Evaluation of Drainage system in Kebena stream catchment, Addis Ababa

By

Eskedar Tafete

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Eskedar Tafete

Addis Ababa

Ethiopia

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Addis Ababa Institute of Technology

APPROVAL

The undersigned certify that they have read and here by recommend to the Addis Ababa University to accept the Thesis submitted by Eskedar Tafete entitled “EVALUATION OF DRAINAGE SYSTEM IN KEBENA STREAM CATCHMENT, ADDIS ABABA “in partial fulfillment of the requirements for the award of Masters of Science Degree in Water Supply and Environmental Engineering.

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I, Eskedar Tafete declare that this thesis is my original work and that it has not been presented and will not be presented by me to any other university for similar or any other degree award.

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Acronyms

AACRA: Addis Ababa City Road Authority

AAEPA: Addis Ababa Environmental Protection Authority

AAU: Addis Ababa University

AAWSSA: Addis Ababa Water Supply and Sewerage Authority

Arc-GIS: Architectural Geographical Information System Cad:

BMP: Best Management Practice

Cad: Computer Assisted Design

CSA: Central Statistics Authority

DEM: Digital Elevation Model

DCIA: Directly Connected Impervious Area

DL-1: Drainage Line One

EDB: Extended Detention Basin

ECA: Economic Commission for Africa

ERA: Ethiopian Road Authority

FUPI: Federal Urban Planning Institute

GWP: Global Water Partnership

GTZ: German Technical Cooperation

IDF: Intensity Duration Frequency Curve

ITCZ: Inter Tropical Convergence Zone

JICA: Japan International Cooperation Agency

LID: Low Impact Development

NEDECO: Netherlands Engineering Consultants

NUPI: National Urban Planning Institute

PLD: Porous Landscape Detention

UD & FCD: Urban Drainage and Flood Control District

UN: United Nation

USWD: Urban Storm Water Drainage

WHO: World Health Organization

WMO: World Meteorological Organization

WQCV: Water Quality Capture Volume

Abstract

This study has investigated the overall challenges of the urban drainage system in three sample Woredas (Woreda 6, 7 and 8) in Kebena Stream Catchment of Addis Ababa. These Woredas were selected because of the fact that they are the most flood prone areas and representative to address the objectives of this study.

Rapid expansion of built environment and poor urban drainage managements are the major problems in the study area. The objective of this research is to evaluate the existing storm water drainage system of Addis Ababa by selecting sample representative sample area. An exploratory and descriptive type of research methods were used to describe and explore the existing condition of the general urban drainage system and the natural water ways with the help of Ms-excel, AutoCAD and ArcGIS, HEC-GEOHMS, Google earth, Flow Master and the results have been presented with known statistical tools.

The result of this study shows that the major cause of flooding in the drained part of Addis Ababa is a changing flood regime due to mainly the expansion of built environment. Sample design flood calculation based on the guideline for three sample Wereda's shows, in Woreda 6, of all the drains 17.74% of the drainages are capable of conveying safely the runoff in to the water ways. In woreda 7 out of the total drains only 29.75% of the drains have the capacity to convey the run off in to the stream. And also in woreda 8 out of the total drains only 16.5 % have the required capacity. Apart from significant flood regime change, field visits and survey reveals that there is inadequate integration between road and urban storm water drainage lines, luck of sustainable urban storm management, extraordinary challenge of damping solid and liquid waste water in the drainage system. Before, the urban drainage becomes a permanent socio-economic nuisance and brings irreversible damage to the city, this study strongly recommends immediate implementation of Best Management Practice (BMP) that is supported by strong institutional setup, policy framework, and the public at large.

1. INTRODUCTION

1.1Background

In the last decades, an intense process of urbanization took place, a current worldwide phenomenon leading to significant environmental impacts in urban areas. These impacts are related to quality and quantity variables of the hydrologic cycle. Urbanization along with its impermeable structures and improper design are the major causes of flooding in most developing urban areas including Addis Ababa (Belete, 2011), this urbanization affects the performance of the drainage lines.

In disturbed areas, the capacity to retain rainfall decreases due to impervious surfaces like roads, gutters, buildings and a parking lot. Undisturbed areas have a greater capacity to retain storms/run offs. Roads that intersect drainage basins generally modify the natural flow of surface water by concentrating flows at certain points and, in many cases, increasing the speed of flow (Tsunokawa & Hoban, 1997). Depending on local conditions, these changes can contribute to flooding, soil erosion, channel modification, and siltation of streams. These effects are often felt well beyond the immediate vicinity of the road.

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

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

The problem in urban storm water drainage net-work 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 (Belete, 2009). Thus, this could be the source of environmental problems like erosion, pollution, over topping, barrier to traffic and other related problems.

In Ethiopian context, where watersheds of many urban centers receive significant amount of annual rainfall and where rainfall intensity is produced high, Control of runoff at the source, flood protection, and safe disposal of the excess water/runoff through proper drainage facilities becomes significant (FUPI, 2008).

Metropolitan Addis Ababa, sprawling at the foothill of Entoto mountain range is traversed by several small streams originating from the mountain range. Torrential rains which are common during the rainy season in the city, cause sudden rise in flow of these streams which bring about flood damages to settlements along the bank of these streams. Such damages have often caused losses of property (WMO & GWP, 2003).Recently a study of flood risks and measures of intervention along these streams has been carried out by the municipality and an implementation program over a 15-year period to contain flood waters within their banks have been drawn out.

The foundation and expansion of Addis Ababa has been associated with the rapid conversion of rural land to urban area. For the last one hundred twenty three years it has been noticed that an intensive conversion of rural land to urban development like buildings, transportation networks and facilities (airports and highways), recreation areas, reservoirs and other manmade structures, where most of them are impermeable structures(Belete,2009). Currently Addis Ababa has undergoing upgrading of existing roads and constructing of new roads this will highly influence the runoff volume of the city. So mitigation measures should be considered in accommodation of incoming surface runoff (Habtamu, 2011).

Kebena stream watershed is a major economic nexus of Addis Ababa City. It is also the oldest and most economically significant part of the city. Unfortunately, street flooding, over topping and other environmental related problems are common in this area. This is particularly severe in areas where road infrastructure appears to be without adequate storm water drainage infrastructure.

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

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

1.2 Problem Statement

Torrential rains with high runoff in Addis Ababa causes flooding in the several streams coming from the nearby mountain range causing damages to houses close to the banks of the streams. This has been the cause for substantial loss of property during the rainy season.

Inadequate urban storm water drainage systems represent one of the most common sources of compliant from the citizens in many towns of Ethiopia, and this problem is getting worse and worse with the ongoing high rate of urbanization(GTZ-IS, 2006).

Significant proportion of the area is exposed to flooding during the rainy season. There is also a problem of overtopping, blockage of drainage facilities and water logging in some of the drainage area and wastes that flow along the drainage system have bad smell, and unwelcoming environment.

In addition to increased urbanization and imperviousness of the urban landscape, the planning as well as implementation of storm water protecting structures is insufficient. The proportion of road to urban storm water drainage in Addis Ababa is 1km to 0.174 km. That is for every kilometer of road, there is 0.174km urban storm water drainage lines (AACRA, 2008) as the water can cause a serious impact on both the road access and its strength, an efficient drainage system that could cover the entire road is the most important part of road construction and maintenance works. However this proportion shows the gap between the actual required urban storm water drainage structures and what is actually present on the ground. There is no specific standard for the proportion but every road and paved surface requires a drainage system to dispose the generated runoff over the impervious surface.

Regardless of the fact that the municipality connect storm water drainage system that should have safely covey the runoff in to the streams, it’s been observed that is not enough yet. The amount of runoff produced within the catchment inundates the overlaying urban area. The rise of the amount of runoff produced in the catchment from time to time overwhelms Kebena stream. To overcome this problem particular study regarding to challenges that have been observed, the coverage, capacity, and performance of storm water drainage system of Addis Ababa is essential.

1.3 Research Objectives

1.3.1General Objective

The main objective of this research is to evaluate the existing storm water drainage system in Addis Ababa by selecting 3 sample Woredas around Kebena Stream catchment and propose best management practice for the problem. These Woredas are selected because they are major flood prone areas.

1.3.2 Specific Objectives

1. To identify the percentage of areas with and without drainage system in the study areas of Kebena Stream catchment,
2. To identify the major challenges in urban storm water drainage management system.
3. To evaluate the capacity of existing urban storm water drainage system in the study area,
4. To propose best management practice to alleviate the problem and provide recommendation on the existing drainage system.

1.4 Research Questions

This research is intended to answer the following research questions in line with the topic and objectives of this study in Kebena Stream Catchment of the selected representative woredas:

1. How much percent of the study area in Kebena Stream Catchment is with and without the drainage system?
2. What are the major challenges in managing the drainage system in the study area?
3. How much is the capacity of existing urban storm water drainage system?
4. Does the existing drainage system performs well?
5. What are major impacts of these drainage lines to Kebena Stream?
6. What are the possible best management practices to alleviate the problem?
7. What are the conditions to be considered to select the best suited management practice for a particular flood prone area?

1.5 Significance of the study

Generally, managing urban storm water 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.

This study, generally has the following major significances:

1. The sub-cities will use it as a reference while they are preparing their annual plans for urban drainage system.
2. It will be an alternative means of ensuring sustainable development in Addis Ababa by strengthening the environmental and socioeconomic activities regarding to urban drainage system.
3. Policy makers and any organization working in the area of urban drainage system can use it as a further reference to fill the existing gap between drainage demand and supply.
4. It will introduce the BMP option, which is not the current practice in the country's management practice in dealing with the challenges and problems of urban drainage system.

1.6 Scope of the study

Evaluating the whole catchment is not necessary to come up with solution for the current storm water problem. Therefore, some representative major flood prone areas are selected. According to the residents these areas have been flooded most of the rainy season and based on field observation three major flood prone woredas are selected. Therefore, this study is geographically limited to Kebena stream catchment particularly in Woreda 6, 7 of Yeka and Woreda 8 of Kirkos sub-cities of Addis Ababa. Generally; it will address issues related to urban storm water drainage. The specific focus of this study includes: evaluating the extent and performance of the existing system, identify some of challenges and factors that enforces people to damp wastes in the drainage facilities as well as proposing best management practice for the existing problem.

1.7 Location

Kebena stream is one of the major stream which flows across Addis Ababa, the delineation of the stream has been made by GIS with outlet location (475,456.2, 995,995.5 Meters). Woreda 6, 7 & 8 are woredas that kebena stream crosses. The DEM used for this delineation was 90m.

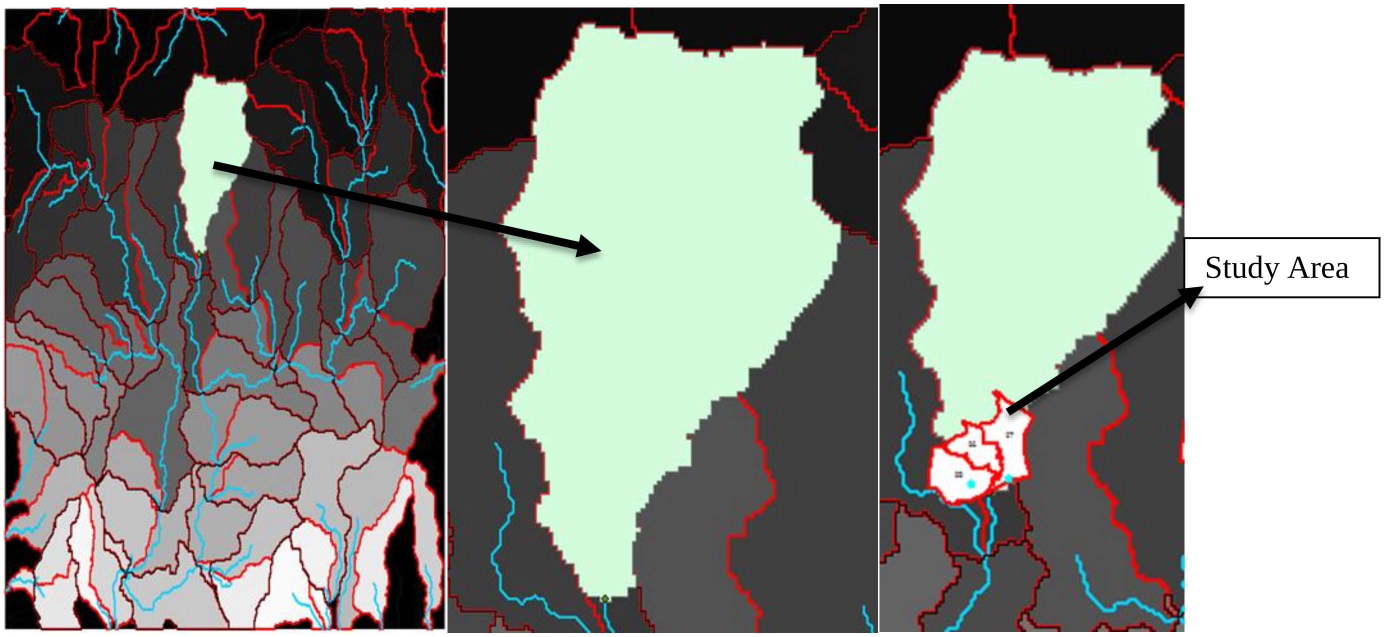


Figure 1.1 Catchment of Kebena River (source: GIS Analysis).

1.8 Natural Condition of the Study Area

This section gives an overview of the existing natural situation of the study area, including climate, rainfall, topography, geology, and land use land cover. These parameters are significant in the design and management of the urban drainage system.

1.8.1 Climate

Addis Ababa is classified as Cold or locally termed as "Woina Dega" Zone. Generally the temperature ranging is between 2^0c –29^0c. The mean annual temperature of Addis Ababa City is indicated in table 1.2 below.

Table 1.1 Mean monthly Temperature (^{0}c) of Addis Ababa (source: Beza Consulting Engineers)

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Max	22.9	23.9	24.4	23.8	24.5	22.7	20	19.9	20.7	22	22.2	22.4
Min	7.7	8.9	10.4	11	11.2	10.4	10.8	10.4	10.2	8.8	7.3	6.9

1.8.2 Rainfall

The seasonality of the rainfall in Addis Ababa is generally governed by the migration of the Inter Tropical Convergence Zone (ITCZ). The forward and the backward migration of the ITCZ produce substantial rainfall bringing moisture from the south Atlantic and Indian Oceans. Addis Ababa receives most of its rainfall (75 %) from June to September. Typical monthly rainfall distribution for Addis Ababa is given in Figure 1.2.

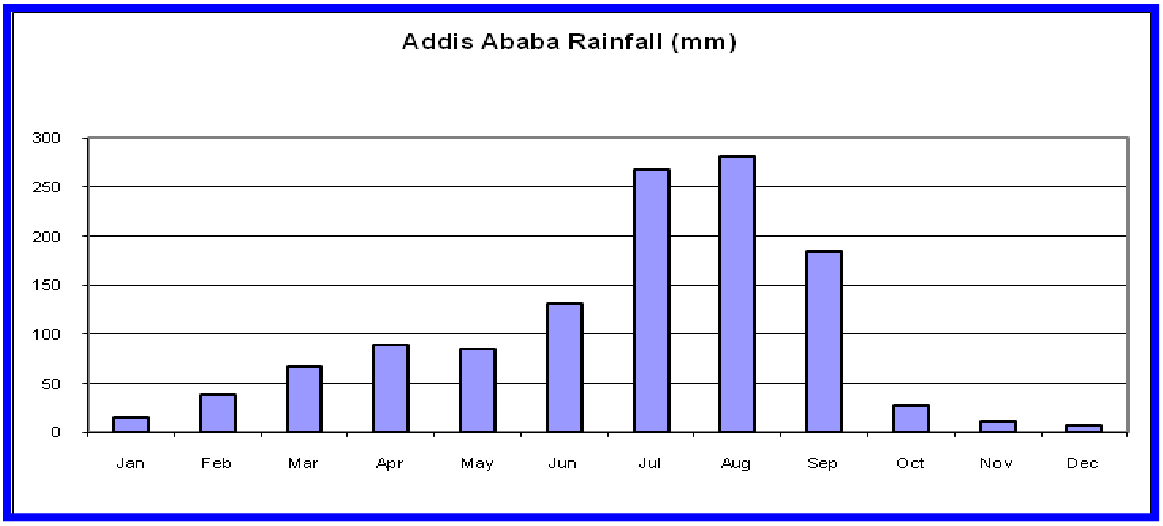


Figure 1.2 Monthly rainfall distributions over Addis Ababa area (1968-2011). (Source: Beza Consulting Engineers)

1.8.3 Geology

The study area is located in Addis Ababa city, which is found on the central highlands of the Ethiopian plateau. The Addis Ababa area is covered by different types of volcanic rocks. The urban area is composed of younger basalts called Addis Ababa basalts which are also covered with volcanic topsoil materials (Dirk Muschalla, 2001).

The western part of Addis Ababa belongs to the younger age stratum; the northern part is mainly composed of Trachey basalts. In the Bole area, a kind of basalt, called ignimbrites, is partly found. The topsoil materials in the western part are thick and soft compared to those of the northern and eastern parts (ibid).

1.8.4 Topography

The study area is located on a plateau with an elevation ranging from 2300 to 2500 meters. The urbanized part of the study area is deeply dissected by various gullies and intermittent natural water ways, which have formed by the major river systems crossing the sub-cities from north-south to east.

1.8.5 Land Use /Land Cover

Addis Ababa has experienced rapid physical expansion in east, west, south and little in north direction. The city had different land use maps which were developed at different time in the history of the city. In these particular study area land use cover includes asphalt road, gravel road, sub urban area, green area, and commercial area.

2. LITERATURE REVIEW

This chapter discusses concepts and theories which are the back bone of the analysis part of this research work. It starts with describing the historical development and basic concept of urban storm water drainage and then followed by: history of urban storm water drainage problem, Urban storm water drainage experience in Ethiopia and major problems, history and policy of urban storm water drainage in Ethiopia, urban storm water drainage in Addis Ababa, environmental and solid waste management in Addis Ababa, finally best management practices and best management selection tools will be discussed.

Generally, it presents various concepts and theories which have been found out by various Researchers/Authors in different periods of time in relation to this research work.

2.1 History of Urban Storm Water Drainage system

Historical accounts of ancient civilizations (e.g., Indus and Minoan) suggest urban drainage systems were constructed with great care and that the objectives of the systems were to collect rainwater, prevent nuisance flooding, and convey wastes (Mumford, 1961). This works under a combined system which comprises storm water drainage and waste sewers. These combined system has its own drawbacks. Lewis Mumford summarized the state of ancient urban infrastructure when he stated that ancient sewer and storm drainage systems were an uneconomic combination of refined technical devices and primitive social planning (ibid).

The Persians were ancient civilization that constructed urban drainage systems and they considered urban runoff sacred and enacted laws to protect it from pollution. Polluting water in Persia was considered a sin (Niemczynowicz, 1997).Moreover, rainwater and urban runoff were collected in cisterns for potable uses (ibid). The Persian perspective of urban runoff was clearly as a vital natural resource. Unfortunately, as time passed changes in the Persian attitudes and behavior contributed to water pollution problems and the eventual downfall of the civilization.

The Mesopotamian Empire states of Assyria and Babylonia marked great advances in civilization during the second millennium BC. The ruins from Mesopotamian cities contain well-constructed storm drainage and sanitary sewer systems. For example, the ancient city of Babylon, located in present day Iraq, had effective drainage systems for stormwater control (Jones, 1967). The systems contained vaulted sewers and drains for household waste, gutters and drains specifically for surface runoff (Maner, 1966). The material of choice was baked brick with an asphalt sealant. Rainwater was also collected for household and irrigation uses. The Babylonians were partially motivated to construct urban drainage systems by their desire to remain clean. The Babylonians, like other ancient civilizations, viewed uncleanness as a taboo; not because of the physical uncleanness but the moral evil it suggested (Reynolds, 1946). In retrospect, the Mesopotamians viewed urban runoff as a nuisance flooding concern, waste conveyor, and a vital natural resource.

The Minoan civilization flourished on the Island of Crete from about 2800 BC to 1100 BC. The ruins from this civilization located on the Aegean Sea revealed elaborate systems of well-built stone drains, which carried sanitary sewage, roof runoff, and general surface drainage (Gray 1940). The drains emptied into a main sewer that disposed of the sewage a considerable distance from the origin of the wastes. The Etruscan civilization built some of the first organized cities in central Italy around 600 BC (Scullard 1967). Marzobotto, one of the more important Etruscan cities, had a skillfully designed drainage system making use of the natural slope to keep the city dry and clean. In addition, paved streets and stepping-stones in the roadways acted as protection for pedestrians against storm water runoff (Strong, 1968). The Etruscans, similar to other ancient civilizations, formed the perspective of urban runoff as a nuisance flooding concern, a waste conveyor, and a vital resource.

There is no enough space to thoroughly review nuisance flooding, pollution concern, a waste conveyance mechanism, and a vital natural resource of every example of ancient urban drainage systems. Other civilizations, most notably the Egyptians, Hittites, Greeks, and Chinese also constructed well-planned urban drainage systems. Even though this study didn’t review about them, it can be stated that their perspectives of urban drainage were similar to the perspectives exhibited by the other civilizations that were reviewed under this section.

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. Most sewers were designed exclusively for storm water drainage. Sanitary wastes accumulated in privy vaults and cesspools and were periodically collected by scavengers and transported to a suitable disposal location (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 storm water and sanitary wastewater (Reynolds, 1946).

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 (Scullard 1967).

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 (Reynolds, 1946).

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

Methods to design and construct sustainable urban drainage systems are currently being researched and tested. Alternative development concepts (e.g., low-impact development) are influencing development practices to minimize the impacts of development on storm water drainage. In addition, alternative on-site wastewater management strategies are being touted as more sustainable than centralized wastewater management for some situations. Communities are searching for innovative techniques to capture, detain, and use rainwater within the watershed instead of constructing massive drainage structures. Many communities are developing watershed-wide storm water quality management plans to meet the dual objectives of flood prevention and water quality control. Urban drainage has indeed expanded significantly during the past few decades beyond a technical challenge to drain the urban area expeditiously to include the consideration of social, economic, political, environmental, and regulatory factors.

2.2 Urban Storm Water 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 socio-economic, 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 (Novatech, Lyon and GRAYE, 2001).

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(Novatech, Lyon and GRAYE 2001).

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 (Uli, 2008). Such urbanization patterns make it difficult to control urban drainage, since it not only causes or aggravates local flooding but can also create problems downstream.

The extent of impermeable cover is directly correlated with runoff coefficients and also with population density, so that an indirect method of evaluating the impact of urbanization on drainage is to relate population density with runoff coefficients. There is evidence world-wide that higher urban population density commonly results in greater storm-water generation, (Debo and Reese, 2003) but many urban planners take no account of this important effect and neglect the wider costs of their storm-water control procedures.

Modern urban drainage calls for detention and infiltration areas, contrary to the philosophy of higher population density. Many cities in developing countries have a density index which already causes critical drainage situations. Besides the problems of control in legal settlements, socio-economic problems lead to the invasion of public areas, forming slums with high population density and high rates of impermeable soil surface. (Debo and Reese, 2003).

2.2.2 Contamination by Foul Sewage

WHO internet data show that urban sanitation coverage for Africa, Asia, Latin America and the Caribbean, where most developing countries are concentrated, at present of the order of 80%, giving an average minimum level of raw sewage dispersed through the environment as 20%. The amount of raw or inadequately-treated sewage discharged into urban rivers is not recorded at the global level. Primary and secondary treatment levels of domestic and industrial waste do not enter the WHO and World Bank sanitation indicators, and this complicates any global evaluation of the quality of life or of environmental sustainability of urban conglomerations and their surrounding regions.

The presence, real or potential, of foul sewage in the storm-sewer network makes it difficult to adopt modern urban drainage practices. The potential for pollution by foul sewage is very high and it cannot be permitted to enter areas set aside for retaining storm runoff or for allowing runoff to infiltrate the soil. Pollution of storm runoff by dirt from streets, and by substances present in the rainfall itself is also important. In general it is expected that storm runoff in developing countries has higher pollution indices in terms of organic material and coliforms.

2.2.3 Excess Sediment and Garbage

Urban areas in developing countries have significant proportions of exposed soil liable to erosion and giving rise to large quantities of sediment. Building sites, 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 (Tucci, 2000). 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 (Tucci, 2000).This is a peculiar feature of developing countries which makes control works for storm runoff control even more expensive to implement.

2.2.4 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 (Jones, D.E., Jr. 1967). 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 Jones D. E. 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.

2.2.5 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 (Novatech, Lyon, and GRAYE 2001. In most developing countries this has been a problem for sustainable storm water drainage management. Lack of community participation leads to the repetition of earlier errors in solving drainage problems, to the discredit of public action, and lack of concern with environmental questions (ibid). It can also bring about low investment in urban facilities.

2.3 Urban Storm Water Drainage Practice in Ethiopia

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 (NUPI, 2000). 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. (FUPI, 2008). After its inception, Federal Urban Planning Institute has been involving in planning and design of urban storm water 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 storm water, Air pollution from stagnated water and Soil from erosion and degradation.

Before the establishment of the National Urban planning institute some twenty year ago, there has been no formal working organization in the area of urban storm water drainage system. Even now a day the attention towards urban storm water system is at its immature stage that is why most of the urban storm water drainage structures gets 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 (FUPI, 2008).

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).

The technologies in handling the environmental problems of urban storm water drainage in Ethiopia, which have been practiced, are not in a position to utilize the flood/runoff for various uses, like the treatment/sedimentation of runoff water, construction of detention ponds and other perforated structures for the water to be infiltrated in to the soil, rather the primary aim of urban storm water drainage system in the country is to safely discharge the storm/run-off out of the urban centers(Belete, 2009).

2.4 Urban Storm Water Drainage Practice in Addis Ababa

A major trouble of Sub-Sahara African roads are a poor drainage system, which allows storm water to sip through newly tarred surfaces and prematurely to riddle them with potholes. Addis Ababa, the capital city of Ethiopia is one of the places in the country that has been damaged by the rainy season. Faced with a problem of this magnitude, municipal authorities have been doing their level best and stepped up timely and effective road maintenance. The main challenge in this regard remains Addis Ababa's poorly developed drainage system. Only 615 kilometers, or only about 29 percent of the city's road mileage, are equipped with drainage lines, with non-asphalted roads the main victims (Uli, 2008). According to research published in 2009, of the city's 395 kilometers of asphalted roads only 193 kilometers had storm drainage lines, and out of 960 kilometers of no asphalted roads only about 143 kilometers had drainage channels. More often than not, unlined channels are to be found in areas where ground profiles are steep, which exposes those areas to erosion through high velocities of flow.

