ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

Performance Evaluation of Stormwater Drainage System: The Case of Hawassa City

A thesis submitted and presented to the school of graduate studies of Addis Ababa University in partial fulfillment of the degree of Masters of Science in Civil Engineering (Major in Water supply and Environmental Engineering)

By

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Declaration

I declare that this thesis, which I submit to School of Graduate Studies of Addis Ababa University in partial fulfilment of the requirement of degree of Master of Science in Civil Engineering, is my own personal effort. The thesis has not submitted previously, in whole or in part, to qualify for any other academic award. Furthermore, I took reasonable care to ensure that the work is original, and, to the best of my knowledge, does not breach copyright law, and has not been taken from other sources except where such work has been cited and acknowledged within the text.

Ydnekachew Adane Heramo

February, 2019

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Last, I thank all who are not listed here, but take part in for this successful study.

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Acronyms

AAEPA: Addis Ababa Environmental Protection Authority

AAU: Addis Ababa University

Arc-GIS: Architectural Geographical Information System Cad:

BMP: Best Management Practice

Cad: Computer Assisted Design

CSA: Central Statistics Authority

DEM: Digital Elevation Model

ECA: Economic Commission for Africa

ERA: Ethiopian Road Authority

FUPI: Federal Urban Planning Institute

GWP: Global Water Partnership

IDF: Intensity Duration Frequency Curve

ITCZ: Inter Tropical Convergence Zone

LID: Low Impact Development

UD & FCD: Urban Drainage and Flood Control District

USWD: Urban Stormwater Drainage

WHO: World Health Organization

WMO: World Meteorological Organization

WQCV: Water Quality Capture Volume

Abstract

The main objective of this study was to investigate the existing Hawassa city stormwater drainage problems with respect to its hydraulic performance. The methodological approaches employed in this study include; the identification of the existing stormwater drainage network flow direction, and delineation of contributing areas. Field surveying work was conducted to inspect the existing drainage condition and to measure channel geometric dimensions. In order to develop the Intensity Duration Frequency curve (IDF) the rainfall intensities for different duration were analyzed for a period of 1985-2016. Probability distribution functions were analyzed and identified using Microsoft Excel.

The analysis from the frequency distribution indicate that General Extreme Value Type I (GEV-I) distribution was fitted well reasonably for the rainfall intensities. Rainfall quantiles for a duration of 24hr with a magnitude of 52.75, 68.67, 79.20, 92.51, 102.4 and 112.2 mm/hr was predicted for a return period of 2,5,10,25, 50 and 100 years respectively. Based on the flow direction of the study area the existing drainage channel capacity were checked by using flow master software. Established on settlement of the city about 66, sub-catchments were delineated in the existing system and by using the intensity estimation (T=10 years) the hydrological peak flow determined by using Bentley CivilStorm software. The rational formula is used to compute the peak flood estimation for (T= 10).

The result from model compared with existing hydraulic capacity of the channels and it shows that at Wanza square stormwater drainage were not sufficient to carry the expected runoff during rainfall events. In general, the flood problems identified at Wanza square and Wanza square to Old bus station were mainly due to in adequacy of the drainage channel capacity and further substantiated by the waste disposal from different sources into the drainage channels. To resolve these problems BMP's have been recommended. Finally, the analysis from this study permits future work on stormwater drainage design should strictly follow the standards of hydrologic and hydraulic design and social and environmental considerations.

Key words: stormwater, stormwater drainage, runoff, channel capacity,

1 Introduction

1.1 General background

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 (Graham, 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. Urbanization along with its impermeable structures and improper design are the major causes of flooding in most developing urban areas in Ethiopia including Hawassa (Belete, 2009), this urbanization affects the performance of the drainage lines. Drainage system seek to manage rainfall in a way similar to natural processes, by using the landscape to control the flow and volume of surface water, prevent or reduce pollution of downstream development.

The basis and expansion of most Ethiopian cities and towns including Hawassa has been associated with the rapid change of rural land to urban area. For the last decade Hawassa has been noticed that an intensive change of rural land to urban development like buildings, transportation networks and facilities (airports and highways), recreation areas and other manmade structures, where most of them are impermeable structures (Belete, 2009). Although, currently Hawassa has undergoing upgrading of existing roads and constructing of new roads this will highly influence the runoff volume of the city, while Hawassa receives significant amount of annual rainfall and where rainfall intensity is generally high, control of runoff at source, flood protection, and safe disposal of excess water/runoff through proper drainage facilities becomes essential (Habtamu, 2011). So mitigation measures should be considered in accommodation of incoming surface runoff.

Poor drainage system can lead to flooding, resulting in property loss, and people may even be forced to move to escape floodwaters. Stormwater drainage problems include flooding, erosion of roads, land degradation, sedimentation, water logging, blockage of drainage lines, and others. With urbanization impervious surfaces increase, drainage pattern changes, overland flow becomes speedy, flooding and environmental problems such as land degradation increases. The problem in urban stormwater drainage network is also the other challenge in urban areas, because the run-off produced with in a particular urban area could not safely be discharged in to the final receiving system (G/wahed, 2016). Thus, this could be the source of environmental problems like erosion, pollution, over topping, barrier to traffic and other related problems. Flooding may also damage water supply infrastructure and contaminate domestic water sources.

Nowadays Hawassa is one of a major economic and tourist link of Ethiopia. Unfortunately, street flooding, over topping and other environmental related problems are common in this city. This is particularly severe in areas where road infrastructure appears to be without adequate stormwater drainage infrastructure.

Beforehand there were few studies conducted in line to the topic what this study has conducted to address the above mentioned challenges. In general, this particular study is intended to find out the major problems, evaluate the existing drainage system in Hawassa, and proposes the best management practice for sustainable solution to handle the periodic urban drainage problems.

1.2 Statement of problem

Heavy rains with high runoff in Hawassa leads flooding in the several areas. Significant proportion of the city is exposed to flooding during the rainy season. This has been the cause for substantial loss of human life and properties. There is also a problem of overtopping, blockage of drainage facilities and water logging in some of the drainage area it leads a serious impact on both the road access and its strength. Runoff generated during rainy season can transport wastes that flow along the drainage system have bad smell, and create unwelcoming environment. This causes the health problems for the community. In addition, the community is in problem to access the roads not only during rainy season but also after rain they should wait more than an hour to access the roads. This study aims will be to identify the major stormwater drainage problems and to determine best management practices. Hence, I came up to focus on my research title called, "**Performance Evaluation of Stormwater Drainage System; the Case of Hawassa City**".

1.3 Objectives

1.3.1 General objectives

The main objective of this study was to evaluate the existing stormwater drainage system in Hawassa for selected drainage line

1.3.2 Specific objectives

1. To evaluate the capacity of existing urban stormwater drainage system in the study area.
2. To evaluate existing stormwater drainage by different channel geometries.
3. To identify the major challenges of stormwater drainage management system.
4. To propose best management practice to improve the problems.

1.4 Research questions

1. Does the existing drainage system perform well?
2. What are the hydraulic properties of Hawassa stormwater drainage system contributing to the flooding problem?
3. What are the hydrologic characteristics of the catchments contributing to stormwater flooding?
4. What are the major challenges in managing the stormwater drainage system in the study area?
5. What are the possible best management practices to improve the problems?

1.5 Significance of the study

Generally, managing urban stormwater drainage system has a significant role for viable environmental management by keeping the service life of urban infrastructures such as roads, buildings, telephone lines, water supply lines and the existing rivers. Therefore; benefits that will be draw from this study may contribute to current efforts by governments and other concerning body to solve the problem of drainage schemes that contribute for better service coverage. The result of this study also may help in filling the data gaps by identifying problems to Sustainability by introducing the BMP option, taking proper designing of stormwater drainage system and proper functioning of drainage schemes in the town. It also the cities will use it as a reference while they are preparing their annual plans for urban drainage system.

1.6 Scope of the study

Evaluating the whole catchment of the city might not be necessary, but representative sample is necessary to come up with solution for the current stormwater problem. Therefore, some representative major flood prone areas are selected. According to the residents these areas have been flooded most of the rainy season and based on field observation two major flood prone drainage lines are selected. Therefore, this study is geographically limited at Wanza square catchments. Generally; it will address issues related to urban stormwater drainage. The specific focus of this study includes: evaluating the extent and performance of the existing drainage system and proposing best management practice for the existing problem.

2 Literature Review

This chapter serves as a summary of the main principles in urban stormwater drainage systems. It starts with describing the historical development and basic concept of urban stormwater drainage and then followed by: evolution of urban stormwater drainage and its problem, Urban stormwater drainage experience in Ethiopia and major problems, history and policy of urban stormwater drainage in Ethiopia, stormwater drainage evaluation criteria, and finally best management practices and best management selection tools were summarized. Generally, it presents various concepts and theories which have been found by various Researchers/Authors in different periods of time in relation to this research work.

2.1 Evolution of urban drainage

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 (J.Parkinson, 2013). Historical accounts provide sights of many interesting and unique urban drainage techniques.

2.1.1 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 & Eddy, 2003). Most sewers were designed exclusively for stormwater drainage. Sanitary wastes accumulated in privy vaults and cesspools and were periodically collected by scavengers and transported to a suitable disposal location (e.g., farm, dump outside city). 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 stormwater 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 (J.Parkinson, 2013). 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 (Belete, 2009).

2.1.2 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 issues (Tafete, 2013). 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 (UD and FC, 2011).

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 stormwater 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 (Graham, 2012). Many communities are developing watershed wide stormwater quality management plans to meet the dual objectives of flood prevention and water quality control. Urban drainage has indeed expanded significantly during the past few decades beyond a technical challenge to drain the urban area expeditiously to include the consideration of social, economic, political, environmental, and regulatory factors.

2.2 Urban stormwater drainage problems

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 (Hassen, 2016).

The specific factors inhibiting modernization of urban drainage in developing countries, basically by means of infiltration and retention of storm runoff, can be grouped under the following headings: (1) concern for the environment is less familiar than concern for conventional sanitary planning; (2) there is no effective control over urban development, whether legal or clandestine; (3) runoff from storm rainfall is highly contaminated; (4) runoff transports large quantities of sediment and garbage; (5) climatic factors can increase risk of epidemics and construction costs; (6) there is a shortage of engineering ‘know-how’ concerning modern approaches to urban drainage; (7) there is a lack of interaction between the population and public administrators seeking solutions to urban drainage problems (Graham, 2012).

2.2.1 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 (Tafete, 2013). Such urbanization patterns make it difficult to control urban drainage, since it not only causes or aggravates local flooding but can also create problems downstream. The extent of impermeable cover is directly correlated with runoff coefficients and also with population density, so that an indirect method of evaluating the impact of urbanization on drainage is to relate population density with runoff coefficients. There is evidence world-wide that higher urban population density commonly results in greater storm-water generation, (Abraha, 2018) but many urban planners take no account of this important effect and neglect the wider costs of their storm-water control procedures.

Modern urban drainage calls for detention and infiltration areas, contrary to the philosophy of higher population density. Many cities in developing countries have a density index which already causes critical drainage situations. Besides the problems of control in legal settlements, socioeconomic problems lead to the invasion of public areas, forming slums with high population density and high rates of impermeable soil surface (Hassen, 2016).

2.2.2 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, whether in areas where the city is expanding or within the developed urban area, do not normally have controls for erosion prevention or for retaining sediment so that it does not reach 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.

The amount of garbage entering the drainage network is reduced corresponding to a production of 0.4 to 0.8% of total garbage produced (Urgessa, 2016). 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 (Werkneh., 2017). This is a peculiar feature of developing countries which makes control works for storm runoff control even more expensive to implement.

2.2.3 Lack of appropriate 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 (Mukherja, 2016). 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 Mukherja, 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.

2.2.4 Absence 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 (Mulualem Bekele, 2018). In most enveloping countries this has been a problem for sustainable stormwater 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.

2.3 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 (UD and FC, 2011). 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 (Hassen, 2016).

Dual drainage

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 stormwater 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 (ERA, 2013). This consideration of distinct surface flow and its interaction with sewer flow is denoted as dual drainage modeling.

i. 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 rivers (Zewdu, 2015). The sewerage system falls into this category.

ii. 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. All surface flow falls into this category (Zewdu, 2015).

2.4 Stormwater drainage system and its management

2.4.1 Stormwater drainage system

An important social aspect is to maintain public health and safety; hence an efficient drainage of stormwater and wastewater is essential to avoid impact of flooding on life and property. In addition, the current environmental awareness involves the protection of the receiving waters from the pollutants that may be dragged by water flowing in the surface during heavy rain events (Werkneh., 2017).

The negative aspect is the spill of untreated water to the watercourses (Mulualem Bekele, 2018). The separated system comprises two separate pipelines for waste and stormwater is protecting from flooding in the basement and floors of houses in low-lying during extreme rainfalls, as well as avoiding the release of pollutants into the environment (UD and FC, 2011). Stormwater is normally less polluted than sewage water, so that it can be led to detention basins or watercourses saving energy and cost, whereas wastewater requires a deeper treatment.

2.4.2 Types of stormwater drainage system

A drainage system will include all the components needed to ensure that the substructure is properly drained, and may be formed of components such as; open ditches, closed ditches with pipe drains, drainage through stormwater drainage pipes, channels and culverts (Asfaw, 2016).

2.4.3 Functions of stormwater drainage system

One of the drainage system's functions is to collect surface water and/or ground water and direct it away, thereby keeping the ballast bed drained (Hailemichael., 2015). The drainage system must also protect the substructure from erosion, from becoming sodden, and from losing its load-bearing capacity and stability. Another main objective of storm sewer is to protect; Public health and safety, environmental protection, sustainable development, occupational health and safety.

Drain and sewer systems are provided in order to prevent spread of disease by contact with fecal and other waterborne waste, to protect drinking water sources from contamination by waterborne waste and to carry runoff and surface water away while minimizing hazards to the public (Hassen, 2016). Additionally, the impact of drain and sewer systems on the receiving waters shall meet the requirements of any national or local regulations or the relevant authority.

2.4.4 Stormwater management

Urban stormwater management simply stated as everything done within a catchment to remedy existing stormwater problems and to prevent the occurrence of new problems (Getachew Kebede et al., 2015). This involves the development and implementation of a combination of structural and nonstructural measures to reconcile the conveyance and storage function of stormwater systems, with space and related needs of expanding urban populations. It also involves the development and implementation of a range of measures or best management practices to improve the quality of urban stormwater runoff prior to the discharge into receiving waters. Before reviewing stormwater management system it is important knowing the type, characteristics and function of the stormwater drainage system.

2.5 Hydrologic considerations

2.5.1 Hydrology and process overview

Streams are fed by runoff from rainfall and snowmelt moving as overland or subsurface flow. Floods occur when large volumes of runoff flow quickly into streams and rivers. The peak discharge of a flood is influenced by many factors, including the intensity and duration of storms and snowmelt, the topography and geology of stream basins, vegetation, and the hydrologic conditions preceding storm and snowmelt events (Urgessa, 2016).

Land use and other human activities also influence the peak discharge of floods by modifying how rainfall and snowmelt are stored on and run off the land surface into streams. In undeveloped areas such as forests and grasslands, rainfall and snowmelt collect and are stored on vegetation, in the soil column, or in surface depressions (Graham, 2012). When this storage capacity is filled, runoff flows slowly through soil as subsurface flow. In contrast, urban areas, where much of the land surface is covered by roads and buildings, have less capacity to store rainfall and snowmelt.

Construction of roads and buildings often involves removing vegetation, soil, and depressions from the land surface. The permeable soil is replaced by impermeable surfaces such as roads, roofs, parking lots, and sidewalks that store little water, reduce infiltration of water into the ground, and accelerate runoff to ditches and streams (Belete, 2009). Even in suburban areas, where lawns and other permeable landscaping may be common, rainfall and snowmelt can saturate thin soils and produce overland flow, which runs off quickly (Brave, 2018). Dense networks of ditches and culverts in cities reduce the distance that runoff must travel overland or through subsurface flow paths to reach streams and rivers. Once water enters a drainage network, it flows faster than either overland or subsurface flow.

Important hydrologic processes for floods are presented in this section. Figure 2.1 gives an overview of the processes that take place during an urban flooding event and their interactions (Mukherja, 2016). Because of that subsurface processes other than infiltration, such as percolation and groundwater base-flow have not been depicted. Furthermore, snowmelt has been left out due to the temperate and climate.

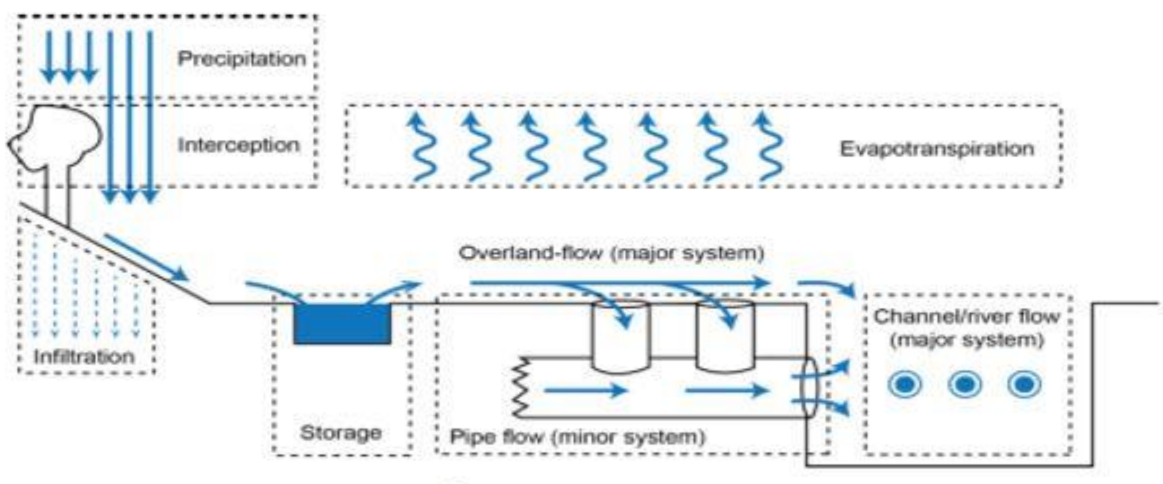

Figure 2-1: An overview of hydrologic processes during urban flooding. Groundwater flow has not been shown in the figure. Source:(Subramanian, 2008)

2.5.2 Hydrologic effects of urban development

With less storage capacity for water in urban basins and more rapid runoff, urban streams rise more quickly during storms and have higher peak discharge rates than do rural streams. In addition, the total volume of water discharged during a flood tends to be larger for urban streams than for rural streams (Tafete, 2013). As with any comparison between streams, the differences in stream flow cannot be attributed solely to land use, but may also reflect differences in geology, topography, basin size and shape, and storm patterns.

