ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CHEMICAL ENGINEERING

(Environmental Engineering Stream)

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

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for Master's of Science in Environmental Engineering

BY

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Advisor

Dr. Tassisa Kaba

April 16, 2009

Addis Ababa

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APPROVAL

The undersigned certify that they have read and here by recommend to the Addis Ababa University to accept the Thesis submitted by Dagnachew Adugna entitled **"STUDY OF THE URBAN DRAINAGE SYSTEM IN ADDIS ABABA, YEKA SUB-CITY"** in partial fulfillment of the requirements for the award of Master's of Science Degree in Environmental Engineering.

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DECLARATIONS

I, Dagnachew Adugna, do here by declare that this Thesis is my original work and that has not been submitted partially or in full by any other person for an award of a degree in other University.

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Acknowledgments

My heartfelt thanks goes to my advisors Dr. Tassisa Kaba for his unreserved assistance for accomplishing such a Thesis work, without his assistance this work would not have come to such a structure.

My deepest appreciation goes to w/ro Mekdes Birru, Beletu, Bizunesh and Tsigereda in printing some of the research works in the Federal Urban Planning Institute.

I would also like to extend my acknowledgment to those employees and households who were voluntary to give a genuine response to questionnaires and interview in the study area and those professionals at Kebele and Sub-city level in Yeka Sub-city and Addis Ababa Environmental Protection Authority.

My thanks also goes to my brother Habtu Adugna who has been assisting me in measuring all the existing widths and lengths of Road and Urban Storm Water drainage infrastructure and natural water ways while I was conducting a field survey in the study area.

Last but not least, I would like to acknowledge all my families, particularly, to Dr. Menberu Ferede, W/o Sefanit Demissie, Dr. Mola Demlie, Firehiwot Adugna, Melat Menberu, Genet Menberu and Liku Menberu who have encouraged me to effectively carry out this study and to my colleagues with a special reference to Ato Melku Mola, Ato Yalemtsega Tiruneh, Ato Tarekegn G/yesus, Ato Adgo Berhanu (Ministry of Works and Urban Developmnet) and others whose name is not listed here.

Above all, Glory to my God, who is in all my steps from the Start to End.

Dagnachew Adugna

April, 2010.

Abstract

Urbanization along with its impervious structures is the major challenge of urban centers. The foundation and expansion of Addis Ababa was associated with the rapid conversion of land from rural to urban uses more than anywhere else in the country. For the last one hundred twenty years it has been noticed that there is an intensive conversion of rural land to urban development such as buildings, transportation networks, recreation areas, reservoirs and others where most of them are impermeable. This study has investigated the overall environmental challenges of the urban drainage system. This study has particularly carried out in three sample kebeles (kebele 01/02, 08/15 and 13/14) within Yeka sub-city. These kebeles were selected because of the fact that they are representative to address the objectives of this study. Deforestation and pavement of structures are the major problems in the study area. An exploratory and Descriptive type of research design methods were used to describe and explore the existing condition of the general urban drainage system and the natural water ways. Data collection methods were carried out using both primary and secondary data sources. The secondary data source was only relevant to reinforce the primary data. The collected data were analyzed with Ms-excel, AutoCAD and ArcGIS. The results have been presented with known statistical tools. The findings of this study indicated that the major causes of flooding was found due to the deforestation of Yeka mountain, inadequate integration between road and urban storm water drainage lines. Solid and liquid waste damping was also the biggest challenges on the general urban drainage system. This study strongly recommends the implementation of the planned and designed urban drainage. The use of porous structures like grassing on compounds and road sides instead of pavements will contribute valuable advantages towards the sustainable urban drainage management. Furthermore, the existing natural water ways or rivers had better provided with buffer zones to use them for various recreation purposes and to keep the well being of residents. Besides, the Yeka Mountain shall be vegetated with good conservation practices with a strong emphasis to fast growing indigenous trees which can replace the ever existing eucalyptus trees with its allelophatic effect to other indigenous trees and shrubs.

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Acronyms

AACRA	Addis Ababa City Roads Authority
AAEPA	Addis Ababa Environmental Protection Authority
AAWSA	Addis Ababa water and Sewerage Authority
ArcGIS	Architectural Geographical Information System
BMP	Best Management Practices
CAD	Computer Assisted Design
FUPI	Federal Urban Planning Institute
GTZ	German Technical Cooperation
NGOs	Non-Government Organizations
NUPI	National Urban Planning Institute
UN	United Nation
USWD	Urban Storm Water Drainage

CHAPTER ONE: INTRODUCTION

1.1 Background

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

The differences that can be expected between undeveloped-natural watersheds and developed-urban watersheds are associated with water shed characteristics that affect the speed and volume of run-off events. In disturbed areas, the capacity to retain rainfall increases due to impervious surfaces like roads, gutters and a parking lot. Undisturbed areas have a greater capacity to retain storms/run offs. This increased retention is associated with interception and infiltration of rain fall.

In natural systems, the run-off process produces a net-work of channels that increase in size as the water shed area increases. That is, the final receiving system for all run-offs is a water way such as: stream or river. For example, in Addis Ababa, all the storm water and most of the private sewerage systems are discharged in to the existing natural water ways/rivers. That is why all the rivers in Addis Ababa, such as kebena, kechene, Banteyiketu, Jelissa, Jamo, and others are dead, because they are highly polluted. If they were healthier, they would be a good source of income either from recreational point of view or source of irrigation water.

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 becomes significant (FUPI, 2008).

Drainage problems in urban areas include flooding, deterioration of roads, land degradation, sedimentation, blockage of drainage facilities, water logging, and others. With urbanization, impermeability increases with the increase in impervious surfaces, drainage pattern changes, overland flow gets faster, flooding and environmental problems such as land degradation increases.

