0.396	0.660	0.666	0.666	0.667	0.667	0.668

(Source: Vente Chow, 1998)

Annex O: Reduced standard deviation Sn in N, sample size

N	0	1	2	3	4	5	6	7	8	9
10	0.9496	0.9676	0.9833	0.9971	1.0095	1.0206	1.0316	1.0411	1.0493	1.0565
20	1.0628	1.0696	1.0754	1.0811	1.0864	1.0915	1.0961	1.1004	1.1047	1.1086
30	1.1124	1.1159	1.1193	1.1226	1.1255	1.1285	1.1313	1.1339	1.1363	1.1388
40	1.1413	1.1436	1.1458	1.148	1.1499	1.1519	1.1538	1.1557	1.1574	1.159
50	1.1607	1.1623	1.1638	1.1658	1.1667	1.1681	1.1696	1.1708	1.1721	1.1734
60	1.1747	1.1759	1.177	1.1782	1.1793	1.1803	1.1814	1.1824	1.1834	1.1844
70	1.1854	1.1863	1.1873	1.1881	1.189	1.1898	1.1906	1.1915	1.1923	1.193
80	1.1938	1.1945	1.1953	1.1959	1.1967	1.1973	1.198	1.1987	1.1994	1.2001
90	1.2007	1.2013	1.202	1.2026	1.2032	1.2038	1.2044	1.2049	1.2055	1.206
100	1.2065									

Source (Vente Chow, 1998)

Annex P: Reduced Standard Deviation Sn in N, Sample Size

t(mint)	5	10	15	20	30	60	90	120	130	140	160	180
t(hr)	0.08	0.17	0.25	0.33	0.50	1.00	1.50	2.00	2.17	2.33	2.67	3.00
b+24	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30
$(b+24)^n$	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83
b+t	0.38	0.47	0.55	0.63	0.80	1.30	1.80	2.30	2.47	2.63	2.97	3.30
$(b+t)^n$	0.41	0.50	0.58	0.66	0.81	1.27	1.72	2.15	2.29	2.44	2.72	3.00
RRt	0.16	0.26	0.34	0.40	0.48	0.62	0.69	0.73	0.74	0.75	0.77	0.78

Annex Q: Rainfall of Shorter Duration for Gilgel Beles Town Using Gumbel Method

Duration(mint)	T(year)	2	5	10	25	50	10
	R 24 =	**69.03**	**91.03**	**105.6**	**124**	**137.7**	**151.2**
5		130.83	172.52	200.13	235.01	260.87	286.57
10		109.17	143.96	167.00	196.10	217.69	239.13
15		93.85	123.76	143.57	168.59	187.15	205.59
20		82.43	108.70	126.10	148.07	164.37	180.56
30		66.49	87.68	101.71	119.43	132.58	145.64
60		42.54	56.09	65.07	76.41	84.82	93.17
90		31.53	41.58	48.23	56.64	62.87	69.07
120		25.16	33.18	38.50	45.20	50.18	55.12
130		23.60	31.12	36.10	42.39	47.05	51.69
140		22.22	29.30	33.99	39.91	44.31	48.67
160		19.91	26.26	30.46	35.77	39.70	43.62
180		18.05	23.81	27.62	32.43	36.00	39.55

Annex R: Goodness of fit for different probability distribution method

Distribution	Kolmogorov-Smirnov		Anderson Darling		Chi-Squared	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
Gumbel	0.05695	1	0.24700	1	1.1240	1
Normal	0.06925	2	0.37496	4	1.3617	2
Log - Pearson III	0.06937	3	0.34186	2	1.3618	3
Log-normal	0.07316	4	0.34187	3	1.3619	4

Appendices Two: Peak discharge Estimation for Gelgel Beles town using rational method

B. **Time of concentration**

- ☑ Sheet flow Time:-Sheet flow is flow over plan surfaces. It usually occurs in the headwater of the streams (usually for the first 100 m run), but from topographic map obtained 100 m Sheet flow, natural range and short grass slope of 0.055 m/m, and length of 100 m and Manning's roughness coefficient is 0.0125. The 2-year, 24-hour rainfall depth is calculated to be 69.03 mm.