No up-to-date data is available regarding to the proportion of housing units that are connected to drainage lines. According to various studies, this was the case for only about 33 percent of them in 1996. A community-based infrastructure upgrading program has done a lot to improve drainage in the city during the last 10 years. However, the difference made by the program is lessened by the sheer size of the problem. According to Mr. Dagnachew Belete's study of Addis Ababa drainage lines, the existing drainages have lower capacity to convey the runoff generated. Apparently the drainage system of Addis Ababa is sadly underdeveloped by any standard.

2. 5 Rivers Flows across Addis Ababa

City of Addis Ababa is situated at latitude varying from 2350 to 2700 meters. Undulating and flat topography of the city spreads to the southern slopes of Intoto Ridge. The urban land includes valleys formed by five river systems flowing towards south. Flat topography gradually slopes to the south easterly direction (JICA, 1998). The following table shows the principal features of the river system flowing in Addis Ababa.

Table 2.1 Principal Features of the River system in Addis Ababa Source: JICA, 1998

River System	Basin Area (Km^2)	River Length(Km)	River Slope
West Akaki	172.2	35.6	1/50-1/100
Little Akaki	30.8	20.5	1/25-1/100
Kebena	59.8	23.9	1/20-1/100
Uper Kebena	54.8		
Lower Kebena	5.0		
Bantyiketu	29.3	11.2	
(Bantyiketu)	5.4		1/100
(Kechene)	13.6		1/20-1/50
(Kurtume)	10.3	9.3	1/20-1/50
Hanku	11.1	8.6	1/50-1/70

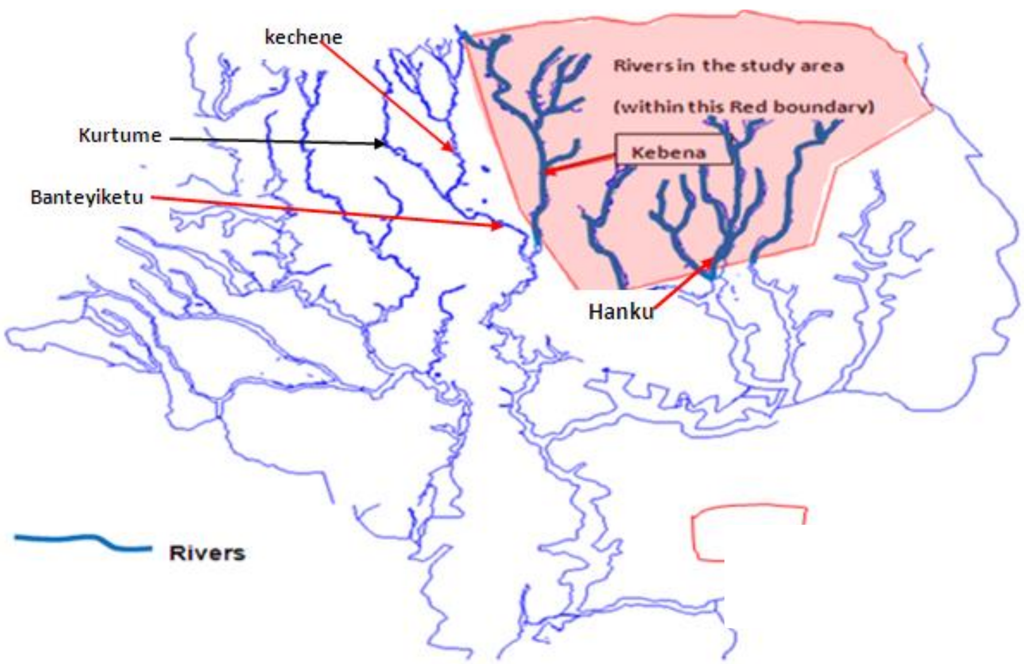


Figure 2.1 River systems in Addis Ababa (source: Belete, 2011)

Flood runoff analysis was conducted by Nippon Koei and associates JICA using rational method in conjunction with the triangular unit hydrograph. Rivers discharge for return periods ranging from 2-30 year was computed.

Table 2.2 Probable Flood Peak Discharges of Addis Ababa Rivers Source: (JICA, 1998)

River System	Flood Peak Discharge (m^3/s)				
	2yr	5yr	10yr	20yr	30yr
West Akaki	280	380	450	510	550
Little Akaki	110	145	170	195	215
Kebena	200	280	320	370	400
Bantyiketu					
(Bantyiketu)	120	160	190	215	230
(Kechene)	65	90	105	120	130
(Kurtume)	50	70	85	95	100
Hanku	50	65	75	90	95

Based on the river surveys and the hydraulic analysis Nippon Koei and Associates JICA computed river channel characteristics. Channel width and the river carrying capacity were among the important information complied.

Table 2.3 Channel Characteristics of Addis Ababa River Source: (JICA, 1998)

River System	Average slope	Channel Width (m)		Carrying Capacity (m^3/s)
		Minimum	Average	
West Akaki	1/100	15	40	400-800
Little Akaki	1/50	5	20	50-300
Kebena	1/50	5	25	150-800
Bantyiketu	1/120	10	20	30-150
Kechene	1/30	8	15	50-250
Kurtume	1/35	8	10	30-150
Hanku	1/160	5	10	20-150

Table 2.3 indicates that Addis Ababa have steep bed gradient. The beds are generally composed of volcanic rock this would indicate quite stable beds (JICA, 1998).

2.6 Waste Water and Solid Waste Management Practice in Addis Ababa

The rapid and mostly uncontrolled demographic growth and spatial expansion of large cities in developing countries often results in considerable damage to the environment. This is particularly true in the case of Addis Ababa, which today is suffering from high levels of water and air population, soil degradation and contamination (WMO & GWP, 2003).

The population and built up area of Addis Ababa is rapidly expanding as a result of urbanization. One of the important basic needs of its growing population is water. While the city is growing, dependency on primarily rural areas upstream to supply water is increasing. The area downstream of the city that is affected by industrial and domestic pollution seems to be growing as well.

Less than 10 percent of the urban area sewered while in the major part of the remaining area pit latrines are used that dispose their wastewater in the storm drainage network (AAWSSA, 2008). Current waste water treatment capacity is very small in Addis Ababa (NEDECO, 2002). Therefore, waste water is discharged directly in to natural water courses of the Akaki River, which eventually joins the Awash River. The Akaki River is an important source of water for small scale farmers in and around Addis who are producing vegetables and fodder for livestock. The Akaki River serves as an important drainage system that disposes abundant runoff and waste water in to the Awash River (Rooijen & G/hana 2009).

With regard to solid waste management, Addis Ababa's performance has improved slightly in the recent past. The overall rate of solid waste collection stood at about 50 percent in 1996 (Uli, 2008). More recently, the citywide municipal solid waste collection rate has risen to about 60 percent. The rate of municipal solid waste generation for the city is currently estimated to be about 0.252 kg. per capita per day (ibid). This figure is relatively low when compared to those for most cities of similar status where the solid waste generation per capita per day is estimated to be somewhere in the range of 0.4 to 0.6 kg. per capita per day (ibid).

Addis Ababa generates a daily 2,297 m3 (ibid) of solid waste on average. This is significantly below the capacities of the Solid Waste Management Department of the city, which can collect, and dispose of, as much as 3000 m^3 of solid waste per day. Unless the estimated per capita generation of solid waste in the city is far below reality, the Department seems to be operating way below capacity. If that is the case, it appears that its performance is seriously constrained by two main factors: (1) shortcomings in its own management; and (2) a substantial portion of the city remains outside its scope, owing either to poor access to some neighborhoods, or to inadequate cooperation by households, or both. Growing traffic congestion also hinders waste collection truck ability to make as many round trips as desirable between city streets and the dumping grounds (UN-Habitat, 2008).

2.7 Best Management Practice for USWD

The physical and chemical characteristics of storm water runoff change as urbanization occurs, requiring comprehensive planning and management to reduce adverse effects on receiving waters. As storm water flows across roads, rooftops, and other hard surfaces, pollutants are picked up and then discharged to streams and lakes (UD & FCD, 2010). Additionally, the increased frequency, flow rate, duration, and volume of storm water discharges due to urbanization can result in the scouring of rivers and streams, degrading the physical integrity of aquatic habitats, stream function, and overall water quality.

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

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 storm water management practice (ibid).

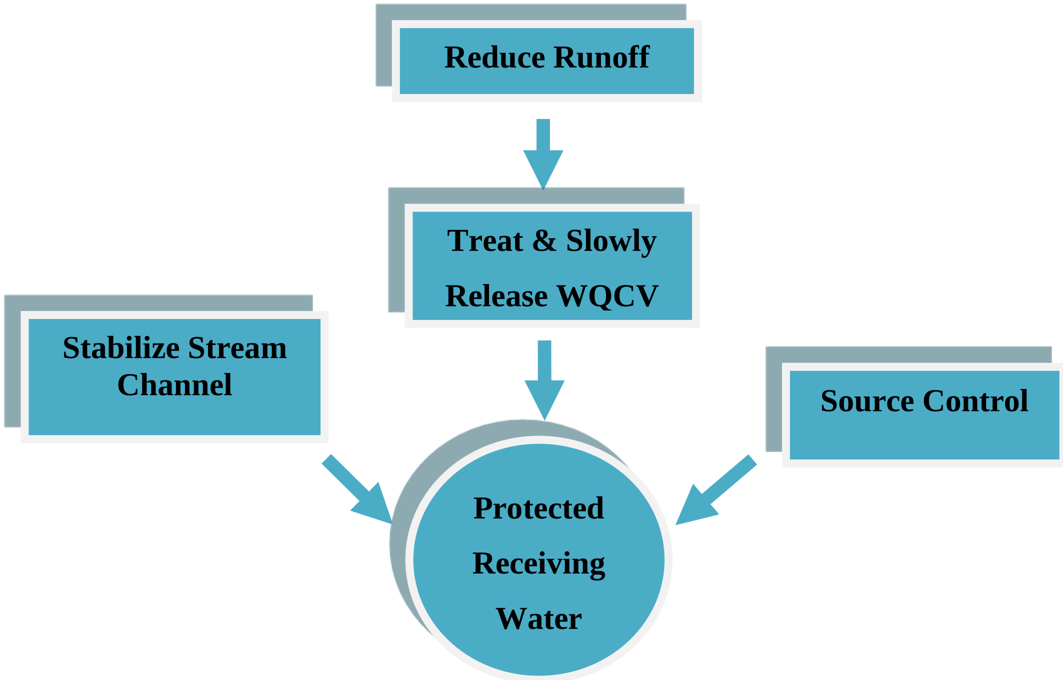


Figure 2.2 The Four Step Process for Storm water Quality Management (ibid)

2.7.1 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 and therefore the volume and rate of runoff and the associated pollutant load; and outlines various approaches to reduce or minimize this impact through planning and design techniques.

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

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:

1. 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 (ibid).

2. Minimize Directly Connected Impervious Areas (DCIA)

Impervious areas directly connected to the storm drain system are the greatest contributor to non-point source pollution. The first effort in site planning and design for storm water quality protection is to minimize the "directly connected impervious area (DCIA)" as shown in fig 2.3. Any impervious surface that drains into a catch basin, area drain, or other conveyance structure is a "directly connected impervious area." As storm water runoff flows across parking lots, roadways, and paved areas, the oils, sediments, metals and other pollutants are collected and concentrated. If this runoff is collected by a drainage system and carried directly along impervious gutters or in material or infiltration into the soil, it also increases in speed and volume, which may cause higher peak flows downstream, and may require larger capacity storm drain systems, increasing flood and erosion potential (ibid).

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.

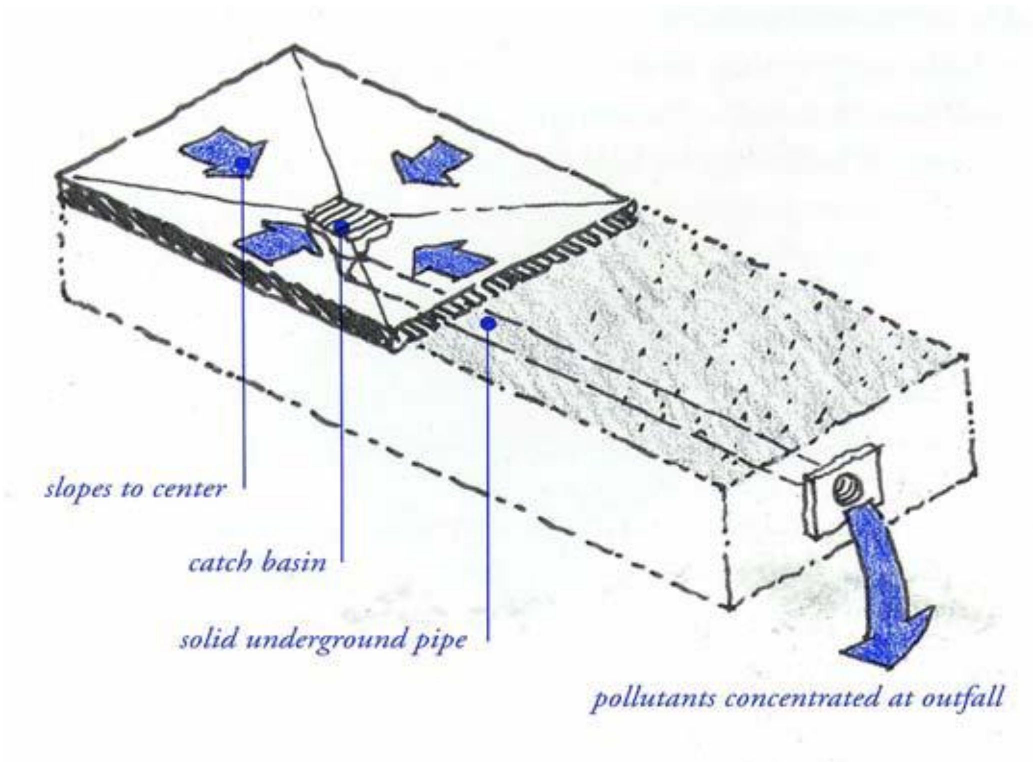


Figure 2.3 Directly Connected Impervious Area**3. Incorporate Zero Discharge Areas**

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 storm water 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 (ibid). 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 storm water 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 (Maryland's Urban Stormwater Best Management Practices by Era Proposal, 2009).

Figure 2-3 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.

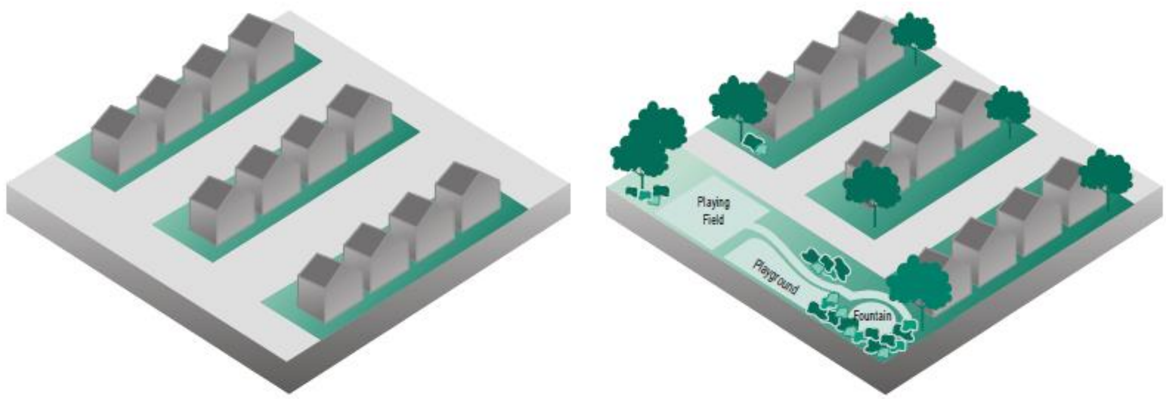


Figure 2-4 Zero Discharge Area Usage

4. 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 & FCD, 2010).

2.7.2 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 storm water management.

- **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 (ibid).

- **Grass Buffer:** Grass buffers are densely vegetated strips of grass designed to accept sheet flow from upgradient 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 (ibid).
- **Bioretention:** engineered, depressed landscape area designed to capture and filter or infiltrate the water quality capture volume (WQCV). BMPs that utilize bioretention are frequently referred to as rain gardens or porous landscape detention areas (PLDs) (ibid).
- **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 (ibid).
- **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 (ibid).
- **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 (ibid).
- **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) (ibid).
- **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

the layers below the pavement surface. Depending on the design, permeable pavements can be used to promote volume reduction, provide treatment and slow release of the water quality capture volume (WQCV), and reduce effective imperviousness, etc. (ibid).

2.7.3 Source Control BMPs

Proactively controlling pollutants at their source is fundamental to effective storm water quality management and is part of the Four Step Process. Typically, it is easier and more cost-effective to prevent storm water 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 (Maryland's Urban Stormwater Best Management Practices by Era Proposal, 2009).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.

2.7.4 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.

3. MATERIALS AND METHODS

This chapter include materials and methods used in this research in order to meet the desired objective. It includes: material such as base map, rainfall data, contour map and tap meter. A rigorous literature review was conducted to understand urban drainage system well, how best Management Practices would help to eradicate problems regarding to urban drainage. Different methodologies have been employed to reach the desired goal which was focused to eradicate urban storm water drainage problem in a sustainable way.

3.1 Materials

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 Storm Water Drainage system, natural water ways/rivers and integration of storm water drains and roads in the study area. To determine areas with and without drainage system in Kebena stream catchment by integrating with Google Earth.

3. Tape meter: to measure the existing storm water drainage lines depth, width and diameter which helps to evaluate the capacity of the drainage system.

3.1.1 Data Types and Sources

This part contains of the types and sources of data which were used in this study. Consequently, the qualitative as well as quantitative type of data has been used for this research. Rainfall data were used to develop IDF curve and data sources for this research were both primary and secondary sources.

3.1.1.1 Primary data sources

Field survey/observation, interview and laboratory results were the primary data sources which were engaged in this study.

3.1.1.2 Secondary data sources

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.

3.2 Methodology

3.2.1 Research Development

Evaluating urban storm water drainage system is challenging and hence needs an ample methodology. Two types of methodologies were used to perform this research.

The descriptive type was used to describe challenges and factors which impaired the performance of storm water drainage system and the condition of the Kebena stream watershed. Whereas, the exploratory type was particularly used to explore the existing condition and coverage of urban storm water drainage facilities which have been used by the sub-cities and best management practices for the existing drainage problem.

3.2.2 Sampling Techniques

Purposive sampling technique was involved in this study. Evaluating the whole catchment is not necessarily important to come up with solution for storm water drainage problem. Therefore, some representative major flood prone areas with their impact to Kebena stream and the area where the problem is most encountered are selected. This study conducted on three woredas. These three woredas (Woreda 6 & 7 from Yeka sub city and Woreda 8 from Kirkos subcity) are located around Kebena stream and most their storm drainages outlet is Kebena stream. They are selected for this study because of their influence to Kebena stream and since these woredas have been facing high flooding during the rainy season.

3.2.3 Data Collection Techniques

Field Survey

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, check list and contour map as per the objective of this study. The check list has included issues such as the effects of urban storm water drainages on the environment, flooded areas, the condition of Kebena stream,

Interview

Generally, this was employed for the dwellers in the study area to collect data related to flooding and causes of flooding, major challenges to storm water drainage management, impacts of drainage system on Kebena stream, damages caused by Kebena and other small streams on the Sub cities and possible suggestions from residents point of view so as to handle the challenges of the drainage system in the study area. The residents in the study area were interviewed to get reliable data as they are the most vulnerable people in the past years and they have been observing the flooding problem, the challenge that has been faced over the years.

Laboratory Analysis

This was employed to investigate the permeability of the soil which helps to select the appropriate BMP for the specific sample area.

3.2.4 Data Analysis

The collected data were analyzed with the help of known computer software including:

- Microsoft excels: to calculate the runoff on the excel spreadsheet and prepare a comparison graph between the capacity of the existing drainage system and the estimated runoff.
- Auto Cad: to integrate it with contour map and determine the flow direction for each drainage line.
- Google Earth: to visualize the study area.
- Arc GIS & HEC-GEOHMS: to analyze the spatial data and delineate Kebena Catchment.
- Flow Master: to calculate the capacity of the drainage system with the measured dimensions of the drainage lines.

3.2.5 Research Flow

This flow chart shows the steps and methods which were followed to conduct this research.

Steps

Study Current Condition of the Drainage System

Calculate Capacity of the Existing Drainage

Methods

1. Field Survey
2. Interview
3. Laboratory Analysis

Manning's formula was used to calculate the capacity of the drainage systems and checked by FLOW MASTER Software which calculates the flow in the channels.

$$Q = \frac{1}{n}\frac{A^{5/3}}{P^{2/3}}S^{1/2}$$

Where, n=manning's roughness coefficient

A= Area of the channel (m^2)

P= Wetted perimeter (m)

S= Channel bed slope (m/m)

The selection of manning's roughness 'n' is generally based on observation which was found from field observation and Google Earth. The range of 'n' values for various types of channels and flood Plains is given in ANNEX G.

Runoff Estimation for the Study Area

1. Determining the **design flood** for minor and major drainage including road storm-water drains were based on the 2004 Addis Ababa City Roads Authority Drainage Design manual.
2. For catchment areas less than 80 ha, the rational formula were used, while for catchment areas greater than 80 ha, the SCS method were supposed to be used following the guideline in AACRA Drainage Design Manual, but since all drainage areas were less than 80 ha SCS method was not used.
3. Rational Method is appropriate for estimating the design storm peak runoff for areas up to 80 ha (0.8 km^2). The rational formula is expressed as:

Q = 0.278C I A

Where: Q = Maximum rate of runoff, m^3/s

C = Runoff coefficient representing a ratio of runoff to rainfall (Recommended Runoff coefficient is given in ANNEX H. The average runoff coefficient is calculated by the following equation.

$$C = \frac{\sum AiCi}{\sum Ai}$$

Runoff Estimation for the Study Area

I = Rainfall intensity for a duration equal to the time of concentration and for design return period, mm/hr

A = catchment area tributary to the design location, km2

a) Tc=0.0147* L1.155 H-0.385 (Kirpich / SCS Equation)

Where, Tc = time of concentration for the catchment, minutes

L = maximum length of flow, m

H = elevation difference between the most remote and outlet, m.

Kirpich method was selected because for such small watershed it relatively reliable.

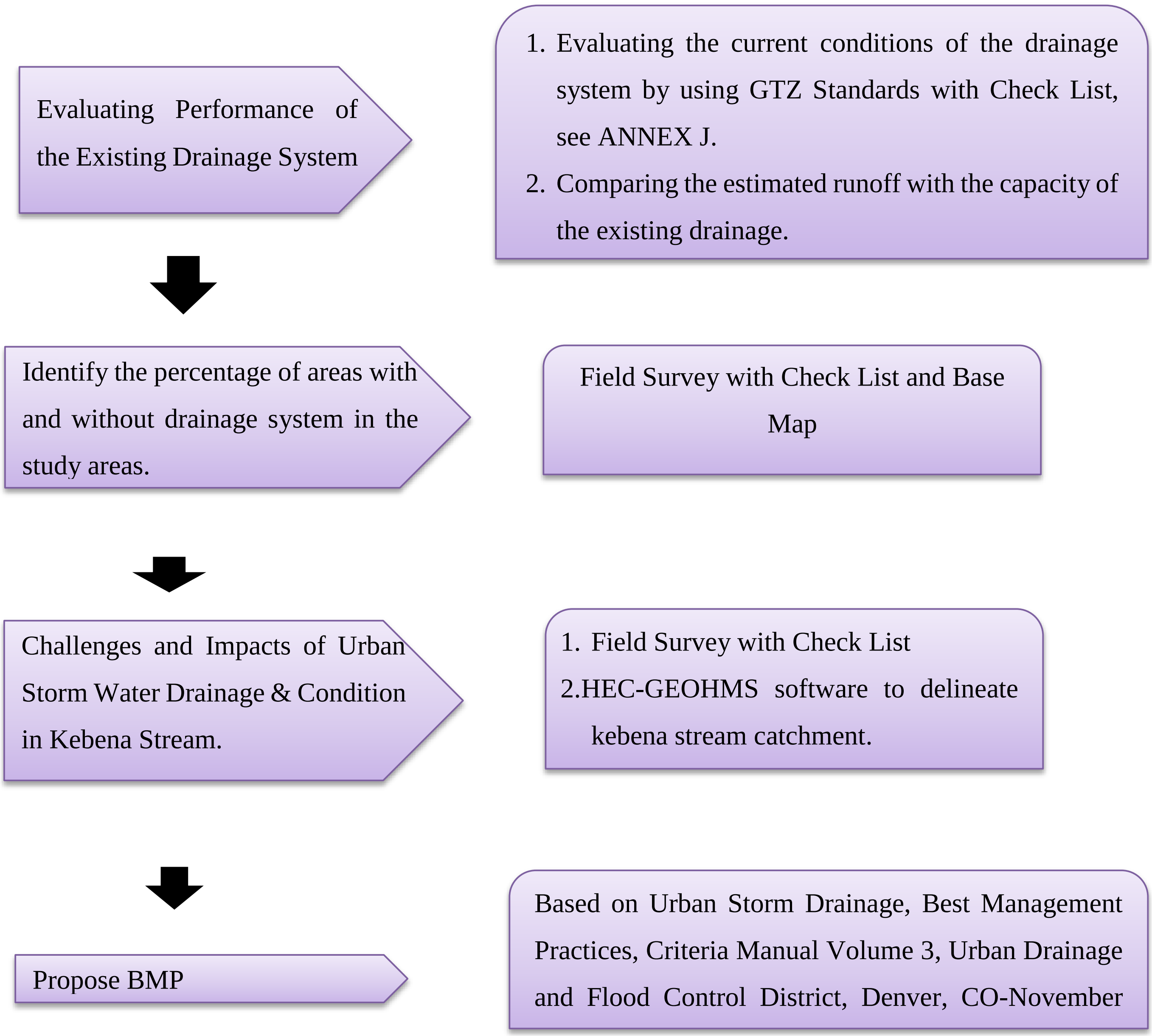
b) Upstream drainage flow time (min) = $^{L}/_{V}$, where, L is channel length and V is flow velocity.