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

The foundation and expansion of Addis Ababa has been associated with the rapid conversion of land from rural to urban uses more than anywhere else in the country. For the last one hundred twenty three years it has been noticed that there is 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.

The study area within Yeka sub-city is also the drainage system where all the above mentioned challenges have been facing. Thus, this sub-city as one of the oldest and most economical part of Addis Ababa, where many low income people are living has a significant negative impact on environmental management.

In the previous times there were no specific researches conducted in line to the topic what this research has been conducted to address the above mentioned challenges, but only the natural drainage system in the central Part of Addis Ababa was studied by the Engineering Darmstadt University of Technology in co-operation with the Addis Ababa university in 2001. The general objective of this study was concentrated on the natural drainage system in the central part of Addis Ababa, followed by the presentation of an assessment of the existing capacity as estimated using the deterministic rainfall runoff. This research was not in a position to discover the environmental challenges resulted due to inadequate integration between roads and USWD infrastructure, the direct impact of the nearby mountains, Entoto and Yeka, and urban storm water drainage net-work design options to handle the challenges of the drainage system.

The rationale or basic principle of conducting this research in the aforementioned area was to fill the knowledge gap which has been existing with no due attention to the environmental challenges of the Drainage system and their impacts on the community and environment in Yeka sub-city, in particular and in Addis Ababa, in general.

This particular study was intended to find out the major environmental problems and causes of urban storm water drainage system in Yeka sub-city and then it has been designed and presented appropriate urban storm water drainage net-work design as a sustainable solution to handle the yearly repeating urban drainage problems with overloading the drainage system and the serious consequences on the environment including on the inhabitants, existing rivers and infrastructure such as water supply lines, residences, roads and others, particularly during rainy season.

1.2 Problem statement

Lack of urban Storm water drainage(USWD) management represent one of the most common sources of compliant from the residents in many urban centers of Ethiopia, and this problem gets worse and worse with the rate of urbanization.

In Addis Ababa, with increasing densification and urban infrastructure development of various types, such as road, building construction, there is a change in the run-off characteristics of rainfall within the city, leading to increased run-off and greater susceptibility to flooding hazards and pollution of rivers crossing the city including kebena and Jelissa Rivers in Yeka sub-city.

In addition to increased densification and impermeability of the urban landscape, the planning as well as implementation of storm water protecting structures is insufficient. As a witness 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).

This indicates the mismatch between the actual required Urban Storm Water Drainage structures and what is actually present on the ground. On the other hand, this is an indication for the presence of a big gap in the provision of Urban Storm Water Drainage

(USWD) structures to safely discharge the run-off produced within and entering in to the city as an external source from Entoto and Yeka mountains, which are the notable external flooding sources of Addis Ababa.

Besides, the location of Yeka sub-city being at the base of mount Yeka is also the other challenge to properly manage/handle the flooding problem. Because, this mountain is bare and predominantly covered by eucalyptus tree, which further exposes the ground for degradation and thus contributes for the generation of external flood.

Generally, flooding from the bare Yeka hill side Mountain and improper management of the urban drainage system due to various reasons is the major problem driving force to undertake this work in the aforementioned particular sub-city, Yeka.

1.3 Objective of the research

1.3. 1 General objective

- The general objective of this work is to study the urban drainage system in Yeka sub-city.

1.3.2 Specific objectives

1. To identify the major challenges in urban drainage management system.
2. To investigate the impact of Yeka mountain on Yeka sub-city.
3. To discover the major impacts of the Urban storm water drainage system on existing natural water ways.
4. To assess the level of integration between Road and Urban Storm Water Drainage infrastructure.
5. To design urban storm water drainage net-work as an option to sustainably manage the Urban Storm Water Drainage system.

1.3.3 Research Questions

This research is intended to answer the following research questions in line with the topic and objectives of this study in Yeka sub-city:

1. What are the major challenges in managing the Urban Drainage system in Yeka sub-city?
2. What major impacts the Yeka Mountain has on Yeka sub-city and its residents?
3. What are the major problems of the Urban Storm Water Drainage system on existing natural water ways/rivers?
4. What is the level of integration between Road and Urban Storm Water Drainage infrastructure in the study area?
5. What urban storm water drainage design option is present to handle the problems of the Urban Storm Water Drainage system?

1.4 Significance of the study

Generally, managing urban storm water drainage system has a significant role for sustainable environment management by keeping the service life of urban utilities like roads, buildings, telephone lines, power supply lines, water supply lines and the existing rivers. But, due to lack of proper environmental management on the surrounding mountainous and built-up areas and due to inadequate integration between Road and Urban Storm Water Drainage infrastructure there exists poor urban storm water drainage management in Yeka sub-city and Addis Ababa, as a whole.

Thus, this research is expected to address/reverse the above mentioned problems at sub-city and then, at city level and to the down catchment environment.

Furthermore, this study will contribute paramount advantages by creating a good opportunity to keep the aesthetic and recreational value of rivers and improves the environmental condition of the surrounding areas, as a whole. Besides, it will have a greater advantage by enabling the ground water to recharge itself.

This study will also enable the Addis Ababa city and any environmentally concerned body to use it as a reference for future decision making and planning purposes. The residents will also be benefited from the sustainable environmental values added by this study.

Last not least, this study enables the researcher to have an in-sighted understanding and further knowledge towards urban drainage system management and planning, and will open good and additional opportunities to the researcher's future research studies and capabilities.