Hence, from equation travel time for sheet flow is determined as: $Tt= [0.091(nL)^{0.8} / (P2)^{0.5} S^{0.4}]$ $= [0.091(0.0125*100)^{0.8} / (69.03)^{0.5} 0.055^{0.4}]$ = **$Tt_1 = 0.166hr$.**

- ☑ For shallow concentrated flow, unpaved watershed slope is approximated S1=0.01 and length from topography map is 562m. $V=4.9178(0.055)^{0.5}$ for unpaved watershed. $V=4.9178(0.055)^{0.5}$ = 0.483127m/sec. Finally, travel-time is determined as: The estimation of shallow concentrated flow (Time of concentration Tt2) for given catchment unpaved watershed is **$Tt_2 = 0.323hr$.**
- ☑ For channel flow, natural stream channel, winding with weeds and pools, Slope is 0.013m/m, and Length is 562m. Rectangular channel for main cachement-1 (MDL-1): 1V:1H, Width (B_1) =1.25m, Depth (y_1) =0.55m, S_1=0.01, Manning's n channel (n=0.0125), Area of channel (A1) =0.69m^2, Perimeter of channel=2.35m and V channel= 8.23m/s. The time is equal to **$Tt_3 = 0.019hr$.**

The time of concentration is the sum of Tt values for the various consecutive flow segments: $Tc=Tt_1+Tt_2+Tt_3$ = 0.166hr +0.323hr +0.019hr = **0.508hr**

Annex S: Time of concentration result for existed drainage system

Location	Main-Line ID	B (m)	Y(m)	S (m/m)	Length (m)	Sheet Flow (t1)	Shallow Flow (t2)	Open Channels(t3)	Total (Tc)
G/Mariam Kebele	MDL-1	1.25	0.55	0.055	562	0.166	0.323	0.019	0.508
	MDL-2	1.25	0.55	0.010	508	0.303	1.142	0.040	1.486
	MDL-3	1.25	0.55	0.014	377	0.209	0.648	0.025	0.882
	MDL-4	1.25	0.55	0.043	309	0.114	0.216	0.012	0.342
	MDL-5	1.25	0.55	0.011	365	0.224	0.761	0.028	1.012
	MDL-6	1.25	0.55	0.019	410	0.198	0.552	0.024	0.773
	MDL-7	0.70	1.2	0.047	503	0.162	0.328	0.019	0.509
	MDL-8	0.70	1.2	0.036	463	0.169	0.374	0.020	0.563
	MDL-9	1.32	1.72	0.011	378	0.230	0.788	0.021	1.039
	MDL-10	1.32	1.72	0.021	408	0.189	0.507	0.016	0.712
Kuter-2 Kebele	MDL-1	1.25	0.55	0.020	382	0.183	0.493	0.021	0.698
	MDL-2	1.25	0.55	0.020	417	0.196	0.539	0.023	0.758
	MDL-3	1.25	0.55	0.020	500	0.227	0.646	0.028	0.901
	MDL-4	1.25	0.55	0.040	425	0.151	0.315	0.017	0.483
	MDL-5	1.25	0.55	0.011	365	0.224	0.761	0.028	1.012
	MDL-6	1.25	0.55	0.033	374	0.147	0.324	0.016	0.487
	MDL-7	1.32	1.72	0.012	371	0.175	0.721	0.019	0.916
	MDL-8	1.32	1.72	0.010	423	0.262	0.951	0.024	1.237
Edida Kebele	MDL-1	1.25	0.55	0.040	455	0.159	0.338	0.018	0.515
	MDL-2	1.25	0.55	0.040	344	0.127	0.255	0.014	0.396
	MDL-3	1.25	0.55	0.040	282	0.109	0.209	0.011	0.329
	MDL-4	1.25	0.55	0.010	326	0.213	0.733	0.026	0.971
	MDL-5	1.32	1.72	0.010	388	0.244	0.872	0.022	1.139

Annex T: Typical Range of Manning's Coefficient (n) for Channels and Pipes (FHWA, 2014)

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

Appendix Three: Community involved in questionnaires and there location

Here out the 100 respondent 40 people are randomly selected from ***G/Mariam Kebele*** which account of (40%) of the total respondent where as 35 people are randomly selected from ***Kuter-2 Kebele*** which account of (35%) of the total respondent and finally 25 (25%) people are randomly selected from ***Edida Kebele*** to to collect information on the title of **Performance Assessment of Storm water Drainage System of Gelgel Beles Town as shown in (Table 5.1).**

Annex U: Location area of surveyed respondents

No	A sample is taken from	Respondent's number	Percentage (%)
1	G/Mariam Kebele	40	40
2	Kuter-2 Kebele	35	35
3	EdidaKebele	25	25
Total		100	100%

Appendix Four: Performance Assessment of Storm water Drainage System of Gelgel Beles Town

Part I. Interview among the Community Living in the town

Dear respondents,

I am a post graduate student at Jimma University. I am conducting research on **Performance of Storm Water Drainage System: A Case of Gelgel Beles town**, this thesis has been submitted in partial fulfillment of the requirement for the degree of Master of Science. Thus, this questionnaire is designed to collect information on main causes for performance of storm water drainage system under the effect of urban expansion in Gelgel Beles town. Since the information you provided is highly valuable to the success of the study, you are kindly requested to give your genuine responses for the following questions. The information you give will not be used for any purpose other than the achievement of the objectives of this research.