Time of concentration= $a + b$

4. The drainage system design (used for conveying surface water runoff) is based on 5 year return period for small channels & 10 year return period for culverts.
5. The channel slope = ((terminal – initial) elevation / channel or drain length)*100
6. Develop IDF Curve for Addis Ababa Area.

   Steps followed to develop the IDF curve

   a) Select a design storm duration
   b) Extract annual maximum rainfall depth for the selected duration from n years of historic data.
   c) Determine the applicable probability distribution and fit with the annual maximum rainfall data. Calculate Mean and Standard Deviation of the series.
   d) Calculate the D-hr storm depths for various return period T-yr using fitted probability equation. $XT=\mu+K_T\,\sigma$, where; μ, σ and K_T are Mean, Standard Deviation and frequency factor, respectively.
   e) Calculate the average intensity and repeat step a) through d) for various design storm durations.
   f) Construct the IDF curves.


Evaluating Performance of the Existing Drainage System
1. Evaluating the current conditions of the drainage system by using GTZ Standards with Check List, see ANNEX J.
2. Comparing the estimated runoff with the capacity of the existing drainage.
Identify the percentage of areas with and without drainage system in the study areas.
Field Survey with Check List and Base Map
Challenges and Impacts of Urban Storm Water Drainage & Condition in Kebena Stream.
1. Field Survey with Check List
2.HEC-GEOHMS software to delineate kebena stream catchment.
Propose BMP
Based on Urban Storm Drainage, Best Management Practices, Criteria Manual Volume 3, Urban Drainage and Flood Control District, Denver, CO-November

4. RESULT AND DISCUSSION

This chapter describes and discuss the result obtained in this research, it includes: current condition of the drainage system and kebena stream, performance and capacities of the drainage systems, challenges and problems of storm water drainage system in the study area and percentage of area with and without urban storm water drainage system.

4.1 Current Condition of the Study Area

From field survey, field observation and interviewing the community in Woreda 6, 7, & 8 the current status of the storm water drainage system has been investigated.

4.1.1 Capacities of the Existing Drainage System in the Study Area

Urban storm water 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 three woredas. Therefore, an effort has been done here to evaluate the capacity, percentage of coverage 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 4.1 shows a sample calculation of the discharge that is conveyed through the existing drainage system using the methodology described in chapter 3. The rest of the calculation is given in the ANNEX (A-C).

Table 4.1 Computation of the capacity of the existing drainage system (own analysis, 2012)

No	Flow direction		Drainage Types											
	From	To	Trapizoidal			Rectangular		Circular						
			B(m)	Y(m)	T(m)	Br(m)	Yr(m)	D(m)	n	A(m^2)	P(m)	S_o (%)	Q(m3/s)	V(m/s)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	DL-1	DL-2				0.4	0.2		0.013	0.08	0.8	4.5	0.09	1.14
2	DL-2	DL-3						0.6	0.013	0.28	1.88	2.5	0.97	3.43
3	DL-3	DL-4				0.65	1		0.035	0.65	2.65	2.6	1.17	1.81
4	DL-4	Outlet						0.8	0.013	0.79	3.14	2.9	4.08	5.2
5	DL-5	Outlet				0.3	0.4		0.04	0.12	1.1	5	0.15	1.28
6	DL-6	DL-7				0.35	0.5		0.04	0.18	1.35	1.4	0.13	0.76
7	DL-7	DL-8				0.3	0.5		0.04	0.15	1.3	5.6	0.18	0.21
8	DL-8	DL-4				0.45	0.6		0.04	0.27	1.65	3.6	0.38	1.42
9	DL-9	DL-7				0.35	0.4		0.04	0.14	1.15	1	0.09	0.61
10	DL-10	DL-18				0.2	0.35		0.04	0.07	0.9	1	0.03	0.46
11	DL-11	DL-18				0.3	0.4		0.04	0.12	1.1	4.5	0.15	1.12
12	DL-12	DL-13	0.45	0.7	0.75				0.04	0.81	2.43	1.1	1.01	1.26
13	DL-12.1	DL-13				0.35	0.4		0.04	0.14	1.15	2.3	0.13	0.93
14	DL-13	DL-14				0.5	0.6		0.04	0.3	1.7	3.7	0.45	1.51
15	DL-14	DL-2				0.55	0.7		0.04	0.39	1.95	2.2	0.48	1.26
16	DL-15	DL-16				0.4	0.5		0.04	0.2	1.4	1.1	0.14	0.72
17	DL-16	DL-17				0.5	0.6		0.04	0.3	1.7	1.4	0.28	0.93
18	DL-17	DL-46	0.4	0.5	0.65				0.04	0.45	1.81	0.7	0.37	0.83
19	DL-18	DL-16				0.2	0.35		0.04	0.07	0.9	4.5	0.07	0.97
20	DL-19	DL-17				0.2	0.3		0.03	0.06	0.8	3.3	0.06	1.08
21	DL-20	DL-22	0.3	0.2	0.45				0.013	0.04	0.57	1.5	0.06	1.61
22	DL-21	DL-22				0.35	0.4		0.04	0.14	1.15	1.1	0.09	0.64
23	DL-22	Outlet	0.4	0.6	0.7				0.035	0.33	1.64	3.5	0.61	1.84

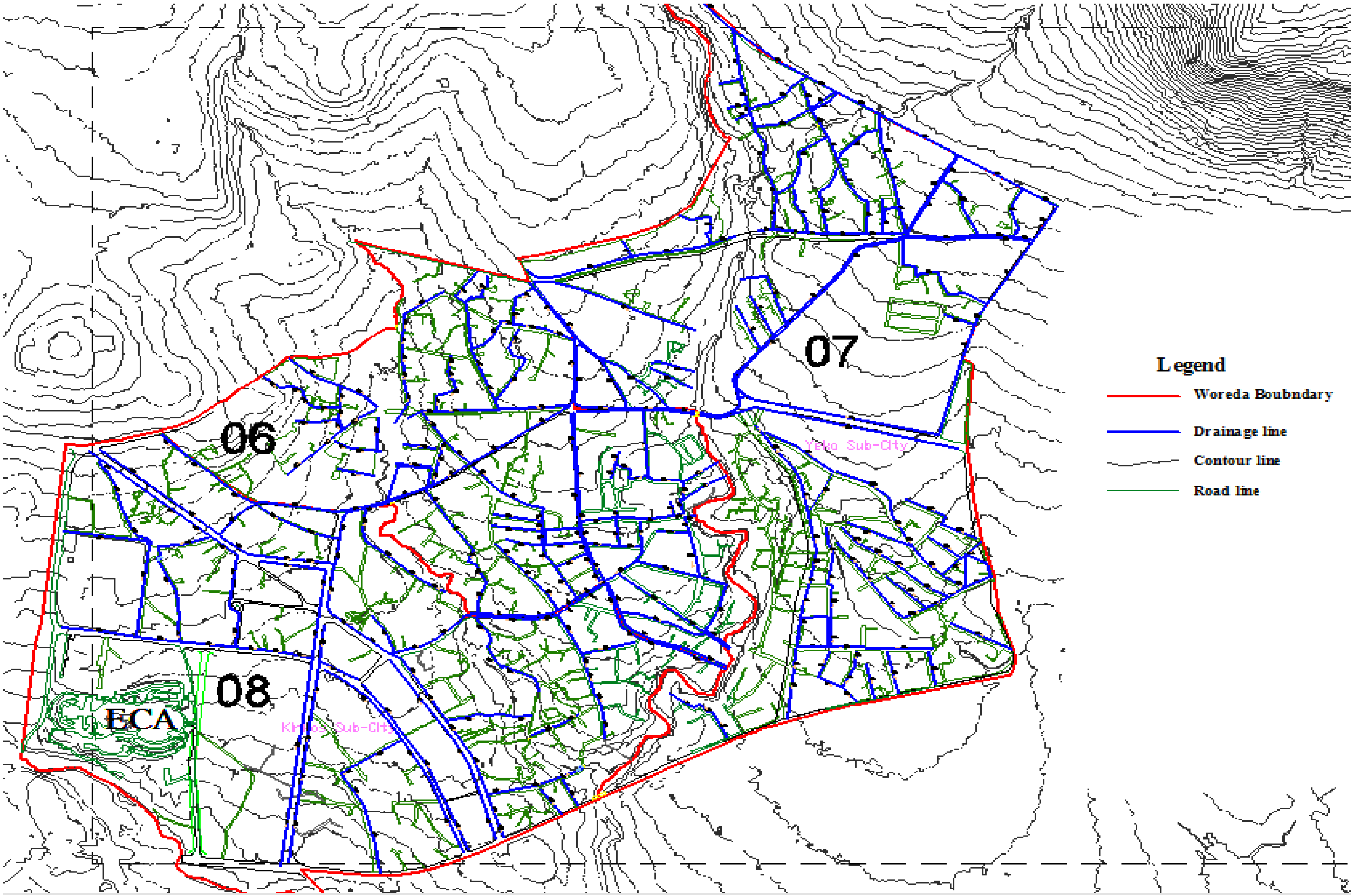


Figure 4.1 Map of the drainage lines in the study area

4.1.2 Estimated Runoff for the Study Area

In order to evaluate the capacities of the drainage system the current runoff has to be estimated. Therefore this part is prepared to brief the Hydrologic Investigation and evaluation of major and minor storm water drainages of these three woredas which includes Kasanchis, Road to Signal, Edna Addis Hotel, road from Kasanchis to Betemengist and to Urael and other minor drainage lines for minor roads. Most of minor roads were gravel surfaced and the major ones were Bitumen Asphat road and some part of woreda 7 roads were proposed road so as their drainage system. From Woreda 8 the evaluation did not include part of ECA and construction site around ECA because there were no accesses to measure their dimension and moreover it was on progress.

As some of the existing cross drainage systems are overtopped during heavy rainfalls the road side drains, walkways and the asphalt are flooded sometimes even during average storm. Thus, the hydrological study of this research aimed at determining the current runoff and providing solution to such problems.

The dominant soil types in the catchment area that constitute the crossings of the road are essentially dark to dark brown silty clay soils and Red Silty clay soil in some section of the road were observed.

Design Flood

IDF Curves for Addis Ababa Area

Critical data for the drainage design is the rainfall intensity of Addis Ababa. The 1 hour and 1 day maximum rainfall at Addis Ababa over the period of 1969 to 2004 were used for this study. IDF curves for the study area is established with the collected data. The equations for different return period and duration of rainfall are estimated based on maximum one hour and one day rainfall data for Addis Ababa measured at the National Meteorological Services Agency Observatory. Figure 4.1 shows the graphical result of the IDF curve for 5, 10, 20, 25, 50, and 100 years return period. It is to be noted that this result is very close to the AACRA IDF curves given in the Drainage Manual which is estimated based on 26 years of data. See fig 4.2.

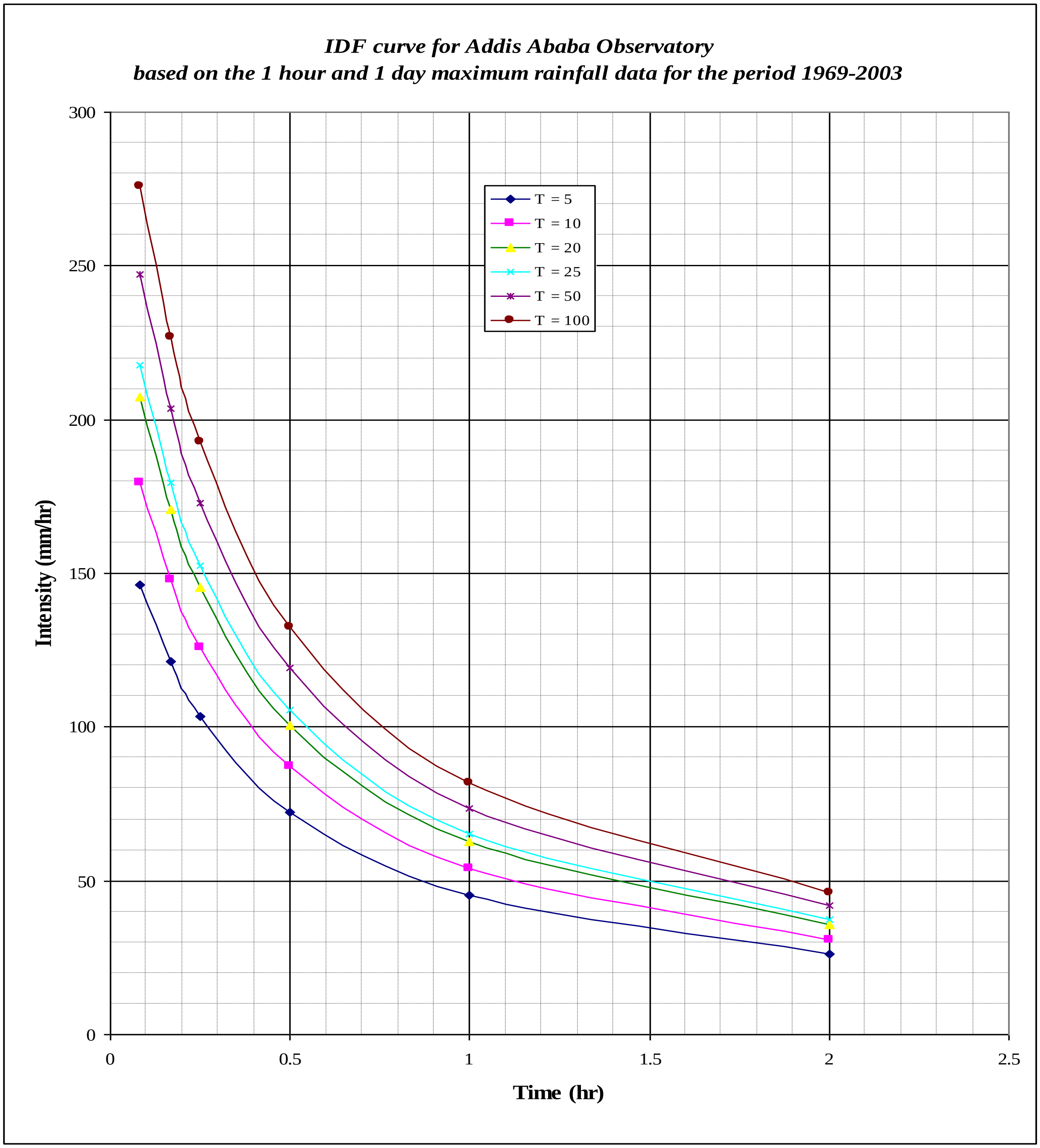


Figure 4.2 Intensity – Duration – Frequency Curves for Addis Ababa (Own analysis, 2012)

Here is a sample estimated runoff for the study area; the rest of the calculated runoff is included in ANNEX (D-F).

Table 4.2 Estimated current runoff for the study area (own analysis, 2012)

Plot No.	Flow Direction From	Flow Direction To	Descriptions of sub catchment	Sub-basin area A_s, (ha)	Runoff coefficient. (c)	Total basin area A_t, (ha)	length of the basin L_c (m)	Lowest elevation of the basin, H_1(m)	Highest elevation of the basin, H_2(m)	Average slope of the basin ,S_o	Time of Concen tartion(hr)	Rainfall Intensity I, (mm/hr) 5 years	Rainfall Intensity I, (mm/hr) 10 years	Total runoff for plot of basins Qs, (m^3/sec)
1	2	3	4	5	6	7	8	9	10	11	12	14	15	16
1	DL-1	DL-2	Gravel Road (A1)	0.12	0.80	0.118	211	2368	2378	0.045	0.066	150		0.04
2	DL-2	DL-3	Apartment Area (A2)	5.65	0.59	6.855	98	2366	2368	0.026	0.069		180	2.03
3	DL-3	DL-4	Gravel Road (A3)	0.08	0.71	6.939	57	2364	2366	0.026	0.034	160		2.19
4	DL-4	Outlet	Apartment Area (A4)	0.59	0.51	8.814	140	2360	2364	0.029	0.079		177	2.23
5	DL-5	Outlet	Gravel road&parking	0.41	0.80	0.411	110	2360	2366	0.050	0.038	158		0.14
6	DL-6	DL-7	Single family Area(A1)	0.40	0.40	0.774	147	2367	2369	0.014	0.079	148		0.13
7	DL-7	DL-8	Apartment Area (A2)	0.29	0.78	1.061	100	2366	2367	0.015	0.093	145		0.21
8	DL-8	DL-4	Gravel road (A3)	0.22	0.75	1.285	42	2364	2366	0.036	0.029	160		0.43
9	DL-9	DL-7	Gravel Road	0.29	0.80	0.287	49	2367	2368	0.010	0.038	158		0.10
10	DL-10	DL-18	Gravel Road(A1)	0.26	0.8	0.260	101	2371	2372	0.010	0.067	149		0.09
11	DL-11	DL-18	Neighborhood Area(A2)	0.01	0.76	0.013	22	2372	2373	0.045	0.025	162		0.20
12	DL-12	DL-13	Gravel Road(A1)	0.12	0.8	0.121	45	2372	2373	0.011	0.034	160		1.00
13	DL-12.1	DL-13	Suburban (A2)	0.18	0.61	0.181	44	2372	2373	0.023	0.035	160		0.15
14	DL-13	DL-14	Suburban (A3)	0.12	0.7	0.302	81	2369	2372	0.037	0.058	151		0.48
15	DL-14	DL-2	Suburban (A3)	0.78	0.75	1.084	46	2368	2369	0.022	0.035	160		0.51

Estimated runoff over the entire basin is higher than the capacity of the existing drainage lines (see fig 4.2, 4.3 & 4.4). The fact that most of the drainage lines in the area have not been maintained makes the problem even worse. This result shows the flood regime of these woredas have been changed.

4.1.3 Performance of the Drainage System in the Study Area

One of the most important factors in designing sustainable 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, coverage of the drainage system and evaluating the current conditions of the drainage system by using GTZ standards, see ANNEX J.

As presented in fig 4.3, out of the total storm water drainage existed in woreda 6 only 44% of the drainages are capable of conveying safely the runoff in to the water ways. In woreda 7 (see fig 4.4) out of the total drains only 40% of the drains have the capacity to convey the run off in to the stream. And also in woreda 8 (see fig 4.5) out of the total drains only 34 % of the total drainage system have the capacity to convey the runoff generated under current condition. This shows that most of the drainage lines have lower capacity and the flood generated within this woreda cannot safely be discharged in to the nearby river. On the other hand this will stagnate on open surfaces, overflow or inundate over road surfaces and also causes flood hazards in these woredas.

There are different reasons why the capacities of these drainage systems are poor. Of all the reasons this is mostly due to the fact that most of the drainage systems in these woredas have been installed long time ago and failing to consider and forecast the correct land cover changes while designing the drainages' capacities. Since then the land use cover has been changed resulting much more runoff than the capacities of the drainage system could handle.

According to the land use map of Addis Ababa in 1984 the pervious area was 441.8115 km^2 but in 2002 the pervious area become 220.0115 km^2 (Habtamu, 2011) which means the land use cover of Addis Ababa has been changed by 50% since then. Presumably the land use cover change was not considered properly. The major causes of flooding in drained part of Addis Ababa is a changing flood regime due to mainly the expansion of built up Environment. Urbanization is unstopping process which changes the hydrology of the environment. Therefore, estimation of the hydrology should have taken this factor in to consideration.

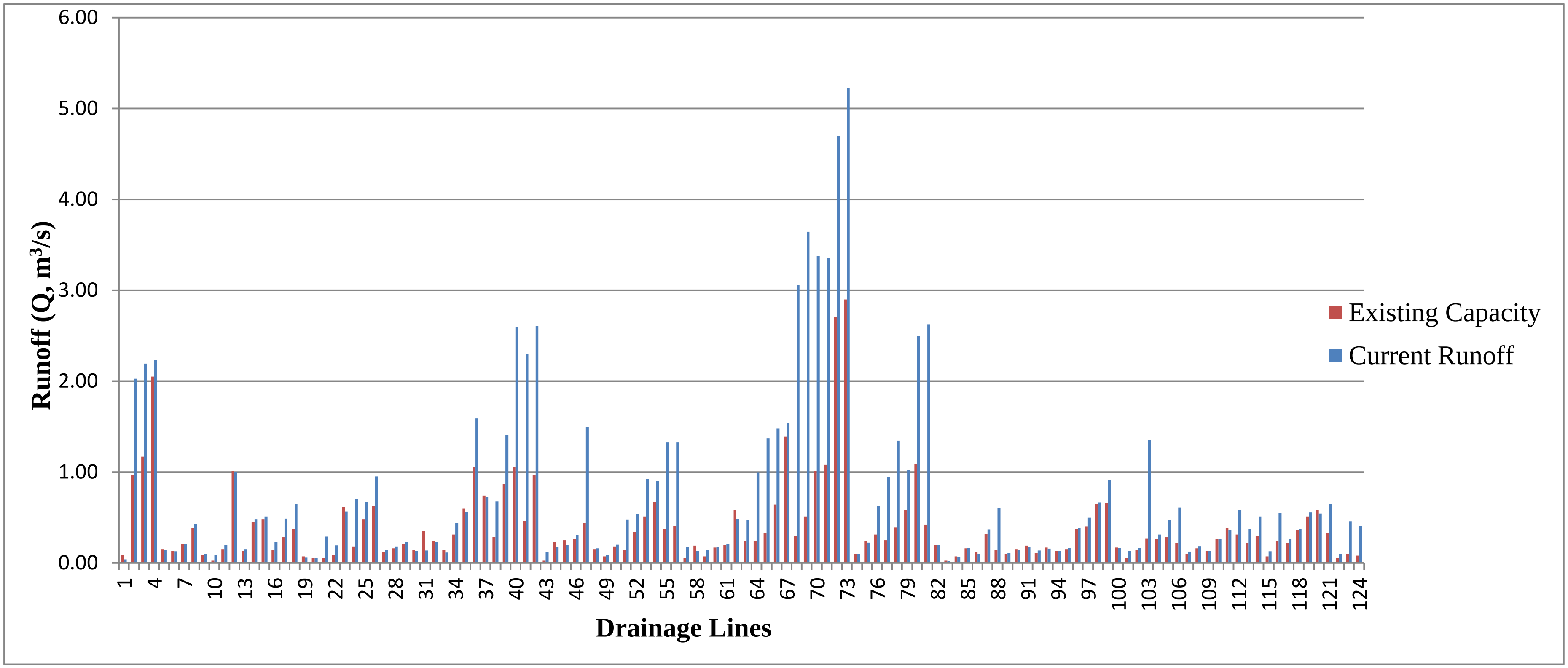


Figure 4.3 Comparison of the capacity and the current runoff for Woreda 6(Source: Own Analysis, calculating the existing capacity by measuring dimensions of the drainages and compare it with the current runoff).

In this woreda drainage line 40, 41, and 42 have low capacity to carry on the amount of runoff emanated. These lines are located around Awaree, road from Awaree to Kasanchis. And drainage line 68, 69,70,71,72 and 73 have also lower capacity, and they are also located around Awaree. As it is shown in fig 4.2 line 77, 78, 79, 80 and 81 have the capacity that can't deliver the runoff came along the way to the nearby Kebena River.

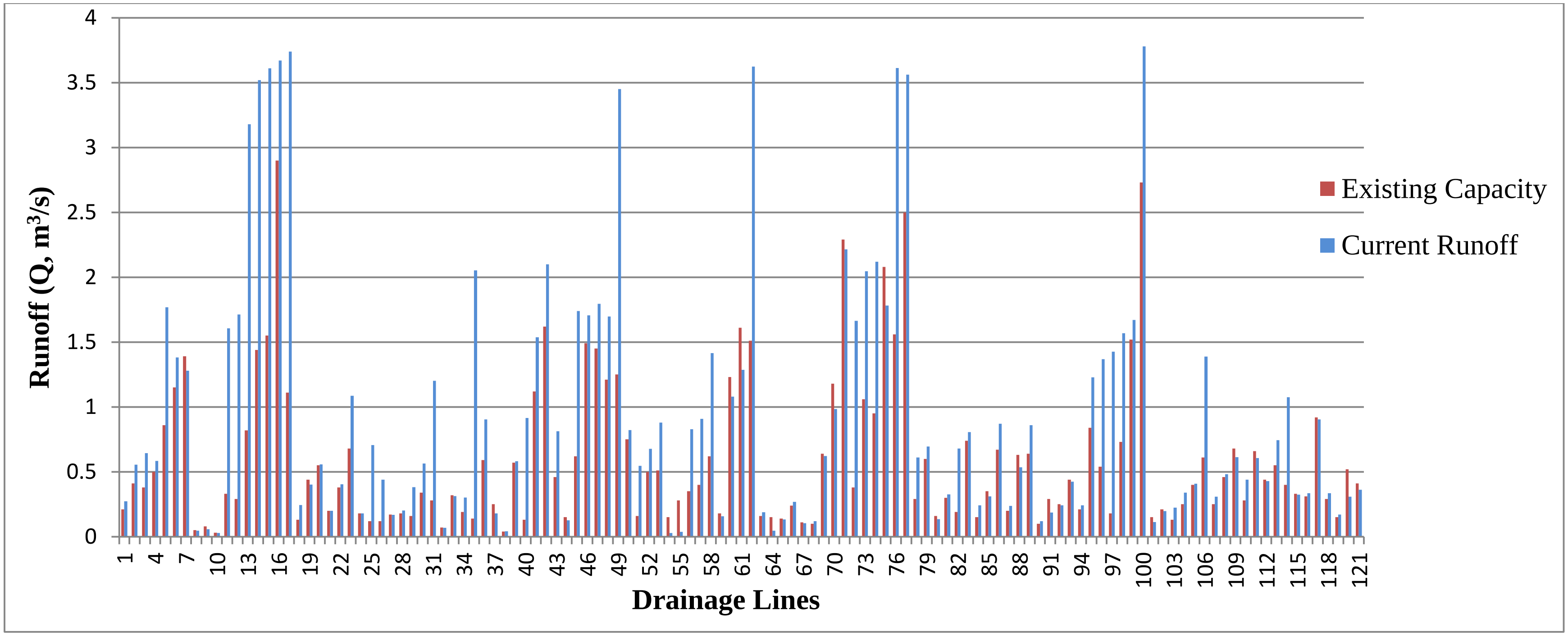


Figure 4.4 Comparison of the capacity and the current runoff for Woreda 7(Source: Own Analysis, calculating the existing capacity by measuring dimensions of the drainages and compare it with the current runoff).