1.5 Rationale of the research

Yeka is one of the oldest parts of Addis Ababa with most degraded hill side mountain Yeka and is the major external flooding source of the sub-city. Relatively the largest polluted river Kebena which serves as a predominant storm water receiving river is also found in this sub-city. In addition to this most of the human settlements in the sub-city are located on the hilly parts of Yeka Mountain that is significant proportion of mountain Yeka is originally encroached by informal settlements. This is to mean it has no proper land use plan to properly manage the urban drainage system.

As a result of inadequate sanitation facilities significant portion of the residents use the available open spaces for defecation and most of the residents do connect their sewerage system to nearby/adjacent natural water ways. These are some of the major causes of pollution on existing rivers. According to various studies, these polluted rivers, on the other hand have negative impacts on the downstream/catchment dwellers. Generally, it is these the aforementioned issues that has insisted this research to be conducted in Yeka sub-city.

1.6 Location

Yeka is one of the ten sub-cities in Addis Ababa. It is found in North-Eastern part of Addis Ababa. It is located at a geographical coordinate of 9^0 01' 30.73''N and 38^0 46' 27.55''E on the Earth's surface. For Additional information the location map of Yeka sub-city is presented at Appendix-2.

1.6 Natural situation

This section gives an overview of the existing natural situation of the study area, including the climate, the temperature, the rainfall, the vegetation, the geology and the topography. Because, these parameters are significant in the design and management of the urban drainage system in the study area.

Climate

The climate of the study area is subjected to low pressure, which is moving across the equator seasonally northward and southward on the African Continent (Muschalla, 2001).

Temperature

The average maximum temperature in the study area varies from 24.3°C in May to 20.3°C in August; the average minimum temperature varies from 11.8°C in May to 7.7°C in December (ibid). Generally, the temperature varies less through the year.

Rain fall

The average annual rainfall in Addis Ababa is 1178 mm (ibid). The main wet season lasts from June to September, causing about 70% of the annual rainfall with the highest peak in August (ibid). Another small peak of rainfall is observed in March and April.

A ten year rain fall data has been incorporated and depicted in Table1.1.

Table 1.1: Maximum daily rainfall data of Addis Ababa.

Year	J	F	M	A	M	J	Jl	A	S	O	N	D
1998	32.2	8.5	14.9	16.6	43.3	26.7	27.2	28.9	24.7	78.3	0.0	0.0
1999	2.9	0.3	5.8	5.8	4.4	21.8	27.4	37.4	20.5	15.4	0.0	0.0
2000	0.0	0.0	15.2	15.3	28.5	25.9	29.3	26.4	37.1	25.1	19.6	0.0
2001	0.0	11.6	96.3	13.5	23.8	20.3	42.5	41.4	33.5	4.7	0.0	0.0
2002	4.6	14.6	23.3	25.9	29.5	20.2	29.3	25.8	25.6	0.2	0.0	11.4
2003	10.5	26.5	33.4	31.1	18.9	17.9	46.2	31.3	40.1	0.8	1.2	54.9
2004	12.7	19.7	17.1	29.6	10.5	16.4	33.2	36.5	24.3	44.2	0.0	0.0
2005	21.4	26.2	32.8	58.6	35.6	24.4	42.6	46.8	25.5	-	2.3	0.0
2006	0.7	5.2	70.9	16.0	51	42.6	40.8	30.3	61.9	27.2	0.3	3.0
2007	24.8	11.9	24.4	25.2	34.1	33.8	46.3	64.0	16.6	11.8	0.0	0.0

Source: Ethiopian Meteorology Agency, 2009.

Geology

The largest part of the study area is covered with volcanic material. The situated hill chain (Intoto and Yeka) in the northern part of Addis Ababa is composed of Termaber basalts. It is called Intoto Cilcic and it is covered with volcanic topsoil materials of about one to two meters thick. The urban area is composed of younger basalts called Addis Ababa basalts which are also covered with volcanic topsoil materials (ibid).

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).

Vegetation

With the foundation of Addis Ababa, a number of eucalyptus plantations were established on the hills surrounding (Intoto and Yeka) the city. Currently about 6,000 hectare of land are covered by Eucalyptus plantations (ibid). As a result of enormous population growth and lack of adequate fuel wood, illegal clearing became a serious problem in the last two decades. In addition, mismanagement of the forest resources and failure of the afforestation programs resulted in consequent deforested hills in the mountainous part of Intoto and Yeka (ibid). According to various studies, as a result of its allelopathic effects, eucalyptus tree exposes the ground surface for flooding as it does not let shrubs and other indigenous trees to grow underneath (Kissa, 2001). Indigenous trees are good in infiltrating rainfall in to the ground than eucalyptus tree.

Topography

The study area is located on a plateau with an elevation ranging from 2500 to 3200 meters and it extends to the central Ethiopian highland. The elevation of the Yeka ridge ranges from 2600 to 3200 meters. The urbanized area of the study area is deeply dissected by numerous gullies and intermittent natural water ways, which have formed by the major river systems crossing the sub-city from north-south to east.

1.7 Organization of the research paper

The study has five chapters. The first chapter is Introduction of the study including, background of the study, statement of the problem, Objectives of the study, research questions, scope of the study, Location, definitions of basic terms and organization of the study itself.

The second chapter contains the extensive literature review particularly what has been done throughout the Globe in relation to this study. And the third chapter comprises of the methodology of this research, which is core to address each research objectives.

The fourth chapter comprises of data presentation and interpretation. The fifth chapter consists of the conclusion and recommendation part of the study.