The hydrologic effects of urban development often are greatest in small stream basins where, prior to development, much of the precipitation falling on the basin would have become subsurface flow, recharging aquifers or discharging to the stream network further downstream. Moreover, urban development can completely transform the landscape in a small stream basin, unlike in larger river basins where areas with natural vegetation and soil are likely to be retained (G/wahed, 2016).

2.6 Hydraulic considerations

2.6.1 Alignment of drainage structures

Culverts that have internal diameter less than or equal to 1.22m are minor drainage structures. The vertical alignment of a culvert with respect to the stream channel is important to its hydraulic performance, to stream stability, to construction and maintenance costs, and to the safety & integrity of the roadway (ERA, 2013). Proper alignment is also particular importance to prevent outlet scour or excessive sediment buildup in the culvert barrels. A culvert placed too low in relation to the channel bottom may lose hydraulic performance if the channel aggrades. In addition, a culvert placed at a slope different from the natural channel slope may have problems related to both sediment deposition and bed scour, and this affects hydraulic performance.

A culvert invert slope should match the streambed slope. Placing the culvert on a flatter or steeper gradient from the natural streambed can cause sediment deposition in the barrel. It can also cause scour that removes sediment from the barrel (Asfaw, 2016).

2.6.2 Storm sewer design

Population growth and urban development can create potentially severe problems in urban water management. One of the most important facilities in preserving and improving the urban water environment is an adequate and properly functioning stormwater drainage system. Construction of houses, commercial buildings, parking lots, paved roads, and streets increases the impervious cover in a watershed, and reduces infiltration(Getachew Kebede et al., 2015). 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. These factors increase the volume and velocity of runoff and produce larger peak flood discharges from urbanized watersheds than occurred in the pre urbanized condition. Many urban drainage systems constructed under one level of urbanization are now operating under a higher level of urbanization and have in adequate capacity (Tafete, 2013).

2.7 Stormwater drainage performance evaluation criteria

The need to have an adequately performing urban drainage network would seem to be an obvious requirement, as would be its link with asset maintenance and rehabilitation (discussed in the next chapter). The performance objectives are relatively straightforward and have already been highlighted in this book: to efficiently carry away wastewater from properties, efficiently carry away stormwater from properties and their environs, and safely returning both to the environment. Of course consistently achieving these objectives is less straightforward, as is measuring and demonstrating that it has been done. Increasingly, the water industry is turning to performance indicators as a means of checking whether the system is consistently performing correctly or, put another way, if an adequate service is being delivered to customers. (Urgessa, 2016) lists several reasons for wanting to develop robust performance indicators to: represent the effects of complex processes and physical interactions in a simple manner, measure progress made towards targets and provide benchmarking information to allow comparisons to be made.

2.8 Urban stormwater experiences in Ethiopia

Tremendous efforts have been taken to assess the existing performances of stormwater drainage infrastructure in different parts of Ethiopia. Few of these studies are presented either as academic outputs or project reports. Section 2.7.1. and 2.7.2 below summarizes some of the research findings.

Table 2-1: Urban stormwater experiences in Ethiopia

Item	**Topic**	**Author/s (Year)**	**Area of study**	**Scientific contribution**	**Model used**
1.	Integrated urban drainage system; the case of Ayat to Megenagna light rail transit system route	Anteneh Zewdu Deriba, (2015)	Addis Ababa	Msc. Thesis at AAU/AAiT	
2.	Improving Stormwater Management Capacity of Cobblestone Paved Local Streets through Green Infrastructure Design and Technologies (The Case of Residential District in the Eastern and North Eastern Part of Addis Ababa)	Fikreselam G/wahed, (2016)	Addis Ababa	Msc. Thesis at AAU/AAiT	SWMM and Arc GIS
3	Flood Assessment on Addis Ababa Light Rail Transit System (LRT) (Meshualekiya – Gotera)	Fisha Hailemichael, (2015)	Addis Ababa	Msc. Thesis at AAU/AAiT	SWMM and Arc GIS
4	Assessment of the Effect of Urban Road Surface Drainage: A Case Study at Ginjo Guduru Kebele of Jimma Town	Getachew Kebede,Warati Tamene,Adugna Demissie	Jimma	Published on International Journal of Science, Technology and Society June 29, 2015	Eagle point and EP-SWMM5

Item	Topic	Author/s, Year	Area of Study	Scientific Contribution	Model used
5	Modeling and analyses of urban flooding in bole sub-city System performance and	Nejib Hassen	Addis Ababa	Msc. Thesis at AAU/AAiT	SWMM and Arc GIS
	evaluation of possible Improvements using epa swmm5	November, (2016)			
6	Hydrologic and Hydraulic Analyses of Drainage Structures In Case of Shishinda-Tepi Road	Kassahun Urgessa (2016)	AAU/AAiT	Msc. Thesis at AAU/AAiT	HEC-RAS
7	Application of GIS in Cross Drainage Structure (Case study taken on major drainage structure on Goro-Akaki road)	Melat Kaleab (2015)	AAU/AAiT	Msc. Thesis at AAU/AAiT	HEC-HMS
8	Performance Assessment of Road Drainage Systems of Burayu Town, Oromia Region, Ethiopia	Mulualem Bekele and K. Naga Sahadeva, (2018)	Burayu	Published on International Journal of engineering and management	SCS-CN

Item	Topic	Author/s, Year	Area of Study	Scientific contribution	Model used
9	Assessment of Stormwater Drainage Systems in Kemise Town	Biniyam Asfaw,(2016)	Kemise	Msc. Thesis at AAU/AAiT	SCS-CN
10	Sustainable Urban Drainage Options for Mekelle City	Teamir Abraha,2018	Mekele	Msc. Thesis at AAU/AAiT	SWMM
11	Evaluation of Drainage system in Kebena stream catchment, Addis Ababa	Eskedar Tafete,2013	Addis Ababa	Msc. Thesis at AAU/AAiT	HEC-GEOHMS
12	Study of the Urban Drainage System in Addis Ababa, Yeka Sub-city.	Dagnachew Adugna,2009	Addis Ababa	Msc. Thesis at AAU/AAiT	

In Ethiopian context, where watersheds of many urban centers receive significant amount of annual rainfall and where rainfall intensity is generally high, control of runoff at the source, flood protection, and safe disposal of the excess water/runoff through proper drainage facilities become essential (Tafete, 2013). Drainage problems in Ethiopian urban centers include flooding, deterioration of roads, land degradation, sedimentation, water logging, blockage of drainage facilities and the like. With urbanization, impermeability increases with the increase in impervious surfaces (i.e. residential houses, commercial buildings, paved roads, parking lots, etc.), drainage pattern changes, overland flow gets faster, flooding and environmental problems such as land degradation increases. It is a crucial problem facing the existing and future environmental conditions of urban centers (ERA, 2013).

After its inception, Federal Urban Planning Institute has been involving in planning and design of urban stormwater drainage facilities as part of the Master/Development Plan of a city/town with the objective of keeping the life of urban infrastructure and to protect the urban environment like water pollution from non-point sources of stormwater, Air pollution from stagnated water and Soil from erosion and degradation. The Federal urban planning institute under the Ministry of Works and urban development has been trying to put a considerable effort in controlling run-off, which is produced as a result of urban structural pavements and external sources, like flooding from Entoto and Yeka mountains in Addis Ababa (Belete, 2009).

Before the three decades ago, there has been no formal working organization in the area of urban stormwater drainage system. Even now a day the attention towards urban stormwater system is at its immature stage that is why most of the urban stormwater 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 (Werkneh., 2017). The technologies in handling the environmental problems of urban stormwater 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 stormwater drainage system in the country is to safely discharge the storm/run-off out of the urban centers (Belete, 2009).

2.9 Best management practice (BMP)

This section provides guidance on factors that should be considered when selecting BMPs for stormwater 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.

2.9.1 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 (e.g., construction activity) (UD and FC, 2011).

2.9.2 Space constraints

Space constraints 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 (UD and FC, 2011). This is most common when a site plan for roads, structures, etc., is developed and BMPs are embraced into the remaining spaces. The most effective and integrated BMP designs begin by determining areas of a site that are best Suited for BMPs (e.g., natural low areas, areas with well-drained soils) and then designing the layout of roads, buildings, and other site features around the existing drainage and water quality resources of the site (Zewdu, 2015).

2.9.3 BMP processes

The physical and chemical characteristics of stormwater runoff change as urbanization occurs, requiring comprehensive planning and management to reduce adverse effects on receiving waters. As stormwater flows across roads, rooftops, and other hard surfaces, pollutants are picked up and then discharged to streams and lakes (UD and FC, 2011). Additionally, the increased frequency, flow rate, duration, and volume of stormwater 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.

Stormwater drains traditionally lead to local creeks and waterways where the stormwater is dispersed without treatment. Unmanaged stormwater 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 stormwater infiltration which typically occurs with urbanization, and consequent increased velocity and extended duration of flow entering the natural water system. If stormwater is left unmanaged, pollution and physical changes caused by stormwater can cause considerable damage to the environment and, in particular, to waterways (Zewdu, 2015). There is Four Step Process pertains to management of smaller, frequently occurring events, as opposed to larger storms for which drainage and flood control infrastructure are sized. Implementation of these four steps helps to achieve a well-developed stormwater management practice (UD and FC, 2011).

1. Reduce Runoff

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 stormwater 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 soils that, before development, allows rainwater to infiltrate (UD and FC, 2011). Techniques for reducing runoff range from land use planning on a regional scale by local planning agencies, to methods that can be incorporated into specific projects. These techniques include actions:

i. Manage Watershed Impervious Area

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 (UD and FC, 2011).

ii. Minimize Directly Connected Impervious Areas (DCIA)

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 stormwater quality protection is to minimize the “directly connected impervious area (DCIA)” as shown in fig 2.2. Any impervious surface that drains into a catch basin, area drain, or other conveyance structure is a “directly connected impervious area.” As stormwater 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 (UD and FC, 2011). 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 Example strategies for infiltration, retention/detention, and bio-filtration include: Vegetated swales, vegetated basins (ephemeral- seasonally wet), Constructed ponds and lakes (permanent always wet). Crushed stone reservoir base rock under pavements or in sumps, Cisterns and tanks, Infiltration basins, Drainage trenches, Dry wells, and Others.

iii. Incorporate Zero Discharge Areas

An area within a development project can be designed to infiltrate, retain, or detain the volume of runoff requiring treatment from that area. The term "zero discharge" in this philosophy applies at stormwater treatment design storm volumes. For example, consider an area that functionally captures and then infiltrates the 80th percentile storm volume. If permits require treatment of the 80th percentile storm volume, the area generates no treatment-required runoff (UD and FC, 2011). Site design techniques available for designing areas that produce no treatment-required runoff include: Retention/Detention Ponds, Wet Ponds, Infiltration Areas, Large Fountains, Retention Rooftops and Green roofs (roofs that incorporate vegetation) and blue roofs (roofs that incorporate detention or retention of rain.

Infiltration areas, ponds, fountains, and green/blue roofs can provide "dual use" functionality as stormwater retention measures and development amenities. Detention ponds and infiltration areas can double as playing fields or parks. Wet ponds and infiltration areas can serve dual roles when meeting landscaping requirements (ERA, 2013). Figure 2-2 illustrates a residential tract, and a tract incorporating Zero Discharge Area techniques (infiltration areas). The Zero Discharge Area designed tract represents a design to infiltrate (i.e., achieve zero discharge from) a portion of the tract's runoff, reducing total runoff from the tract.

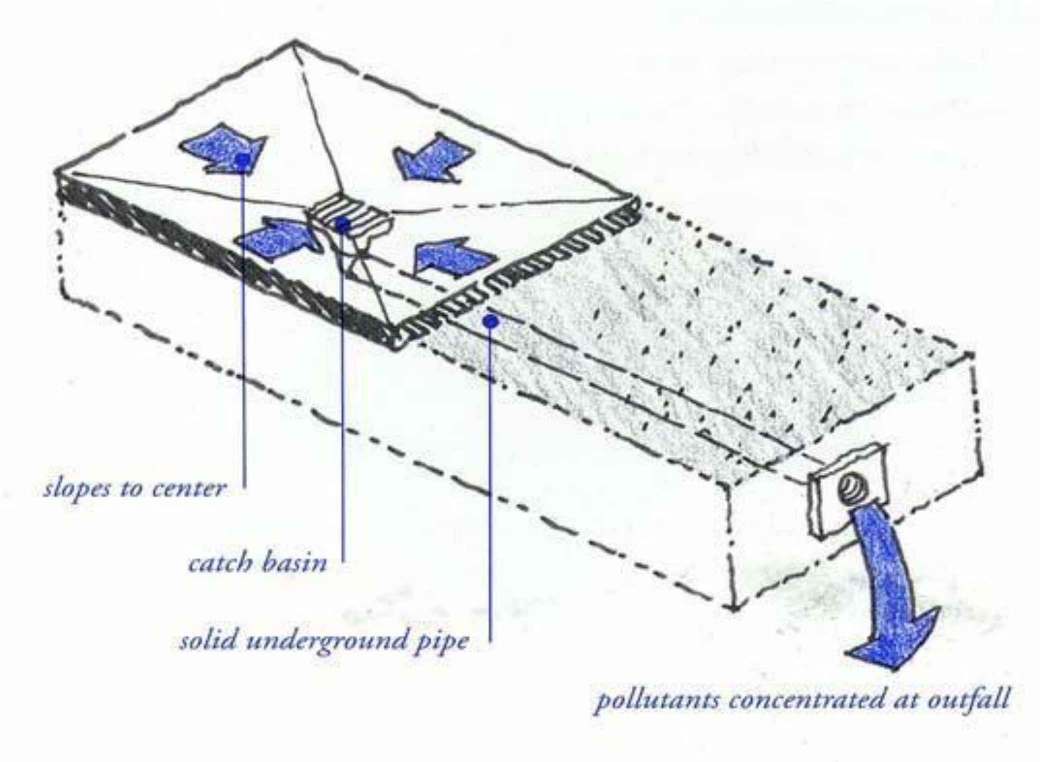

Figure 2-2: Directly connected impervious area

iv. Consider Runoff Reduction Areas

Using alternative surfaces with a lower coefficient of runoff or "C-Factor" may reduce runoff from developed areas. The C-Factor is a representation of the surface's ability to produce runoff. Surfaces that produce higher volumes of runoff are represented by higher C-Factors, such as impervious surfaces. Surfaces that produce smaller volumes of runoff are represented by lower C-Factors, such as more pervious surfaces (UD and FC, 2011).

2. Treatment Best Management Practice

The functions provided by BMPs may include volume reduction, treatment and slow release of the water quality capture volume (WQCV), and combined water quality/flood detention. Ideally, site designs will include a variety of source control and treatment BMPs combined in a treatment train that controls pollutants at their sources, reduces runoff volumes, and treats pollutants in runoff. Few examples of treatment BMPs for urban stormwater management are summarized below.

a. **Grass Swale:** Grass swales are densely vegetated trapezoidal or triangular channels with low pitched side slopes designed to convey runoff slowly. Grass swales have low longitudinal slopes and broad cross-sections that convey flow in a slow and shallow manner, thereby facilitating sedimentation and filtering (straining) while limiting erosion. Berms or check dams may be incorporated into grass swales to reduce velocities and encourage settling and infiltration (UD and FC, 2011).

b. **Grass Buffer:** Grass buffers are densely vegetated strips of grass designed to accept sheet flow from up gradient development. Properly designed grass buffers play a key role in LID, enabling infiltration and slowing runoff. Grass buffers provide filtration (straining) of sediment. Buffers differ from swales in that they are designed to accommodate overland sheet flow rather than concentrated or channelized flow (UD and FC, 2011).

c. **Bio-retention:** engineered, depressed landscape area designed to capture and filter or infiltrate the water quality capture volume (WQCV). BMPs that utilize bio-retention are frequently referred to as rain gardens or porous landscape detention areas (PLDs) (UD and FC, 2011).

d. **Green Roof:** Green roofs could be defined as "contained" living systems on top of human made structures. This green space can be below, at, or above grade involving systems where plants are not planted in the ground (UD and FC, 2011).

e. **Extended Detention Basin (EDB):** An extended detention basin (EDB) is a sedimentation basin designed to detain stormwater for many hours after storm runoff ends. This BMP is similar to a detention basin used for flood control, however; the EDB uses a much smaller outlet that extends the emptying time of the more frequently occurring runoff events to facilitate pollutant removal (UD and FC, 2011).

f. **Sand Filter:** A sand filter is a filtering or infiltrating BMP that consists of a surcharge zone underlain by a sand bed with an underdrain system (when necessary). During a storm, accumulated runoff collects in the surcharge zone and gradually infiltrates into the underlying sand bed, filling the void spaces of the sand. The underdrain gradually dewaters the sand bed and discharges the runoff to a nearby channel, swale, or storm sewer (UD and FC, 2011).

g. **Retention Pond:** A retention pond, sometimes called a "wet pond," has a permanent pool of water with capacity above the permanent pool designed to capture and slowly release the water quality capture volume (WQCV) over 12 hours. The permanent pool is replaced, in part, with stormwater during each runoff event so stormwater runoff mixes with the permanent pool water. This allows for a reduced residence time compared to that of the extended detention basin (EDB) (UD and FC, 2011).

h. **Permeable Pavement Systems:** The term Permeable Pavement System, as used in this case, is a general term to describe any one of several pavements that allow movement of water into e layers below the pavement surface. Depending on the design, permeable pavements can be used to promote volume reduction, provide treatment and slow release of the water quality capture volume (WQCV), and reduce effective imperviousness, etc. (UD and FC, 2011).