In this woreda drainage line 11, 12, 13, 14, 15, 16, and 17 have low capacity to carry on the amount of runoff originated. These lines are located in Kebena Road and drainage line 35, 49, 62,76, and 77 have also lower capacity, and they are located around Signal. As it is shown in fig 4.3 drainage line 95, 96, 97 and 100 are with low capacity that can't deliver the runoff that came along and it is located near to Adwa Dildiy.

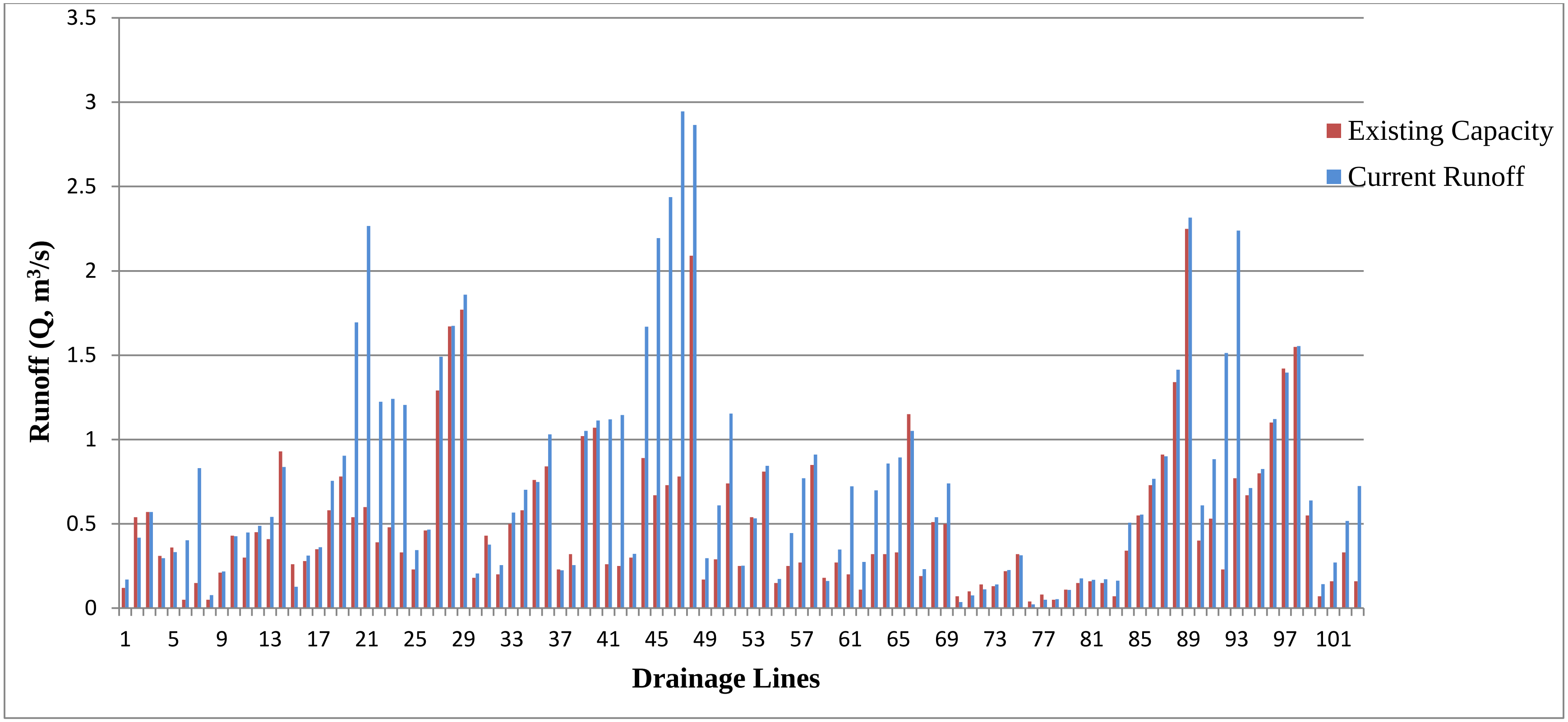


Figure 4.5 Comparison of the capacity and the current runoff for Woreda 8(Source: Own Analysis, calculating the existing capacity by measuring dimensions of the drainages and compare it with the current runoff).

In this woreda drainage line 20, 21, 22, 23, and 24 have the capacity that can't deliver the runoff that came along around Menaharia photo Studio to Kebena stream. And also drainage line 44, 45,46,47,48 and 49 have also lower capacity, and they are located around Gabriel Church. As it is shown in fig 4.4 line 91, 92, and 93 have lower capacity and they are located on the way from Denver Café to Uriel.

Establishment of road and storm water drainage infrastructure are crucial, particularly, in an urban center to protect flood damage on urban infrastructure and utilities, which results due to pavements or imperviousness. There is a need to integrate Road and drainage infrastructure and proper connection of drainage networks to elongate or keep the service life of other urban infrastructure and utilities like water supply lines, telephone lines, electric lines, buildings, and roads by safely discharging the flood originated as a result of pavement of structures. But, during field survey it was observed that most of the roads surface have been degraded and eroded.

In addition to evaluating the performance of the drainages of the area by comparing the capacity of the drainage system with the estimated current runoff, the drainage system has been evaluated one by one for these three woredas with the help of a base map, GTZ standards and check list. This was done to study the existing condition , coverage of the urban storm water drainage infrastructure and to check whether the flood originated in the study area is safely discharged in to the final receiving natural water ways or not. See ANNEX J for check list and GTZ standards.

Using the GTZ standard located in ANNEX J the following assessment was made about the condition of the drainage lines existed in each woredas.

Table 4.3 Woreda 6 urban storm water drainage condition: Field survey, 2012.

Drainage Shape Type	Drainage Pavement	Total Length(m)	Existing Condition	Length(m)	Percentage (%)	Percentage from Total (%)
Rectangular	Masonry & Rock	6855	Good	1165	17	56
			Light	1577	23	
			Sever	4113	60	
Trapezoidal		3833	Good	767	20	31
			Light	1112	29	
			Sever	1955	51	
Circular		1637	Good	1015	62	13
			Light	-	-	
			Sever	622	38	
Total Length(m)		12325	Total Percentage (%)			100

Table-4.3 reveals that, from the total drains about 47% is 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 (Fig 4.6), which is an obstacle to vehicles and pedestrians.

Table 4.4 Woreda 7 urban storm water drainage condition, Source: Field survey, 2012.

Drainage Shape Type	Drainage Pavement	Total Length(m)	Existing Condition	Length(m)	Percentage (%)	Percentage from Total (%)
Rectangular	Masonry & Rock	7491	Good	1573	21	46
			Light	1873	25	
			Sever	4045	54	
Trapezoidal		3596	Good	1079	30	22
			Light	396	11	
			Sever	2122	59	
Circular		5092	Good	4277	84	31
			Light	-	-	
			Sever	815	16	
Total Length(m)		16179	Total Percentage (%)			100

As shown in Table-4.4 In this woreda, from the total drains about 43% is severely degraded. This shows that the flood generated within this woreda cannot safely be discharged in to the nearby river. On the other hand, this will stagnate on open surfaces, run over road surfaces to cause flood hazards. The drainage system in this woreda has been damaged by erosion and over flow. Some of them are with smaller catch pit which cannot give proper service to slow down the flow velocity and also from field observation it was realized that some of the drainage systems were constructed poorly (See fig 4.15).

Table 4.5 Woreda 8 urban storm water drainage condition, Source: Field survey, 2012.

Drainage Shape Type	Drainage Pavement	Total Length(m)	Existing Condition	Length(m)	Percentage (%)	Percentage from Total (%)
Rectangular	Masonry & Rock	6543	Good	1025	16	45
			Light	1423	22	
			Sever	4057	62	
Trapezoidal		3188	Good	414	13	22
			Light	606	19	
			Sever	1977	62	
Circular		4746	Good	1614	34	33
			Light	-	-	
			Sever	3132	66	
Total Length(m)		14477	Total Percentage (%)			100

As presented in Table-4.5 In this woreda out of the total drains 63% is severely degraded. In summary, the problem gets worse in this woreda is because the drainage system is very old and there is no proper drainage network.

Figure 4.6 severely damaged drainage lines in the three woredas (source field survey, 2012)

Urban streets inundate by stormwater runoff and this water on a street can create sliding effects, and can severely affect the traffic flow. For these reasons, a street drainage system must be properly designed to quickly drain away stormwater from the traffic lanes. Yet in woreda 7 & 8 runoff flows over minor and major streets has not been safely discharged in to the natural water ways or infiltrated in to the ground. During a major storm event, street gutters and roadside ditches overtop and flood the treets.

Figure 4.7 Flood over major and minor streets of the three woredas (source field survey, 2012)

Generally, the performance of the current drainage system is poor because from the findings it's noticed that the capacity of the drainage system is lower than that of the current runoff amount and also because of lack of good maintenance its function has been deteriorate.

4.1.4 Coverage of the Drainage System in the Study Area

This section gives information about how much percentages of the area is with and without storm water drainage system.

Table 4.6 Areas with and without Drainage System (source: field survey and own analysis)

Woredas	Woreda 6	Woreda 7	Woreda 8
Total Area(ha)	101.1	172.6	118.2
Area with Drainage (ha)	80.6	111.8	75.8
Area without Drainage (ha)	20.5	60.8	42.5

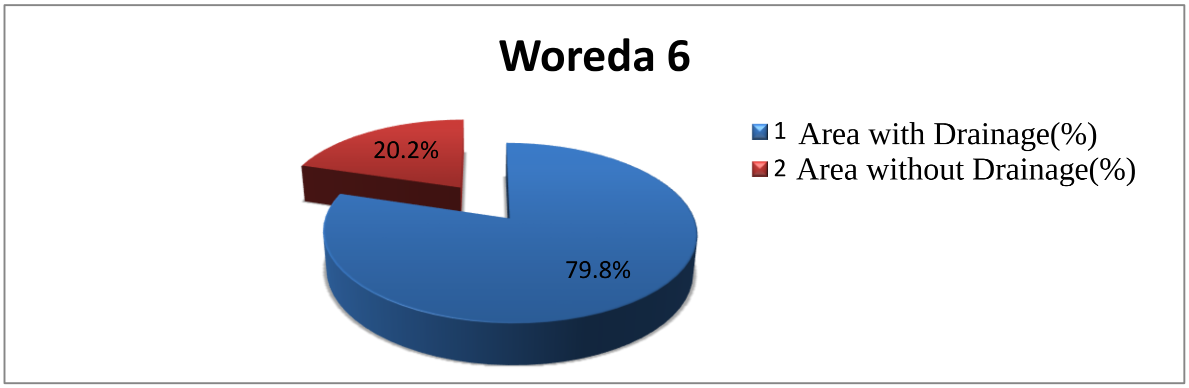


Figure 4.8 Area with and without Drainage in woreda 6

Since there is no proper recorded data about the coverage of drainage system, these values have been taken from field observation. From the chart it is noticed that out of the entire area of woreda 6, 20.2% of the area has been without a drainage system. This could cause damages on the subways and streets of this woreda. (See figure 4.10)

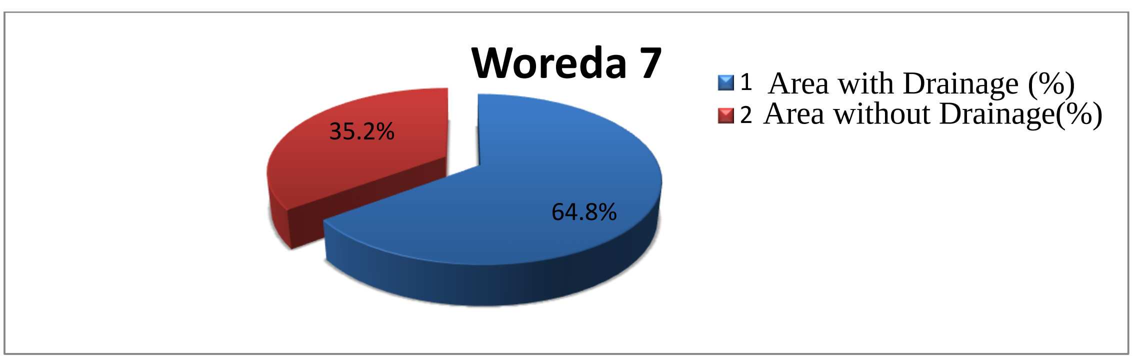


Figure 4.9 Area with and without Drainage in woreda 7

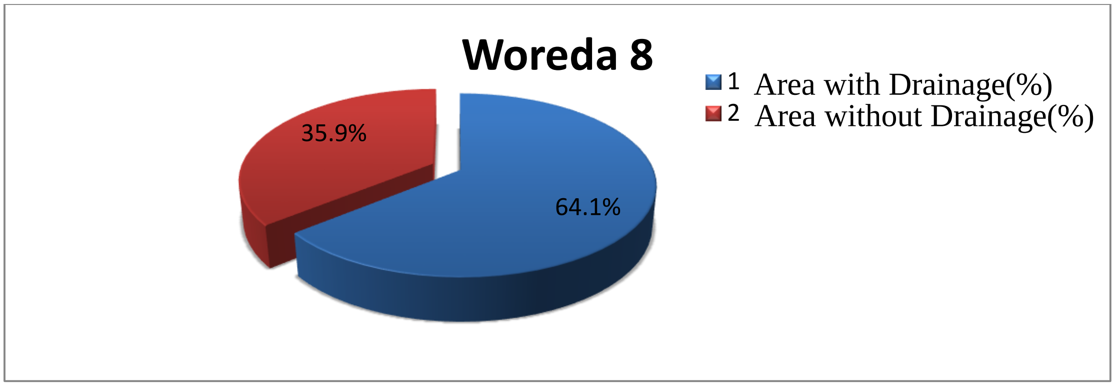


Figure 4.10 Area with and without Drainage in woreda 8

Generally woreda 6 has a better coverage of drainage system when it is compared to woreda 7& woreda 8. Woreda 7 & woreda 8 have almost similar coverage of drainage system. These results show that there is lack of drainage system in the area, which could be alleviated with the help of different best management practices.

Based on the analysis out of the total study area 32 % didn't have storm water drainage system. The percentage seems lower however, the fact is the amount of runoff that is generated from this area inundates the area with storm water drainage.

Figure 4.11 Roads without drainage network (source: Field survey July, 2012).

As it is revealed in Fig 4.11 inadequate integration between road and urban storm water drainage lines causes flooding over the roads and the residence area.

4.2 Challenges of Storm Water Drainage 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 difficult in this area. The challenges are:

4.2.1 Topography and Impervious surface

Basically, the topographical nature of the Addis Ababa area creates a very high run-off, and a good adequate drainage system would be a proactive method of combating the effect of excess flood menace both in Addis Ababa and the surrounding towns. Additionally due to the highly impervious surface as a result of built up area, paved asphalts and some rock surface, the rain fall doesn't infiltrate in to the ground. This causes inundation over the entire area, reduce ground water recharges, higher velocity which creates scouring of the drainage structures and increases the surface runoff by which it affects those channel that convey this runoff in to the existing stream.

4.2.2 Absence of River buffers around streams

Most stream flows across Addis Ababa don't have the required buffer zone set by AAEPA. As AAEPA states, every stream or river should have buffer zones of 15m to 30m from the center of the river on both sides, unfortunately most of the river banks are surrounded by illegal residents and used for different purposes. Due to these mismanagement the river banks have been eroded and extended by erosion and land sliding. This problem caused overtopping and flooding over the near area and later on caused loss of property. According to residences the authorities tried to eliminate this problem but the management they have implemented was not good enough.

Figure 4.12 Kebena river without buffer zone (source: Field survey July, 2012).

4.2.3 Dumping of solid wastes in to storm water drainages and streams

Dumping solid waste materials in to drainages and streams is the other challenge of storm water drainage system. Urban litter (alternatively called trash, debris, junk, floatables, gross pollutants, rubbish or solid waste) has become a major problem in these woredas it typically 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. According to CSA's recent Welfare Monitoring Survey (2004) about 65 percent of the solid waste in the City is disposed using vehicles and containers, whilst about 35 percent of household waste remains uncollected. Which means this 35% household waste disposed in to authorized places including storm water drains.

Figure 4.13 Dumping of solid waste in to streams and drainage system around Kebena river (source: Field survey July, 2012).

4.2.4 Release of liquid wastes in to storm water drainages and streams

The water that is running directly into the streams is often picking up pollutants along the way. These pollutants can include motor oils and gasoline that leak from vehicles, waste from sewer lines and anything else that will float or dissolve in water. Illegitimate joining of sewerage system in to existing drains and streams is one of the challenges which have been observed in these woredas. Most of the drainage lines in woreda 6 oblige as waste disposal and clogged by liquid and solid wastes. Aside its' challenge to the drainage system, it could also cause a health problem and also it degrades the aesthetic value of the environment.

Figure 4.14 Liquid and solid waste in the drainage system around kebena river (source: Field survey July, 2012).

4.2.5 Lack of Community Awareness to Environmental Management

Community awareness is one of the best proactive measures for the sustainable urban drainage management. Unfortunately, from the interview it was studied about 44% (22 out of 50 people) of the residents thought that damping wastes in to the natural water ways and storm water drainage system is the right thing so as to keep their homes clean and they don't even know what is wrong with the idea of dumping waste outside their home as long as their residence is clean. The other 56% of the residents knew that damping liquid wastes in to existing drainage system and water ways is wrong however, they have been enforced to damp the wastes in to the water ways irrespective of the effects that could cause to their environment. They have implied that there is no proper sewage system to collect wastes extracted from each household. From the observation it was realized that even though few people have the awareness, the authority should create awareness among the communities and also should provide proper waste management technique.

4.2.6 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.

4.2.7 Poor Construction of drainage lines

From the field observation it was recognized that some of the drainage lines failed because of poor construction. In addition they have not been maintained regularly. As Figure 4.14 shows that failed drainage system in woreda 6 was because of crooked construction and this clearly manifested by the fact that this drainage failed to give service after 3 months since it was constructed.

Figure 4.15 Failed drainage ditches in woreda 6 (source: Field survey July, 2012).

4.2.8 Land use Land cover change

Addis Ababa is one of the fastest growing cities in east Africa. Ever since 1984, cities' land use has been changed from rural area in to urban area. According to the 2002 land use map all parts of the city shows high increasing trend of built environment. Between the 1986 and 2002 years the city undergoes many land use changes due to its unplanned as well as planned rapid urbanization (Habtamu, 2011). This shows that many Agricultural lands changed to urban areas. Generally the land use change in the 2002 land use map is due to expansion of residential area, industrialization and paved road. Because of this reason most of the drainage lines designed for the earlier land use have lower capacity to handle the amount of runoff currently produced over the changed land use. Specially woreda 7and 8 have been extensively changed from undeveloped area in to commercial area. Most of the roads in woreda 7 changed from gravel road in to asphalt resulting increment of runoff due to increasing of impervious area.

4.2.9 Manholes (Catch pit) Problems

Some of the manholes or catch pits in woreda 7 and 6 have been clogged with waste and blocked due to lack of clearance. As a result the runoff that is generated in that sub basin over flows with higher velocity which erodes the ditches as well as the road and walk ways. Figure 4.16 shows flow over the manholes.

Figure 4.16 Flow over manholes in woreda 7 (source: Field survey July, 2012).

4.2.10 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 woreda 6 and 8.

Figure 4.17 Blocked drainage networks in woreda 6 and 8(source: Field survey July, 2012).

4.2.11 Diminished Roads and Inlets

Ruined roads have their own challenge over the drainage systems because their damaged surface couldn’t convey the runoff generated over the impervious area. This problem has been noticed in most of wored 6 suburban roads.

Figure 4.18 Diminished roads in woreda 6 (source: Field survey July, 2012).

4.3 Impacts of Storm Water drainage on Kebena Stream

No matter where a proposed drainage may lie, it must intersect a drainage basin, and where this intersection occurs, alteration of the local hydrology is inevitable. In these three woreda the drainage systems have their own impact on the water ways around kebana stream and its watershed. This leads to the modification of the natural hydrological environment. The impacts of the drainage system on the water ways in these three woreda are discussed below.

4.3.1 Changing of Kebena Stream Morphology

According to the residences around kebena stream, kebena stream course has been changed ever since 1973 E.C due to development around the area which increases the runoff in the watershed. In 1973 the stream has a straight course below Adwa Bridge, however currently the river mender crossed three houses. Even though the geology of the area played its own role for the changing of the river course, the amount of runoff also affects the river mender. Fig 4.19 shows kebena stream after 3 houses taken out by the flood. The authority provided temporary as well as permanent solution by constructing a retaining wall across the river course but it was taken by the flood. Although urbanization cannot be avoided, the runoff that can be generated due to these impervious areas can be reduced with the help of infiltration in to the ground through different best management practices.

Figure 4.19 Kenena stream (source: Field survey July, 2012).

4.3.2 Deteriorate Water Qualities of the Rivers

It seems that the runoff water quality is only diminished by sediment that could be overtaken by the storm water. However, there are different pollutants that decrease the water quality of storm water which finally reaches natural water ways. From filed survey it was observed that storm water drainages convey the storm water runoff with solid and liquid wastes to streams around the study area.

Table 4.7 Major pollutants in Kebena River (source: Adugna 2009)

No	Pollutant Type	Kebena River		
		S_1	S_2	S_3
1	Total suspended Solid(mg/ml)	334	350	340
2	Total solids (mg/ml)	584	606	596
3	Total Dissolved Solid (mg/ml)	250	256	256
4	Nitrite (mg/ml NO2)	0.625	1	1.4
5	Nitrate (mg/ml NO3)	81.50	77.5	62.3
6	Phosphate(mg/ml PO4)	1.2	0.97	0.89
7	Total Coliform per 100ml	9900	9200	9400
8	Fecal Coliform per 100ml	5450	4800	5010

Note: S1= sample Number-1(before a rain fall)

S2= sample Number-2 (with a rain fall)

S3= sample number-3 (after a rain fall)

Total suspended, total dissolved and total solids were high during rainfall event than before and after a rainfall event (ibid). This indicates that it is the runoff in the drainage system which contributes for greater amount of solids to be found in the river .Whereas, both total and fecal coli-form are maximum before a rain event than within and after a rain event (ibid). The maximum coli-form before a rainfall indicates that the river is highly concentrated as a result of wash off animal feces, organic matter from the drainage system and from illegal sanitary waste disposal on the other hand in rainy season the river water diluted because of high peak flow rain water.

Urban runoff contains significant concentration of nitrogen, phosphorus, and carbon compounds, which accelerate the nutrient enrichment and eutrophication of receiving waters. The sources of nutrients in the study area were oozing of vegetation, agricultural fertilizers in downstream of kebena stream and residential waste water sewer connections.

This river is currently serving as a means of disposal of solid and liquid wastes from the neighborhood area and yet it is used as a source of water for irrigation purpose at downstream of the stream with this polluted water.

Figure 4.20 Dumped solid and liquid waste in kebena River (source: Field survey July, 2012).

The downstream catchment drainage system suffers from pollution load of the upstream catchment of the river. Kebena River is the wider and longer river system in the study area in collecting and transporting pollutants and other unnecessary loads from all its tributaries and other unnecessary loads from illegally connected sewerage systems and untreated drainage facilities.

If kebena stream have been kept clean, it would be a good source of water for irrigation & aesthetically it would have an attractive environment. If proper measure will not take, the current condition could even get worse. Before, the urban drainage becomes a permanent socio-economic nuisance and brings irreversible damage to the city the authority has to take actions to alleviate this problem.

5. BEST MANAGEMENT PARACTICE (BMP)

This section provides proposed best management practices to solve the problem of urban storm water 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, 2010.

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 Kebena River and this area is located in a suburban area around Awarea and Ksanchis.

5.1 BMP for Sample Area in Woreda 6

In order to select the best management practice that could fit to this area Urban Storm Drainage Criteria Manual Volume 3 was used ((UD & FCD, 2010).The following factors have been considered to decide the best suited practice.

1. Physical Site Characteristics

- Existing drainage around this area has been eroded due to high flow velocity and its capacity is lower than the amount of discharge generated in that sub-basin.
  The capacity of the channel is $0.14m^3/s$ but the current runoff that passes through this channel is $0.24m^3/s$.
- Topography of this area is moderately steep, which has a slope of 1.10%.
- According to the laboratory result, the soil type of this area is silty clay and the permeability of the soil is $2.73*10^{-5}$ cm/sec. See ANNEX K.
- Contributing drainage area is about 0.64ha.
- This place is surrounded by pavements with suburban area.

2. Treatment Objectives

In the selected area the storm water has been polluted by sediment drove with runoff from the overlaying suburban area.

3. Available total area for practicing the best management is about 261m^2.

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.

1. Grass Swale
2. Grass Buffer
3. Constructed Wetland Channel

a) Grass Swale

b) Grass Buffer

c) Constructed Wetland

Figure 5.1 Pictures of each BMP

So in order to select the best suited BMP from the above three BMPs the following factors had to be evaluated.

1. Aesthetic

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

2. 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 in the case of wetland channel, Ponding depth can pose safety concerns requiring additional considerations for public safety during design and construction and the other two practice could worked out better than the wetland channel regarding to safety of the environment.

3. Maintenance Requirement

Grass buffer frequently damaged by vehicles when they are adjacent to roadways and unprotected which requires frequent maintenance and in Wetland channel sediment, floating litter, and algae blooms can be difficult to remove or control that makes it difficult to maintain. 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 swales is best suited BMP. According to Table 5.1 the best suited practice for sedimentation and biological uptake would be Construction Wetland Channel however, the area of this site is very small to apply this practice, so the choice will be the second best suited practice which is Grass Swale. And with reference to Table 5.2 regarding to cost wise and function for the given site Grass Swale is better suited.