CHAPTER TWO: 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: urban storm water drainage system design, urban storm water drainage experience in Ethiopia, urban storm water drainage policy issues in Ethiopia, Run off characteristics in Addis Ababa, Urban storm water drainage in Addis Ababa, environmental and solid Waste Management in Addis Ababa, Urban storm water pollution and its prevention and the importance of urban storm water drainage facilities.

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 The Historical Development and Basic concept of USWD system

The practice of urban drainage system has been traced back to some hundred years ago (Bruce, 1998). The efficient conveyance of storm water from urbanized areas was motivated primarily by reasons of convenience and the reduction of flood damage potential.

Such practices which were aimed to improve the quality of urban life have resulted in other problems, such as artificially induced flooding, increased erosion and environmental degradation originating from the pollution of receiving waters (ibid). As a result, attention has given to the comprehensive management of urban drainage systems including the implementation of storage and treatment facilities.

The objective of such practice was to effectively utilize components of drainage systems for the betterment of urban life and to protect the environment in a cost-effective manner. To facilitate the effective management of the complex natural elements and engineering works, mathematical modeling is often employed to better understand system behavior and performance which in turn leads to better engineering and Management decisions.

Generally, storm water management lies near the heart of basic landscape architecture and engineering. Professional ethics enforces every practitioner to integrate storm water and meaningfully with every community and ecosystem (Adams and Papa, 2000).

Essentially all site developments, of all kinds, involve impervious and compacted surfaces. The change in land cover increases runoff over the surface, dumps flood waters in to streams, reduces ground water recharge, diverts water from base flows, and turns oils from the streets to pollutants.

That is urban storm water drainage system has started to prevent the environment and the human health from various flooding hazards by safely removing floods.

2.1.1 History of Urban drainage system problems

Some of the earliest cities were served by sewers. Archaeological excavations of settlements in the Indus and Tigris river basins have revealed the utilization of drainage conduits as far back as possibly 3500B.C (Bruce, 1998). The Romans were great builders of sewers, roads and bridges. The greater sewer, cloaca maxima, built in the sixteen century B.C to drain the Forum in Rome is still in use today (ibid). Since that time sewers were built to drain only runoff from storm water. Strictly this was enacted to specifically prohibit the entry of anything but rain water in the sewer/drainage systems. Thus sewers/drains were placed largely for reasons of convenience, to minimize the detention of water on road ways and other surfaces in wet weather.

London and Paris in 1840s and 1850s were converting storm sewers to combined sewers (ibid), and new sewers were designed to act as combined sewers, this was done because there were an epidemic broke out due to the increased in number of urban people and discharging of domestic waste in to everywhere. This practice was also followed by North America. These combined sewers were discharging the wastes in to local/natural water courses (ibid), as a result these receiving water courses had got polluted, in addition to these ecological and aesthetic problems, the fecal contamination of surface waters further impaired the quality of surface water supplies.

Soon it was decided that the combined sewers to be treated before discharged to natural water courses. The implementation of sewage treatment was confounded by a large number of combined sewer outfalls (pipes entering watercourses).

2.1.2 Urban Storm water drainage and Environment

Storm water is not a mechanical system. It is an environmental process, joining the atmosphere, the soil, vegetation, land use and natural water ways.

Undisturbed soil and vegetation evolve to absorb rain and make it part of the living eco-system. In contrast to this, impervious surfaces are the origins of runoff. When urban run-off occurs, a disturbance has taken place, thus mitigation and restoration is necessary.

Some of the measures which have been carried out since human civilization includes:

- Disconnect impervious surfaces- that is let floods to drain in to vegetated soil. This is to increase the infiltration capacity of the land.
- Turn impermeable surfaces in to permeable ones.
- Open-grade stone sizes, which leave open voids between uniformly sized aggregate particles, are highly permeable.
- Porous concrete are capable of meeting the structural needs of heavy loads.
- Swales – unlike paved surfaces, vegetated soil infiltrates and stores rainfall, treats it, and discharges it gradually to streams weeks after storms are last.
- Basins and Dams- locating storm water basins centrally and integrally within a community makes them visible and accessible. Meaningful amenities are there by created, nearby residents are likely to act as overseers of basin maintenance and safety.

2.2 Urban storm water drainage system design

Early drainage system design was based largely on peak discharge rates estimated observations of runoff rates that occurred in existing systems (Bruce, 1998).The rational formula (Q=C*I*A, where Q=discharge, I= intensity and A=catchment Area) was established by Mulvaney in 1850, Kuichling in 1889 and Lloyd-Davies in 1906 (UNESCO, 1987). This formula depends on rainfall intensity (I), run-off coefficient), catchment Area(A), time of concentration(Tc) and others.

1. **Rational formula** (Q= 0.00278* C*I*A) , this method involves the following procedures:

I. the following information should be obtained:

a. Drainage/catchment area (A) in hectare (ha).

b. Land use (% of impermeable area such as pavement, sidewalks or roofs)

c. Soil types (highly permeable or impermeable soils).

d. Distance from the farthest point of the drainage area to the point of discharge.

e. Difference in elevation from the farthest point of the drainage area to the outlet.

II. Selection of the appropriate runoff coefficient(C) value from standardized table values

III. Determination of the time of concentration (Tc).

IV. Determination of the rainfall intensity rate (I) for the selected recurrence intervals

V. Computation of the design flow, Discharge (Q = 0.00278 CIA)

2. **Determination of Rainfall Intensity Rate (I):**

The rainfall intensity, I, is the average rainfall rate in millimeters per hour for a particular drainage area. The intensity is selected on the basis of the design rainfall duration and recurrence interval. The design duration is equal to the time of concentration for the drainage area under consideration.