3. Source Control BMPs

Proactively controlling pollutants at their source is fundamental to effective stormwater quality management and is part of the Four Step Process. Typically, it is easier and more cost-effective to prevent stormwater pollution than to remove contaminants once they have entered the storm sewer system or receiving water. Local governments, industries, businesses and homeowners all have opportunities to implement source control practices that help prevent pollution. A good source control BMP is one that is effective at stopping and/or redirecting pollutants prior to entering the storm sewer system (ERA, 2013). A source control BMP can be a structural component of a planned site (e.g. a covered area for material storage) or a procedural BMP.

4. 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.

2.10 Model selection criteria

There are various computer-based modeling tools for modeling stormwater quantity and quality. By considering their availability, user friendly the following tools will be used for these work.

2.10.1 Stormwater management model (SWMM-5)

SWMM is a full dynamic wave simulation model used for single event or long-term simulation of runoff quantity and quality, primarily from urban areas. Version 5 is a completer-write of the previous release, running under Microsoft Windows and providing an integrated environment for editing data, running hydrologic, hydraulic and water quality simulations, and viewing the results. It conceptualizes a drainage system as a series of water and material flows between several major environmental compartments, namely: the atmosphere compartment, from which precipitation falls and pollutants are deposited onto the land surface compartment; the land surface compartment, which is represented by sub-catchment objects; the groundwater compartment, which receives infiltration from the land surface compartment and transfers a portion of this inflow to the transport compartment; and the transport compartment, which contains a network of conveyance, storage, regulation and treatment elements. Not all compartments need appear in a particular SWMM model (Abraha, 2018).

2.10.2 PCSWMM

PCSWMM is a third-party interface for SWMM and is developed by Computational Hydraulics Inc. (CHI). It is a GIS integrated model that uses SWMM 5.0 as the model computational engine for hydrologic and hydraulic calculations. It is a stand-alone modeling tool with all necessary IS-tools included and it has support for various CAD and GIS formats (Lind, 2015).

2.10.3 XPSWMM

XPSWMM is another hydraulic and hydrologic modeling tool from XP-solutions and has been used for analysis, design and simulations for over 25 years. Like XP Storm, XPSWMM includes stormwater and river systems/floodplains. Additionally, it also includes wastewater management. The model simulates 1D network flows in combination with 2D overland flows, LID structures and stormwater quality. The tool can be used for natural systems like for example ponds, rivers and lakes and manmade environments like pipes, conduits and streets (Lind, 2015).

2.10.4 CivilStorm

Another product from Bentley is Civil Storm. It is stormwater modeling software that models more aspects of the system than Storm CAD. Civil Storm is a dynamic model that accounts for storage, detention and flows over time and is therefore a more advanced modeling tool than Storm CAD. It is used for master planning, modeling the effect of LID Structures as well as studying the water quality (Lind, 2015).

Table 2-2: Comparison some features of the modelling tools

Some features of the modelling tools		**SWMM 5.0**	**PCSWMM**	**StormCAD**	**CivilStorm**	**XPSWMM**
Developer/ Publisher		EPA	CHI	Bentley	Bentley	XP Solutions
Water systems	Stormwater	Yes	Yes	Yes	Yes	Yes
	Wastewater	Yes	Yes	No	No	Yes
	River systems	No	Yes	No	No	Yes
Area of use	Water quantity	Yes	Yes	Yes	Yes	Yes
	Water quality	Yes	Yes	No	Yes	Yes
	Sewer system	Yes	Yes	No	No	No

	LID/ SuDs/ LOD/ WSUD	Yes	Yes	No	Yes	Yes
	Long term predictions/ single event	Both	Both	No	No	Both
	Simulation of 1D pipe flow	Yes	Yes	Yes	Yes	Yes
	2D Overland low	No	Yes	No	No	Yes
Import/ Export/ Connections	GIS	Interchange	Integration	Some conversion utilities from GIS databases	Some conversion utilities from GIS databases	Import/ Export
	CAD	No	Yes (various formats)	can be used within AutoCAD	can be used within AutoCAD	Import/ Export

source: - Johanna Lind, 2015 Stormwater modelling tools: - a comparison and evaluation

2.11 Design storm

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 capacity of the catchment (S) are easily calculable parameters using GIS tools.

3 Materials and Methodology

3.1 Description of study area

3.1.1 Location

Hawassa city is found in the Sidama zone of Sothern Nations, Nationalities and Peoples Regional State (SNNPR's). The city is a regional administrative capital as well as an important business center for the region. Moreover, it is also an important tourist destination site in the south whereby a number of foreign and domestic tourists visited the city. The town is located at a distance of 273 km south of Addis Ababa, the capital city of Ethiopia. The geographic coordinates of the town are; approximately 7^{o}03' latitude north and 38^{o}29' longitudes east (Brave, 2018).

The city covers an area of approximately 15,720 ha of which 6,465 ha is municipal boundary (area covered by structural plan) and the altitude ranges from 1656 to 2137 m above sea level (see figure 3.1). In different literatures the area of the city is reported differently. According to (Wondrade et al., 2014) the Hawassa City Administration covers an area of 16062 hectares (ha) and is sub-divided into eight Sub-Cities and 32 "Kebeles" The difference is raised due to their considered area of interest in their own study.

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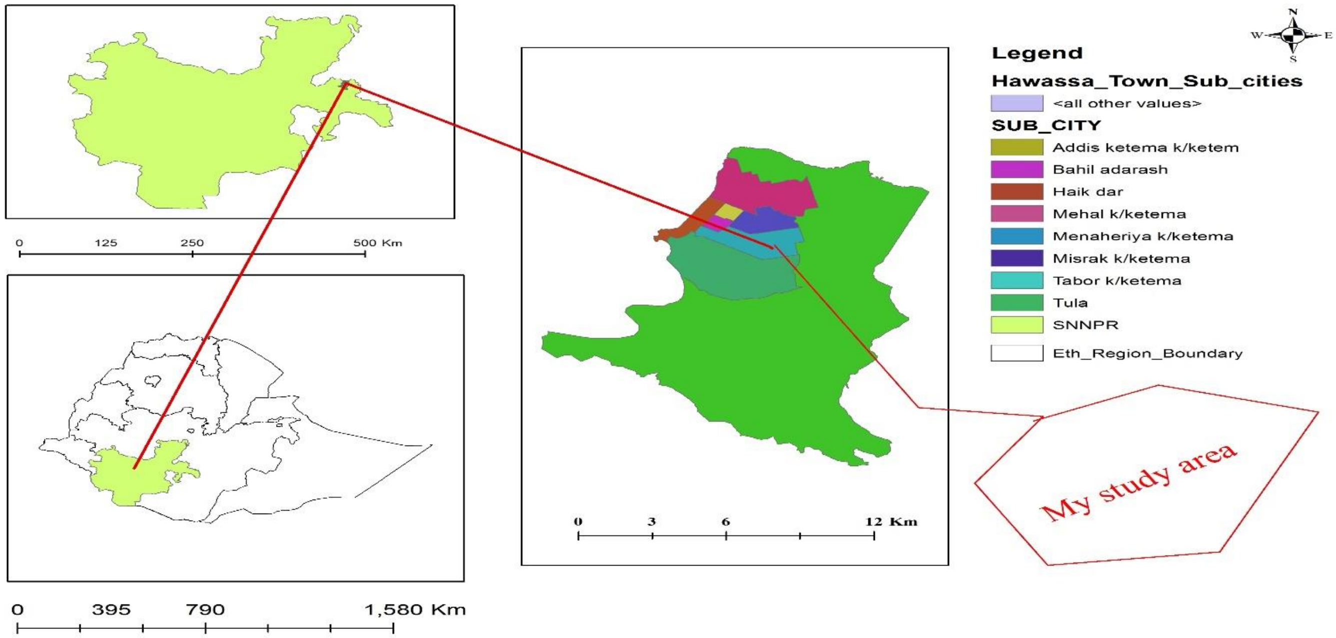


Figure 3-1: Location map of Hawassa city

3.1.2 Topography of the city

Hawassa city is situated at the eastern shore of Lake Hawassa close to eastern fault-belt of the central part and the great Ethiopian rift valley in a large volcano-tectonic collapse. The city is located on a plain between Lake Hawassa and Chelelaka wetland with general slope towards Lake Hawassa. The average elevation at the town is 1700m and that of the lake surface is 1680m above the sea level. The drainage of the town is towards the Lake Hawassa (Brave, 2018).

3.1.3 Rainfall of the city

Based on Hawassa meteorological station, the long term annual rainfall amount is computed to be 960 mm/year over the period of 1985-2016. The maximum annual rainfall observed in a year 2006 with an amount of 1198 mm and the minimum value observed in a year 2008 with a value of 704 mm. The annual maximum daily rainfall value of 110 mm depicted in a year 2000 and the minimum annual maximum value of 32.8 mm observed in a year 2008 over the 32 years (19585-2016).

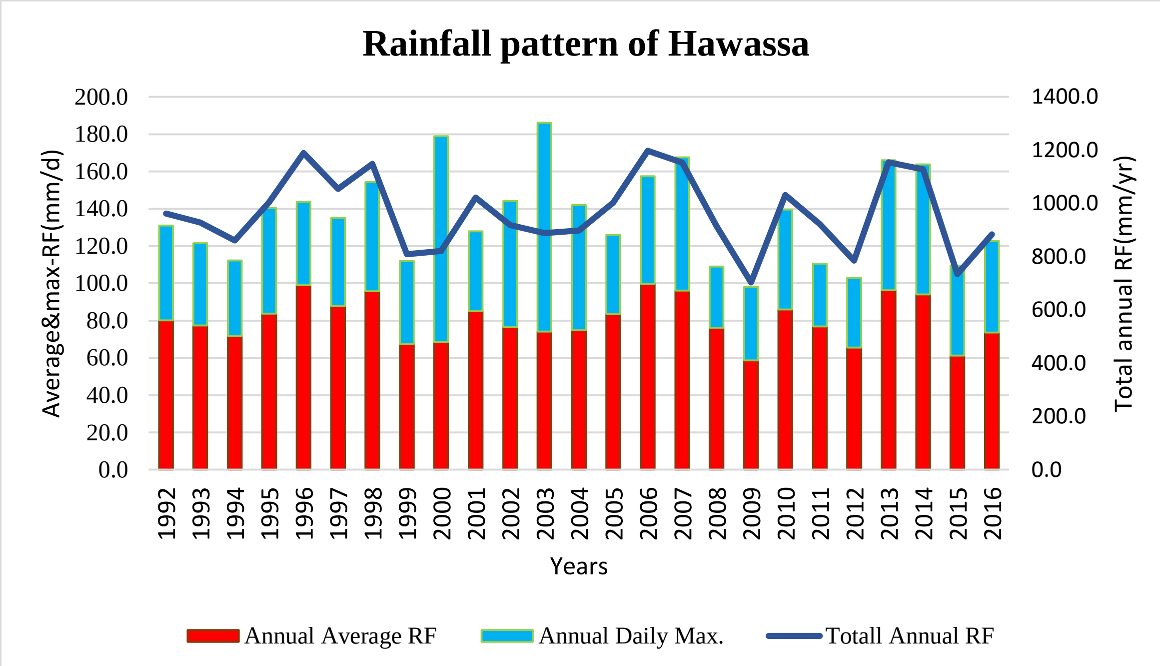


Figure 3-2: Daily maximum rainfall and annual rainfall with long-term mean annual

Figure 3.4 presents the long-term mean monthly rainfall over the period 1985-2016 in Hawassa. The rainfall distribution has a bi-modal pattern having two peaks observed in May (108.7 mm) and in August (113.65 mm) in a year which is computed over long-term average during the period 1985-2016.

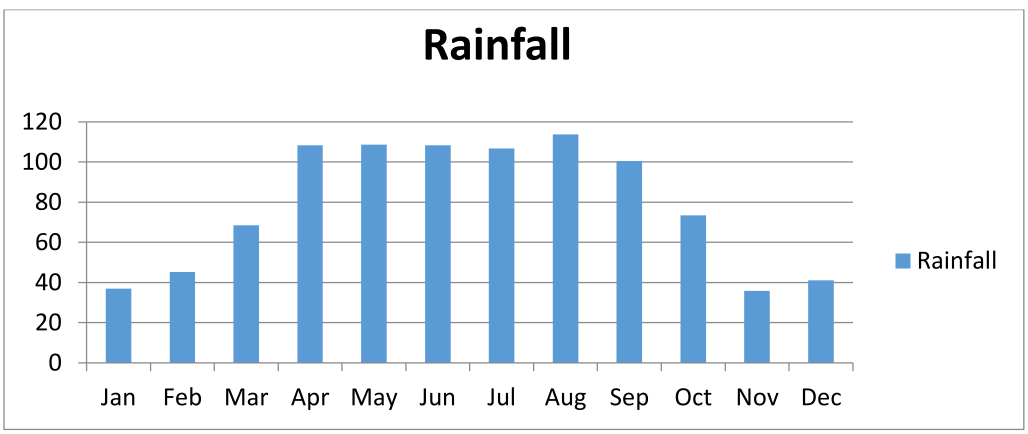


Figure 3-3: Mean monthly rainfall over the period 1985-2016 in Hawassa

3.1.4 Temperature of the city

The temperature of the city over the period 1985-2016 the maximum temperature is 29.7°C observed in a month's February and March whereas the minimum value of 24,2°C observed in a moth of July. The minimum air temperature maximum value observed in a month of July14.4°C and the minimum value of 10°C observed in a month of December.

3.1.5 Land use of the city

Urbanization in Hawassa is expanding at an alarming rate. Imperviousness due to many built up areas had been started since, 2006. A recent study (Wondrade et al., 2014) reported that the built areas increased about 234.5% between the years 1987 to 2011. According to the city municipality study 2018 based on 2017 satellite imagery about nine land use types are classified.

3.1.6 Population characteristics

According to the Southern Nation Nationalities People Regional States Finance and Economy Bureau, the population in the city is increasing over time. Figure3.4 shows that the population in 2006, 219,023 increased to 355,405 in 2015, which is increased about 62.27% over 10 years. The increment in built up area and many development e.g. factories and industries necessitate the proper design of drainage canal in the city.

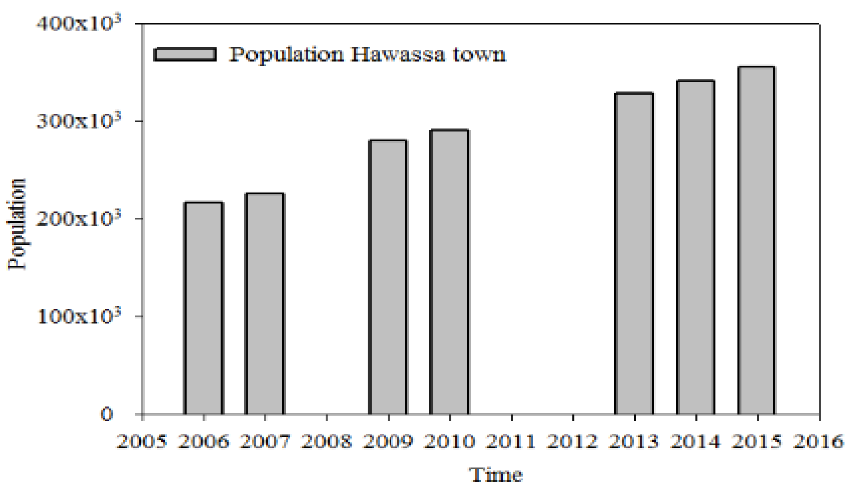


Figure 3-4: Population of Hawassa City (2006-2015)

3.1.7 Socio-economic activities

There are large and diversified modern investments activities such as hotels and tourism, social services, real estate development, small and large industries including Hawassa industrial park and constructions in the town. There is one university with additional three independently located faculties, one teachers training institute, one Health College, two TVET centers, and a number of private health, engineering and other educational colleges; and schools (Wondrade et al., 2014).

3.1.8 Geology, hydrogeology and soil

The Lake Hawassa catchment represents a Pliocene-age faulted caldera, underlain by fractured volcanic. The soil in the Hawassa city is the clay loam/ sandy loam is dominant texture.

The Hawassa city is a result of volcano tectonic movement situated in the central part of the great Ethiopian rift valley. Shallow ground water occurs around the lakes, springs and marshy are in the lacustrine deposits. Deep ground water occurs in the underlying fractured acid volcanic products mainly of ignimbrites, tuffs and rhyolites. The springs and ground water table around the lake show that the ground water has hydraulic continuity with the lake. The recent continuous lake level rise seems due to continuous supply of the ground water to the lake (W.W.D.S.E, 2001).