Research Information

Research Title: on performance of storm water drainage system a case of Gelgel Beles town

University: Jimma Institute of Technology, School of Research and Graduate Studies Faculty of civil and environmental engineering

Prepared by: Tikdem Morka

Supervised by: Dr. Zeinu Ahamed

Instructions: Tick or give reliable answers for the questions presented here with.

- ✓ ***Part II: General Profile of the Interviewee***

  Name………………...Sex……………. Age……………………

1. Education level of interviewee

__below matriculation ___Basic reading and writing ____Elementary ___High School___

__Preparatory ___Diploma ___Degree ____M.Sc. Specify if other__________________

2. Occupation of the interviewee

___Public sector ____Government_____ Private Sector _____Own Business If other______

3. How long have you lived in Gelgel Beles?

>10year____ 10- 15 years___ 15- 20 years____ 20 – 30 years____30< years_____

Part III: Interview question on performance of storm water drainage system: a case of Gelgel Beles town.

1. Total land area of Gelgel Beles city--------ha. Green area in Gelgel Beles town --------ha

2. Does flooding a major problem in your town? Yes----------------No -----------------

3. Does urbanization have negatively affect vegetation cover of the area and how it can?

4. If your answer is yes, how do you rate the extent: very serious-------serious---------not serious---.

5. Which specific sites are most prone to flooding and why: Use the table below

Name of local site	Kebele	Rank	Reason of flooding (why?)

6. What do you think is the major causes of flood problem in Gelgel Beles town?

A. Absence of urban storm water drainage infrastructure

B. Inadequate urban storm water drainage infrastructure

C. Blockage of urban storm water drainage structures

D. Deforestation of vegetation

E. Rugged topography

F. If others specify____

7. What temporary solutions have ever been taken to flood problems in Gelgel Beles?

A. Cleaning drainage channels

B. Earth embankments

C. Sand bags

D. Afforestation

E. Constructing new urban storm water drainage facilities-

F. Specify, if any ____

____

____

Part IV: Interview Question executed by Group Discussion

1. Which specific sites are most prone to flooding form the town and why?
2. What temporary solutions/measures have ever been taken to the urban flooding problems?
3. What solutions you suggest to handle such flooding problems on existing storm water drainage system?
4. How the storm water management problems can be minimized and what measures are?
5. What do you think should be done to have Storm water drainage problem for the future?
6. What role is set for the community in the expansion of storm water drainage systems?
7. What reasons you believe are accounted for the unsustainably use of the urban storm water drainage facilities in the area?
8. What supports did the community get from the Government organizations in relation to managing the storm water drainage system to make properly functional and sustainable?
9. Generally any comments/suggestion regarding in management the impact of the urban drainage system on Gelgel Beles town_________________________
10. What makes the existing drainage system to be filled with solid and liquid waste
    A. Lack of awareness
    B. Shortage of disposing area
    C. Carelessness
    D. Ifothers,Explain____
    ____
11. How urbanization can create urban flooding in most developing city like Gelgel Beles town
    ____
    ____
    ____

Part V: Interview question for concerned Kebele leader and concerned town authority

Name of the officer: ___________________________________

Position: ____

Name of the Institution: ________________________________

1. What are the major challenges in the provision of integrated road and urban storm water drainage infrastructure: finance-------plan--------profession--------lack of awareness------------.
2. Do you plan to provide urban storm water drainage infrastructure in Gelgel Beles town? yes------no------If so, for what purpose:--
3. What major impacts the drainage system has on rivers in Gelgel Beles town? ------------
4. What impacts do rivers have on Gelgel Beles town? ---
5. What solutions you suggest to handle such problems on existing rivers ----------------
6. What do you suggest to manage the problem of flooding in Gelgel Beles town? -------------
7. Who is the responsible body or organization in urban storm water drainage provision in Gelgel Beles town? ---
8. What are the major challenges in handling urban storm water drainage system in Gelgel Beles town? ---
9. If there flooding problem to the Gelgel Beles town? Yes------- no-----
   If yes how could it be reduced /solved? --
10. General comments/suggestions in handling the impact of the urban drainage system on Gelgel Beles town?

    ____

    ____

    ____

Thank you