The general equation (Bell, 1969) to estimate rain fall intensity, I, is given by:

$$R^{t}_{T} = (0.21\ln T + 0.52)*(0.54t^{0.25} - 0.5)\,R6010 \text{ ------------------------------------ } (1)$$

Where, t = rain fall duration (minute),

T = recurrence interval (years)

R^{t}_{T} = rain fall depth in mm of 'T' years return period and 't' minute rain fall duration.

This equation is valid for 2≤ T ≤ 100 Years and 5≤ t≤120 minutes.

Then, "I" will be obtained from the following equations by regression:

$$i = \frac{a}{(b + td)^{c}} \text{ -- } (2)$$

Where, i = intensity

B = regional constant

a = obtained by linear regression,

t_d = rainfall duration(hours)

c = for practical purposes it is taken as unity

3. Estimation of Time of concentration(Tc)

The time of concentration is the time required for the runoff to become established and flow from the most distant point of the drainage area to the point of discharge. Of the many equations for estimating Tc, for this study, following Air port formula was employed.

$$Tc = 3.64\,(1.1 - c)\,L^{0.83} / H^{0.33} \text{ --- } (3)$$

Where, Tc = Time of Concentration (hrs),

H = Elevation difference (m),

C = Runoff coefficient (unitless)

L = Flow length (km)

2.3 Urban Storm water drainage experience 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, blockage of drainage facilities, water logging 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.

After its inception, Federal Urban Planning Institute (FUPI) (the then NUPI) 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 (NUPI) some twenty years ago, there has been no formal working organization in the area of urban storm water drainage system. Even now a day the attention towards urban storm water system is at its immature stage that is why most of the urban storm water drainage structures get blocked with solid waste of various types after huge 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.

Generally, the urban storm water drainage system in Ethiopia is at its poor condition, some of the facts are:

- the unforgettable flooding event/problem, which were occurred in Diredawa some two years ago and
- the yearly repeated flooding problems in various parts of Addis Ababa, which have been resulting in congested traffic movement, property loss, soil and water degradation and other infrastructure, particularly around “Filwoha”, National bank of Ethiopia, Addis Ketema Comprehensive Secondary School, general vegetables market are some of the notable ones.
- The flooding and the sedimentation problem in Awassa Town and its lake resource is also the other significant problem which has been occurring due to inadequate urban storm water drainage provision and management.
- The land sliding and soil erosion problem in Dessie and Adigrat Towns.
- The run-off water stagnation problem in Bahirdar due to inadequate USWD system is also the other big challenge in spreading malaria & water borne diseases.

These and the other problems are the notable challenges of inadequate urban storm water drainage system in Ethiopia. The only mechanism in alleviating such environmental challenges is at the hand of urban storm water drainage system.

The technologies in handling the environmental problems of urban storm water drainage in Ethiopia, which have ever 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.

2.4 Urban storm water drainage policy issues in Ethiopia.

For an urban storm water drainage system to be effected appropriately in a given urban area, policy issues should get priority & thus must focuses on following significant points (FUPI, 2008):

- The overall policy goal should focus to improve and enhance the health, safety and quality of life of the urban and hinterland population and enhance the environment in a sustainable basis.
- Storm water is a component of the total water resources of an area and should not be casually discarded but rather, where feasible, should be used to replenish that resource. In many instances, storm water problems signal either misuse of a resource or unwise land activity.
- Development of storm water drainage system is not possible in isolation from other infrastructure and environmental sectors. Coordination is necessary between different departments, government and other stakeholders and planning should take cognizance of processes such as integration. Storm water drainage planning, design and management activities should ensure the participation of the people and other stakeholders at all levels.
- Environmental considerations such as soil erosion and sedimentation must also be taken in to account.

2.5 Runoff Characteristics in Addis Ababa

The flow of any stream is determined by climatic factors (particularly precipitation) and the physical characteristics of the drainage system. The physical characteristics of the drainage system includes land use, type of soil, type of vegetation, area, shape, elevation slope, orientation and type of drainage network (Wisler et al.,1959; Ward, 1967; Fetter, 1988). Most of the streams originate from the steeply and rugged ridges of Entoto and Yeka flow crossing the city towards the relatively flat land areas of southern Addis Ababa. These and other natural conditions contribute for rapid movement of water in the rivers.

Moreover, because of urbanization the urban land in Addis Ababa is more or less built up with impervious materials like corrugated iron roof, asphalt or compacted gravel roads, drainage system, airfields, car parks, recreational areas and other man made impermeable structures. These human induced structures significantly increase the amount and movement of water in the streams crossing the city.

In general, due to the aforementioned natural and man-induced structures along with the rapid population growth in the city, the magnitude of peak flow shows increment towards the southern parts of the city Ward et. al (1990) found that increase in the magnitude of peak flows, below large urban areas, is the results of an increase in the volume of quick flow and more rapid movement of runoff, which is possible in urbanized areas.

On the other hand, the numerous construction works which have been carried out on the bank and floor of the natural water ways have reduced the amount of water to be held in the channel. In addition to this, as a consequence of the above indicated factors, poor and inadequate drainage system and lack of flood control techniques have resulted in temporary flooding of the area adjoining the river. The area around Police hospital, Filwoha, Kebena, Big Akaki and Little Akaki are some of the places in the city that are commonly affected by the flood particularly during the rainy season. The flood causes considerable losses of property.

The Big Akaki River was gauged near Akaki Town on Addis Ababa - Debrezeit road. The station is equipped with an automatic water level recorder and is capable of discharge measurements (Addis Ababa University, 2003).