With all those mentioned services, the city needs proper stormwater drainage system with required facilities to convey the runoff into the outfall areas (final destinations). Nevertheless, the city stormwater drainage system has created flooding problem in various location immediately after rainfall events. Solving this serious drainage problem is vital from the perspective of social, economic and environmental consideration. Apart from the flooding problem, stormwater from Hawassa city is identified as one of the pollution source to the Lake Hawassa and the eco-system as well (Girma et al., 2014).

3.2 Materials used

The following materials have been used to conduct this research:

1. **Contour map (Topo map):** In order to successfully delineate a watershed boundary, it is needed to visualize the landscape as represented by a topographic map. This map helps to examine the elevation, determine flow direction and flow length of the catchment areas.

2. **Base map:** to look into the overall conditions of urban Stormwater drainage system, natural water ways/rivers and integration of stormwater drains and roads in the study area. The first step in the development of a concept storm drainage plan is preparation of a project base map. The base map should identify the watershed areas and subareas, land use and cover types, soil types, existing drainage patterns, and other topographic features. This base information is then supplemented with underground utility locations (and elevations if available), a preliminary roadway plan and profile, and locations of existing and proposed structures.
3. **Tape meter:** to measure the existing stormwater drainage lines length, depth and width which helps to evaluate the capacity of the drainage system.

3.3 Methodology

Evaluating urban stormwater 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 stormwater drainage system. Whereas, the exploratory type was particularly used to explore the existing condition of urban stormwater drainage facilities which have been used by the selected study area and best management practices for the existing drainage problems.

3.3.1 Research design

3.3.1.1 Study area selection

Purposive sampling technique was involved in this study. Evaluating the whole catchment is not necessarily important to come up with solution for stormwater drainage problem. Therefore, some representative major flood prone areas are selected. This study conducted on drainage line starting from Wolde Amanuel circle to Wanza circle. This line is selected for this study because of its influence to drainage line starting from Wanza circle to old Bus station has been facing high flooding during the rainy season.

3.3.1.2 Data source and collection

This part contains types, sources and collection method of data which were used in this study. Consequently, the qualitative as well as quantitative type of data has been used for this research.

A. Data location

The daily rainfall data of four recording station in the study area were collected from Ethiopian national meteorological service agency as shown below in table 3.1

Table 3-1: Location and year of recording rain gauge station at the sites.

No.	Station Name	Latitude	Longitude	Year of records
1	Lake Hawassa	**38.483067.065**	**7.065**	32
2	Hawassa Tabore	**538.48306**	**7.05**	11
3	Tula	**9538.48306**	**6.95**	11

B. Data type

Both primary and secondary data types were used in this study. Field survey or observation was the primary data sources which were engaged in this study. Meteorological data (climatic data, rainfall data) from National Meteorological Agency of Ethiopia, contour map, other findings/ literatures and reports were Secondary data sources which that were used for this particular research

C. Data collection

Field survey was employed to measure the dimensions of drainage lines located in the study area, to gather information about the current condition of the drainage system with the help of base map, and contour map as per the objective of this study.

3.3.2 Rainfall data analysis

3.3.2.1 Filling missing data

Table 3-2: The percentage of missed data at each stations.

Stations	Observed Year	Available data(day)	Observed data(day)	Missing data(day)	% of missing
Lake Hawassa	32	11315	10690	625	**5.5236**
Hwassa Tabore	11	4015	3161	854	**21.27**

Tulla	11	4015	3090	925	**23.039**

Hawassa Station having inadequate daily records were identified and considered to be missed. The station missed information in percentage presented in (Table 3.2). The missed data is less than 30%, the available data is representative. Therefore, the missed values were filled for the given stations by simple Regression method using equation:

$$P_X = b_o + b_1 P_1 + b_2 P_2 + \ldots + b_n P_n$$

Where

P_X is the missing precipitation value for station X for certain time period

P_1, P_2, …, P_n are precipitation values at the neighboring stations for the same period

b_0, …, b_n are coefficients calculated by least-squares methods

n is the number of nearby gages

Method suitable when there is a large number of days when observations are available for all gages

3.3.2.2 Data processing and quality checking

1. Data quality checking for consistency

The consistencies of the data set of the given stations were checked by the double mass-curve method in-reference to their neighborhood stations. The double mass curve was plotted by using the annual cumulative total rainfall of the base station as ordinate and the average annual cumulative total of neighboring stations as abscissa.

2. Data quality checking for higher and lower outlier

From the annual daily maximum rainfall data, the highest and lowest values are 112 mm and 32.8 mm respectively are less than the higher outlier and greater than lower outlier 112.823 mm and 25.2205 mm respectively. Therefore, no higher and lower outlier data are eliminated.

3.3.2.3 Frequency analysis

i. Design rainfall estimation from daily time step

Frequency analysis of the rainfall data were conducted to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions (District, 2011). The design rainfall was determined by frequency analysis from previous years' rainfall data of the study area. Furthermore, the IDF curve were also developed using the frequency analysis.

The historical rainfall data available for the study area was a 24-hour duration rainfall hence an appropriate IDF reduction method were used to obtain rainfall intensities of shorter duration. The IDF reduction method used in this study were suggested in Ethiopian Road Authority Drainage Design Manual 2013 is used for this study.

ii. Fitting the probability distributions

For the selection of the appropriate distribution function to compute the maximum rainfall events for desired return periods, the extracted annual maximum rainfall data series for durations of 24 hours arranged in descending order of magnitude were fitted against Gumbel (Extreme Value Distribution Type I) and Log Pearson Type III distributions using the frequency analysis technique.

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

Fitting the data to Gumbel-Extreme Value Distribution Type I distribution

It is based on the assumption that the cumulative frequency distribution of the largest values of samples drawn from a large population can be described by the following equation:

$$F(X)= e{-}e\alpha(X{-}\beta)\ where\ \alpha\ and\ \beta.$$

Computing the magnitude of an extreme event in excel Given return period and; maximum annual rainfall data

- Compute Annual extreme values using =max (Y_o) function, where Y_o represents all record of 24-hour daily rainfall data
- Compute sample parameters i.e. minimum, Average, standard deviation and coefficient of skewness by using equations $Y_T{=}{-}\ln[\ln(T/T{-}1)]$ and X_T= $X_{(mean)}$+K_TS where, X_T is event

magnitude of the record, $X_{(mean)}$ and S are the mean and standard deviation of sample data. Y_T is the reduced variate of a given return period T and S_n is the reduced mean and standard deviation as a function of sample size n, respectively. Their values are read from the tables (Subramanian, 2008). The result is tabulated for different return period.

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

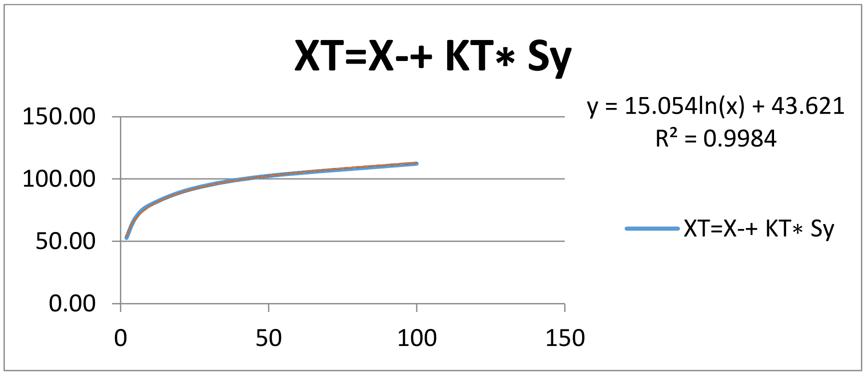


Figure 3-5: Fitting distribution test by Gumbel-Extreme Value Distribution Type I (logarithmic fit)

Fitting the data to Log Pearson Type III distribution: - is a three-parameter gamma distribution with a logarithmic transform of the variable. Mean, standard deviation, and coefficient of skew are the three necessary parameters that are necessary to describe the distribution. Using the Log Pearson Type III distribution, the frequency factors corresponding to the annual maximum rainfall magnitude were estimated the following procedure in excel.

The methods employed in Ms. Excel are as follows

- Transform the data to log
- Calculate sample parameters of log data i.e. $Y_{(average)}$, S_y, coefficient of skewness
- Using return period and coefficient of skewness read K value from table
- Calculate $Y_T = Y_{(average)} + KS_Y$
- Calculate $X_T = 10^{\wedge}Y_T$
- Then R-squared value test was carried to obtain best fitted distribution methods

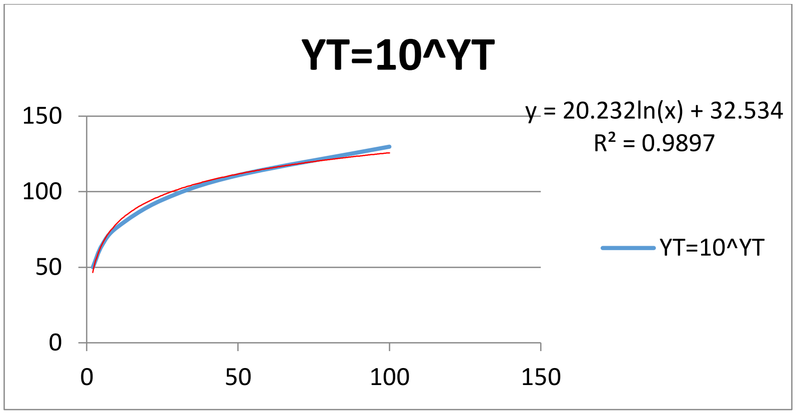


Figure 3-6: Fitting distribution test by Log Pearson Type III

iii.**Design rainfall of shorter duration**

The rainfall depths obtained from gauging station are of 24hr duration depth. Design and analysis of drainage structures require rainfall intensity duration relationship of shorter duration. Because rainfall data of shorter duration is unavailable appropriate IDF derivation for shorter duration is required. Ethiopian Road Authority Drainage Design Manual of 2013 suggests the following equation.

$$RRt = t(b + 24)^n/24(b + t)^n$$

Where:

RRt = Rainfall depth ratio (R_t: R_{24})

Rt = Rainfall depth in a given duration t

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

The methods employed to develop IDF curve for the shorter duration events using the above equations were as follows:

- Using Gumbel-Extreme Value Distribution Type I method of frequency analysis, R24 were calculated for 2, 5, 10, 25, 50 and 100-year return period.
- Rearranging the above equation gives

$$R_t = t(b+24)^n / 24(b+t)^n * R24$$

- Intensity (mm/hr) $I_t = R_t$ / t. Substituting in the above equation gives

$$I_t = R_{24}(b+24)^{n} / 24(b+t)^{n}.$$

- The resulting table is graphed for each return period.

3.4 Existing drainage system

From field survey, site visit and the cities CAD file document, stormwater drainage system consists mainly of open channel drainage/ rod side (ditches and culverts). The stormwater drainage system collects the runoff and discharges into lake Hawassa through numerous directions. In this study evaluation was carried by taking a case study i.e. stormwater drainage contributing to Wanza square (see figure 4-1).

3.5 Stormwater modelling

The model was developed in Bentley CivilStorm vi8 software. The software offers comprehensive hydrologic and hydraulic modelling capabilities and is used internationally for stormwater, sanitary sewer, and watershed modeling's. The following sections provide an overview of stormwater model development processes as well as its limitations i.e. model calibration as stated in scope and limitation part of this document.

3.5.1.1 Hydraulic model overview

The first task was to construct the physical network of the drainage system which includes components such as stormwater ditches, ditch cross-sections, catchments, and outfalls. Various modelling elements in Bentley Civil Storm vi8 software were used to represent these drainage components in the model and are summarized in Table 3-5.

Table 3-5: Summary of Model Elements

Bentley CivilStorm vi8 elements	Used to Represent	Elements (by number)
Junctions	Catch basin	NA
	Manhole	NA
	Transition	NA
	Cross sections for connecting	87
	Ditch sections	
Layout	Conduit	NA

	Channel	82
	Gutter	
Outfall	Discharge location such us to water bodies	2
Catchment	Catchments	66

NB. NA: - Not applicable

Each modelling element has a specific set of input data requirements, most of the data was available from the Citiy CAD files, which was the primary input for developing the drainage model. The CAD files were imported into Bentley CivilStorm vi8 software as background and the model elements were developed. Field survey data were used as supplementary sources of data to develop the model. The following subsections provide further descriptions of the approach used and assumptions applied to each of the modelling elements.

i. Cross-sections

In a conveyance system, cross-sections are the nodes where links (channels) join. The model cross sections were created in the model from road drainage CAD file that was imported to Bentley CivilStorm vi8. The principal input parameters for cross-sections are ground elevations, invert elevations, cross-section type, materials which the drainage was constructed and roughness type. The primary sources for the input parameter were field survey and contour data.

ii. **Channels**

The ditches were modelled as channel in the hydraulic model. The principal input parameters for channels are invert start, invert stop elevations, length, and Manning's roughness coefficient (n) and material type. Approximately 6 km of ditches were modelled. The ditch cross sections were assumed to be rectangular based on field survey data and the material type were known i.e. stone masonry, since no information about the cross section were available. The cross sections were modeled as irregular cross section in the model. The existing depth and width were measured using tap meter and location navigator. Finally, the manning's roughness coefficient used for ditches is applied as 0.032 for stone masonry from the software catalog.

iii. Outfall

Deadly nodes within the drainage system were modelled as outfalls in the drainage model. They represent outfall discharges into rivers, lakes or pond. The invert elevations and ground elevations are principal input parameters for outfall. A “free” outfall condition is assumed for the modelled outfall. Since the basic aim of this study was to identify the flooding causes at wanza square, the researcher considers wanza square as outfall.

3.5.1.2 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, stormwater 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. The runoff is then applied directly to the receiving channel. The following describes our approach to delineating the drainage sub-catchments in the study area as well as the runoff calculations completed for each of the sub-catchments.

a. Catchment delineation

Sub-catchments are hydrologic units of land whose topology and drainage system elements direct surface runoff to a single discharge point. Evaluating the whole catchment is not necessarily important to come up with solution for stormwater drainage problem. In this study representative major flood prone area contributing to Wanza square were analyzed. The natural catchment area was delineated using Arc Hydro tools 10.3 based on DEM as input and the shape file was imported in to the software and overplayed with the CAD flow direction of drainage line, the sub-catchments was traced based on blocks polygon in the hydraulic model. The area which is 134.796 (ha) covers part of wolde Amanuel square to wanza square had been delineated to investigate the hydraulic performance of the existing drainage system with respect to hydrology. This area was used for computation of discharge using rational method.

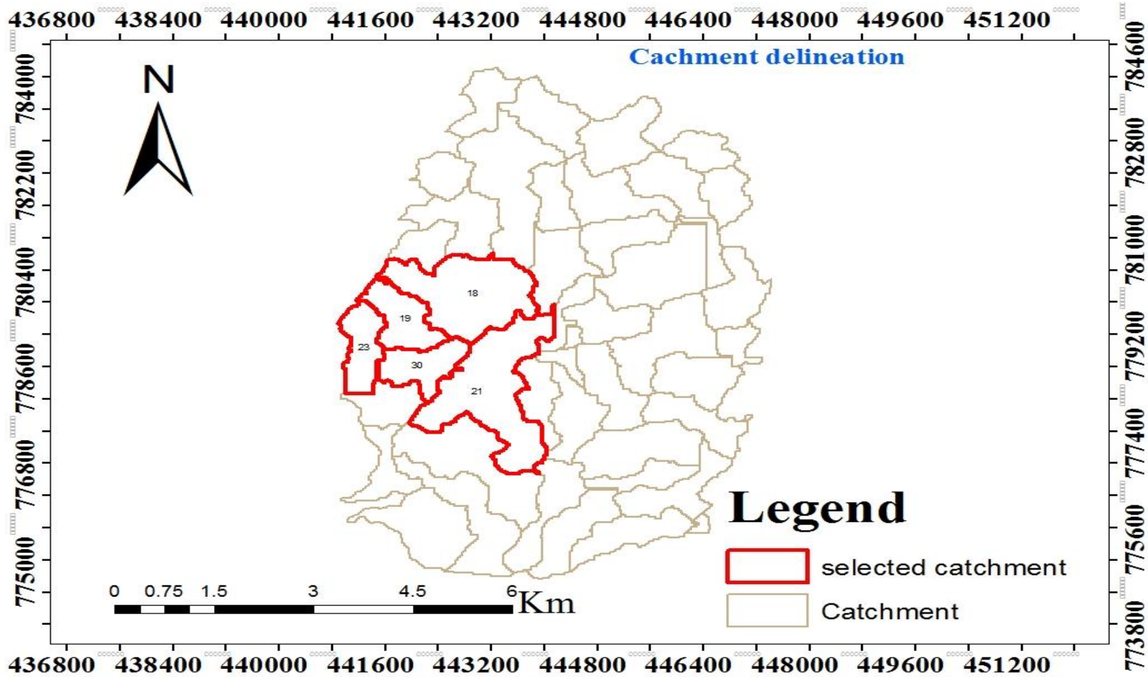


Figure 3-7: Selected major catchments

b. Runoff calculation

Once all the sub-catchments have been delineated and a discharging channel assigned, the Rational Method was used to determine their runoff rates. The runoff is then applied directly to the discharging channel in the model for capacity assessment. It is one of the most commonly used equations for the calculation of peak flow from small areas is the Rational/ modified rational formula, given below.

$$Q = 0.278CIA$$

Where, n=manning's roughness coefficient

A= Area of the channel (m

P= Wetted perimeter (m)

S= Channel bed slope (m/m)

- Assumptions inherent in the Rational formula are as follows:
- Peak flow occurs when the entire watershed is contributing to the flow.
- Rainfall intensity is the same over the entire drainage area.