Table 5.1 Primary, Secondary and Incidental Treatment Process Provided by BMPs, source USD, BMP, Criteria V. 3, 2010

	Hydrologic Processes			Treatment Processes				
	Peak	Volume		Physical			Chemical	Biological
UDFCD BMP	Flow Attenuation	Infiltration	Evapo-Transpiration	Sedimentation	Filtration	Straining	Adsorption/ Absorption	Biological Uptake
Grass Swale	I	S	I	S	S	P	S	S
Grass Buffer	I	S	I	S	S	P	S	S
Constructed Wetland Channel	I	N/A	P	P	S	P	S	P
Green Roof	P	S	P	N/A	P	N/A	I	P
Permeable Pavement Systems	P	P	N/A	S	P	N/A	N/A	N/A
Bioretention	P	P	S	P	P	S	S[1]	P
Extended Detention Basin	P	I	I	P	N/A	S	S	I
Sand Filter	P	P	I	P	P	N/A	S[1]	N/A
Constructed Wetland Pond	P	I	P	P	S	S	P	P
Retention Pond	P	I	P	P	N/A	N/A	P	S
Underground BMPs	Variable	N/A	N/A	Variable	Variable	Variable	Variable	N/A

Notes:

P=Primary, S=Secondary, I=Incidental, N/A=Not Applicable

[1] Depending on media

Table 5.2 Effectiveness of the three BMPs based on functions and cost wise, source USD, BMP, Criteria V. 3, 2010

Constructed Wetland Basin	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	Moderate
[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org). [4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis is based on a single installation (not based on the maximum recommended watershed tributary to each BMP).	

Grass Buffer	
Functions	
LID/Volume Red.	Yes
WQCV Capture	No
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs	Low
[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).	

Grass Swale	
Functions	
LID/Volume Red.	Yes
WQCV Capture	No
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs	Low
[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).	

4. Limitations of the three BMP

Limitations of Construction Wet land

- Requires both physical supply of water and a legal availability (in Colorado) to impound water.
- Ponding depth can pose safety concerns requiring additional considerations for public safety during design and construction.
- Sediment, floating litter, and algae blooms can be difficult to remove or control.
- Ponds can attract water fowl which can add to the nutrients leaving the pond.

Limitations of Grass Buffer

- Frequently damaged by vehicles when adjacent to roadways and unprotected.
- A thick vegetative cover is needed for grass buffers to be effective.
- Nutrient removal in grass buffers is typically low.
- High loadings of coarse solids, trash, and debris require pretreatment.
- Space for grass buffers may not be available in ultra urban areas (lot-line-to-lot-line).

Limitations of Grass Swale

- 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.

Design of Grass Swale for the Selected Area

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.

1. Design Discharge: to determine the 2-year flow rate to be conveyed in the grass swale under fully developed conditions, rational formula can be applied.

Q = 0.278C I A

Tc = 0.0147* L1.155 H-0.385 (Kirpich /SCS Equation)

Tc= (0.00013*(87/0.3048) ^0.77)/ ((0.011) ^0.385) = 0.057

The reading of rainfall intensity from IDF curve for the given time of duration and 2 year return period is 150.

Area=0.64ha

C=0.85

Q=0.23m^3/s

2. Hydraulic Residence Time

Increased hydraulic residence time in a grass swale improves water quality treatment. Maximize the length of the swale when possible. Provide 87m length of grass swale, the velocity for this grass swale is 0.26m/s, there for the hydraulic residence time is 5.6 min.

3. Longitudinal Slope

Establish a longitudinal slope that will meet Froude number, velocity, and depth criteria while ensuring that the grass swale maintains positive drainage. Positive drainage can be achieved with a minimum 2% longitudinal slope.

So, for the given discharge

Let's take longitudinal slope 2%

4. Swale Geometry

The cross section should be either trapezoidal or triangular with side slopes not exceeding 4:1 (horizontal: vertical), preferably flatter. To be more economical triangular grass swale with side slop 4:1 was selected which increases the wetted area of the swale to reduce velocity with less scouring and acceptable Froude number. Lowering velocities result in improved pollutant removal efficiency and greater volume reduction.

5. Vegetation

Turf grass is a general term for any grasses that will form a turf or mat as opposed to bunch grass, which will grow in clumplike fashion. Native turf grasses may also be selected where a more natural look is desirable. This will also provide the benefit of lower irrigation requirements.

6. Design Flow Velocity, Design Flow Depth, and Froude Number

Table 5.3 Grass Swale Design Criteria

Design Flow	Maximum Froude Number	Maximum Velocity(m/s)	Maximum Flow Depth(m)
2 Years Event	0.5	0.3748	0.3748

Velocity, Froude Number and Flow Depth of the Trapezoidal Grass Swale

By Using Flow Master

Table 5.4 Grass Swale Velocity, Froude number and Flow Depth

Design Flow	Froude Number	Velocity(m/s)	Flow Depth(m)
2 Years Event	0.28	0.38	0.37

7. Soil preparation

Soil type of the area is Silty Loam, therefore in order to improve infiltration and reduce ponding provide 0.1m of sandy loam at the invert of the swale extending up to the 2-year water surface elevation.

8. Irrigation

Grass swales should be equipped with irrigation systems to promote establishment and survival in during the dry season. Permanent Pipe should be installed to provide irrigation water from the city water supply line. Irrigation practices have a significant effect on the function of the grass swale. Avoid Overwatering because it decreases the permeability of the soil, reducing the infiltration capacity of the soil and contributing to nuisance base flow. Conversely, under watering may result in delays in establishment of the vegetation in the short term and unhealthy vegetation that provides less filtering (straining) and increased susceptibility to erosion and riling over the long term, so proper timing for the irrigation is necessary.

Table 5.5 Grass Swale Design Summary

1. Design Discharge for 2-Year Return Period	$0.23m^3/s$
2. Hydraulic Residence Time a. Length of Grass Swale b. Calculated Residence Time (based on design velocity below)	LS = 87m T_{HR}= 5.6 minutes
3. Longitudinal Slope (vertical distance per unit horizontal) a. Available Slope (based on site constraints) b. Design Slope	Savail = 0.011 m/m SD = 0.002 m/m
4. Swale Geometry a. Channel Side Slopes (Z = 4 m/m., horizontal distance per unit vertical) b. Bottom Width of Swale (enter 0 for triangular section)	Z = 4.00 m/m
5. Vegetation a. Type of Planting (seed vs. sod, affects vegetal retardance factor)	Choose One ○ Grass From Seed ◉ Grass From Sod
6. Design Velocity (0.3748m/s maximum)	V = 0.38 m / s, which is acceptable
7. Design Flow Depth (0.3748m maximum) a. Flow Area b. Top Width of Swale c. Froude Number (0.50 maximum) d. Manning's n	D2 = 0.37m $0.56m^2$ 2.5m 0.28 0.038

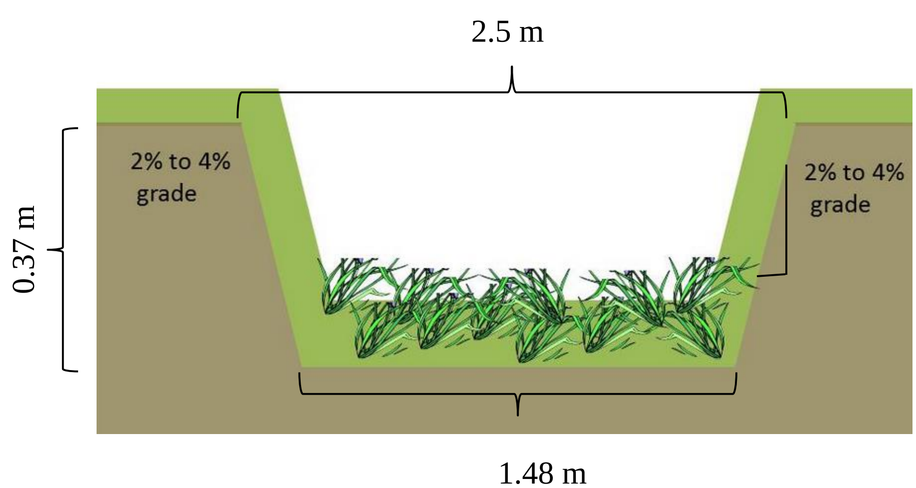


Figure 5.2. The proposed Grass Swale

The effectiveness of this BMP regarding to suspended solid is 30-65 % (UD & FCD, 2010) and it can provide some ground water recharge as infiltration is achieved within the practice and reduce the amount of runoff and velocity of the flow. In this case the amount of runoff generated can be easily discharged since it was designed with the current estimated runoff.

Adopting different BMP that suits the specific area helps to control flooding and the collected water through the practice could help for different purpose for example introducing water harvesting programs for domestic use and urban agriculture will help to reduce peak runoff, flooding hazards, to recharge the ground water, to keep soil moisture and to reduce natural resource degradation.

6. CONCLUSION & RECOMENDATION

6.1 Conclusion

In this study storm water drainage around Kebena River has been evaluated with the help of check list, Base map for the roads, Tap meter and including different software to analyze the quantitative data. Woreda 6, 7 and 8 have been evaluated and it is concluded that they have been facing overflowing and flooding which was mainly caused by the increment 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:

- Capacities of most of the drainage system can't handle the current runoff that flows over the area. In Woreda 6, of all the drains 44% of the drainages are capable of conveying safely the runoff in to the water ways. In woreda 7 out of the total drains only 40% of the drains have the capacity to convey the run off in to the stream. And also in woreda 8 out of the total drains only 34 % have the required capacity. This is due to urbanization and lack of good assessment of the hydrology of the area.
- It is observed that 32% of the total study area doesn't have a drainage system to convey the generated runoff in to the streams. This result shows that there was lack of integration between road and drainage system in the area. And the amount of runoff drifts over this area flooded the other area with drainage system.
- It is concluded that there was no proper sewage system to collect wastes extracted from each household, as a result solid and liquid wastes were directly disposed into the storm drainage system which results in decreasing the efficiency of the system. 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.
- Majority of infrastructure development in the sub cities have less concern to the drainage system and made the function of the drainage system difficult and also some of the drainages were poorly constructed and fail to give the required service.

- Kebena's river morphology has been changed and it's polluted by disposal of wastes from the vicinity, unless some measures taken, it could cause a lot of problem in terms of water quality for the neighborhood across the river and downstream users.
- Generally, the performance of these storm water drainages were not satisfactory. Therefore, it is recognized that its capacity has shown lower results which needs some adjustment or improvement to give the best service, and needs a serious of regular maintenance and also provide drainage networking for the areas without drainage systems for its complete service.

6.2 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 storm water 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.
- In order to handle the increased runoff due to the increment of built up area, the existing stormwater management system need to be improved or modified to prevent future flash flood in the area.
- Introduce water harvesting programs for domestic use and urban agriculture to reduce peak runoff, flooding hazards, to recharge the ground water, to keep soil moisture, to reduce natural resource degradation,
- Immediate adaptation of different Best Management Practices (BMP) which will not only reduces 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.
- Establish appropriate sewerage lines to safely release waste water and to properly manage and use storm water drainage lines as it were their objective.
- Regular maintenance and frequent clearance of drainage lines should be at regular terms for sustainable storm water drainage system.

- For kebena river bank serious geomorphologic study and assessment of the generated amount of runoff entering to the basin will help to control the flooding problem inside the watershed.
- Design and implementation of storm water drainage system network is crucial for those areas which happens to be without drainage system.
- Prevention of illegal settlements on the river banks and Soil and water conservation measures should be done on the upstream side of the study area.

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ANNEX

Annex A : Capacity of the Existing Storm Water Drainage System of Woreda 6

No	Flow direction		Drainage Types											
	From	To	Trapizoidal			Rectangular		Circular						
			B(m)	Y(m)	T(m)	Br(m)	Yr(m)	D(m)	n	A(m^2)	P(m)	S_o(%)	Q(m3/s)	V(m/s)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	DL-1	DL-2				0.40	0.20		0.01	0.08	0.80	4.50	0.09	1.14
2	DL-2	DL-3						0.60	0.01	0.28	1.88	2.50	0.97	3.43
3	DL-3	DL-4				0.65	1.00		0.04	0.65	2.65	2.60	1.17	1.81
4	DL-4	Outlet						0.80	0.01	0.79	3.14	2.90	2.05	4.20
5	DL-5	Outlet				0.30	0.40		0.04	0.12	1.10	5.00	0.15	1.28
6	DL-6	DL-7				0.35	0.50		0.04	0.18	1.35	1.40	0.13	0.76
7	DL-7	DL-8				0.30	0.50		0.04	0.15	1.30	5.60	0.21	1.40
8	DL-8	DL-4				0.45	0.60		0.04	0.27	1.65	3.60	0.38	1.42
9	DL-9	DL-7				0.35	0.40		0.04	0.14	1.15	1.00	0.09	0.61
10	DL-10	DL-18				0.20	0.35		0.04	0.07	0.90	1.00	0.03	0.46
11	DL-11	DL-18				0.30	0.40		0.04	0.12	1.10	4.50	0.15	1.12
12	DL-12	DL-13	0.45	0.70	0.75				0.04	0.81	2.43	1.10	1.01	1.26
13	DL-12.1	DL-13				0.35	0.40		0.04	0.14	1.15	2.30	0.13	0.93
14	DL-13	DL-14				0.50	0.60		0.04	0.30	1.70	3.70	0.45	1.51
15	DL-14	DL-2				0.55	0.70		0.04	0.39	1.95	2.20	0.48	1.26
16	DL-15	DL-16				0.40	0.50		0.04	0.20	1.40	1.10	0.14	0.72
17	DL-16	DL-17				0.50	0.60		0.04	0.30	1.70	1.40	0.28	0.93
18	DL-17	DL-46	0.40	0.50	0.65				0.04	0.45	1.81	0.70	0.37	0.83
19	DL-18	DL-16				0.20	0.35		0.04	0.07	0.90	4.50	0.07	0.97
20	DL-19	DL-17				0.20	0.30		0.03	0.06	0.80	3.30	0.06	1.08
21	DL-20	DL-22	0.30	0.20	0.45				0.01	0.04	0.57	1.50	0.06	1.61
22	DL-21	DL-22				0.35	0.40		0.04	0.14	1.15	1.10	0.09	0.64
23	DL-22	Outlet	0.40	0.60	0.70				0.04	0.33	1.64	3.50	0.61	1.84

24	DL-23	DL-24						0.30	0.01	0.07	0.94	3.30	0.18	2.49
25	DL-24	DL-25	0.40	0.50	0.65				0.01	0.26	1.43	5.10	0.48	1.82
26	DL-25	Outlet				0.45	0.60		0.01	0.27	1.65	7.40	0.63	2.33
27	DL-26	DL-25	0.20	0.30	0.40				0.03	0.09	0.83	3.10	0.12	1.33
28	DL-27	DL-28				0.35	0.50		0.04	0.18	1.35	2.20	0.16	0.91
29	DL-28	Outlet						0.30	0.01	0.07	0.94	4.90	0.21	3.03
30	DL-29	DL-27	0.20	0.60	0.30				0.04	0.15	1.40	2.90	0.14	0.96
31	DL-30	DL-31	0.45	0.60	0.75				0.04	0.36	1.69	2.80	0.35	1.71
32	DL-31	Outlet				0.40	0.60		0.04	0.24	1.60	2.00	0.24	1.00
33	DL-32	DL-33	0.30	0.20	0.40				0.03	0.10	0.87	3.30	0.14	1.44
34	DL-33	DL-34				0.40	0.50		0.04	0.20	1.40	5.00	0.31	1.53
35	DL-34	DL-35						0.50	0.01	0.20	1.57	2.50	0.60	3.04
36	DL-35	DL-36						0.60	0.01	0.28	1.88	3.00	1.06	3.76
37	DL-36	DL-37	0.50	0.60	0.70				0.04	0.53	2.01	1.90	0.74	1.41
38	DL-37	DL-38	0.50	0.65	0.80				0.04	0.42	1.83	2.20	0.29	1.39
39	DL-38	DL-39						0.60	0.01	0.28	1.88	2.00	0.87	3.07
40	DL-39	DL-40						0.60	0.01	0.28	1.88	3.00	1.06	3.76
41	DL-40	DL-41				0.50	0.65		0.04	0.33	1.80	3.10	0.46	1.41
42	DL-41	Outlet				0.60	0.80		0.03	0.48	2.20	2.80	0.97	2.02
43	DL-42	DL-43	0.60	0.60	0.80				0.04	0.06	1.22	2.50	0.03	0.52
44	DL-43	DL-44						0.30	0.01	0.07	0.94	5.50	0.23	3.21
45	DL-44	DL-45						0.50	0.01	0.20	1.57	3.10	0.25	3.39
46	DL-45	DL-46				0.50	0.60		0.01	0.30	1.70	1.20	0.26	0.86
47	DL-46	DL-38						0.40	0.01	0.13	1.26	4.40	0.44	3.48
48	DL-47	DL-35				0.30	0.40		0.01	0.12	1.10	0.50	0.15	1.24
49	DL-48	DL-36				0.30	0.45		0.04	0.14	1.20	0.50	0.07	0.52
50	DL-49	DL-50				0.35	0.50		0.04	0.18	1.35	1.90	0.18	1.01
51	DL-50	DL-51				0.40	0.50		0.04	0.20	1.40	0.80	0.14	0.70
52	DL-51	DL-52				0.45	0.55		0.04	0.25	1.55	3.50	0.34	1.38
53	DL-52	DL-53				0.50	0.60		0.04	0.30	0.70	4.70	0.51	1.71

54	DL-53	DL-54				0.60	0.60		0.04	0.36	1.80	4.80	0.67	1.87
55	DL-54	DL-55				0.50	0.60		0.04	0.30	1.70	2.50	0.37	1.24
56	DL-55	DL-39				0.55	0.65		0.04	0.36	1.85	1.90	0.41	1.15
57	DL-56	DL-51	0.40	0.60	0.70				0.04	0.09	1.24	1.10	0.05	0.52
58	DL-57	DL-53				0.45	0.60		0.04	0.27	1.65	0.70	0.19	0.72
59	DL-58	DL-54				0.30	0.40		0.04	0.12	1.10	0.80	0.07	0.58
60	DL-59	DL-60	0.35	0.40	0.50				0.04	0.17	1.16	2.10	0.17	1.01
61	DL-60	DL-61	0.50	0.45	0.60				0.04	0.84	2.48	1.70	0.20	1.58
62	DL-61	DL-40				0.80	1.00		0.04	0.80	2.80	1.70	0.58	1.41
63	DL-62	DL-63	0.45	0.50	0.65				0.04	0.28	1.47	0.90	0.24	0.89
64	DL-63	DL-64				0.35	0.45		0.04	0.16	1.25	5.90	0.24	1.53
65	DL-64	DL-65				0.40	0.50		0.04	0.20	1.40	5.90	0.33	1.66
66	DL-65	DL-66	0.50	0.35	0.60				0.04	0.30	1.49	4.80	0.64	2.14
67	DL-66	Outlet	0.45	0.60	0.70				0.04	0.63	2.15	4.00	1.39	2.21
68	DL-67	DL-68				0.50	0.60		0.04	0.30	1.70	1.60	0.30	0.99
69	DL-68	DL-69						0.45	0.01	0.16	1.41	3.20	0.51	3.21
70	DL-69	DL-70						0.60	0.01	0.28	1.88	2.70	1.01	3.57
71	DL-70	DL-71						0.60	0.01	0.28	1.88	3.10	1.08	3.82
72	DL-71	DL-72						0.80	0.01	0.50	2.51	1.90	2.71	4.14
73	DL-72	Outlet						0.80	0.01	0.50	2.51	4.80	2.90	4.98
74	DL-73	DL-74				0.40	0.20		0.04	0.08	0.80	4.90	0.10	1.19
75	DL-74	DL-76				0.60	0.40		0.04	0.24	1.40	1.70	0.24	1.01
76	DL-75	DL-76				0.40	0.50		0.04	0.20	1.40	4.00	0.31	1.56
77	DL-76	DL-77	0.35	0.35	0.45				0.04	0.28	1.44	1.10	0.25	0.88
78	DL-77	DL-79	0.50	0.35	0.60				0.04	0.33	1.59	1.80	0.39	1.18
79	DL-78	DL-79				0.60	0.75		0.04	0.45	2.10	1.60	0.58	1.29
80	DL-79	DL-80				0.65	0.80		0.04	0.52	2.25	3.80	1.09	2.10
81	DL-80	Outlet	0.50	0.30	0.70				0.04	0.24	1.35	5.00	0.42	1.77

82	DL-81	Outlet	0.60	0.40	0.70				0.04	0.26	1.41	0.90	0.20	0.77
83	DL-82	DL-83				0.25	0.20		0.04	0.05	0.65	2.20	0.03	0.67
84	DL-83	DL-84				0.25	0.35		0.04	0.09	0.95	2.50	0.07	0.81
85	DL-84	DL-72				0.35	0.55		0.04	0.19	1.45	1.60	0.16	0.82
86	DL-85	DL-86	0.35	0.40	0.40				0.04	0.15	1.15	1.20	0.12	0.80
87	DL-86	DL-87	0.50	0.35	0.60				0.04	0.30	1.49	1.20	0.32	1.07
88	DL-87	DL-75				0.35	0.40		0.04	0.14	1.15	2.60	0.14	0.99
89	DL-88	DL-89				0.25	0.40		0.04	0.10	1.05	4.00	0.10	1.04
90	DL-89	DL-87				0.25	0.55		0.04	0.14	1.35	2.50	0.15	1.09
91	DL-90	DL-74				0.40	0.20		0.04	0.08	0.80	4.90	0.19	2.38
92	DL-91	DL-92	0.30	0.25	0.40				0.03	0.09	0.81	2.60	0.11	1.22
93	DL-92	DL-77	0.40	0.30	0.45				0.03	0.13	1.00	2.60	0.17	1.36
94	DL-93	DL-94	0.30	0.30	0.40				0.04	0.11	0.91	4.20	0.13	1.22
95	DL-94	DL-95				0.35	0.50		0.04	0.18	1.35	1.80	0.15	0.86
96	DL-95	DL-96				0.50	0.55		0.04	0.28	1.60	3.10	0.37	1.36
97	DL-96	DL-97	0.50	0.60	0.70				0.04	0.36	1.72	1.60	0.40	1.12
98	DL-97	DL-98	0.50	0.70	0.80				0.04	0.45	1.93	2.30	0.65	1.44
99	DL-98	DL-80				0.60	0.80		0.04	0.48	2.20	2.30	0.66	1.37
100	DL-99	DL-71				0.40	0.50		0.04	0.20	1.40	1.60	0.17	0.86
101	DL-100	DL-101				0.30	0.20		0.04	0.06	0.70	2.40	0.05	0.75
102	DL-101	DL-102				0.45	0.30		0.04	0.14	1.05	2.70	0.14	1.05

103	DL-102	Outlet	0.40	0.35	0.50				0.04	0.23	1.25	1.70	0.27	1.19
104	DL-103	DL-104	0.40	0.35	0.40				0.04	0.17	1.13	3.20	0.26	1.47
105	DL-104	DL-105				0.35	0.50		0.04	0.18	1.35	6.40	0.28	1.62
106	DL-105	DL-102				0.40	0.50		0.04	0.20	1.40	2.60	0.22	1.10
107	DL-106	Outlet				0.35	0.20		0.04	0.07	0.75	7.00	0.10	1.36
108	DL-107	Outlet				0.30	0.40		0.04	0.12	1.10	5.30	0.16	1.31
109	DL-108	DL-109	0.30	0.35	0.40				0.04	0.12	1.01	3.10	0.13	1.08
110	DL-109	DL-110	0.50	0.35	0.60				0.04	0.19	1.21	2.60	0.26	1.35
111	DL-110	DL-111				0.40	0.70		0.03	0.28	1.80	2.00	0.38	1.36
112	DL-111	DL-80				0.45	0.65		0.03	0.29	1.75	1.10	0.31	1.06
113	DL-112	DL-113				0.40	0.35		0.04	0.14	1.10	6.20	0.22	1.58
114	DL-113	Outlet				0.45	0.40		0.04	0.18	1.25	5.80	0.30	1.65
115	DL-114	DL-115	0.15	0.25	0.50				0.04	0.08	0.76	2.30	0.07	0.85
116	DL-115	Outlet	0.35	0.60	0.40				0.04	0.15	1.15	6.90	0.24	1.66
117	DL-116	DL-117				0.30	0.50		0.04	0.15	1.30	6.30	0.22	1.49
118	DL-117	DL-118				0.45	0.50		0.04	0.23	1.45	4.90	0.36	1.60
119	DL-118	DL-119				0.45	0.60		0.04	0.27	1.65	6.50	0.51	1.91
120	DL-119	Outlet	0.45	0.65	0.50				0.04	0.31	1.75	5.70	0.58	1.88
121	DL-120	Outlet				0.40	0.50		0.04	0.20	1.40	4.40	0.33	1.64
122	DL-121	DL-122				0.20	0.40		0.03	0.08	1.00	1.20	0.05	0.68
123	DL-122	DL-123	0.35	0.20	0.40				0.03	0.08	0.75	3.20	0.10	1.28
124	DL-123	Outlet				0.30	0.40		0.04	0.12	1.10	1.40	0.08	0.68