The average monthly and total annual runoff measured at the station from 1981 to 1998 is indicated in this study. It is known that the volumetric stream flow records in the station show variation in the total amount of runoff from year to year in the basin. The maximum annual stream flow occurs in 1996 and it was 640,600 million m^3 while the minimum annual stream flow, which was 117.975 million m^3, occurred in the year 1987. The variation in annual flow is due to changes in the climatic condition of the basin in particular and the country in general.

According to Figure 2.1, the mean monthly flow of Big Akaki River Hydro-geological investigation which was carried out in the Akaki area by AAWSA-THAL (1992) showed that from the total water supplied to Addis Ababa about 70% returns as waste water and 60% of the return is discharged to Big Akaki river and the remaining 40% to the Little Akaki river.

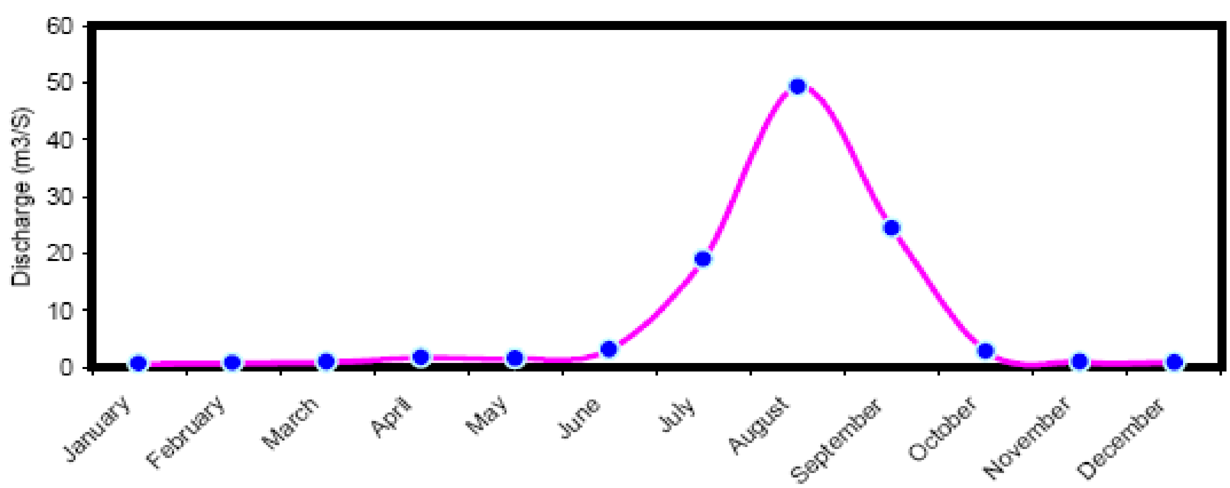

Fig-2.1 Mean monthly flow of Big Akaki river (source: Addis Ababa University, 2003).

The average supply of water to Addis Ababa from surface reservoir and ground water abstraction is about 163,000 m^3/d. Thus, the contribution of sewage to the runoff in Big and Little Akaki River is 0.79 m^3/s and 0.53 m^3/s respectively (Addis Ababa University, 2003). The corrected mean monthly discharge of Big Akaki River is presented in the Table 6.

Table-2.1 Mean monthly discharge of Big Akaki River.

Months	J	F	M	A	M	J	Jy	A	S	O	N	D	Annual mean
Q (m^3/s)	0.69	0.79	0.96	1.73	1.56	3.12	19.06	49.34	24.49	2.84	0.98	0.83	8.86

Source: Addis Ababa University, 2003.

According to Addis Ababa University (2003) peak stream discharge occurs in August (49.34 m^3/s) and the minimum discharge occurred in January (0.69 m^3/s). Besides, the proportion of waste water (sewage) to the natural runoff varies from a minimum of 1.56% in August to a maximum of 53.38% in January. The seasonal variation in the stream flow reflects the amounts of rainfall in the area. Thus, there is a direct correlation between the average monthly rainfall and runoff. Usually there is high stream flows after the rainy months.

The runoff coefficient of Little Akaki River is 38 %, thus the runoff depth become 142.4mm. The annual discharge of Little Akaki River can be inferred from the catchment area and runoff depth. The annual mean discharge of Little Akaki River for the year between 1981 and 1998 is 135.23×10^6 m^3 (or 4.29 m^3/s) (ibid).

2.6 Urban storm water drainage in Addis Ababa.

A major plight of Sub-Sahara African roads is a poor drainage system, which allows storm water to sip through newly tarred surfaces and prematurely to riddle them with potholes. As one of the rainiest places in the country Addis Ababa is a case in point. 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 kilometres, 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 2002, of the city's 395 kilometers of asphalted roads only 193 kilometres had storm drainage lines, and out of 960 kilometres of non-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 as regards 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. As mentioned below, 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 dwarfed by the sheer size of the problem. Thus, the fact remains that the drainage system of Addis Ababa is woefully underdeveloped by any standard.

To make matters worse, household refuse blocks the existing drainage channels, especially in and around the inner-city slums. As a result, it is common to see streets that are significantly damaged by overflowing runoff. Some of the floods that accompanied hours of torrential rainfall in the recent past, as for instance in August 1978 and August 1994, have inflicted considerable damage to human life and property. Even in years when major floods affecting thousands do not occur, the streams that cross the city in a north-south direction tend suddenly to swell after heavy downpours, a significant threat to the lives of the people and animals that attempt to cross them.

2.7 Environmental and Solid Waste Management 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 (HN-Habitat, 2008).

Among other indicators of environmental quality, the city has a very low density of public parks: only 0.66 m^2 per capita, against expectations of at least 6 m^2 per capita (Uli, 2008). But then Addis Ababa's environmental protection expenditure amounts only to 1% of gross regional domestic product.