- Rainfall intensity is uniform over a time duration equal to the time of concentration, Tc. The time of concentration is the time required for water to travel from the hydraulically most remote point of the basin to the point of interest.
- Frequency of the computed peak flow is the same as that of the rainfall intensity, i.e., the 25-year rainfall intensity y is assumed to produce the 25-year peak flow.
- Coefficient of runoff is the same for all storms of all recurrence probabilities.

c. Runoff coefficient (C) determination

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.

$$C = \sum \frac{Ci * Ai}{At}$$

Where,

C = weighted runoff coefficient

Ci = individual runoff coefficient

Ai = individual land use area

At = total land use area

The table 3.3 was used to assign runoff coefficient to study area.

Table 3-3: Runoff Coefficient for Use in Rational Method, (ERA, 2013)

<table>
<tr><th colspan="2">Type of Drainage Area</th><th>Runoff Coefficient C</th></tr>
<tr><td colspan="2">Business: Downtown areas</td><td>0.7-0.95</td></tr>
<tr><td colspan="2">Neighborhood areas</td><td>0.5-0.7</td></tr>
<tr><td rowspan="3">Residential</td><td>Single-family</td><td>0.3-0.5</td></tr>
<tr><td>Multi units, detached</td><td>0.4-0.6</td></tr>
<tr><td>Multi units, attached</td><td>0.6-0.75</td></tr>
</table>

	Suburban	0.25-0.4
Residential (0.5 hectares lots or more)		0.3-0.45
Apartment dwelling areas		0.5-0.7
Industrial	Light areas	0.5-0.8
	Heavy areas	0.6-0.9
Parks, cemeteries		0.1-0.25
Playgrounds		0.2-0.4
Railroad yard areas		0.2-0.4
Unimproved areas		0.1-0.3

d. Time of concentration determination

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

1. 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:

$$Tt = L/(3600V)$$

Where:

Tt = 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

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

Where:

V= average velocity, m/s

R= hydraulic radius, m (equal to a/pw) A = cross sectional flow area, m2

Pw = wetted perimeter, m

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

2. Sheet flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams and its determined from the friction value (Manning' s n) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment.

$$Tt = [0.091\ (n\ L)^{0.8} / (P_2)^{0.5}\ S^{0.4}]$$

Where:

Tt = travel time, hr.

n = Manning's roughness coefficient L = flow length, m

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

s = slope of hydraulic grade line (land slope), m/m,

Manning's kinematic solution is based on the following assumptions.

- Shallow steady uniform flow,
- Constant intensity of rainfall excess (rain available for runoff),
- Rainfall duration of 24 hours, and
- Minor effect of infiltration on travel time

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 ditches ditch material type and assigning the value from the software catalog.

4 Result and Discussion

4.1 Current condition of the study area

From field survey, field observation and interviewing the community the current status of the stormwater drainage system has been investigated. The sample collected existing stormwater drainage conditions are presented in table 4.1 and the rest of the collected data was given in the APPENDIX C.

Table 4-1: Sample urban stormwater drainage condition: Field survey, 2018.

Road Start	**Road End**	**Position**	**Drainage Type**	**Length**	**Width**	**Depth**	**Condition**
Atote Trafic Light	Wanza square	Left	Open	1136	0.6	0.7	Fair
Atote Trafic Light	Wanza square	Right	Open	1121	0.6	0.7	Fair
Wanza square	Old Bus station	Left	Open	541.35	2.1	0.7	poor
Wanza square	Old Bus station	Right	Open	541.35	0.8	1.2	poor
Wolidiamanuel square	Wanza square	Left	Open	1646	1.1	0.45	Good
Wolidiamanuel square	Wanza square	Right	Open	1491	1.25	0.55	Good

NB. All of the drainage lines are rectangular in shape, constructed by stone masonry

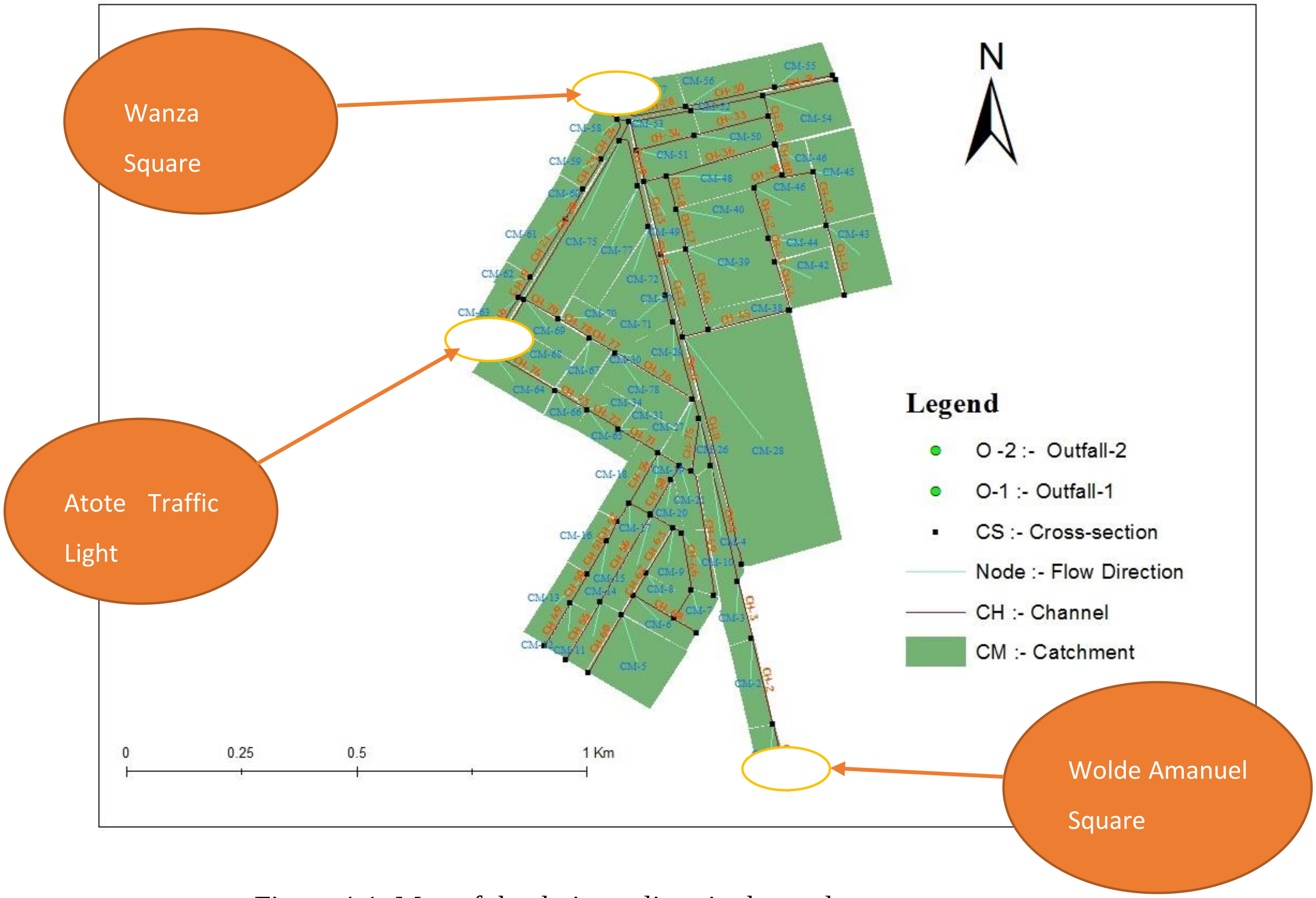


Figure 4-1: Map of the drainage lines in the study area

4.1.1 Capacities of the existing drainage system in the study area

Urban stormwater drainages are designed based on different criteria so that they can give better services regarding to safely removing the urban runoff in to the water ways. Flooding over asphalts, walkways and near the residences has been such a big problem in these drainage line.

Therefore, an effort has been done here to evaluate the capacity, and performance of these drainage systems. Since there is no recorded data about the dimensions of these drainage systems a field survey was made to measure their dimensions so that the amount of discharge conveyed in the existing drainage system could be determined. Table 4.2 shows a sample calculation of the discharge that is conveyed through the existing drainage system by using the manning’s formula. The rest of the result is given in the APPENDIX D.

Table 4-2: Capacity of the existing drainage system (own analysis by flow master, 2018)

No.	Flow direction		n	S (m/m)	D (m)	W (m)	R(m)	P (m)	A (m²)	V (m/s)	Q (m³/s)
	From	To									
1	CH-1	CH-2	0.032	0.047	0.55	1.25	0.29	2.35	0.69	2.99	2.05
2	CH-2	CH-3	0.032	0.055	0.55	1.25	0.29	2.35	0.69	3.23	2.22
3	CH-3	CH-4	0.032	0.026	0.55	1.25	0.29	2.35	0.69	2.22	1.53
4	CH-4	CH-5	0.032	0.026	0.55	1.25	0.29	2.35	0.69	2.22	1.53
5	CH-5	CH-6	0.032	0.026	0.55	1.25	0.29	2.35	0.69	2.22	1.53
6	CH-6	CH-7	0.032	0.013	0.55	1.25	0.29	2.35	0.69	1.57	1.08
7	CH-7	CH-8	0.032	0.014	0.55	1.25	0.29	2.35	0.69	1.63	1.12
8	CH-8	CH-9	0.032	0.01	0.55	1.25	0.29	2.35	0.69	1.38	0.95
9	CH-9	CH-10	0.032	0.011	0.55	1.25	0.29	2.35	0.69	1.44	0.99
10	CH-10	CH-25	0.032	0.02	0.55	1.25	0.29	2.35	0.69	1.95	1.34
11	CH-25	CH-26	0.032	0.02	0.7	0.7	0.23	2.1	0.49	1.68	0.82
12	CH-26	CH-82	0.032	0.021	0.7	0.7	0.23	2.1	0.49	1.72	0.84
13	CH-82	O-2	0.032	0.01	0.7	2.1	0.42	3.5	1.47	1.75	2.58

4.2 Hydrology analysis by using Bentley CivilStorm

4.2.1 Intensity duration frequency curve

The IDF curve is developed from a 24-hour rainfall data of 32 years' duration i.e. from 1985 to 2016, obtained from Ethiopia n Meteorological Agency. Downscaling equation as depicted in the methodology section have been applied. Consequently, the following IDF curve has been produced. The data obtained for production of IDF curve is the result of calculations using downscaling formula stated by Ethiopian road authority and it is tabulated below. Then, it has been compared with computed by ERA for the station. The ERA computation is reported in appendix A

Table 4-3: IDF table

Duration(mint)	T = 2	T = 5	T = 10	T = 25	T = 50	T= 100
5	88.6274	115.362	133.063	155.428	172.02	188.489
10	75.9663	98.8819	114.054	133.224	147.445	161.562
15	67.5256	87.895	101.381	118.421	131.063	143.611
20	58.5574	76.2215	87.9167	102.694	113.656	124.537
30	47.479	61.8012	71.2838	83.265	92.1534	100.976
60	30.5976	39.8274	45.9384	53.6597	59.3878	65.0735
90	22.8602	29.7561	34.3218	40.0906	44.3702	48.6182
120	18.2003	23.6905	27.3254	31.9183	35.3255	38.7075
130	17.2872	22.502	25.9546	30.317	33.5533	36.7657
140	16.5046	21.4833	24.7796	28.9445	32.0343	35.1012
160	14.6393	19.0554	21.9792	25.6734	28.414	31.1343
180	13.1886	21.4833	19.801	23.1292	25.5982	28.0489

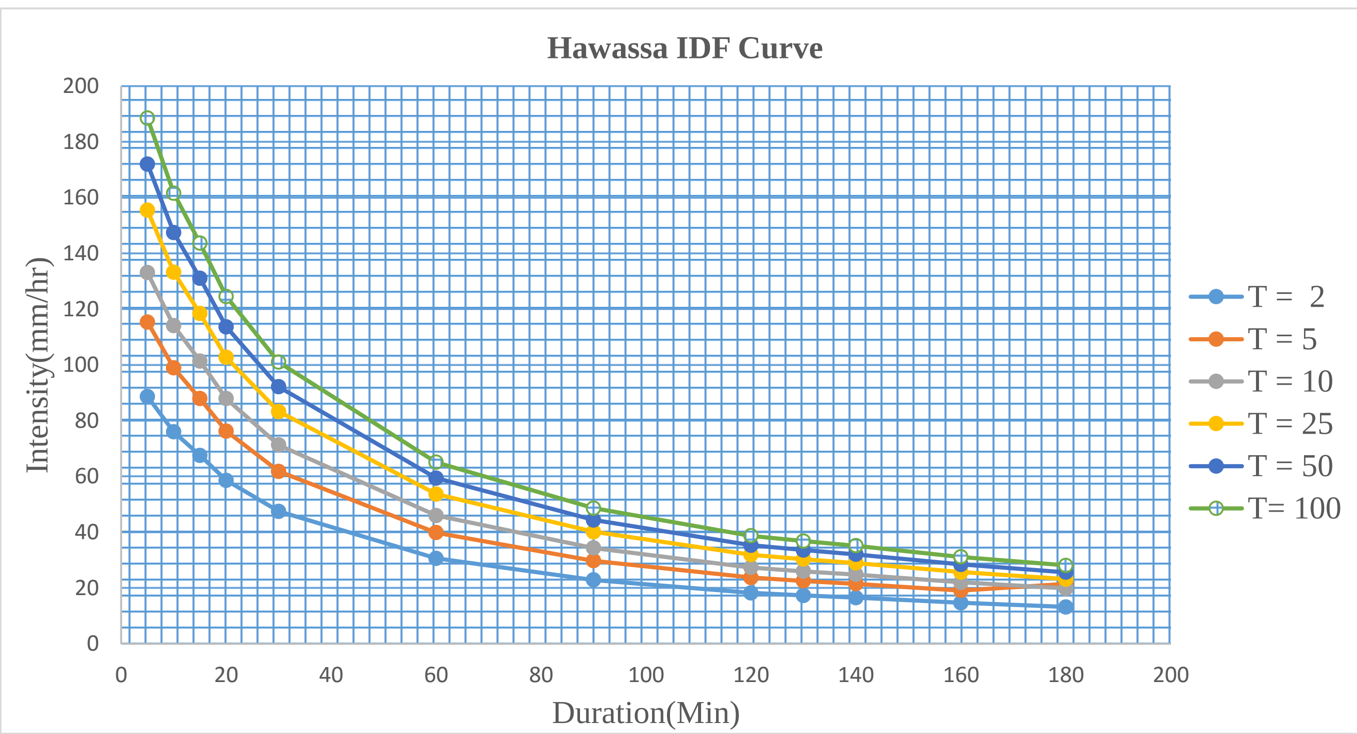


Figure 4-2: Intensity duration Frequency Curve Lake Hawassa station (1985-2016)

Because of these inherent assumptions, the Rational formula should only be applied to drainage areas smaller than up to 50 ha

4.2.2 Bentley civil storm simulation result for channels

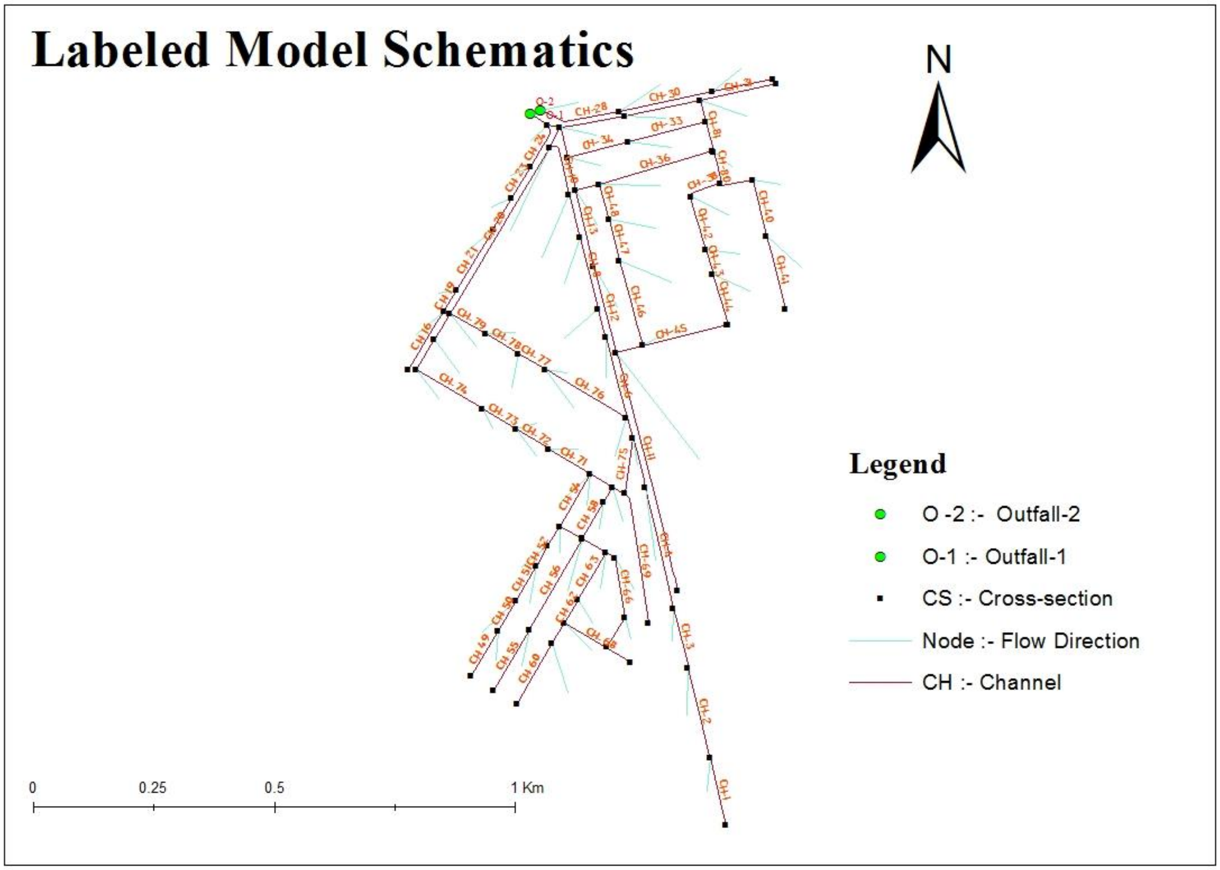


Figure 4-3: Channels label

In order to evaluate the capacities of the drainage system the current runoff has to be estimated by using CivilStorm software. Therefore, this part was prepared to briefly the hydrologic investigation and evaluation of major and minor stormwater drainages of the selected roots which includes road starts from Atote to wanza square, Road to Nock from wanza square and road starts from wolde Amanuel square to Wanza square and other minor drainage lines for minor roads. Most of minor roads were cobblestone surfaced and the major ones were Bitumen Asphalt road. obtained sample result were presented in table 4.3. The rest of the result is given in the APPENDIX E.