Annex B: Capacity of the Existing Storm Water Drainage System of Woreda 7

Sr.No.	Flow direction		Drainage Types											
	From	To	Trapizoidal			Rectangular		Circular						
			B(m)	Y(m)	T(m)	Br(m)	Yr(m)	D(m)	n	A(m^2)	P(m)	S_o(%)	Q(m3/s)	V(m/s)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	DL-1	DL-2	0.3	0.6	0.5				0.04	0.17	1.3	3.7	0.21	1.24
2	DL-2	DL-3				0.5	0.5		0.04	0.23	1.45	6.4	0.41	1.83
3	DL-3	DL-4				0.5	0.6		0.04	0.3	1.7	2.6	0.38	1.27
4	DL-4	DL-5	0.5	0.7	0.7				0.04	0.41	1.91	1.9	0.5	1.23
5	DL-5	DL-6	0.4	0.8	1.0				0.04	0.52	2.08	2.8	0.86	1.66
6	DL-6	DL-7				0.6	0.8		0.04	0.48	2.2	7	1.15	2.4
7	DL-7	DL-14				0.7	0.9		0.04	0.63	2.5	4.9	1.39	2.21
8	DL-1.1	Outlet				0.15	0.35		0.035	0.05	0.85	4.8	0.05	0.98
9	DL-2.1	Outlet				0.20	0.30		0.035	0.06	0.8	7.6	0.08	1.4
10	DL-3.1	Outlet				0.15	0.20		0.035	0.03	0.55	4.9	0.03	0.91
11	DL-8	DL-9				0.5	0.5		0.04	0.25	1.5	3.1	0.33	1.33
12	DL-9	DL-10				0.4	0.5		0.04	0.2	1.4	4.6	0.29	1.47
13	DL-10	DL-11						0.5	0.013	0.20	1.57	4.7	0.82	4.17
14	DL-11	DL-12						0.6	0.013	0.28	1.88	5.5	1.44	5.09
15	DL-12	DL-13						0.6	0.013	0.28	1.88	6.4	1.55	5.49
16	DL-13	DL-14						0.8	0.013	0.50	2.51	4.8	2.90	5.76
17	DL-14	Outlet	0.7	0.8	1.0				0.04	0.75	2.37	1.6	1.11	1.74
18	DL-15	DL-16	0.25	0.30	0.50				0.04	0.11	0.9	3.6	0.13	1.19
19	DL-16	DL-17				0.40	0.50		0.035	0.2	1.4	7.8	0.44	2.18
20	DL-17	DL-4				0.50	0.45		0.035	0.23	1.4	8.5	0.55	2.46

21	DL-18	DL-19	0.30	0.50	0.35				0.03	0.16	1.3	2.1	0.20	1.21
22	DL-19	DL-20				0.40	0.35		0.013	0.16	1.2	1.4	0.38	2.38
23	DL-20	DL-21				0.40	0.65		0.013	0.28	1.8	1.2	0.68	2.44
24	DL-18.1	DL-6				0.20	0.35		0.013	0.07	0.9	3.2	0.18	2.51
25	DL-21	DL-10	0.3	0.4	0.5				0.04	0.14	1.11	1.9	0.12	0.87
26	DL-22	DL-12				0.35	0.25		0.04	0.12	1.00	2.6	0.12	0.98
27	DL-23	DL-20				0.40	0.35		0.04	0.14	1.10	3.8	0.17	1.23
28	DL-24	DL-9				0.35	0.40		0.04	0.14	1.15	4.6	0.18	1.32
29	DL-25	DL-26	0.3	0.4	0.5				0.035	0.15	1.09	2.2	0.16	1.08
30	DL-26	DL-27	0.4	0.4	0.5				0.035	0.18	1.21	5.5	0.34	1.89
31	DL-27	DL-8	0.4	0.4	0.6				0.035	0.2	1.22	2.7	0.28	1.4
32	DL-28	DL-8				0.2	0.35		0.04	0.07	0.9	4.9	0.07	1.01
33	DL-29	DL-30				0.4	0.5		0.04	0.2	1.4	5.5	0.32	1.6
34	DL-30	DL-31				0.35	0.4		0.04	0.14	1.15	5.1	0.19	1..39
35	DL-31	Outlet	0.4	0.2	0.5				0.04	0.09	0.81	6.8	0.14	1.5
36	DL-29.1	DL-35						0.45	0.013	0.16	1.41	4.3	0.59	3.72
37	DL-32	DL-34						0.3	0.013	0.1	0.84	1.8	0.25	2.52
38	DL-33	DL-34				0.2	0.3		0.06	0.8	1.8	2	0.04	0.63
39	DL-34	DL-35				0.45	0.7		0.04	0.32	1.85	5.6	0.57	1.82
40	DL-35	DL-31				0.4	0.65		0.04	0.26	1.7	0.5	0.13	0.51

41	DL-36	Outlet						0.6	0.013	0.28	1.88	3.3	1.12	3.94
42	DL-37	DL-31						0.8	0.013	0.5	2.51	1.5	1.62	3.22
43	DL-38	DL-37						0.45	0.013	0.16	1.41	2.6	0.46	2.89
44	DL-39	DL-43				0.3	0.4		0.04	0.12	1.1	4.5	0.15	1.21
45	DL-40	DL-41						0.45	0.013	0.16	1.41	4.8	0.62	3.93
46	DL-41	DL-42						0.6	0.013	0.28	1.88	5.9	1.49	5.27
47	DL-42	DL-43						0.6	0.013	0.28	1.88	5.6	1.45	5.14
48	DL-43	DL-44						0.6	0.013	0.28	1.88	3.9	1.21	4.29
49	DL-44	Outlet						0.8	0.013	0.5	2.51	0.9	1.25	2.5
50	DL-44.1	Outlet						0.6	0.013	0.28	1.88	1.5	0.75	2.66
51	DL-45	DL-46				0.4	0.5		0.04	0.2	1.4	1.3	0.16	0.78
52	DL-46	DL-47				0.5	0.6		0.04	0.3	1.7	4.5	0.5	1.67
53	DL-47	Outlet				0.45	0.5		0.04	0.23	1.45	9.7	0.51	2.25
54	DL-48	DL-45	0.4	0.25	0.5				0.04	0.11	0.91	4.9	0.15	1.37
55	DL-49	DL-46	0.4	0.35	0.5				0.04	0.16	1.11	6.7	0.28	1.76
56	DL-50	Outlet				0.4	0.55		0.04	0.22	1.5	5.1	0.35	1.57
57	DL-51	DL-52						0.45	0.013	0.16	1.41	2	0.4	2.54
58	DL-52	DL-56				0.5	0.6		0.04	0.3	1.7	6.9	0.62	2.07
59	DL-53	DL-54						0.45	0.013	0.16	1.41	3.6	0.18	2.6
60	DL-54	DL-55						0.6	0.013	0.28	1.88	4	1.23	4.34
61	DL-55	DL-56						0.6	0.013	0.28	1.88	6.9	1.61	5.7
62	DL-56	Outlet						0.8	0.013	0.5	2.51	1.3	1.51	3

63	DL-57	DL-55				0.4	0.5		0.04	0.2	1.4	1.4	0.16	0.81
64	DL-58	Outlet	0.3	0.45	0.4				0.035	0.16	1.21	1.6	0.15	0.93
65	DL-59	Outlet	0.3	0.4	0.4				0.035	0.15	1.11	1.7	0.14	0.94
66	DL-60	Outlet				0.4	0.6		0.035	0.24	1.6	1.5	0.24	0.99
67	DL-61	Outlet				0.35	0.5		0.035	0.18	1.35	0.7	0.11	0.61
68	DL-62	Outlet				0.35	0.4		0.035	0.14	1.15	1	0.10	0.7
69	DL-63	DL-64						0.6	0.013	0.28	1.88	1.1	0.64	2.28
70	DL-64	DL-65						0.8	0.013	0.5	2.51	0.8	1.18	2.35
71	DL-65	Outlet						0.9	0.013	0.64	2.83	1.6	2.29	3.6
72	DL-66	DL-67						0.45	0.013	0.16	1.41	1.8	0.38	2.41
73	DL-67	DL-68						0.6	0.013	0.28	1.88	3	1.06	3.76
74	DL-68	DL-69						0.6	0.013	0.28	1.88	2.4	0.95	3.36
75	DL-69	DL-70						0.8	0.013	0.5	2.51	2.5	2.08	4.16
76	DL-70	DL-71						0.8	0.013	0.5	2.51	1.4	1.56	3.11
77	DL-71	Outlet						0.9	0.013	0.64	2.83	1.9	2.5	3.92
78	DL-72	DL-73	0.6	0.6	0.7				0.04	0.39	1.8	0.7	0.29	0.75
79	DL-73	DL-65	0.4	0.65	0.7				0.04	0.36	1.73	3.7	0.6	1.68
80	DL-74	DL-75				0.45	0.5		0.04	0.23	1.45	1	0.16	0.72
81	DL-75	DL-76				0.5	0.65		0.04	0.33	1.8	5.9	0.3	1.94
82	DL-76	DL-77				0.35	0.55		0.04	0.19	1.45	2.4	0.19	1.01
83	DL-77	DL-80	0.5	0.7	0.75				0.04	0.44	1.92	3.3	0.74	1.69
84	DL-78	DL-79				0.45	0.6		0.04	0.27	1.65	2.8	0.15	1.25
85	DL-79	DL-80				0.7	0.65		0.04	0.46	2	4.1	0.35	1.89
86	DL-80	DL-70	0.6	0.6	0.75				0.04	0.41	1.81	3.2	0.67	1.65

87	DL-81	DL-82	0.3	0.5	0.4				0.035	0.29	1.46	2.2	0.20	1.43
88	DL-82	DL-83	0.5	0.6	0.8				0.03	0.42	1.76	1.4	0.63	1.51
89	DL-83	Outlet				0.65	0.8		0.04	0.52	2.25	1.7	0.64	1.23
90	DL-84	DL-85				0.3	0.5		0.04	0.24	1.6	5.6	0.1	1.67
91	DL-85	DL-83				0.45	0.5		0.04	0.23	1.45	3.2	0.29	1.29
92	DL-86	Outlet				0.35	0.7		0.04	0.25	1.75	2.3	0.25	1.02
93	DL-87	Outlet	0.4	0.5	0.65				0.035	0.26	1.43	3.3	0.44	1.68
94	DL-88	Outlet				0.4	0.5		0.04	0.2	1.4	2.4	0.21	1.06
95	DL-89	DL-90	0.5	0.85	0.7				0.03	0.53	2.22	1.5	0.84	1.58
96	DL-90	DL-91				0.55	0.6		0.04	0.33	1.75	4	0.54	1.64
97	DL-91	DL-92				0.35	0.4		0.04	0.14	1.15	4.6	0.18	1.32
98	DL-92	DL-93				0.6	0.7		0.04	0.42	2	3.9	0.73	1.74
99	DL-93	DL-94				0.65	1		0.04	0.65	2.65	5.7	1.52	2.34
100	DL-94	Outlet						1	0.013	0.79	3.14	1.3	2.73	3.48
101	DL-95	DL-96	0.4	0.5	0.6				0.035	0.6	2.35	0.8	0.15	1.02
102	DL-96	DL-97	0.4	0.4	0.5				0.035	0.26	1.43	2.6	0.21	1.49
103	DL-97	DL-68				0.4	0.55		0.04	0.22	1.5	0.7	0.13	0.58
104	DL-98	DL-99				0.45	0.6		0.04	0.27	1.65	1.5	0.25	0.92
105	DL-99	DL-100				0.5	0.45		0.03	0.52	2.25	1.4	0.40	1.49
106	DL-100	DL-94				0.5	0.65		0.04	0.33	1.8	5.6	0.61	1.89
107	DL-101	Outlet				0.3	0.35		0.035	0.46	2.05	2.7	0.25	1.72
108	DL-102	DL-103				0.6	0.75		0.04	0.45	2.1	1.3	0.46	1.02
109	DL-103	DL-104				0.55	0.9		0.04	0.5	2.35	2.4	0.68	1.37

110	DL-104	DL-105				0.45	0.65		0.04	0.29	1.75	1.6	0.28	0.96
111	DL-105	DL-100				0.6	0.8		0.04	0.52	2.25	1.8	0.66	1.26
112	DL-106	DL-99				0.55	0.7		0.035	0.39	1.95	1.4	0.44	1.15
113	DL-107	DL-108				0.5	0.6		0.035	0.3	1.7	4.2	0.55	1.84
114	DL-108	Outlet	0.45	0.35	0.7				0.035	0.21	1.21	4.5	0.4	1.88
115	DL-109	DL-91	0.4	0.6	0.45				0.04	0.47	1.82	0.5	0.33	0.71
116	DL-110	DL-111				0.55	0.6		0.04	0.33	1.75	1.3	0.31	0.94
117	DL-111	Outlet				0.65	0.9		0.04	0.59	2.45	2.7	0.92	1.58
118	DL-112	DL-111				0.4	0.5		0.04	0.2	1.4	4.4	0.29	1.43
119	DL-113	DL-114				0.35	0.4		0.035	0.14	1.15	2.2	0.15	1.04
120	DL-114	DL-115				0.45	0.6		0.035	0.27	1.65	5	0.52	1.91
121	DL-115	Outlet				0.45	0.55		0.04	0.25	1.55	5.1	0.41	1.66

Annex C: Capacity of the Existing Storm Water Drainage System of Woreda 8

Sr.No.	Flow direction		Drainage Types											
	From	To	Trapizoidal			Rectangular		Circular						
			B(m)	Y(m)	T(m)	Br(m)	Yr(m)	D(m)	n	A(m^2)	P(m)	S_o(%)	Q(m3/s)	V(m/s)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	14
1	DL-1	DL-2				0.4	0.35		0.04	0.14	1.1	1.8	0.12	0.85
2	DL-2	DL-3				0.7	0.6		0.04	0.42	1.9	2	0.54	1.29
3	DL-3	Outlet				0.7	0.6		0.04	0.42	1.9	2.2	0.57	1.36
4	DL-4	DL-5				0.7	0.5		0.04	0.35	1.7	1	0.31	0.87
5	DL-5	DL-84				0.75	0.45		0.035	0.32	1.6	1.4	0.36	1.14
6	DL-6	DL-7				0.35	0.2		0.035	0.07	0.75	1.2	0.05	0.64
7	DL-7	Outlet				0.3	0.35		0.03	0.11	1	3.9	0.15	1.47
8	DL-8	DL-6				0.25	0.35		0.04	0.09	0.95	1.5	0.05	0.62
9	DL-9	DL-10	0.4	0.45	0.5				0.04	0.2	1.31	2	0.21	1.02
10	DL-10	DL-11	0.4	0.5	0.65				0.04	0.26	1.43	4.1	0.43	1.63
11	DL-11	DL-12				0.4	0.5		0.04	0.2	1.4	4.9	0.3	1.51
12	DL-12	DL-13				0.5	0.6		0.04	0.3	1.7	3.7	0.45	1.51
13	DL-13	DL-14				0.4	0.65		0.04	0.26	1.7	4.9	0.41	1.58
14	DL-14	Outlet				0.8	0.65		0.04	0.52	2.1	3.3	0.93	1.79
15	DL-15	DL-16						0.45	0.013	0.16	1.41	0.8	0.26	1.6
16	DL-16	DL-17				0.65	0.7		0.04	0.46	2.05	2.2	0.28	1.36
17	DL-17	Outlet	0.4	0.35	0.5				0.035	0.6	2.35	3.3	0.35	2.08

18	DL-18	DL-19						0.5	0.013	0.2	1.57	2.4	0.58	2.98
19	DL-19	DL-20						0.6	0.013	0.28	1.88	1.6	0.78	2.75
20	DL-20	DL-21				0.6	0.7		0.04	0.42	2	2.1	0.54	1.28
21	DL-21	Outlet				0.65	0.7		0.04	0.46	2.05	2.1	0.6	1.33
22	DL-22	DL-23				0.75	0.45		0.04	0.34	1.65	1.8	0.39	1.16
23	DL-23	DL-24				0.7	0.5		0.04	0.35	1.7	2.5	0.48	1.38
24	DL-24	Outlet				0.7	0.55		0.04	0.39	1.8	0.9	0.33	0.85
25	DL-25	DL-26						0.3	0.013	0.16	1.41	5.6	0.23	4.24
26	DL-26	DL-27						0.45	0.013	0.2	1.57	4.8	0.46	4.21
27	DL-27	DL-28						0.6	0.013	0.28	1.88	4.4	1.29	4.56
28	DL-28	DL-29						0.8	0.013	0.5	2.51	1.6	1.67	3.33
29	DL-29	DL-22						0.8	0.013	0.5	2.51	1.8	1.77	3.53
30	DL-30	DL-31	0.35	0.35	0.45				0.04	0.14	1.06	4	0.18	1.3
31	DL-31	DL-23	0.5	0.35	0.6				0.04	0.19	1.21	9.3	0.43	2.24
32	DL-32	DL-33				0.4	0.35		0.04	0.14	1.1	5.1	0.2	1.43
33	DL-33	DL-34				0.4	0.6		0.04	0.24	1.6	8.6	0.5	2.07
34	DL-34	DL-35				0.5	0.6		0.04	0.3	1.7	6	0.58	1.93
35	DL-35	DL-36	0.4	0.7	0.7				0.035	0.38	1.83	3.9	0.76	1.99
36	DL-36	Outlet						0.8	0.013	0.5	2.51	0.4	0.84	1.66
37	DL-37	DL-38						0.3	0.013	0.2	1.57	5.5	0.23	3.24
38	DL-38	DL-39						0.45	0.013	0.2	1.57	5.6	0.32	3.32
39	DL-39	DL-40						0.6	0.013	0.28	1.88	4.6	1.02	4.66
40	DL-40	DL-41						0.6	0.013	0.28	1.88	4.5	1.07	4.61
41	DL-41	DL-42				0.4	0.5		0.04	0.2	1.4	3.5	0.26	1.258
42	DL-42	DL-45				0.3	0.4		0.04	0.29	1.75	3.5	0.25	1.42
43	DL-43	DL-44						0.45	0.013	0.16	1.41	4.2	0.3	3.67
44	DL-44	DL-45						0.5	0.013	0.2	1.57	5.6	0.89	4.55
45	DL-45	DL-46						0.6	0.013	0.28	1.88	1.2	0.67	2.38
46	DL-46	DL-47						0.6	0.013	0.28	1.88	1.4	0.73	2.57
47	DL-47	Outlet						0.6	0.013	0.28	1.88	1.6	0.78	2.75
48	DL-48	Outlet						0.8	0.013	0.5	2.51	2.5	2.09	4.16

49	DL-49	DL-50				0.35	0.4		0.04	0.12	1.1	6.5	0.17	1.46
50	DL-50	DL-51				0.45	0.5		0.04	0.23	1.45	3.2	0.29	1.29
51	DL-51	DL-48				0.6	0.7		0.04	0.42	2	4	0.74	1.77
52	DL-52	DL-53				0.6	0.5		0.04	0.3	1.6	1	0.25	0.82
53	DL-53	DL-54	0.6	0.7	0.75				0.04	0.47	2.01	2.7	0.54	1.57
54	DL-54	DL-44				0.6	0.75		0.04	0.7	2.7	4.7	0.81	2.2
55	DL-55	DL-56				0.45	0.4		0.04	0.18	1.25	1.5	0.15	0.84
56	DL-56	DL-57				0.5	0.6		0.04	0.3	1.7	1.1	0.25	0.82
57	DL-57	DL-58	0.5	0.35	0.6				0.04	0.3	1.49	1.1	0.27	0.9
58	DL-58	Outlet	0.5	0.7	0.8				0.035	0.45	1.93	3	0.85	1.88
59	DL-59	DL-60	0.45	0.35	0.45				0.03	0.18	1.17	5.2	0.18	2.21
60	DL-60	DL-61				0.4	0.5		0.04	0.2	1.4	4	0.27	1.37
61	DL-61	Outlet				0.45	0.6		0.04	0.27	1.65	1	0.2	0.75
62	DL-62	DL-63				0.35	0.4		0.04	0.14	1.15	1.5	0.11	0.75
63	DL-63	DL-64				0.4	0.65		0.04	0.26	1.7	3	0.32	1.24
64	DL-64	DL-65	0.4	0.5	0.65				0.04	0.24	1.41	3.1	0.32	1.34
65	DL-65	DL-66	0.4	0.5	0.75				0.04	0.26	1.43	2.4	0.33	1.25
66	DL-66	Outlet				0.65	0.8		0.04	0.52	2.25	5.5	1.15	2.21
67	DL-67	DL-68	0.25	0.5	0.4				0.04	0.38	1.83	3.1	0.19	1.55
68	DL-68	DL-69	0.5	0.5	0.6				0.04	0.45	1.93	3.6	0.51	1.8
69	DL-69	Outlet				0.6	0.4		0.04	0.24	1.4	7.2	0.5	2.07
70	DL-70	DL-71	0.2	0.4	0.35				0.035	0.37	1.91	1.7	0.07	1.26
71	DL-71	DL-72	0.3	0.4	0.35				0.035	0.36	1.69	3.3	0.1	1.85
72	DL-72	DL-73				0.6	0.45		0.035	0.27	1.5	5.9	0.14	2.21
73	DL-73	Outlet				0.3	0.4		0.035	0.38	2	7.3	0.13	2.53
74	DL-74	DL-75				0.45	0.5		0.04	0.23	1.45	3.6	0.22	1.37
75	DL-75	Outlet				0.5	0.6		0.04	0.3	1.7	1.8	0.32	1.06
76	DL-76	DL-77	0.25	0.3	0.35				0.04	0.14	1.01	6.6	0.04	1.68
77	DL-77	Outlet	0.3	0.3	0.35				0.04	0.26	1.43	6.1	0.08	1.99
78	DL-78	DL-79				0.2	0.3		0.04	0.14	1.15	1.9	0.05	0.85
79	DL-79	DL-80				0.55	0.6		0.04	0.33	1.75	8.7	0.11	2.42

80	DL-80	Outlet				0.5	0.45		0.04	0.48	2.2	5.4	0.15	2.11
81	DL-81	Outlet	0.4	0.5	0.5				0.03	0.23	1.4	1.5	0.16	1.2
82	DL-82	Outlet	0.4	0.25	0.5				0.04	0.11	0.91	2.2	0.15	0.92
83	DL-83	DL-63				0.45	0.3		0.04	0.12	1	1	0.07	0.61
84	DL-84	DL-85						0.45	0.013	0.16	1.41	1.4	0.34	2.12
85	DL-85	DL-86						0.5	0.013	0.2	1.57	2.1	0.55	2.79
86	DL-86	DL-87						0.6	0.013	0.28	1.88	1.4	0.73	2.57
87	DL-87	DL-88						0.6	0.013	0.28	1.88	2.2	0.91	3.22
88	DL-88	DL-89						0.8	0.013	0.5	2.51	2.2	1.34	3.9
89	DL-89	Outlet						0.9	0.013	0.64	2.83	2.9	2.25	4.85
90	DL-90	DL-91	0.4	0.5	0.65				0.04	0.26	1.43	3.5	0.4	1.51
91	DL-91	DL-92	0.4	0.5	0.75				0.04	0.29	1.46	4.8	0.53	1.85
92	DL-92	DL-93				0.45	0.4		0.04	0.18	1.25	3.4	0.23	1.27
93	DL-93	Outlet	0.45	0.6	0.8				0.04	0.37	1.7	5.1	0.77	2.06
94	DL-94	DL-95						0.6	0.013	0.28	1.88	2.3	0.67	3.29
95	DL-95	DL-96						0.6	0.013	0.28	1.88	2.6	0.8	3.5
96	DL-96	DL-97						0.6	0.013	0.28	1.88	3.2	1.1	3.88
97	DL-97	DL-98						0.8	0.013	0.5	2.51	4.7	1.42	5.7
98	DL-98	Outlet						0.9	0.013	0.64	2.83	2.8	1.55	4.76
99	DL-99	DL-51						0.6	0.013	0.28	1.88	0.8	0.55	1.94
100	DL-100	DL-101				0.2	0.4		0.04	0.08	1	3.7	0.07	0.89
101	DL-101	DL-102				0.35	0.5		0.04	0.18	1.35	2.1	0.16	0.93
102	DL-102	DL-103				0.4	0.65		0.04	0.26	1.7	3.2	0.33	1.28
103	DL-104	Outlet				0.3	0.4		0.03	0.12	1.1	3.2	0.16	1.36

Annex D: Runoff Estimation for Woreda 6

Plot No.	Flow Direction From	Flow Direction To	Descriptions of sub catchment	Sub-basin area A_s, (ha)	Runoff coeff. (c)	Total basin area $A_{t,}$ (ha)	length of the basin L_c (m)	Lowest elevation of the basin, H_1(m)	Highest elevation of the basin, H_2(m)	Average slope of the basin ,S_o	Time of Concen tartion(hr)	Rainfall Intensity I, (mm/hr) 5 years	Rainfall Intensity I, (mm/hr) 10 years	Total runoff for plot of basins Qs, (m^3/sec)
1	2	3	4	5	6	7	8	9	10	11	12	14	15	16
1	DL-1	DL-2	Gravel Road (A1)	0.12	0.80	0.118	211	2368	2378	0.045	0.066	150		0.04
2	DL-2	DL-3	Apartment Area (A2)	5.65	0.59	6.855	98	2366	2368	0.026	0.069		180	2.03
3	DL-3	DL-4	Gravel Road (A3)	0.08	0.71	6.939	57	2364	2366	0.026	0.034	160		2.19
4	DL-4	Outlet	Apartment Area (A4)	0.59	0.51	8.814	140	2360	2364	0.029	0.079		177	2.23
5	DL-5	Outlet	Gravel road parking	0.41	0.80	0.411	110	2360	2366	0.050	0.038	158		0.14
6	DL-6	DL-7	Single-family Area(A1)	0.40	0.40	0.774	147	2367	2369	0.014	0.079	148		0.13
7	DL-7	DL-8	Apartment Area (A2)	0.29	0.78	1.061	100	2366	2367	0.015	0.093	145		0.21
8	DL-8	DL-4	Gravel road (A3)	0.22	0.75	1.285	42	2364	2366	0.036	0.029	160		0.43
9	DL-9	DL-7	Gravel Road	0.29	0.80	0.287	49	2367	2368	0.010	0.038	158		0.10
10	DL-10	DL-18	Gravel Road(A1)	0.26	0.8	0.260	101	2371	2372	0.010	0.067	149		0.09
11	DL-11	DL-18	Neighborhood Area(A2)	0.01	0.76	0.013	22	2372	2373	0.045	0.025	162		0.20
12	DL-12	DL-13	Gravel Road(A1)	0.12	0.8	0.121	45	2372	2373	0.011	0.034	160		1.00
13	DL-12.1	DL-13	Suburban (A2)	0.18	0.61	0.181	44	2372	2373	0.023	0.035	160		0.15
14	DL-13	DL-14	Suburban (A3)	0.12	0.7	0.302	81	2369	2372	0.037	0.058	151		0.48
15	DL-14	DL-2	Suburban (A3)	0.78	0.75	1.084	46	2368	2369	0.022	0.035	160		0.51
16	DL-15	DL-16	Asphalt Road (A1)	0.64	0.85	0.642	87	2368	2369	0.011	0.057	150		0.23
17	DL-16	DL-17	Gravel Road(A2)	0.43	0.83	1.421	71	2367	2368	0.014	0.073	148		0.49
18	DL-17	DL-46	Suburban(A3)	0.68	0.69	2.394	143	2366	2367	0.007	0.143	142		0.65
19	DL-18	DL-16	Suburban	0.35	0.4	0.348	78	2369	2372	0.045	0.031	160		0.06
20	DL-19	DL-17	Suburban	0.29	0.4	0.291	91	2368	2371	0.033	0.039	157		0.05