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 m^3 (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 neighbor hoods, 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).

2.8 Urban storm water quantity and quality control

Various control strategies are available for the remediation or mitigation of current problems in urban drainage and runoff control. Most of these strategies address rather specific problems and hence provide only partial solutions. In this section the focus is on available strategies for the quantity and quality control of urban drainage with emphasis on combined sewer systems and separated storm water drainage systems. Combined sewer system problems are related to pollutant delivery from the continual erosion and wash-off of water pollutants from the land surface as well as from sanitary and industrial sewage in addition to sewer excessive load and back-up problems.

Some of the strategies which have been practiced in Urban Storm Water quality and quantity control include the following:

2.8.1 Source controls

This strategy seeks to reduce the quantity of storm water run-off by increasing the infiltration and storage capacity of the catchment through vegetative and grassing techniques and to improve downstream water quality by preventing pollutants from entering the run-off cycle.

Through reducing the amount of storm water entering (single or combined) sewer systems, the probability of sewer surcharging and sewer system overflows is also reduced. Source control techniques are generally applicable to both combined and storm sewerage systems.

2.8.2. Collection system controls

Many collection system controls are common to both combined and storm sewer system such as the regular cleaning of catch basins as well as flow reduction techniques that may be implemented to reduce the magnitude of sewer over-flows. Flow reduction techniques reduce the quantities of inflow infiltration/inflow (I/I) thus also reducing sanitary sewer surcharging and over flow problems. It includes: sewer separation, and in-system storage.

Sewer separation

To alleviate the problems resulting from combined sewer systems, the practice of sewer separation has been widely applied not only to new drainage systems but also to existing combined systems.

In-system storage

Rainfall on urban catchment occurs with both temporally and spatially varying intensity. That is, rainfall may be heavier in one location and lighter in another at any given time. As a result, the flows in combined sewers may be at or above capacity in some locations and below capacity in others. The utilization of in-system storage is a combined sewer operation strategy whereby flow is directed from locations with higher run-off rates to locations with lower run-off rates, the flow being temporarily stored or detained in the part of the system with the lower flows.

2.8.3 Storage and treatment controls

Downstream storage facilities and centralized waste water treatment plants are implemented to take advantage of economic of scale. Additionally, downstream storage facilities may be designed for water quality control by providing treatment of storm water and/or combined sewage, primarily through sedimentation.

2. 9 Urban storm water pollution and its prevention

Urban storm water pollution results from the small, incremental, and collective activities of the public (Adams and Papa, 2000). The origins of urban storm water pollution are often the result of the unintended and unrecognized consequences of thousands of routine, seemingly inconsequential decisions made daily. Routine home and yard projects can contribute pollutants to the urban storm drain system if preventive measures are not taken.

Public education is one key to prevent urban storm water pollution. The better the public understands what causes urban storm water pollution, and the simple measures that can be taken to prevent urban storm water pollution, the cleaner the storm water and local streams will become.

To address urban storm water pollution through the cooperative efforts of an informed community it is paramount to increase public awareness about urban storm water pollution and educate the community about specific pollutant sources and on what they can do to reduce them in urban storm water (ibid). Thus, the purpose of public outreach and educational efforts should be to increase community awareness about storm water pollution and to discourage the release of non-storm water discharges into the storm drain system.

Construction Site Storm water Runoff Control

In the absence of proper management, construction sites can release significant amounts of sediment into storm water and eventually into the storm drain system. Land disturbance leaves soils vulnerable to erosion. Sediment in runoff from construction sites, and wastes generated during construction, can pollute creeks and waterways. Long term, increases in the amount of paved and roofed areas cause increases in the volume and peak flow runoff. Increased runoff mobilizes and transports pollutants into storm drains, creeks and waterways.

Construction Site Runoff Control Programs should be designed to reduce pollutants generated by construction activities such preventing mechanisms may include (Adams and Papa, 2000):

- Effectively prohibit non-storm water discharges and require controls to reduce the discharge of pollutants during construction.
- Minimize land disturbance at construction sites.
- Protect water quality from pollutants generated by construction activities.
- Require best management Practices implementation at construction sites.
- Develop and implement measurable goals to evaluate the success of the BMPs

2.10 The importance of urban storm water drainage infrastructure.

Urban drainage infrastructure is designed to remove the rainfall which accumulates on relatively impermeable surfaces in towns and cities. In doing so, they further increase the speed of runoff and reduce the natural attenuation (=infiltration capacity) of the land surface. The runoff from an urban area may have a significant effect on the hydrograph of a natural watercourse which is receiving the runoff, since the later may not have responded the rainfall. More attention is now being paid to increasing the attenuation of urban drainage systems by the use of tanks and reducing the flows by promoting infiltration (Thomas N. Debo and Andrew J. Rees, 2002).

The importance of urban drainage infrastructure is therefore to collect and convey storm water to receiving water ways, with safety and minimal damage. Besides, it includes limitation of adverse impacts on urbanization, such as pollution, erosion and sedimentation, water conservation in areas of low rainfall, and integration of large-scale drainage works in to over all environmental management schemes with multiple use of land for drainage, recreation or transportation (NUPI, 2000). This system is the ultimate to keep expected life of infrastructure and the aesthetic value of a given urban area.

CHAPTER THREE: MATERIALS AND METHODS

This chapter has focused on materials and methods which were employed to address the indicated research objectives. It includes: materials, literature survey, research design, data source, sampling techniques, data collection, data analysis, and interpretation with appropriate statistical tools.