Table 4-4: Model result for Channels

No.	**Flow direction**		**Section type**	**Flow (m^3/s)**
	From	**To**		
1	CH-1	CH-2	Rectangular	0.02
2	CH-2	CH-3	Rectangular	0.049
3	CH-3	CH-4	Rectangular	0.094
4	CH-4	CH-5	Rectangular	0.119
5	CH-5	CH-6	Rectangular	0.182
6	CH-6	CH-7	Rectangular	0.278
7	CH-7	CH-8	Rectangular	0.32
8	CH-8	CH-9	Rectangular	0.357
9	CH-9	CH-10	Rectangular	0.413
10	CH-10	CH-25	Rectangular	0.465
11	CH-25	CH-26	Rectangular	1.518
12	CH-26	CH-82	Rectangular	2.883
13	CH-82	O-2	Rectangular	3.041

4.2.3 Comparison of hydraulic capacity and model runoff

The hydraulic capacities of the open channels in the study area were determined using the flow master. Accordingly, the peak rate of runoff and hydraulic capacities of the channel constructed were computed and the obtained sample result were presented in table 4.5.

Table 4-5: Comparison of peak runoff rate and hydraulic capacity of channels.

No. (1)	Flow direction		Section type (4)	Model Flow Q (m^3/s) (5)	Hydraulic capacity Q (m^3/s) (6)	Difference (7) (6-5)
	From (2)	To (3)				
1	CH-1	CH-2	Rectangular	0.02	2.05	2.03
2	CH-2	CH-3	Rectangular	0.049	2.22	2.171
3	CH-3	CH-4	Rectangular	0.094	1.53	1.436
4	CH-4	CH-5	Rectangular	0.119	1.53	1.411
5	CH-5	CH-6	Rectangular	0.182	1.53	1.348
6	CH-6	CH-7	Rectangular	0.278	1.08	0.802
7	CH-7	CH-8	Rectangular	0.32	1.12	0.8
8	CH-8	CH-9	Rectangular	0.357	0.95	0.593
9	CH-9	CH-10	Rectangular	0.413	0.99	0.577
10	CH-10	CH-25	Rectangular	0.465	1.34	0.875
11	CH-25	CH-26	Rectangular	1.518	0.82	**-0.968**
12	CH-26	CH-82	Rectangular	2.883	0.84	**-2.043**
13	CH-82	O-2	Rectangular	3.041	2.58	**-0.461**

As some of the existing drainage systems are overtopped during heavy rainfalls. The road side drains, walkways and the asphalt are flooded sometimes even during average storm. As it can be seen from table 4.5, all the channels except that of channel (CH-25, CH-26 and CH-82) are sufficient to carry the runoff water contributed to them with regard to their hydraulic property. This show that the hydraulic capacity of the channels at the Wanza square is insufficient to carry runoff generated based on 10 years of return period design discharge. The main problem of this area is in sufficient capacity of the channel and inlet sizes of the culverts, which did not design based on the contributing catchment area. The contributing catchment area is 76.936ha. To overcome this problem resizing the drainage system for both inlets and channels are mandatory. Also changing the channels section is an alternative way to reduce the flooding problem.

4.2.4 Bentley civilstorm simulation result for catchment

In this study, the runoff generated from the drainage basin was determined based on urban stormwater drainage design manual of our country recommended by Ethiopian Road Authority drainage manual 2013. It recommends Rational method, where the drainage basin area is less than 50 ha. The peak rate run off were simulated using rational method in Bentley CivilStorm Vi8 software.

The study area was divided in to 66 sub-catchment areas for modeling with Bentley CivilStorm Vi8 software. The required parameters determined for each sub catchment to input for running the simulation and the obtained sample results are indicated in table 4-6 and the other result is indicated in APPENDIX F.

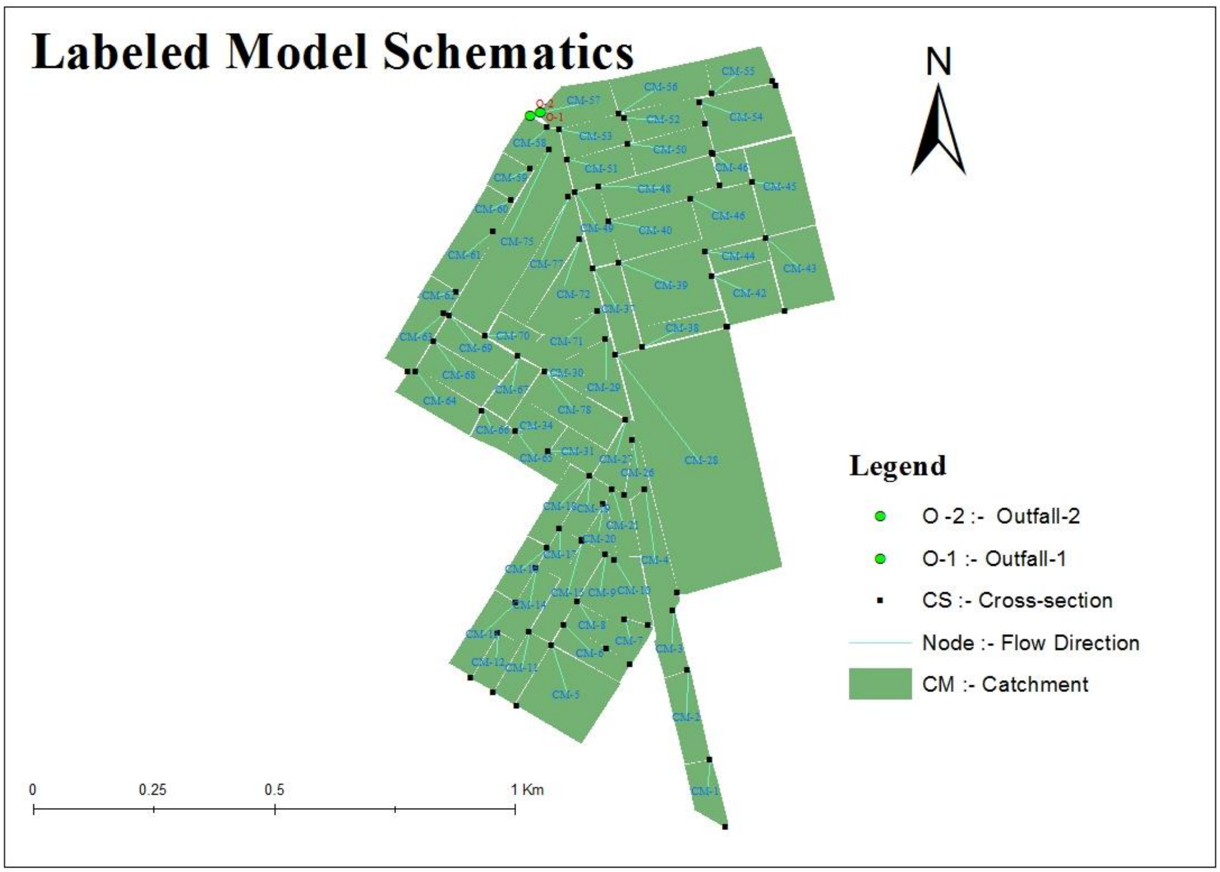


Figure 4-4: Catchment label

Table 4-6: Simulated catchment characteristics result

Label	Scaled Area (ha)	Runoff Coefficient (Rational)	Time of Concentration (hours)	Discharge (m^3/s)
CM-1	0.726	0.738	0.049	0.029
CM-2	1.048	0.768	0.114	0.044
CM-3	0.586	0.774	0.189	0.025
CM-4	1.518	0.765	0.316	0.064
CM-5	2.395	0.782	0.064	0.103
CM-6	0.78	0.74	0.185	0.032
CM-7	0.492	0.757	0.068	0.02
CM-8	0.529	0.55	0.226	0.016
CM-9	0.828	0.527	0.421	0.024

According to the above table it can be seen that the most flow output which is 0.103 m^3/s belongs to the catchment number 5 with an area of 2.395 hectares and the least output with an amount of 0.016 m^3/s belongs to catchment number 8 with an area of 0.529hectares.

4.2.5 Runoff comparison bentley civilstorm vs rational method

The evaluation of hydrologic model behavior and performance is commonly made and reported through comparison of simulated and observed variables. Frequently, comparisons are made between simulated and measured streamflow at the catchment outlet. In this study the model simulated flow using Bentley CivilStorm was compared with calculated flow using Rational method. As result shows that the model result is lower than that of rational method. This shows that model simulation by model is considers real time computation.

Table 4-7: Runoff Comparison Bentley civil storm vs Rational method

Label	Scaled Area (ha)	Runoff Coefficient (Rational)	Time of Concentration (hours)	Model Discharge (m^3/s)	Discharge(m^3/s) by Rational Method
CM-1	0.726	0.738	0.049	0.029	0.33679888
CM-2	1.048	0.768	0.114	0.044	0.21746601
CM-3	0.586	0.774	0.189	0.025	0.07391805
CM-4	1.518	0.765	0.316	0.064	0.11701967
CM-5	2.395	0.782	0.064	0.103	0.9013761
CM-6	0.78	0.74	0.185	0.032	0.09610109
CM-7	0.492	0.757	0.068	0.02	0.16829169
CM-8	0.529	0.55	0.226	0.016	0.04085897
CM-9	0.828	0.527	0.421	0.024	0.03192512
CM-10	0.732	0.671	0.126	0.027	0.12007063

4.2.6 Evaluation of existing drainage system by different channel geometry

The existing channels were designed and constructed as rectangular section for the selected study area. This study tries to see the effect of channel geometries to reduce the flooding problems by changing the channel geometry in to trapezoidal cross-section. the reason why trapezoidal cross section is due to it is easy to modify or change from rectangular cross-section into trapezoidal. The obtained sample result was presented in table 4.8. The rest of the result is given in the APPENDIX G.

Table 4-8: Model result for Channels

No.	Flow direction		Section type	Flow (m^3/s)
	From	To		
1	CH-1	CH-2	Trapezoidal	0.002
2	CH-2	CH-3	Trapezoidal	0.033
3	CH-3	CH-4	Trapezoidal	0.077
4	CH-4	CH-5	Trapezoidal	0.102
5	CH-5	CH-6	Trapezoidal	0.166
6	CH-6	CH-7	Trapezoidal	0.181
7	CH-7	CH-8	Trapezoidal	0.222
8	CH-8	CH-9	Trapezoidal	0.259
9	CH-9	CH-10	Trapezoidal	0.315
10	CH-10	CH-25	Trapezoidal	0.367
25	CH-25	CH-26	Trapezoidal	1.442
26	CH-26	CH-82	Trapezoidal	2.714
81	CH-82	O-2	Trapezoidal	2.872

4.2.7 Comparison of trapezoidal and rectangular model runoff

Once the system elements for model had been adjusted for the existing drainage system, it was studied how the different channel geometries perform under constant cross-section area and rainfall conditions. The main purpose of this analysis was the comparison of different channel geometries. Therefore, in this study the rectangular and trapezoidal cross sections were compared. The comparison was done by their peak flow only. The other parameters are constant.

Table 4-9: Comparison of trapezoidal and rectangular section runoff from model

No.	Flow direction		Flow by Trapezoidal section (m^3/s)	Flow by Rectangular section (m^3/s)	Difference (trip-rec)
	From	To			
1	CH-1	CH-2	0.002	0.02	**-0.018**
2	CH-2	CH-3	0.033	0.049	**-0.016**
3	CH-3	CH-4	0.077	0.094	**-0.017**
4	CH-4	CH-5	0.102	0.119	**-0.017**
5	CH-5	CH-6	0.166	0.182	**-0.016**
6	CH-6	CH-7	0.181	0.278	**-0.097**
7	CH-7	CH-8	0.222	0.32	**-0.098**
8	CH-8	CH-9	0.259	0.357	**-0.098**

9	CH-9	CH-10	0.315	0.413	**-0.098**
10	CH-10	CH-25	0.367	0.465	**-0.098**
11	CH-25	CH-26	1.442	1.518	**-0.076**
12	CH-26	CH-82	2.714	2.883	**-0.169**
13	CH-82	O-2	2.872	3.041	**-0.169**

From the table 4.10 the trapezoidal section can reduce significant amount of runoff than that of rectangular section. this shows that changing or modifying the existing channel cross section in to trapezoidal with constant channel section.

4.2.8 Comparison hydraulic capacity with model runoff by trapezoidal section

Table 4-10: Comparison of peak runoff rate and hydraulic capacity of channels.

No. (1)	Flow direction		Existing Q(m^3/s) (4)	Flow by Trapezoidal section (m^3/s) (5)	Difference (4-5)
	From (2)	To (3)			
1	CH-1	CH-2	2.05	0.002	2.048
2	CH-2	CH-3	2.22	0.033	2.187
3	CH-3	CH-4	1.53	0.077	1.453
4	CH-4	CH-5	1.53	0.102	1.428
5	CH-5	CH-6	1.53	0.166	1.364
6	CH-6	CH-7	1.08	0.181	0.899
7	CH-7	CH-8	1.12	0.222	0.898
8	CH-8	CH-9	0.95	0.259	0.691
9	CH-9	CH-10	0.99	0.315	0.675
10	CH-10	CH-25	1.34	0.367	0.973
11	CH-25	CH-26	0.82	1.442	**-0.622**
12	CH-26	CH-82	0.84	2.714	**-1.874**
13	CH-82	O-2	2.58	2.872	**-0.292**

4.2.9 Performance of the drainage system in the study area

One of the most important factors in designing stormwater drainage systems is the physical storage volume that needs to be provided to achieve flood control and minimize the pollution impact of urban stormwater runoff. This section on stormwater drainage begins by examining the performance of current drainage systems and evaluating the current conditions of the drainage system by using ERA standards based on the field survey data and model simulation results.

As presented in table 4-5, some of the drainage lines have lower capacity and the flood generated within this area cannot safely discharged through the system. On the other hand, this will stagnate on open surfaces, overflow or inundate over road surfaces and also causes flood hazards in these area.

Table-4.1 reveals that, from the total drains about almost all of the drainage lines are severely degraded. 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. Because of these during the rainy season it is common to see flood over the surface of roads and subways, which is an obstacle to vehicles and pedestrians.

Figure 4-5: Wanza square to Old bus station flood event on august 12/08/2018 (11:30) (source: Hawassa city administration web site)

4.3 Assessment of existing stormwater drainage challenges in the study area

Apart from significant flood regime change, field visits and survey reveals that there are different challenges which makes the process of disposing runoff in to water ways made difficulties in this area.

4.3.1 Absence of natural river in the city

There is no natural river which cross the city. Due to these the runoff generated in the city travels large length and it takes long time to reach outfall. This leads to negative impact on the downstream storm drainage infrastructures and creates flooding problem.

4.3.2 Dumping of solid and liquid wastes in to stormwater drainages

Dumping solid waste materials in to drainages and streams is the other challenge of stormwater drainage system. Urban litter (alternatively called trash, debris, junk, floatables, gross pollutants, rubbish or solid waste) has become a major problem in these 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.

Figure 4-6: Dumping of solid and liquid wastes in to stormwater drainages

4.3.3 Damaged drain lines due to construction

Majority of infrastructure development in the sub cities have less concern to the drainage system. For example, housing construction, water supply lines and telephone line installation and expansion have been damaging drainage lines. Most of the time after the construction they didn't care enough to maintain what they damage.

Figure 4-7: Damaged drain lines due to construction

4.3.4 Lack of frequent clearance of drainage system

Due to lack of frequent clearance of drainage lines they have become out of services. 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. Figure 4.17 shows blocked ditches in the study area.

Figure 4-8: Lack of Frequent Clearance of Drainage system

4.4 Proposed best management practice (BMP)

This section provides proposed best management practices to solve the problem of urban stormwater drainage that has been hindering the drainage systems.