21	DL-20	DL-22	School Area(A1)	0.90	0.8	0.900	169	2365	2368	0.015	0.085	147		0.29
22	DL-21	DL-22	School Area(A2)	0.59	0.8	0.593	142	2365	2367	0.011	0.109	145		0.19
23	DL-22	Outlet	Asphalt Road (A3)	0.16	0.83	1.649	83	2362	2365	0.036	0.071	149		0.57
24	DL-23	DL-24	Asphalt Road & Residence	1.65	0.85	1.650	210	2360	2367	0.033	0.074		180	0.70
25	DL-24	DL-25	Neighborhood Area(A2)	0.41	0.74	2.064	78	2356	2360	0.051	0.038	158		0.67
26	DL-25	Outlet	Neighborhood Area(A3)	0.04	0.73	2.973	81	2350	2356	0.074	0.038	158		0.95
27	DL-26	DL-25	Suburban	0.87	0.4	0.868	239	2356	2364	0.031	0.083	146		0.14
28	DL-27	DL-28	Asphalt Road(A1)	0.11	0.85	0.479	50	2366	2367	0.020	0.030	160		0.18
29	DL-28	Outlet	Gravel Road(A2)	0.05	0.83	0.527	31	2364	2366	0.049	0.024		190	0.23
30	DL-29	DL-27	School Area	0.37	0.8	0.372	87	2367	2369	0.029	0.039	157		0.13
31	DL-30	DL-31	Suburban(A1)	0.81	0.4	0.811	143	2357	2361	0.028	0.059	150		0.14
32	DL-31	Outlet	Green Area(A2)	0.75	0.35	1.560	74	2355	2357	0.020	0.052	151		0.23
33	DL-32	DL-33	Unimproved Area(A1)	0.95	0.3	0.954	181	2379	2385	0.033	0.066	149		0.12
34	DL-33	DL-34	Suburban(A2)	2.11	0.35	3.063	169	2371	2379	0.050	0.086	146		0.44
35	DL-34	DL-35	Suburban(A3)	0.35	0.32	3.409	60	2369	2371	0.025	0.042		186	0.56
36	DL-35	DL-36	Asphalt Road (A4)	0.42	0.78	3.827	34	2368	2369	0.030	0.022		192	1.59
37	DL-36	DL-37	Suburban(A5)	0.05	0.38	4.327	54	2367	2368	0.019	0.037	158		0.72
38	DL-37	DL-38	Suburban(A6)	0.04	0.35	4.367	46	2366	2367	0.022	0.036	160		0.68
39	DL-38	DL-39	Suburban(A7)	0.39	0.35	8.027	75	2364	2366	0.020	0.056		180	1.41
40	DL-39	DL-40	Suburban(A8)	0.21	0.34	14.697	66	2362	2364	0.030	0.037		187	2.60
41	DL-40	DL-41	Suburban(A9)	0.58	0.33	16.834	129	2358	2362	0.031	0.062	149		2.30
42	DL-41	Outlet	Suburban(A10)	2.83	0.32	19.664	106	2355	2358	0.028	0.067	149		2.61
43	DL-42	DL-43	Asphalt Road(A1)	0.36	0.85	0.360	303	2373	2380	0.025	0.110	144		0.12
44	DL-43	DL-44	Asphalt Road(A2)	0.03	0.85	0.387	27	2371	2373	0.055	0.027		190	0.17
45	DL-44	DL-45	Asphalt Road(A3)	0.06	0.85	0.447	81	2369	2371	0.031	0.044		186	0.20
46	DL-45	DL-46	Asphalt Road(A4)	0.43	0.85	0.877	126	2367	2369	0.012	0.084	147		0.30
47	DL-46	DL-38	Asphalt Road(A5)	3.27	0.85	3.271	23	2366	2367	0.044	0.019		193	1.49
48	DL-47	DL-35	Neighborhood Areas	0.47	0.7	0.470	102	2369	2370	0.005	0.088		176	0.16
49	DL-48	DL-36	Suburban	0.45	0.4	0.447	89	2368	2369	0.006	0.076		179	0.09

50	DL-49	DL-50	Gravel Road(A1)	0.61	0.8	0.607	106	2374	2376	0.019	0.054	151		0.20
51	DL-50	DL-51	Sport Filed (A2)	1.30	0.5	2.393	125	2373	2374	0.008	0.120	143		0.48
52	DL-51	DL-52	Suburban(A3)	0.15	0.48	2.539	42	2372	2373	0.035	0.038	159		0.54
53	DL-52	DL-53	Suburban(A4)	2.16	0.4	5.079	32	2370	2372	0.047	0.022	164		0.93
54	DL-53	DL-54	Single family Area(A5)	0.10	0.35	5.693	42	2368	2370	0.048	0.025	162		0.90
55	DL-54	DL-55	Multi units, detached(A6)	0.28	0.52	5.974	59	2367	2368	0.025	0.040	154		1.33
56	DL-55	DL-39	Multi units, detached(A7)	0.49	0.51	6.459	135	2364	2367	0.019	0.096	145		1.33
57	DL-56	DL-51	Asphalt Road	0.49	0.85	0.490	134	2372	2373	0.011	0.079	148		0.17
58	DL-57	DL-53	Asphalt Road	0.38	0.85	0.378	136	2370	2371	0.007	0.095	145		0.13
59	DL-58	DL-54	Multi units, attached	0.52	0.7	0.517	132	2368	2369	0.008	0.091	145		0.15
60	DL-59	DL-60	Multi units attached (A1)	0.56	0.7	0.561	94	2365	2367	0.021	0.047	157		0.17
61	DL-60	DL-61	Neighborhood Area(A2)	0.16	0.7	0.718	60	2364	2365	0.017	0.053	151		0.21
62	DL-61	DL-40	Gravel Road(A3)	0.84	0.76	1.556	117	2362	2364	0.017	0.081	147		0.48
63	DL-62	DL-63	Store & Office (A1)	1.48	0.8	1.483	230	2368	2370	0.009	0.133	142		0.47
64	DL-63	DL-64	Apartment (A2)	1.41	0.77	2.897	43	2366	2368	0.059	0.031	160		0.99
65	DL-64	DL-65	Commercial Area(A3)	0.86	0.81	3.753	43	2363	2366	0.059	0.025	162		1.37
66	DL-65	DL-66	Commercial Area(A4)	0.43	0.82	4.186	83	2359	2363	0.048	0.045	155		1.48
67	DL-66	Outlet	Commercial Area(A5)	0.26	0.82	4.445	100	2355	2359	0.040	0.052	152		1.54
68	DL-67	DL-68	Asphalt Road (A1)	8.93	0.85	8.932	212	2393	2397	0.016	0.098	145		3.06
69	DL-68	DL-69	Asphalt Road (A2)	0.19	0.85	9.124	216	2386	2393	0.032	0.137		169	3.64
70	DL-69	DL-70	Asphalt &Green Area(A3)	0.28	0.71	9.404	127	2383	2386	0.027	0.065		182	3.38
71	DL-70	DL-71	Neighborhood (A4)	1.71	0.62	11.117	193	2377	2383	0.031	0.086		175	3.35
72	DL-71	DL-72	Asphalt Road (A5)	0.46	0.82	11.581	130	2374	2377	0.019	0.072		178	4.70
73	DL-72	Outlet	Asphalt Road (A6)	0.60	0.83	12.183	125	2368	2374	0.048	0.052		186	5.23
74	DL-73	DL-74	Single family Area (A1)	0.73	0.3	0.730	102	2386	2391	0.049	0.037	158		0.10
75	DL-74	DL-76	Multi-unit Detached (A2)	0.73	0.45	1.216	146	2384	2387	0.017	0.106	145		0.22

76	DL-75	DL-76	Neighborhood Area(A1)	0.49	0.7	2.081	124	2386	2391	0.040	0.046	155		0.63
77	DL-76	DL-77	Neighborhood Area(A2)	1.22	0.7	3.297	91	2385	2386	0.011	0.076	148		0.95
78	DL-77	DL-79	Neighborhood Area(A3)	0.50	0.7	4.764	114	2383	2385	0.018	0.095	145		1.34
79	DL-78	DL-79	Neighborhood Area(A4)	3.70	0.7	3.697	185	2383	2386	0.016	0.132	142		1.02
80	DL-79	DL-80	Neighborhood Area(A5)	0.32	0.7	8.783	156	2377	2383	0.038	0.089	146		2.50
81	DL-80	Outlet	Neighborhood Area(A6)	2.62	0.7	8.281	40	2375	2377	0.050	0.023	163		2.63
82	DL-81	Outlet	Neighborhood Area	0.68	0.7	0.679	113	2374	2375	0.009	0.076	148		0.20
83	DL-82	DL-83	Asphalt Road (A1)	0.05	0.85	0.048	31	2373	2374	0.022	0.020	165		0.02
84	DL-83	DL-84	Suburban(A2)	0.20	0.65	0.251	52	2372	2373	0.025	0.050	151		0.07
85	DL-84	DL-72	Neighborhood Area(A3)	0.35	0.65	0.602	64	2371	2372	0.016	0.062	149		0.16
86	DL-85	DL-86	Commercial Area(1)	0.26	0.85	0.263	85	2392	2395	0.035	0.036	160		0.10
87	DL-86	DL-87	Store(A2)	0.81	0.85	1.069	86	2391	2392	0.012	0.085	146		0.37
88	DL-87	DL-75	Commercial Area (3)	0.08	0.85	1.589	38	2390	2391	0.026	0.031	160		0.60
89	DL-88	DL-89	Gravel Road (A1)	0.31	0.8	0.310	63	2394	2396	0.040	0.027	163		0.11
90	DL-89	DL-87	Gravel Road(A2)	0.13	0.8	0.441	81	2392	2394	0.025	0.062	149		0.15
91	DL-90	DL-74	Office	0.49	0.85	0.486	124	2387	2393	0.049	0.042	155		0.18
92	DL-91	DL-92	Suburban (A1)	0.81	0.4	0.810	117	2389	2392	0.026	0.052	151		0.14
93	DL-92	DL-77	Suburban (A2)	0.15	0.4	0.963	155	2385	2389	0.026	0.100	145		0.16
94	DL-93	DL-94	Suburban Area(A1)	0.79	0.4	0.793	132	2375	2380	0.042	0.047	152		0.13
95	DL-94	DL-95	Unimproved Area(A2)	0.37	0.33	1.165	55	2374	2375	0.018	0.046	153		0.16
96	DL-95	DL-96	Neighborhood Area(A3)	0.49	0.53	1.658	49	2372	2374	0.031	0.041	155		0.38
97	DL-96	DL-97	Neighborhood Area(A4)	0.55	0.54	2.209	63	2371	2372	0.016	0.052	151		0.50
98	DL-97	DL-98	Neighborhood Area(A5)	0.45	0.57	2.657	43	2370	2371	0.023	0.036	158		0.67
99	DL-98	DL-80	Neighborhood Area(A6)	0.85	0.63	3.505	111	2368	2370	0.023	0.074	148		0.91
100	DL-99	DL-71	Asphalt Road	0.46	0.85	0.464	95	2377	2378	0.016	0.053	150		0.16

101	DL-100	DL-101	Gravel Road(A1)	0.38	0.8	0.380	106	2375	2378	0.024	0.024	0.050		0.13
102	DL-101	DL-102	Gravel Road(A2)	0.12	0.8	0.496	92	2373	2375	0.027	0.027	0.076		0.16
103	DL-102	Outlet	Gravel Road (A3)	1.55	0.8	4.205	116	2372	2374	0.017	0.017	0.091		1.36
104	DL-103	DL-104	Apartment Area(A1)	0.86	0.8	0.855	47	2377	2379	0.032	0.032	0.024		0.31
105	DL-104	DL-105	Suburban (A2)	0.90	0.6	1.758	62	2373	2377	0.064	0.064	0.034		0.47
106	DL-105	DL-102	Suburban (A3)	0.40	0.63	2.159	39	2372	2373	0.026	0.026	0.029		0.61
107	DL-106	Outlet	Single family Area	0.69	0.4	0.688	86	2369	2375	0.070	0.070	0.028		0.12
108	DL-107	Outlet	Gravel Road	0.51	0.8	0.515	95	2367	2372	0.053	0.053	0.034		0.18
109	DL-108	DL-109	Suburban Area(A1)	0.71	0.4	0.707	33	2380	2381	0.031	0.031	0.018		0.13
110	DL-109	DL-110	Neighborhood Area(A2)	0.38	0.55	1.092	39	2379	2380	0.026	0.026	0.033		0.27
111	DL-110	DL-111	Neighborhood Area(A3)	0.35	0.61	1.438	75	2378	2379	0.020	0.020	0.056		0.37
112	DL-111	DL-80	Neighborhood Area(A4)	0.72	0.63	2.160	46	2377	2378	0.011	0.011	0.045		0.58
113	DL-112	DL-113	Commercial Area(A1)	1.04	0.85	1.037	161	2375	2385	0.062	0.062	0.047		0.37
114	DL-113	Outlet	Commercial Area(A2)	0.41	0.85	1.444	121	2368	2375	0.058	0.058	0.060		0.51
115	DL-114	DL-115	Office Area(A1)	0.33	0.85	0.333	65	2374	2376	0.023	0.023	0.034		0.13
116	DL-115	Outlet	Apartment & Store(A2)	1.22	0.85	1.550	73	2374	2379	0.069	0.069	0.049		0.55
117	DL-116	DL-117	Suburban Area(A1)	1.49	0.4	1.486	88	2389	2394	0.063	0.063	0.029		0.27
118	DL-117	DL-118	Suburban Area (A2)	0.54	0.4	2.031	30	2387	2389	0.049	0.049	0.020		0.37
119	DL-118	DL-119	Gravel Road (A3)	0.32	0.53	2.351	61	2383	2387	0.065	0.065	0.033		0.55
120	DL-119	Outlet	Green Area(A4)	0.27	0.47	2.625	70	2379	2383	0.057	0.057	0.036		0.54
121	DL-120	Outlet	Neighborhood Area	2.13	0.7	2.133	103	2367	2371	0.044	0.044	0.038		0.65
122	DL-121	DL-122	Suburban(A1)	0.53	0.4	0.531	536	2360	2367	0.012	0.012	0.020		0.10
123	DL-122	DL-123	Multi-unit attached (A2)	1.37	0.58	1.903	77	2367	2369	0.032	0.032	0.066		0.46
124	DL-123	Outlet	Single family Area(A3)	0.09	0.5	1.990	107	2365	2367	0.014	0.014	0.084		0.41

Annex E: Runoff Estimation for Woreda 7

Plot No.	Flow Direction From	Flow Direction To	Descriptions of sub catchment	Sub-basin area A_s, (ha)	Runoff coeff. (c)	Total basin area A_t, (ha)	length of the basin L_c (m)	Lowest elevation of the basin, H_1(m)	Highest elevation of the basin, H_2(m)	Average slope of the basin ,S_o	Time of Concentartion(hr) equation	Rainfall Intensity I, (mm/hr) 5 years	Rainfall Intensity I, (mm/hr) 10 years	Total runoff for plot of basins Qs, (m^3/sec)
1	2	3	4	5	6	7	8	9	10	11	14	15	16	17
1	DL-1	DL-2	Gravel Road (A1)	0.82	0.80	0.823	164	2401	2407	0.037	0.059	149		0.27
2	DL-2	DL-3	Gravel road & Suburban(A2)	0.96	0.71	1.780	62	2397	2401	0.064	0.036	158		0.56
3	DL-3	DL-4	Suburban (A3)	0.46	0.68	2.244	77	2396	2398	0.026	0.049	152		0.64
4	DL-4	DL-5	Green Area(A4)	1.09	0.41	3.335	54	2395	2396	0.019	0.044	154		0.59
5	DL-5	DL-6	Gravel road&Green Area(A5)	1.73	0.69	5.658	36	2394	2395	0.028	0.028	163		1.77
6	DL-6	DL-7	Suburban (A6)	0.17	0.52	5.827	43	2392	2395	0.070	0.024	164		1.38
7	DL-7	DL-14	Green area & Suburban(A7)	0.23	0.50	6.053	101	2387	2392	0.049	0.048	152		1.28
8	DL-1.1	Outlet	Suburban	0.27	0.40	0.274	126	2395	2401	0.048	0.043	155		0.05
9	DL-2.1	Outlet	Green Area	0.41	0.30	0.415	66	2393	2398	0.076	0.022	165		0.06
10	DL-3.1	Outlet	Suburban	0.16	0.4	0.161	81	2392	2396	0.049	0.030	160		0.03
11	DL-8	DL-9	Asphalt&Commercial Area(A1)	0.42	0.85	4.248	64	2407	2409	0.031	0.030	160		1.61
12	DL-9	DL-10	Asphalt&Office Area(A2)	0.32	0.85	4.474	44	2405	2407	0.046	0.029	162		1.71
13	DL-10	DL-11	Commercial&Green Area(A3)	0.50	0.76	9.215	107	2400	2405	0.047	0.059		179	3.18
14	DL-11	DL-12	Apartment(A4)	0.40	0.74	9.614	55	2397	2400	0.055	0.025		189	3.52
15	DL-12	DL-13	Apartment(A5)	0.23	0.74	9.846	47	2394	2397	0.064	0.021		190	3.61
16	DL-13	DL-14	Apartment(A6)	0.17	0.73	10.012	83	2390	2394	0.048	0.035		187	3.67
17	DL-14	Outlet	Green Area(A7)	1.36	0.67	15.848	190	2387	2390	0.016	0.100	145		3.74

18	DL-15	DL-16	Gravel Road &Suburban(A1)	0.84	0.65	0.843	84	2410	2413	0.036	0.035	160		0.24
19	DL-16	DL-17	Suburban(A2)	0.80	0.58	1.644	90	2410	2417	0.078	0.048	152		0.40
20	DL-17	DL-4	Suburban(A3)	0.80	0.55	2.445	165	2396	2410	0.085	0.064	149		0.56
21	DL-18	DL-19	Green Area &Suburban(A1)	0.98	0.48	0.980	93	2410	2412	0.021	0.047	153		0.20
22	DL-19	DL-20	Gravel Road(A2)	0.77	0.56	1.747	73	2409	2410	0.014	0.063	149		0.41
23	DL-20	DL-21	Apartment&Gravel Road(A3)	1.46	0.71	3.794	164	2407	2409	0.012	0.109	145		1.09
24	DL-18.1	DL-6	Neighborhood Area	0.59	0.7	0.589	95	2407	2410	0.032	0.041	156		0.18
25	DL-21	DL-10	Suburban Area	4.24	0.4	4.238	104	2405	2407	0.019	0.053	150		0.71
26	DL-22	DL-12	Neighborhood Area	1.52	0.7	1.516	153	2397	2401	0.026	0.064	149		0.44
27	DL-23	DL-20	Neighborhood Area	0.59	0.7	0.586	160	2407	2413	0.038	0.057	149		0.17
28	DL-24	DL-9	Commercial Area	0.54	0.85	0.545	109	2407	2412	0.046	0.039	157		0.20
29	DL-25	DL-26	Commercial Area(A1)	1.09	0.85	1.095	182	2416	2420	0.022	0.078	148		0.38
30	DL-26	DL-27	Suburban(A2)	0.66	0.73	1.759	55	2413	2416	0.055	0.036	158		0.56
31	DL-27	DL-8	Commercial Area(aA3)	1.87	0.81	3.631	146	2409	2413	0.027	0.081	147		1.20
32	DL-28	DL-8	Asphalt Road	0.20	0.85	0.198	286	2409	2423	0.049	0.081	147		0.07
33	DL-29	DL-30	Asphalt Road(A1)	0.83	0.85	0.830	90	2418	2423	0.055	0.032	160		0.31
34	DL-30	DL-31	Asphalt Road(A2)	0.05	0.85	0.880	197	2408	2418	0.051	0.094	145		0.30
35	DL-31	Outlet	Apartment &Asphalt Road(A3)	2.71	0.85	6.297	488	2375	2408	0.068	0.148	138		2.05
36	DL-29.1	DL-35	Neighborhood Area	2.58	0.7	2.583	210	2409	2418	0.043	0.067		180	0.90
37	DL-32	DL-34	Residential (Suburban)(A1)	0.92	0.4	0.918	168	2412	2415	0.018	0.079		177	0.18
38	DL-33	DL-34	Residential (Suburban)(A2)	0.23	0.4	0.234	51	2412	2413	0.020	0.036	159		0.04
39	DL-34	DL-35	Asphalt &Suburban Area (A3)	0.59	0.67	1.739	89	2407	2412	0.056	0.070	147		0.58
40	DL-35	DL-31	Asphalt &Suburban Area (A4)	0.97	0.65	2.706	197	2407	2408	0.005	0.176	128		0.91
											0.035	160		0.24

41	DL-36	Outlet	Asphalt Road & Green Area	5.00	0.65	5.004	306	2419	2429	0.033	0.099		170	1.54
42	DL-37	DL-31	Asphalt Road & Apartment	5.38	0.85	5.383	335	2407	2412	0.015	0.144		165	2.10
43	DL-38	DL-37	Residential(Suburban)	4.33	0.4	4.330	303	2399	2407	0.026	0.107		169	0.81
44	DL-39	DL-43	Residential(Suburban)	0.61	0.4	0.607	89	2395	2399	0.045	0.034		186	0.13
45	DL-40	DL-41	Asphalt Road(A1)	4.00	0.85	3.999	125	2413	2419	0.048	0.043		184	1.74
46	DL-41	DL-42	Asphalt Road(A2)	0.06	0.85	4.056	203	2401	2413	0.059	0.072		178	1.71
47	DL-42	DL-43	Asphalt Road(A3)	0.03	0.85	4.086	108	2395	2401	0.056	0.042		186	1.80
48	DL-43	DL-44	Apartment&Asphalt Road(A4)	0.40	0.81	4.488	363	2381	2395	0.039	0.126		168	1.70
49	DL-44	Outlet	Apartment&Asphalt Road(A5)	12.03	0.82	16.518	422	2377	2381	0.009	0.139		165	3.45
50	DL-44.1	Outlet	Apartment & Green Area	3.94	0.5	3.940	410	2370	2376	0.015	0.170		150	0.82
51	DL-45	DL-46	Store(A1)	1.71	0.85	1.710	269	2394	2398	0.013	0.128	135		0.55
52	DL-46	DL-47	Green Area &Suburban(A2)	1.54	0.6	3.250	220	2384	2394	0.045	0.146	125		0.68
53	DL-47	Outlet	Unimproved Area(A3)	0.81	0.5	4.058	93	2375	2384	0.097	0.042	156		0.88
54	DL-48	DL-45	Office	0.08	0.85	0.075	61	2394	2397	0.049	0.025	165		0.03
55	DL-49	DL-46	Green Area &Suburban	0.17	0.35	0.247	163	2384	2395	0.067	0.046	154		0.04
56	DL-50	Outlet	Suburban	4.90	0.4	5.146	431	2375	2397	0.051	0.109	145		0.83
57	DL-51	DL-52	Asphalt &Suburban(A1)	2.90	0.67	2.902	295	2391	2397	0.020	0.116		168	0.91
58	DL-52	DL-56	Multi-unit Attached(A2)	2.11	0.7	5.013	247	2374	2391	0.069	0.090	145		1.41
59	DL-53	DL-54	Asphalt Road(A1)	0.37	0.85	0.369	193	2386	2393	0.036	0.093		180	0.16
60	DL-54	DL-55	Asphalt&Commercial Area(A2)	2.10	0.85	2.472	126	2381	2386	0.040	0.060		185	1.08
61	DL-55	DL-56	Asphalt&Neighborhood (A3)	-0.04	0.82	3.020	116	2373	2381	0.069	0.043		187	1.29
62	DL-56	Outlet	Asphalt Road(A4)	0.56	0.82	8.592	75	2372	2373	0.013	0.051		185	3.62

63	DL-57	DL-55	Gravel Road	0.58	0.8	0.583	214	2390	2393	0.014	0.105	145		0.19
64	DL-58	Outlet	Suburban Area	0.29	0.4	0.287	127	2378	2380	0.016	0.067	149		0.05
65	DL-59	Outlet	Store	0.38	0.85	0.381	116	2379	2381	0.017	0.060	149		0.13
66	DL-60	Outlet	Multi-unit detached	1.32	0.5	1.317	165	2388	2390	0.015	0.083	147		0.27
67	DL-61	Outlet	Multi-unit detached	0.52	0.5	0.517	143	2384	2385	0.007	0.100	145		0.10
68	DL-62	Outlet	Multi-unit detached	0.59	0.5	0.594	151	2381	2383	0.010	0.091	146		0.12
69	DL-63	DL-64	Asphalt Road&Suburban(A1)	1.59	0.81	1.595	183	2371	2373	0.011	0.102		173	0.62
70	DL-64	DL-65	Asphalt Road(A2)	0.90	0.82	2.499	127	2370	2371	0.008	0.103		173	0.99
71	DL-65	Outlet	Asphalt Road(A3)	0.33	0.85	5.294	122	2368	2370	0.016	0.078		177	2.21
72	DL-66	DL-67	Asphalt &Suburban(A1)	4.44	0.71	4.436	55	2370	2371	0.018	0.033		190	1.66
73	DL-67	DL-68	Asphalt Road (A2)	0.21	0.83	4.645	50	2368	2370	0.030	0.031		191	2.05
74	DL-68	DL-69	Asphalt &Suburban(A3)	0.61	0.78	5.257	82	2366	2368	0.024	0.046		186	2.12
75	DL-69	DL-70	Suburban(A4)	0.39	0.62	5.647	121	2363	2366	0.025	0.064		183	1.78
76	DL-70	DL-71	Asphalt &Suburban(A5)	5.16	0.65	10.808	72	2362	2363	0.014	0.050		185	3.61
77	DL-71	Outlet	Asphalt &Suburban(A6)	0.43	0.63	11.235	154	2359	2362	0.019	0.085		181	3.56
78	DL-72	DL-73	Apartment(A1)	2.32	0.7	2.323	217	2378	2379	0.007	0.139	135		0.61
79	DL-73	DL-65	Apartment(A2)	0.14	0.7	2.465	147	2372	2378	0.037	0.108	145		0.70
80	DL-74	DL-75	Office(A1)	0.38	0.85	0.383	103	2370	2371	0.010	0.069	149		0.13
81	DL-75	DL-76	Neighborhood Area(A2)	0.64	0.78	1.018	101	2364	2370	0.059	0.073	148		0.33
82	DL-76	DL-77	Neighborhood Area(A3)	1.16	0.75	2.174	85	2362	2364	0.024	0.054	150		0.68
83	DL-77	DL-80	Neighborhood Area(A4)	0.45	0.74	2.628	90	2362	2365	0.033	0.063	149		0.81
84	DL-78	DL-79	Suburban(A1)	1.47	0.4	1.474	179	2365	2370	0.028	0.070	148		0.24
85	DL-79	DL-80	Suburban(A2)	0.40	0.4	1.871	98	2366	2370	0.041	0.060	149		0.31
86	DL-80	DL-70	Suburban(A3)	0.72	0.4	5.219	93	2363	2366	0.032	0.054	150		0.87