Typically, there is not a single answer to the question of which BMP (or 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. In order to select specific BMP for the area which has a problem, there are factors that were considered based on the Urban Storm Drainage Criteria Manual Volume 3, Best Management Practices, 2011.

In this study one sample place from the study area is selected to propose these BMP, the selection was based on the fact that this place has been damaged by runoff during the rainy season and contribute most of its flow to wanza circle.

4.4.1 Selecting BMP for study area

In order to select the best management practice that could fit to this area Urban Storm Drainage Criteria Manual Volume 3 was used (UD and FC, 2011). The following factors have been considered to decide the best suited practice.

1. Physical site characteristics

i. Topography of this area is moderately steep, which has a slope of 1.1%.
ii. Contributing drainage area is about 8.023ha.
iii. This place is surrounded by pavements with suburban and urban area.

2. Types of best management practice fit for area

Since this area has not been polluted with sewages from the surrounding environment, those best management practices with chemical and biological treatment were screened and the only source of pollution in this case is sediment. Based on the manual, for this specific site the following best management practices could fit. i) Grass Swale, or ii) Grass Buffer Channel

3. Criteria for the best management practice

i. Aesthetic

Aesthetically both of them could be qualified, however the area of this place quite small. So in order to implement grass buffer enough space is necessary. Since the area for the selected site is very small, this leads us to use Grass Swale channel.

ii. Safety

By safety means, if the BMP implemented, what would be the worst case scenario caused by this management practice regarding to the safety of the environment. So both practice could have worked out better than other BMPs regarding to safety of the environment.

iii. Maintenance requirement

Grass buffer frequently damaged by vehicles when they are adjacent to roadways and unprotected which requires frequent maintenance. However, in Grass swales removal of sediment and associated constituents through filtering (straining) is simpler than in the other BMPs. So based on this factor Grass swale is best suited BMP.

4.4.2 Limitations of the three BMP

Table 4-11:Limitations of the three BMP

Limitation of Grass Buffer	**Limitation of Grass Swale**
- Frequently damaged by vehicles when adjacent to roadways and unprotected. - A thick vegetative cover is needed for grass buffers to be effective. - Nutrients removal in grass buffers is typically low. - High loadings of coarse solids, trash, and debris require pre-treatment. - Space for grass buffers may not be available in ultra-urban areas (lot-line-to-line)	- Requires more area than traditional storm sewers - Underdrains are recommended for slopes under 2%. - Erosion problems may occur if not designed and constructed properly.

From their limitations it can be understood that Grass swale has acceptable limitations. In addition, the limitations of Grass Swale can be easily adjusted and avoid with careful installation and appropriate slope. From the above four factors It is concluded that Grass Swale is Best suited BMP for this site.

5 Conclusion and Recommendation

5.1 Conclusion

In this study the existing stormwater drainage of Hawassa city has been evaluated with the help of Base map for the roads, structural map, contour map, tap meter and including Bentley CivilStorm software to analyze the quantitative data. Drainage lines around Wanza square have been evaluated and it is concluded that they have been facing overflowing and flooding which was mainly caused by the growth of built up area. The results from this study show that the drainage system has been hindered to function well because of the challenges that have been faced over years. After analyzing the results, the following conclusions were drawn:

- The main drainage problem in the existing system is, the capacities of the drainage system can't handle the current runoff that flows over the area. This is due to urbanization and lack of good assessment of the hydrology of the area.
- From the analysis made it is concluded that limitation in hydrologic and hydraulic design studies along with the most economic channel section selection, construction and waste disposal and management potentially corroborated the inadequacy of the storm drainage canals.
- None functional drainage canals also contributed to the flooding problems in the identified problem areas like Atote traffic light to Wanza square.
- Waste disposal from different sources (household, trader's shops, Hotels) and road cleaners are the main contributor for the clogging of the drainage canals. And the awareness of the community towards such issue was quite poor, even those who have the awareness overwhelmed to dump wastes over the storm drainage systems because there were lack of mechanisms to dispose and take care of wastes.
- Generally, the performance of these stormwater drainages were not satisfactory. Therefore, it is recognized that its capacity has shown lower results which needs some adjustment or improvement to give the best service, and needs a serious of regular maintenance and also provide drainage networking for the areas without drainage systems for its complete service.

5.2 Recommendation

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

- Create awareness within the community to use the drainage systems in a way that the drainage systems could be able to serve as their life span and the community should also know how to manage solid and liquid wastes.
- The different Governmental and non-governmental organization, who are involved in stormwater drainage and related activities should work in consultation with the municipality.
- Future expansion plan of the city should be done by take in to account identified locations for stormwater management (e.g. flood control locations to apply the techniques by designing the detention and retention basins, infiltration trenches and bio retention structures).
- Detail feasibility and design study should be done before approval of the drainage design during early stage of the project.
- Supervision of drainage canals during construction should be mandatory to avoid wrong dimensions and quality of the work as a whole.
- Adaptation of different Best Management Practices (BMP) which will not only reduce the peak runoff but also have aesthetic values and improve the environment. Even though urbanization cannot be avoided, the runoff that can be generated due to impervious areas can be infiltrated in to the ground through different best management practices that is supported by strong institutional setup, policy framework, and the public at large.
- In addition to this finding, future studies are recommended to include sustainable urban drainage system (SuDS).

References

ABRAHA, T. 2018 *Sustainable Urban Drainage Options for Mekelle City*.

ASFAW, B. 2016 *Assessment of Stormwater Drainage Systems in Kemise Town*

BELETE 2009. Study of the Urban Drainage System in Addis Ababa, Yeka Sub-city Addis Ababa,.

BRAVE, C. 2018. Hawassa city hydrology.

ERA 2013. Drainage design manual.

G/WAHED, F. 2016. *Improving Stormwater Management Capacity of Cobblestone Paved Local Streets through Green Infrastructure Design and Technologies (The Case of Residential District in the Eastern and North Eastern Part of Addis Ababa)*

GETACHEW KEBEDE, AND, W. T. & DEMISSIE, A. 2015. Assessment of the Effect of Urban Road Surface Drainage: A Case Study at Ginjo Guduru Kebele of Jimma Town.

GIRMA, T., ERMIAS, D., SOLOMON, S. A. & ZINABU, G. 2014. Identifying cost effective mitigation measures to bring down concentrations of pollutants that enter Lake Hawassa. Ethiopia , study report. : SOS Sahel,.

GRAHAM, A. 2012. Sustainable urban drainage systems: Maximizing the potential for people and wildlife.

HABTAMU 2011. Impact of Built Environment on Hydrological Regimes of Addis Ababa.

HAILEMICHAEL., F. 2015. *Flood Assessment on Addis Ababa Light Rail Transit System (LRT) (Meshualekiya – Gotera).*

HASSEN, N. 2016. *Modeling and analyses of urban flooding in bole sub-city System performance and evaluation of possible Improvements using epa swmm5.*

J.PARKINSON. 2013. *Drainage and stormwater management strategies for low-income urban communities.*

LIND, J. 2015. *Stormwater modelling tools: - a comparison and evaluation.*

METCALF & EDDY 2003. *Wastewater engineering: Treatment, Disposal and Reuse,* , McGraw-Hill, New York, .

MUKHERJA, D. 2016. Effect of urbanization on flood. *International Journal of Engineering science and research technology*.

MULUALEM BEKELE, K. N. S. A. Y. 2018 Performance Assessment of Road Drainage Systems of Burayu Town, Oromia Region, Ethiopia.

SUBRAMANIAN 2008. *Engineering Hydrology*

New Delhi, Tata McGraw hill.

TAFETE, E. 2013. *Evaluation of Drainage system in Kebena stream catchment, Addis Ababa.*

UD AND FC, U. 2011. Urban Storm Drainage Criteria Manual Volume 3, Stormwater Best Management Practice.

URGESSA, K. 2016. *Hydrologic and Hydraulic Analyses of Drainage Structures In Case of Shishinda-Tepi Road.*

W.W.D.S.E 2001. The study of Lake Awassa level, Lake Awassa study and design project. *In:* ENTERPRISE, W. W. D. A. S. (ed.). Addis Ababa. .

WERKNEH. 2017. *Investigation of Flooding Problems in Urban Drainage System:the case at Zenebe Werk.*

WONDRADE, N., DICK, B., &, Ø. & H., T. 2014. Landscape Mapping to Quantify Degree of-Freedom, Degree-of-Sprawl, and Degree-of-Goodness of Urban Growth in Hawassa, Ethiopia. *Environment and Natural Resources Research;*, 4.

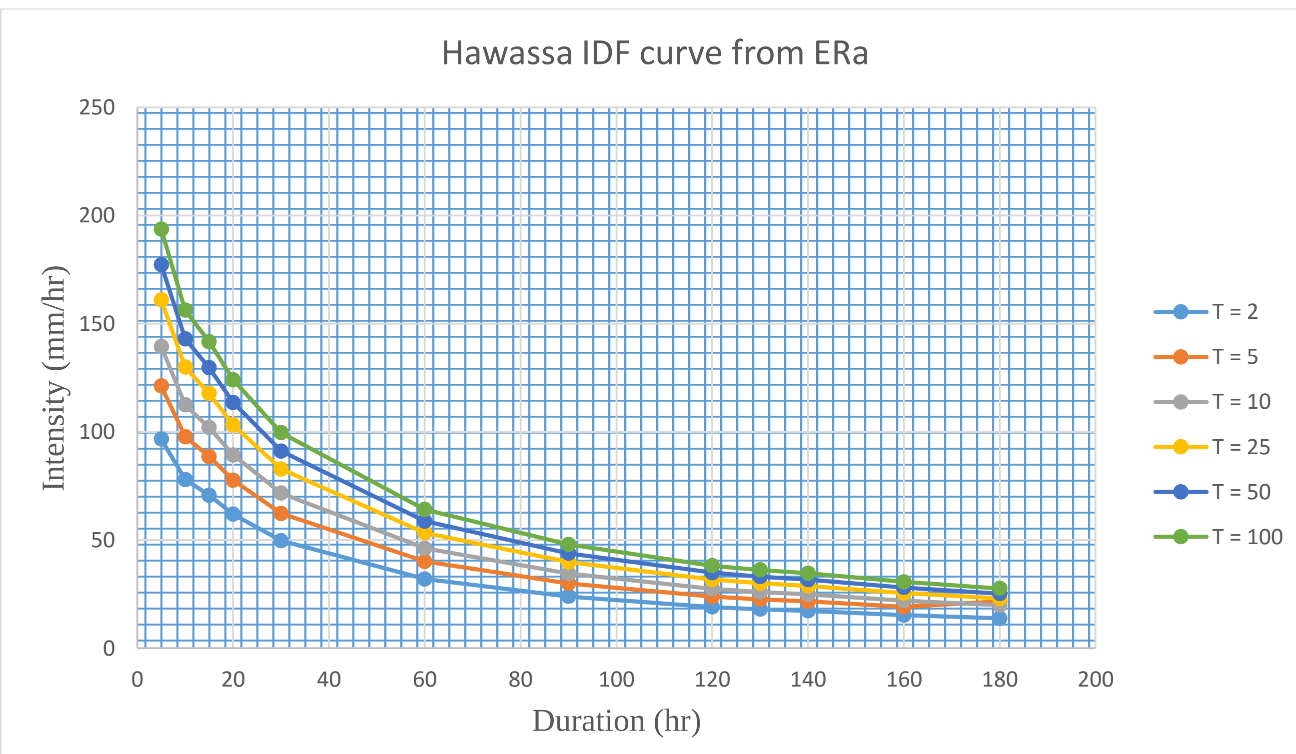
ZEWDU, A. 2015. *Integrated urban drainage system; the case of Ayat to Megenagna light rail transit system route.*

Appendix

Appendix A: IDF table developed by ERA

Duration (Min)	T = 2	T = 5	T = 10	T = 25	T = 50	T = 100
5	96.705	121.205	139.44	161.0525	177.2575	193.6725
10	78.01411	97.778825	112.489	129.924706	142.99765	156.24
15	70.7328	88.6528	101.99	117.7984	129.6512	141.6576
20	61.95818	77.655155	89.3382	103.185152	113.56758	124.0845455
30	49.734	62.334	71.712	82.827	91.161	99.603
60	32.0508	40.1708	46.2144	53.3774	58.7482	64.1886
90	23.946	30.012667	34.528	39.8796667	43.892333	47.957
120	19.0647	23.8947	27.4896	31.75035	34.94505	38.18115
130	18.08046	22.661106	26.0704	30.1111982	33.140968	36.21
140	17.31322	21.699485	24.9641	28.8334335	31.734635	34.67343348
160	15.31556	19.195654	22.0836	25.5064419	28.072884	30.67258427
180	13.815	21.699485	19.92	23.0075	25.3225	27.6675

Appendix B: IDF curve developed by ERA



Appendix C: Hawassa stormwater drainage condition: Field survey, 2018.

Road Start	Road End	Position	Drainage Type	Length (m)	Width (m)	Depth (m)	Condition
Gebriel Circil	Rokin Hotel	Left	Open	614	0.9	0.5	Good
Gebriel Circil	Rokin Hotel	Right	Open	652	0.9	0.5	Good
Gebriel Circle	Logita Hotel	Left	Open	541	1	0.5	Good
Gebriel Circle	Logita Hotel	Right	Open	554	0.85	0.4	Good
Logita hotel	Titufat Trafic light	Left	Open	231.79	0.9		Good
Logita hotel	Titufat Trafic light	Right	Open	231.79	0.9		Good
Atote Trafic Light	wanza Circle	Left	Open	1136	0.6	0.7	Fair
Atote Trafic Light	wanza Circle	Right	Open	1121	0.6	0.7	Fair
Wanza Circe	Bus station	Left	Open	541.35	2.1	0.7	Good
Wanza Circe	Bus station	Right	Open	541.35	0.8		Good
Miliniyem Adarash	Sidama zone Adiministration	Right	Open	221	0.9	0.67	Good
Police Commission	Sidama Zoni Adiministration	Left	Open	299	0.9	0.6	Good
Police Commission	Sidama Zoni Adiministration	Right	Open	278	1.5	0.5	Good
Sidama Zoni Adiministration	Dehiden Office	Left	Closed	174	1	0.46	Good
Sidama Zoni Adiministration	Dehiden Office	Right	Open	180	0.9	0.6	Good
Gebriel Circle	Mesikel adebabay circle	Left	Closed	54	0.5	0.5	Good
Gebriel Circle	Mesikel adebabay circle	Right	Open	544	0.5	0.6	Good
Yahiwel Netise hotel	Menahariya	Right	Open	853	0.6	0.37	Fair
Amanuel Church	Logita hotel	Left	Open	489	0.65	0.6	Good
Amanuel Church	Logita hotel	Right	Open	531	0.65	0.6	Good
Wanza Circe	Welidiamanuel ciricle	Left	Open	1646	1.1	0.45	Good
Wanza Circe	Welidiamanuel ciricle	Right	Open	1491	1.25	0.55	Good

Appendix D: Computation of the capacity of the existing drainage system (own analysis by flow master, 2018)

No.	Flow direction		n	S (m/m)	D (m)	W (m)	R(m)	P(m)	A(m²)	V (m/s)	Q (m³/s)
	From	To									
1	CH-1	CH-2	0.032	0.047	0.55	1.25	0.29	2.35	0.69	2.99	2.05
2	CH-2	CH-3	0.032	0.055	0.55	1.25	0.29	2.35	0.69	3.23	2.22
3	CH-3	CH-4	0.032	0.026	0.55	1.25	0.29	2.35	0.69	2.22	1.53
4	CH-4	CH-5	0.032	0.026	0.55	1.25	0.29	2.35	0.69	2.22	1.53
5	CH-5	CH-6	0.032	0.026	0.55	1.25	0.29	2.35	0.69	2.22	1.53
6	CH-6	CH-7	0.032	0.013	0.55	1.25	0.29	2.35	0.69	1.57	1.08
7	CH-7	CH-8	0.032	0.014	0.55	1.25	0.29	2.35	0.69	1.63	1.12
8	CH-8	CH-9	0.032	0.01	0.55	1.25	0.29	2.35	0.69	1.38	0.95
9	CH-9	CH-10	0.032	0.011	0.55	1.25	0.29	2.35	0.69	1.44	0.99
10	CH-10	CH-25	0.032	0.02	0.55	1.25	0.29	2.35	0.69	1.95	1.34
11	CH-11	CH-12	0.032	0.026	0.45	1.1	0.25	2	0.5	1.99	0.98
12	CH-12	CH-13	0.032	0.01	0.45	1.1	0.25	2	0.5	1.23	0.61
13	CH-13	CH-14	0.032	0.017	0.45	1.1	0.25	2	0.5	1.61	0.8
14	CH-14	CH-15	0.032	0.004	0.45	1.1	0.25	2	0.5	0.78	0.39
15	CH-15	CH-26	0.032	0.013	0.45	1.1	0.25	2	0.5	1.4	0.7
16	CH-16	CH-19	0.032	0.012	0.7	0.7	0.23	2.1	0.49	1.3	0.64
17	CH-17	CH-18	0.032	0.046	0.7	0.7	0.23	2.1	0.49	2.54	1.24
18	CH-18	CH-20	0.032	0.027	0.7	0.7	0.23	2.1	0.49	1.95	0.95
19	CH-19	CH-21	0.032	0.042	0.7	0.7	0.23	2.1	0.49	2.43	1.19
20	CH-20	CH-25	0.032	0.045	0.7	0.7	0.23	2.1	0.49	2.51	1.23
21	CH-21	CH-22	0.032	0.004	0.7	0.7	0.23	2.1	0.49	0.75	0.37
22	CH-22	CH-23	0.032	0.01	0.7	0.7	0.23	2.1	0.49	1.18	0.58
23	CH-23	CH-24	0.032	0.014	0.7	0.7	0.23	2.1	0.49	1.4	0.69
24	CH-24	CH-82	0.032	0.004	0.7	0.7	0.23	2.1	0.49	0.75	0.37
25	CH-25	CH-26	0.032	0.02	0.7	0.7	0.23	2.1	0.49	1.68	0.82
26	CH-26	CH-82	0.032	0.021	0.7	0.7	0.23	2.1	0.49	1.72	0.84
27	CH-27	CH-26	0.032	0.026	0.7	0.7	0.23	2.1	0.49	1.91	0.94
28	CH-28	O-1	0.032	0.012	0.8	1.2	0.34	2.8	0.96	1.68	1.61
29	CH-29	CH-27	0.032	0.018	0.8	1.2	0.34	2.8	0.96	2.05	1.97
30	CH-30	CH-28	0.032	0.017	0.8	1.2	0.34	2.8	0.96	2	1.92
31	CH-31	CH-29	0.032	0.013	0.8	1.2	0.34	2.8	0.96	1.75	1.68
32	CH-32	CH-30	0.032	0.032	0.8	1.2	0.34	2.8	0.96	2.74	2.63
33	CH-33	CH-34	0.032	0.031	0.8	1.2	0.34	2.8	0.96	2.7	2.59

34	CH-34	CH-15	0.032	0.027	0.6	0.7	0.22	1.9	0.42	1.88	0.79
35	CH-36	CH-37	0.032	0.015	0.6	0.7	0.22	1.9	0.42	1.4	0.59
36	CH-37	CH-14	0.032	0.017	0.6	0.7	0.22	1.9	0.42	1.49	0.63
37	CH-38	CH-80	0.032	0.032	0.6	0.7	0.22	1.9	0.42	2.04	0.86
38	CH-39	CH-81	0.032	0.01	0.6	0.7	0.22	1.9	0.42	1.14	0.48
39	CH-40	CH-39	0.032	0.016	0.6	0.7	0.22	1.9	0.42	1.45	0.61
40	CH-41	CH-40	0.032	0.01	0.6	0.7	0.22	1.9	0.42	1.14	0.48
41	CH-42	CH-38	0.032	0.006	0.6	0.7	0.22	1.9	0.42	0.88	0.37
42	CH-43	CH-42	0.013	0.009	0.6	0.7	0.22	1.9	0.42	2.67	1.12
43	CH-44	CH-43	0.032	0.014	0.6	0.7	0.22	1.9	0.42	1.35	0.57
44	CH-45	CH-12	0.032	0.006	0.6	0.7	0.22	1.9	0.42	0.88	0.37
45	CH-46	CH-47	0.032	0.009	0.6	0.7	0.22	1.9	0.42	1.08	0.46
46	CH-47	CH-48	0.032	0.018	0.6	0.7	0.22	1.9	0.42	1.53	0.64
47	CH-48	CH-37	0.032	0.013	0.6	0.7	0.22	1.9	0.42	1.3	0.55
48	CH-49	CH-50	0.032	0.015	0.6	0.7	0.22	1.9	0.42	1.4	0.59
49	CH-50	CH-51	0.032	0.005	0.6	0.7	0.22	1.9	0.42	0.81	0.34
61	CH-62	CH-63	0.032	0.034	0.6	0.7	0.22	1.9	0.42	2.11	0.88
62	CH-63	CH-64	0.032	0.011	0.6	0.7	0.22	1.9	0.42	1.2	0.5
63	CH-64	CH-57	0.032	0.01	0.6	0.7	0.22	1.9	0.42	1.14	0.48
64	CH-65	CH-64	0.032	0.015	0.6	0.7	0.22	1.9	0.42	1.4	0.59
65	CH-66	CH-65	0.032	0.038	0.6	0.7	0.22	1.9	0.42	2.23	0.94
66	CH-67	CH-66	0.032	0.032	0.6	0.7	0.22	1.9	0.42	2.04	0.86
67	CH-68	CH-62	0.032	0.01	0.6	0.7	0.22	1.9	0.42	1.14	0.48
68	CH-69	CH-70	0.032	0.032	0.6	0.7	0.22	1.9	0.42	2.04	0.86
69	CH-70	CH-71	0.032	0.024	0.6	0.7	0.22	1.9	0.42	1.77	0.74
70	CH-71	CH-72	0.032	0.035	0.6	0.7	0.22	1.9	0.42	2.14	0.9
71	CH-72	CH-73	0.032	0.005	0.6	0.7	0.22	1.9	0.42	0.81	0.34
72	CH-73	CH-74	0.032	0.007	0.6	0.7	0.22	1.9	0.42	0.96	0.4
73	CH-74	CH-17	0.032	0.009	0.6	0.7	0.22	1.9	0.42	1.08	0.46
74	CH-75	CH-6	0.032	0.002	0.6	0.7	0.22	1.9	0.42	0.51	0.21
75	CH-76	CH-77	0.032	0.02	0.6	0.7	0.22	1.9	0.42	1.62	0.68
76	CH-77	CH-78	0.032	0.016	0.6	0.7	0.22	1.9	0.42	1.45	0.61
77	CH-78	CH-79	0.032	0.011	0.6	0.7	0.22	1.9	0.42	1.2	0.5
78	CH-79	CH-20	0.032	0.004	0.6	0.7	0.22	1.9	0.42	0.72	0.3
79	CH-80	CH-81	0.032	0.019	0.8	2.1	0.45	3.7	1.68	2.54	4.28
80	CH-81	CH-29	0.032	0.015	0.6	0.7	0.22	1.9	0.42	1.4	0.59
81	CH-82	O-2	0.032	0.01	0.7	2.1	0.42	3.5	1.47	1.75	2.58

Appendix E: Model result for Channels

No.	Flow direction		Section type	Flow (m^3/s)
	From	To		
1	CH-1	CH-2	Rectangular	0.02
2	CH-2	CH-3	Rectangular	0.049
3	CH-3	CH-4	Rectangular	0.094
4	CH-4	CH-5	Rectangular	0.119
5	CH-5	CH-6	Rectangular	0.182
6	CH-6	CH-7	Rectangular	0.278
7	CH-7	CH-8	Rectangular	0.32
8	CH-8	CH-9	Rectangular	0.357
9	CH-9	CH-10	Rectangular	0.413
10	CH-10	CH-25	Rectangular	0.465
11	CH-11	CH-12	Rectangular	0.02
12	CH-12	CH-13	Rectangular	0.521
13	CH-13	CH-14	Rectangular	0.548
14	CH-14	CH-15	Rectangular	0.815
15	CH-15	CH-26	Rectangular	0.881
16	CH-16	CH-19	Rectangular	0.002
17	CH-17	CH-18	Rectangular	0.663
18	CH-18	CH-20	Rectangular	0.712
19	CH-19	CH-21	Rectangular	0.039
20	CH-20	CH-25	Rectangular	0.889
21	CH-21	CH-22	Rectangular	0.051
22	CH-22	CH-23	Rectangular	0.093
23	CH-23	CH-24	Rectangular	0.103
24	CH-24	CH-82	Rectangular	0.124
25	CH-25	CH-26	Rectangular	1.518
26	CH-26	CH-82	Rectangular	2.883
27	CH-27	CH-26	Rectangular	0.449
28	CH-28	O-1	Rectangular	0.118
29	CH-29	CH-27	Rectangular	0.413
30	CH-30	CH-28	Rectangular	0.06
31	CH-31	CH-29	Rectangular	0.02
32	CH-32	CH-30	Rectangular	0.02
33	CH-33	CH-34	Rectangular	0.016
34	CH-34	CH-15	Rectangular	0.068
35	CH-36	CH-37	Rectangular	0.02

36	CH-37	CH-14	Rectangular	0.284
37	CH-38	CH-80	Rectangular	0.138
38	CH-39	CH-81	Rectangular	0.157
39	CH-40	CH-39	Rectangular	0.071
40	CH-41	CH-40	Rectangular	0.001
41	CH-42	CH-38	Rectangular	0.074
42	CH-43	CH-42	Rectangular	0.049
43	CH-44	CH-43	Rectangular	0.001
44	CH-45	CH-12	Rectangular	0.02
45	CH-46	CH-47	Rectangular	0.027
46	CH-47	CH-48	Rectangular	0.144
47	CH-48	CH-37	Rectangular	0.195
48	CH-49	CH-50	Rectangular	0.001
49	CH-50	CH-51	Rectangular	0.025
61	CH-62	CH-63	Rectangular	0.178
62	CH-63	CH-64	Rectangular	0.194
63	CH-64	CH-57	Rectangular	0.285
64	CH-65	CH-64	Rectangular	0.068
65	CH-66	CH-65	Rectangular	0.04
66	CH-67	CH-66	Rectangular	0.02
67	CH-68	CH-62	Rectangular	0.02
68	CH-69	CH-70	Rectangular	0.002
69	CH-70	CH-71	Rectangular	0.064
70	CH-71	CH-72	Rectangular	0.616
71	CH-72	CH-73	Rectangular	0.641
72	CH-73	CH-74	Rectangular	0.684
73	CH-74	CH-17	Rectangular	0.698
74	CH-75	CH-6	Rectangular	0.1
75	CH-76	CH-77	Rectangular	0.026
76	CH-77	CH-78	Rectangular	0.095
77	CH-78	CH-79	Rectangular	0.123
78	CH-79	CH-20	Rectangular	0.136
79	CH-80	CH-81	Rectangular	0.296
80	CH-81	CH-29	Rectangular	0.316
81	CH-82	O-2	Rectangular	3.041

Appendix F: Simulated catchment characteristics result

Label	Outflow Element	Area (ha)	Runoff Coefficient	Time of Concentration (hours)	Flow (m^3/s)
CM-1	CS-70	0.726	0.738	0.049	0.029
CM-2	CS-69	1.048	0.768	0.114	0.044
CM-3	CS-68	0.586	0.774	0.189	0.025
CM-4	CS-60	1.518	0.765	0.316	0.064
CM-5	CS-49	2.395	0.782	0.064	0.103
CM-6	CS-8	0.78	0.74	0.185	0.032
CM-7	CS-67	0.492	0.757	0.068	0.02
CM-8	CS-58	0.529	0.55	0.226	0.016
CM-9	CS-6	0.828	0.527	0.421	0.024
CM-10	CS-59	0.732	0.671	0.126	0.027
CM-11	CS-50	0.737	0.725	0.104	0.029
CM-12	CS-66	0.579	0.756	0.075	0.024
CM-13	CS-64	0.964	0.736	0.167	0.039
CM-14	CS-65	0.815	0.728	0.266	0.033
CM-15	CS-10	1.125	0.773	0.667	0.048
CM-16	CS-63	0.66	0.866	0.31	0.031
CM-17	CS-62	0.495	0.764	1.11	0.021
CM-18	CS-12	0.845	0.343	1.328	0.016
CM-19	CS-12	0.635	0.78	1.264	0.027
CM-20	CS-61	0.377	0.753	0.057	0.016
CM-21	CS-16	0.641	0.65	0.098	0.023
CM-26	CS-18	0.381	0.755	0.461	0.016
CM-27	CS-22	0.678	0.69	0.064	0.026
CM-28	CS-25	11.775	0.546	0.158	0.353
CM-29	CS-72	1.022	0.736	0.54	0.041
CM-30	CS-48	0.354	0.839	0.106	0.016
CM-31	CS-71	0.621	0.736	1.384	0.025

CM-34	CS-51	0.69	0.459	1.472	0.017
CM-37	CS-47	1.018	0.606	0.286	0.034
CM-38	CS-26	0.694	0.679	0.058	0.026
CM-39	CS-83	2.559	0.838	0.184	0.118
CM-40	CS-81	1.563	0.592	0.28	0.051
CM-42	CS-79	1.291	0.662	0.165	0.047
CM-43	CS-45	1.675	0.738	0.107	0.068
CM-44	CS-80	0.587	0.768	0.239	0.025
CM-45	CS-46	2.028	0.774	0.159	0.086
CM-46	CS-82	1.529	0.765	0.366	0.064
CM-47	CS-87	0.452	0.782	0.594	0.019
CM-48	CS-27	1.709	0.74	0.383	0.07
CM-49	CS-35	0.877	0.757	0.781	0.037
CM-50	CS-77	1.058	0.55	0.065	0.032
CM-51	CS-34	0.893	0.527	0.959	0.026
CM-52	CS-38	0.963	0.671	0.172	0.036
CM-53	CS-76	0.896	0.725	1.047	0.036
CM-54	CS-29	1.864	0.756	0.088	0.078
CM-55	CS-40	0.985	0.736	0.058	0.04
CM-56	CS-41	1.443	0.728	0.16	0.058
CM-57	O-1	1.026	0.773	0.238	0.044
CM-58	CS-44	0.708	0.866	2.587	0.034
CM-59	CS-57	0.522	0.764	0.449	0.022
CM-60	CS-56	0.5	0.343	0.396	0.009
CM-61	CS-55	1.037	0.78	0.326	0.045
CM-62	CS-54	0.379	0.753	0.137	0.016
CM-63	CS-53	0.92	0.65	0.096	0.033
CM-64	CS-19	1.092	0.755	1.638	0.045
CM-65	CS-51	0.675	0.69	1.482	0.026
CM-66	CS-52	0.449	0.546	1.542	0.013
CM-67	CS-86	0.69	0.736	0.192	0.028

Appendix G: Model result for Channels for trapezoidal section

No.	flow direction		Section Type	Flow (m^3/s)
	From	To		
1	CH-1	CH-2	Trapezoidal	0.002
2	CH-2	CH-3	Trapezoidal	0.033
3	CH-3	CH-4	Trapezoidal	0.077
4	CH-4	CH-5	Trapezoidal	0.102
5	CH-5	CH-6	Trapezoidal	0.166
6	CH-6	CH-7	Trapezoidal	0.181
7	CH-7	CH-8	Trapezoidal	0.222
8	CH-8	CH-9	Trapezoidal	0.259
9	CH-9	CH-10	Trapezoidal	0.315
10	CH-10	CH-25	Trapezoidal	0.367
11	CH-11	CH-12	Trapezoidal	0.003
12	CH-12	CH-13	Trapezoidal	0.377
13	CH-13	CH-14	Trapezoidal	0.41
14	CH-14	CH-15	Trapezoidal	0.717
15	CH-15	CH-26	Trapezoidal	0.812
16	CH-16	CH-19	Trapezoidal	0.001
17	CH-17	CH-18	Trapezoidal	0.685
18	CH-18	CH-20	Trapezoidal	0.734
19	CH-19	CH-21	Trapezoidal	0.036
20	CH-20	CH-25	Trapezoidal	0.911
21	CH-21	CH-22	Trapezoidal	0.052
22	CH-22	CH-23	Trapezoidal	0.093
23	CH-23	CH-24	Trapezoidal	0.103
24	CH-24	CH-82	Trapezoidal	0.124
25	CH-25	CH-26	Trapezoidal	1.442
26	CH-26	CH-82	Trapezoidal	2.714
27	CH-27	CH-26	Trapezoidal	0.436
28	CH-28	O-1	Trapezoidal	0.113
29	CH-29	CH-27	Trapezoidal	0.401
30	CH-30	CH-28	Trapezoidal	0.074
31	CH-31	CH-29	Trapezoidal	0.006
32	CH-32	CH-30	Trapezoidal	0.028
33	CH-33	CH-34	Trapezoidal	0.014
34	CH-34	CH-15	Trapezoidal	0.061

35	CH-36	CH-37	Trapezoidal	0.002
36	CH-37	CH-14	Trapezoidal	0.264
37	CH-38	CH-80	Trapezoidal	0.14
38	CH-39	CH-81	Trapezoidal	0.157
39	CH-40	CH-39	Trapezoidal	0.07
40	CH-41	CH-40	Trapezoidal	0.002
41	CH-42	CH-38	Trapezoidal	0.075
42	CH-43	CH-42	Trapezoidal	0.051
43	CH-44	CH-43	Trapezoidal	0.002
44	CH-45	CH-12	Trapezoidal	0.001
45	CH-46	CH-47	Trapezoidal	0.026
46	CH-47	CH-48	Trapezoidal	0.144
47	CH-48	CH-37	Trapezoidal	0.195
48	CH-49	CH-50	Trapezoidal	0.002
49	CH-50	CH-51	Trapezoidal	0.026
62	CH-63	CH-64	Trapezoidal	0.155
63	CH-64	CH-57	Trapezoidal	0.229
64	CH-65	CH-64	Trapezoidal	0.05
65	CH-66	CH-65	Trapezoidal	0.023
66	CH-67	CH-66	Trapezoidal	0.002
67	CH-68	CH-62	Trapezoidal	0.002
68	CH-69	CH-70	Trapezoidal	0.004
69	CH-70	CH-71	Trapezoidal	0.055
70	CH-71	CH-72	Trapezoidal	0.581
71	CH-72	CH-73	Trapezoidal	0.602
72	CH-73	CH-74	Trapezoidal	0.644
73	CH-74	CH-17	Trapezoidal	0.657
74	CH-75	CH-6	Trapezoidal	0.002
75	CH-76	CH-77	Trapezoidal	0.026
76	CH-77	CH-78	Trapezoidal	0.095
77	CH-78	CH-79	Trapezoidal	0.123
78	CH-79	CH-20	Trapezoidal	0.136
79	CH-80	CH-81	Trapezoidal	0.302
80	CH-81	CH-29	Trapezoidal	0.323
81	CH-82	O-2	Trapezoidal	2.872