87	DL-81	DL-82	Commercial Area(A1)	0.65	0.85	0.650	90	2363	2365	0.022	0.045	155		0.24
88	DL-82	DL-83	Commercial Area(A2)	0.87	0.85	1.521	74	2362	2363	0.014	0.061	149		0.54
89	DL-83	Outlet	Commercial Area(A3)	0.32	0.85	2.363	58	2361	2362	0.017	0.046	154		0.86
90	DL-84	DL-85	Commercial Area(A1)	0.31	0.85	0.308	45	2365	2367	0.056	0.019	165		0.12
91	DL-85	DL-83	Commercial Area(A2)	0.21	0.85	0.518	77	2362	2365	0.032	0.047	153		0.19
92	DL-86	Outlet	Commercial Area	0.69	0.85	0.686	111	2363	2365	0.023	0.053	150		0.24
93	DL-87	Outlet	Commercial Area	1.20	0.85	1.197	135	2363	2367	0.033	0.053	150		0.42
94	DL-88	Outlet	Commercial Area	0.68	0.85	0.677	105	2363	2365	0.024	0.049	151		0.24
95	DL-89	DL-90	Apartment(A1)	3.58	0.85	3.583	202	2375	2378	0.015	0.098	145		1.23
96	DL-90	DL-91	Neighborhood Area(A2)	0.44	0.78	4.024	63	2373	2375	0.040	0.038	157		1.37
97	DL-91	DL-92	Neighborhood Area(A3)	-0.68	0.75	4.564	98	2368	2373	0.046	0.053	150		1.43
98	DL-92	DL-93	Neighborhood Area(A4)	0.45	0.74	5.016	76	2365	2368	0.039	0.048	152		1.57
99	DL-93	DL-94	Neighborhood Area(A5)	0.20	0.73	5.212	70	2361	2365	0.057	0.037	158		1.67
100	DL-94	Outlet	Neighborhood Area(A6)	0.47	0.73	11.921	78	2360	2361	0.013	0.059		185	3.78
101	DL-95	DL-96	Suburban(A1)	0.69	0.4	0.691	121	2364	2365	0.008	0.092	146		0.11
102	DL-96	DL-97	Suburban(A2)	0.38	0.4	1.074	38	2363	2364	0.026	0.032	165		0.20
103	DL-97	DL-68	Suburban(A3)	0.34	0.4	1.417	142	2362	2363	0.007	0.126	142		0.22
104	DL-98	DL-99	Gravel Road(A4)	0.24	0.5	1.654	67	2361	2362	0.015	0.074	148		0.34
105	DL-99	DL-100	GravelRoad &Suburban(A5)	0.24	0.52	1.896	70	2364	2365	0.014	0.065	149		0.41
106	DL-100	DL-94	Suburban(A6)	0.56	0.5	6.243	54	2361	2364	0.056	0.031	160		1.39
107	DL-101	Outlet	Residential(Suburban)	1.87	0.4	1.870	185	2357	2362	0.027	0.073	148		0.31
108	DL-102	DL-103	Suburban&Gravel Road(A1)	1.72	0.65	1.722	76	2369	2370	0.013	0.048	155		0.48
109	DL-103	DL-104	Suburban(A2)	0.83	0.58	2.551	84	2367	2369	0.024	0.064	149		0.61
110	DL-104	DL-105	Suburban(A3)	0.09	0.4	2.641	62	2366	2367	0.016	0.051	150		0.44

111	DL-105	DL-100	Suburban(A4)	1.15	0.4	3.787	141	2364	2367	0.018	0.110	144		0.61
112	DL-106	DL-99	Gravel Road&Neighborhood	1.30	0.8	1.300	146	2365	2367	0.014	0.079	148		0.43
113	DL-107	DL-108	Neighborhood Area(A1)	2.47	0.7	2.466	119	2370	2375	0.042	0.044	155		0.74
114	DL-108	Outlet	Neighborhood Area(A2)	1.24	0.7	3.711	133	2364	2370	0.045	0.066	149		1.08
115	DL-109	DL-91	Neighborhood Area	1.22	0.7	1.216	189	2370	2371	0.005	0.138	137		0.32
116	DL-110	DL-111	Commercial Area	0.92	0.85	0.923	75	2365	2366	0.013	0.048	154		0.34
117	DL-111	Outlet	Commercial Area	0.72	0.85	2.551	74	2363	2365	0.027	0.058	150		0.90
118	DL-112	DL-111	Commercial Area	0.91	0.85	0.909	113	2365	2370	0.044	0.041	156		0.34
119	DL-113	DL-114	Asphalt Road(A1)	0.47	0.85	0.466	91	2351	2353	0.022	0.046	155		0.17
120	DL-114	DL-115	Asphalt Road(A2)	0.33	0.85	0.800	40	2349	2351	0.050	0.028	163		0.31
121	DL-115	Outlet	Commercial Area(A3)	0.18	0.85	0.979	79	2345	2349	0.051	0.041	156		0.36

Annex F: Runoff Estimation for Woreda 8

Plot No.	Flow Direction		Descriptions of sub catchment	Sub-basin area A(ha)	Runoff coeff. (c)	Total basin area A_t, (ha)	length of the basin L_c (m)	Lowest elevation of the basin, H_1(m)	Highest elevation of the basin, H_2(m)	Average slope of the basin ,S_o	Time of Concen tartion(hr) equation	Rainfall Intensity I, (mm/hr)		Total runoff for plot of basins Qs, (m^3/sec)
	From	To										5 years	10 years	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	DL-1	DL-2	Asphalt&Commercial (A1)	0.49	0.85	0.493	228	2359	2363	0.018	0.100	145		0.17
2	DL-2	DL-3	Asphalt&Commercial(A2)	1.01	0.85	1.498	254	2354	2359	0.020	0.188	118		0.42
3	DL-3	Outlet	Asphalt&Commerical (A3)	0.17	0.85	1.665	157	2350	2354	0.022	0.102	145		0.57
4	DL-4	DL-5	Asphalt&Commercial(A1)	0.84	0.85	0.840	101	2364	2365	0.010	0.067	149		0.30
5	DL-5	DL-84	Asphalt&Commercial(A2)	0.13	0.85	0.972	105	2363	2364	0.014	0.093	145		0.33
6	DL-6	DL-7	School Area(A1)	0.98	0.80	1.212	97	2361	2362	0.012	0.060	149		0.40
7	DL-7	Outlet	School Area(A2)	1.38	0.80	2.592	153	2355	2361	0.039	0.121	144		0.83
8	DL-8	DL-6	Gravel Road	0.23	0.80	0.233	131	2362	2364	0.015	0.069	149		0.08
9	DL-9	DL-10	Asphalt Road(A1)	0.62	0.85	0.620	148	2365	2368	0.020	0.068	149		0.22
10	DL-10	DL-11	Asphalt Road(A2)	0.60	0.85	1.220	121	2359	2364	0.041	0.077	148		0.43
11	DL-11	DL-12	Asphalt Road(A3)	0.05	0.85	1.274	121	2353	2359	0.049	0.062	149		0.45
12	DL-12	DL-13	Asphalt Road(A4)	0.14	0.85	1.417	164	2347	2353	0.037	0.089	146		0.49
13	DL-13	DL-14	Asphalt Road(A5)	0.12	0.85	1.539	113	2342	2347	0.049	0.060	149		0.54
14	DL-14	Outlet	Asphalt&Commercial Area(A6)	0.91	0.85	2.446	196	2335	2342	0.033	0.104	145		0.84
15	DL-15	DL-16	Asphalt Road(A1)	0.35	0.85	0.350	302	2358	2360	0.008	0.167		154	0.13
16	DL-16	DL-17	Commercial Area(A2)	0.58	0.85	0.929	226	2353	2358	0.022	0.130	142		0.31
17	DL-17	Outlet	Commercial Area(A3)	0.13	0.85	1.056	168	2347	2353	0.033	0.097	145		0.36

18	DL-18	DL-19	Asphalt&Commercial (A1)	1.73	0.85	1.725	126	2359	2362	0.024	0.056		185	0.75
19	DL-19	DL-20	Asphalt&Commercial(A2)	0.53	0.85	2.252	213	2359	2362	0.016	0.118		170	0.90
20	DL-20	DL-21	Asphalt&Commercial(A3)	2.73	0.85	4.979	238	2354	2359	0.021	0.121	144		1.69
21	DL-21	Outlet	Asphalt&Commercial(A4)	1.63	0.85	6.612	163	2350	2354	0.021	0.107	145		2.27
22	DL-22	DL-23	Asphalt&Commercial(A1)	2.68	0.85	3.343	83	2368	2370	0.018	0.046	155		1.22
23	DL-23	DL-24	Asphalt&Commercial (A2)	0.16	0.85	3.501	81	2366	2368	0.025	0.059	150		1.24
24	DL-24	Outlet	Asphalt&Commercial(A3)	0.01	0.85	3.516	112	2365	2366	0.009	0.098	145		1.20
25	DL-25	DL-26	Asphalt&Commercial(A1)	0.80	0.85	0.799	251	2386	2400	0.056	0.069		182	0.34
26	DL-26	DL-27	Asphalt&Commercial(A2)	0.27	0.85	1.067	165	2378	2386	0.048	0.064		185	0.47
27	DL-27	DL-28	Asphalt&Commercial(A3)	2.33	0.85	3.394	101	2374	2378	0.044	0.044		186	1.49
28	DL-28	DL-29	Asphalt&Commercial(A4)	0.52	0.85	3.913	126	2372	2374	0.016	0.074		181	1.67
29	DL-29	DL-22	Asphalt&Commercial(A5)	0.34	0.85	4.254	109	2370	2372	0.018	0.065		185	1.86
30	DL-30	DL-31	Neighborhood Area(A1)	0.66	0.7	0.658	88	2375	2379	0.040	0.035	160		0.20
31	DL-31	DL-23	Neighborhood Area(A2)	0.65	0.7	1.307	162	2360	2375	0.093	0.075	148		0.38
32	DL-32	DL-33	Suburban Area(A1)	0.08	0.4	1.390	59	2400	2403	0.051	0.023	165		0.25
33	DL-33	DL-34	Suburban Area(A2)	2.08	0.4	3.468	180	2385	2400	0.086	0.080	147		0.57
34	DL-34	DL-35	Suburban Area(A3)	0.60	0.4	4.070	100	2379	2385	0.060	0.046	155		0.70
35	DL-35	DL-36	Suburban Area(A4)	1.18	0.4	5.255	344	2365	2379	0.039	0.151	128		0.75
36	DL-36	Outlet	Suburban Area(A5)	0.68	0.4	5.940	134	2378	2379	0.004	0.140		156	1.03
37	DL-37	DL-38	Asphalt&Commercial(A1)	0.52	0.85	0.518	264	2387	2401	0.055	0.073		183	0.22
38	DL-38	DL-39	Asphalt&CommercialA2)	0.05	0.85	0.566	54	2384	2387	0.056	0.026		191	0.26
39	DL-39	DL-40	Asphalt&Commercial(A3)	1.82	0.85	2.391	109	2379	2384	0.046	0.048		186	1.05
40	DL-40	DL-41	Asphalt&Commercial(A4)	0.13	0.85	2.520	88	2375	2379	0.045	0.039		187	1.11
41	DL-41	DL-42	Asphalt&Commercial(A5)	0.66	0.85	3.180	158	2369	2375	0.035	0.068	149		1.12
42	DL-42	DL-45	Asphalt&Commercial(A6)	0.14	0.85	3.319	145	2364	2369	0.035	0.087	146		1.14

43	DL-43	DL-44	Asphalt&Green(A1)	0.91	0.67	0.911	71	2367	2370	0.042	0.029		190	0.32
44	DL-44	DL-45	Asphalt&Commercial(A2)	3.49	0.71	4.405	54	2364	2367	0.056	0.025		192	1.67
45	DL-45	DL-46	Asphalt&Commercial(A3)	1.39	0.74	5.798	85	2363	2364	0.012	0.060		184	2.19
46	DL-46	DL-47	Asphalt&CommerciaL(A4)	0.48	0.78	6.278	148	2361	2363	0.014	0.097		179	2.44
47	DL-47	Outlet	Asphalt&Commercial(A5)	0.91	0.81	7.186	122	2359	2361	0.016	0.077		182	2.95
48	DL-48	Outlet	Asphalt Road&Suburban	8.30	0.69	8.299	204	2365	2370	0.025	0.081		180	2.87
49	DL-49	DL-50	Neighborhood Area(A1)	1.02	0.7	1.018	193	2385.5	2398	0.065	0.054	150		0.30
50	DL-50	DL-51	Neighborhood Area(A2)	1.09	0.7	2.104	110	2382	2386	0.032	0.066	149		0.61
51	DL-51	DL-48	Neighborhood Area(A3)	1.32	0.7	4.295	300	2370	2382	0.040	0.155	138		1.15
52	DL-52	DL-53	Gravel Road(A1)	0.77	0.8	0.774	149	2377	2379	0.010	0.090	146		0.25
53	DL-53	DL-54	Suburban Area(A2)	1.58	0.6	2.351	256	2370	2377	0.027	0.179	136		0.53
54	DL-54	DL-44	Suburban Area(A3)	1.14	0.55	3.495	64	2367	2370	0.047	0.037	158		0.84
55	DL-55	DL-56	Apartment(A1)	0.59	0.7	0.592	102	2364	2366	0.015	0.058	150		0.17
56	DL-56	DL-57	Apartment(A2)	0.98	0.7	1.569	95	2363	2364	0.011	0.094	146		0.45
57	DL-57	DL-58	Apartment(A3)	1.06	0.7	2.624	46	2363	2363	0.011	0.051	151		0.77
58	DL-58	Outlet	Apartment(A4)	0.52	0.7	3.143	85	2360	2363	0.030	0.065	149		0.91
59	DL-59	DL-60	Suburban Area(A1)	0.92	0.4	0.922	114	2349	2355	0.052	0.039	157		0.16
60	DL-60	DL-61	Apartment(A2)	0.54	0.55	1.457	75	2346	2349	0.040	0.041	156		0.35
61	DL-61	Outlet	Apartment(A3)	1.49	0.6	2.945	98	2345	2346	0.010	0.085	147		0.72
62	DL-62	DL-63	GravelRoad&Suburban (A1)	1.11	0.6	1.105	137	2360	2362	0.015	0.073	149		0.27
63	DL-63	DL-64	Neighborhood Areas(A2)	0.47	0.63	2.571	51	2359	2360	0.030	0.045	155		0.70
64	DL-64	DL-65	Neighborhood Areas(A3)	0.40	0.65	2.968	48	2357	2359	0.031	0.035	160		0.86
65	DL-65	DL-66	Suburban Area(A4)	0.60	0.6	3.570	85	2355	2357	0.024	0.059	150		0.89
66	DL-66	Outlet	Gravel Road(A5)	0.43	0.63	3.999	91	2350	2355	0.055	0.052	150		1.05
67	DL-67	DL-68	Gravel Road(A1)	0.67	0.8	0.665	98	2364	2367	0.031	0.042	156		0.23
68	DL-68	DL-69	Commercial Area(A2)	0.95	0.83	1.614	209	2356	2364	0.036	0.109	145		0.54

69	DL-69	Outlet	Gravel Road(A3)	0.56	0.82	2.179	153	2345	2356	0.072	0.067	149		0.74
70	DL-70	DL-71	Gravel Road(A1)	0.11	0.8	0.109	143	2364	2367	0.017	0.070	149		0.04
71	DL-71	DL-72	Gravel Road(A2)	0.11	0.8	0.217	61	2362	2364	0.033	0.042	156		0.08
72	DL-72	DL-73	Gravel Road(A3)	0.11	0.8	0.331	101	2356	2362	0.059	0.049	152		0.11
73	DL-73	Outlet	Gravel Road(A4)	0.09	0.8	0.425	150	2345	2356	0.073	0.061	149		0.14
74	DL-74	DL-75	Commercial Area(A1)	0.62	0.85	0.625	124	2353	2358	0.036	0.048	153		0.23
75	DL-75	Outlet	Gravel Road(A2)	0.31	0.82	0.933	114	2351	2353	0.018	0.082	147		0.31
76	DL-76	DL-77	Green Area(A1)	0.17	0.3	0.167	99	2346	2353	0.066	0.032	160		0.02
77	DL-77	Outlet	Suburban Area(A2)	0.17	0.35	0.341	98	2340	2346	0.061	0.049	152		0.05
78	DL-78	DL-79	Green Area(A1)	0.43	0.3	0.426	105	2350	2352	0.019	0.053	150		0.05
79	DL-79	DL-80	Suburban Area(A2)	0.32	0.35	0.745	115	2340	2350	0.087	0.070	149		0.11
80	DL-80	Outlet	Suburban Area(A3)	0.38	0.36	1.126	93	2335	2340	0.054	0.043	156		0.18
81	DL-81	Outlet	Neighborhood Area	0.57	0.7	0.573	98	2344	2345	0.015	0.055	150		0.17
82	DL-82	Outlet	Neighborhood Area	0.57	0.7	0.569	92	2338	2340	0.022	0.046	155		0.17
83	DL-83	DL-63	Suburban Area	1.00	0.4	0.999	148	2360	2362	0.010	0.089	146		0.16
84	DL-84	DL-85	Asphalt&Commercial(A1)	1.17	0.85	1.166	111	2361	2362	0.014	0.064		184	0.51
85	DL-85	DL-86	Asphalt&Commercial(A2)	0.12	0.85	1.283	118	2358	2361	0.021	0.072		183	0.55
86	DL-86	DL-87	Asphalt&Commercial(A3)	0.49	0.85	1.776	108	2357	2358	0.014	0.073		183	0.77
87	DL-87	DL-88	Asphalt&Commercial(A4)	0.35	0.85	2.129	158	2353	2357	0.022	0.086		179	0.90
88	DL-88	DL-89	Asphalt&Commercial(A5)	1.07	0.85	3.198	67	2352	2353	0.022	0.041		187	1.41
89	DL-89	Outlet	Asphalt&Commercial(A6)	2.01	0.85	5.213	68	2350	2352	0.029	0.037		188	2.32

90	DL-90	DL-91	Suburban Area(A1)	3.65	0.4	3.649	144	2353	2358	0.054	150		0.61	0.054
91	DL-91	DL-92	Suburban Area(A2)	1.32	0.4	4.965	52	2350	2353	0.031	160		0.88	0.031
92	DL-92	DL-93	Neighborhood Area(A3)	2.34	0.5	7.303	118	2346	2350	0.065	149		1.51	0.065
93	DL-93	Outlet	Commercial Area(A4)	1.87	0.61	9.169	216	2335	2346	0.111	144		2.24	0.111
94	DL-94	DL-95	Aphalt Road&Suburban(A1)	1.66	0.85	1.656	176	2369	2373	0.075		182	0.71	0.075
95	DL-95	DL-96	Aphalt&Commercial(A2)	0.27	0.85	1.930	152	2365	2369	0.076		181	0.83	0.076
96	DL-96	DL-97	Aphalt&Commercial(A3)	0.66	0.85	2.593	155	2360	2365	0.072		183	1.12	0.072
97	DL-97	DL-98	Aphalt Road(A4)	0.95	0.85	3.540	381	2342	2360	0.129		167	1.40	0.129
98	DL-98	Outlet	Aphalt Road(A5)	0.35	0.85	3.892	254	2335	2342	0.104		169	1.55	0.104
99	DL-99	DL-51	Aphalt&Commercial	1.89	0.85	1.892	198	2382	2384	0.125	143		0.64	0.125
100	DL-100	DL-101	Asphalt&Neighborhood(A1)	0.42	0.78	0.419	94	2364	2367	0.038	157		0.14	0.038
101	DL-101	DL-102	Asphalt&Neighborhood(A2)	0.42	0.78	0.836	71	2362	2364	0.060	149		0.27	0.060
102	DL-102	DL-103	Asphalt&Neighborhood(A3)	0.73	0.78	1.571	63	2360	2362	0.048	152		0.52	0.048
103	DL-104	Outlet	Asphalt&Neighborhood(A4)	0.71	0.78	2.286	154	2355	2360	0.092	146		0.72	0.092

Annex G: Manning's Roughness Coefficient (n)

Various Open Channel Surfaces

a.	Concrete	
b.	Gravel bottom with:	
	Concrete	0.020
	Mortared stone	0.023
	Riprap	0.033
c.	Natural Stream Channels	
	Clean, straight stream	0.030
	Clean, winding stream	0.040
	Winding with weeds and pools	0.050
	With heavy brush and timber	0.100
d.	Flood Plains	
	Pasture	0.035
	Field Crops	0.040
	Light Brush and Weeds	0.050
	Dense Brush	0.070
	Dense Trees	0.100

Annex H: Coefficient of runoff (c)

Type of Drainage Area	C
Business:	
Commercial area	0.70-0.95
Neighborhood areas	0.50-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.25-0.40
Apartment dwelling areas	0.50-0.70
Industrial:	
Light areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yard areas	0.20-0.40
Unimproved areas	0.10-0.30
Lawns:	
Sandy soil, flat, < 2%	0.05-0.10
Sandy soil, average, 2 to 7%	0.10-0.15
Sandy soil, steep, > 7%	0.15-0.20
Heavy soil, flat, < 2%	0.13-0.17
Heavy soil, average 2 to 7%	0.18-0.22
Heavy soil, steep, > 7%	0.25-0.35
Streets:	
Asphaltic	0.70-0.95
Concrete	0.80-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.85
Roofs	0.75-0.95

Annex I: Interview Question for the Neighborhood

1. Name ______________________________Address:__________________.
2. Does flooding a major problem in your Woreda?
   a) Yes
   b) No
3. If your answer is yes, how do you rate the extent:
   a) Very serious
   b) Serious
   c) Not serious
4. Which specific sites are most prone to flooding and why?
5. What do you think is the major causes of flooding problem in your Woreda?
   5.1 Absence of urban storm water drainage infrastructure
   5.2 Inadequate urban storm water drainage infrastructure
   5.3 Blockage of urban storm water drainage structures
   5.4 If others specify---
6. What temporary solutions/measures have ever been taken to the flooding problems?
7. What permanent solutions have ever been taken to the flooding problems?
8. What solutions you suggest to handle such flooding problems on existing rivers?
9. Do the Authorities act to provide some solutions on the problem of flooding of the Kebena River?
10. What are the major challenges of urban storm water drainage system in your neighborhood?
11. What are the reasons of the neighborhood to dispose solid and liquid wastes in to the drainage systems?
    11.1. Luck of awareness
    11.2. Shortage of disposing area
    11.3. Carelessness
    11.4. Others, Explain
12. What major impacts the drainage system has on Kebena River?

Thank You

Annex J: GTZ Standards and Check Lists

GTZ standards

Indicators classification	Surface condition
Very good	Shapes of USWD lines as still in original design condition
Good	No significant depressions, undulations and deformation
Light	Shape of the USWD lines deteriorate, but still sheds water
Severe	Total collapse of the USWD lines structure and barely passable

Source: GTZ, 2006.

Check List

1. Land Use Land Cover in the study area______________.Km.
2. USWD lines in the built up area------------------------------Km
3. Existing Conditions of the urban storm water drainage system in the study woredas,
   3.1 Width of the channel, top and bottom for trapezoidal channel
   3.2 Depth of the channel
   3.3 Length of the channel
   3.4 Side slope for trapezoidal channel
   3.5 Condition of the channel,
      a) Very good
      b) Good
      c) Light
      d) Sever
4. General problems in kebena river

5.1 Disposal of liquid wastes from sewer system_______________.

5.2 Blocked by solid wastes _______________________________.

5.3 Intruded by residents _________________________________.

5.4 Luck of Buffer zone__________________________________.

5.5 Others ____.

6. Evaluation of Urban Storm Water Drainage Facilities

Drainage Shape Type	Drainage Pavement	Total Length(m)	Existing Condition	Length(m)	Percentage (%)	Percentage from Total (%)
Rectangular			Good			
			Light			
			Sever			
Trapezoidal			Good			
			Light			
			Sever			
Circular			Good			
			Light			
			Sever			
Total Length(m)			Total Percentage (%)			100

7. Possible Causes of Flooding in the study woredas

7.1 Urbanization________________________________.

7.2 Luck of hydrologic assessment_____________________________.

7.3 Poor Management____.

8. Area with and without drainage system in the study woredas

8.1 Area with Urban Storm Water Drainage______________________ .

8.2 Area without Urban Storm Water Drainage ____________________.

Annex K: Permeability of the soil in the study area

Company Name	Form N°	
CONSTRUCTION DESIGN SHARE SCo.	OF/CDSCo /139	
Title: Soil Test result	Issue N° 1	Page N° Page 1 of 1

W.O.N° = *-*-*-*
Date = '*-*-*-*

Project :- Evaluation Of Drainage system kebena stream cotchment
Location :- Addis Ababa
Object :- Soil sample
Test :- Permiability Test

Item N°	OMC (%)	Maximum Dry Density (kg/m3)	Permiability Cm/Sec
1	23.9	1695	$2.73*10^{-5}$

Tested by :- Wosen Tadesse
Date :- 15/01/2013
Checked by :- Abate Legesse
Date :- 15/01/2013

Approved by :- Matewos Bekele
Date :-15/01/2013

Construction Design S.C
Central Laboratory

PLEASE MAKE SURE THAT THIS IS THE CORRECT ISSUE BEFORE USE

Annex L: Zoomed Map of the drainage lines in the study area