An intensive literature survey was conducted, particularly, in designing the urban storm water drainage net-work which is appropriate and alternative option to handle the urban storm water drainage problem in a sustainable manner.

3.1 Materials

The following materials were used for this particular study:

Base map- to investigate 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.

Contour map-to examine the elevation and flow length of the catchment areas.

Rainfall data- to estimate the rainfall intensity.

Tape meter- to measure the existing Urban Storm Water Drainage facilities, Road and Natural water ways/Rivers.

3.2 Methods

3.2.1 Research Design

The study of urban storm water drainage system is complex and hence needs a comprehensive method. Two types of methods, as discussed here under, were employed in this study

3.2.1.1 Descriptive method- this method was employed to describe the extent to which urban storm water drainage affects the general environment of the sub-city and the human life. This method was also used to describe various factors which would contribute to the development of urban storm water drainage system in the sub-city.

Generally, this method was adopted to describe the general existing condition and coverage of Road and Urban storm water drainage infrastructure to distinguish their level of integration and existing natural water ways in the study area.

3.2.1.2.1 Exploratory method was particularly employed to explore the existing conditions and coverage of urban storm water drainage system, Yeka mountain, natural water ways and the general environment using base map and a check list.

3.2.2 Types and sources of data

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

3.2.2.1 Primary data sources

Field survey/observation, interview and questionnaires were the primary data sources which were employed in this study with the help of a base map and check list. About 95% of this study was dependant on primary data sources.

3.2.2.2 Secondary data sources

Secondary data was the other type of data collection method using existing records, master plan, and other proceedings and reports. It is only 5% of this study which was dependant on secondary data sources.

3.2.3 Sampling Techniques

Purposive sampling was the sampling technique which was employed in this research study, this is to mean: Of the 11kebeles in the sub-city, this study was conducted only on three kebeles: Because they represented the other Kebeles in line with the objective of this study. These three sample Kebeles were: 01/02(around coffee Abyssinia processing factory, French Embassy, Eyesus, “Arba ande”), 08/15 (around Kokebe tsebeha secondary school, Russia And British Embassy, Yeka Michael, Top view hotel) and 13/14 (the area around megenagna, shola Gebeya, ‘Mekonenoch’ residence/ building, Kia-med and Addis Ababa medical college). The selection of these kebeles has done with the Yeka sub-city environmental protection team.

Generally, the basic reasons to select these kebeles was that they are located at the base of Yeka mountain, relatively the largest river, Kebena, passes through them, most of the illegal settlements on Yeka mountain is found within these kebeles and flooding is more pronounced in these kebeles.

In a similar analogy purposively the urban storm water drainage and Road infrastructure in the study area were selected to investigate the environmental problems of urban storm water drainage system.

The whole part of Yeka Mountain, which drains its run-off (storm water) in to the sub-city, was considered in estimating the total amount of run-off entering in to the sub-city. The sample areas, including Yeka Mountain, comprises of 68.4% (5,598/8,190) of the area of the whole sub-city.

3.2.4 Data collection Methods

The following data collection methods were employed:

3.2.4.1 Field Survey

Field survey was employed with the help of base map and check list as per the objective of this study. The check list has included issues like the level of integration between road and urban storm water drainage, the effects of Urban Storm Water Drainage on the environment, the highly affected/problematic areas, the condition of Yeka Mountain on the sub-city, the condition of natural water ways and other related issues in the study area. About 85**%** of the primary data were collected through field survey, the rest 15**%** through interview and questionnaires.

3.2.4. 2 Interview

Generally, this was employed to collect data related to flooding hazards and causes of flooding, major challenges to storm water drainage management, the enforcing factors to damp solid and liquid wastes to existing drains and to natural water ways, and possible suggestions in the view of residents to handle the challenges of the drainage system in the study area. The residents were interviewed to get reliable data as they are the most affected part in the study area.

3.2.4.3 Questionnaires

This was particularly prepared for kebele and sub-city experts/professionals in a particular reference to office of works and urban development, urban planning institute and Environmental protection team at sub-city level and for Addis Ababa city environmental protection Authority (AAEPA). This has been comprised of those data related to major causes of flooding and suggested solutions, impacts of drainage system on rivers, impact of rivers on Yeka sub-city, major challenges in handling the drainage system in the study area and others related to the study objectives.

3.2.5 Data analysis

The collected data has been analyzed with the help of the known computer softwares including: Microsoft excel, ArcGIS and AutoCAD to analyze the quantitative, qualitative and spatial data.

3.2.6 Data presentation

The analyzed data have been presented with Statistical tools such as tables, graphs and percentages. GIS and CAD figures and digital photos, which were captured during field survey, have also been incorporated as evidence to summarize the findings and field surveys.

CHAPTER FOUR: DATA PRESENTATION AND INTERPRETATION

This chapter is the central part of this study as all the findings/data have presented, analyzed and discussed. Following are the data presentation and interpretation in line with the objective of the study:

4.1 Major challenges in urban drainage management system.

The major challenges in managing the urban storm water drainage system in Yeka Sub-city are summarized below (sources: interviews and field survey, 2009):

i. **Topography and Geological formation:** This includes rugged terrain, larger slope/gradient, high elevation and impervious rocky surfaces. These are the major barriers in managing the urban storm water drainage system in the sub-city. Because its ruggedness and larger slope needs a complicated and highly engineered designs, which on the other hand requires additional financial sources to effectively employ such high level practices. Besides, due to the highly impervious layers as a result of rocky nature of the area, mainly in some hilly parts of Yeka, the rain fall does not infiltrate in to the ground. This result in reduced ground water recharge and lower survival rate of planted plant species leading to both accelerated water and wind erosion.

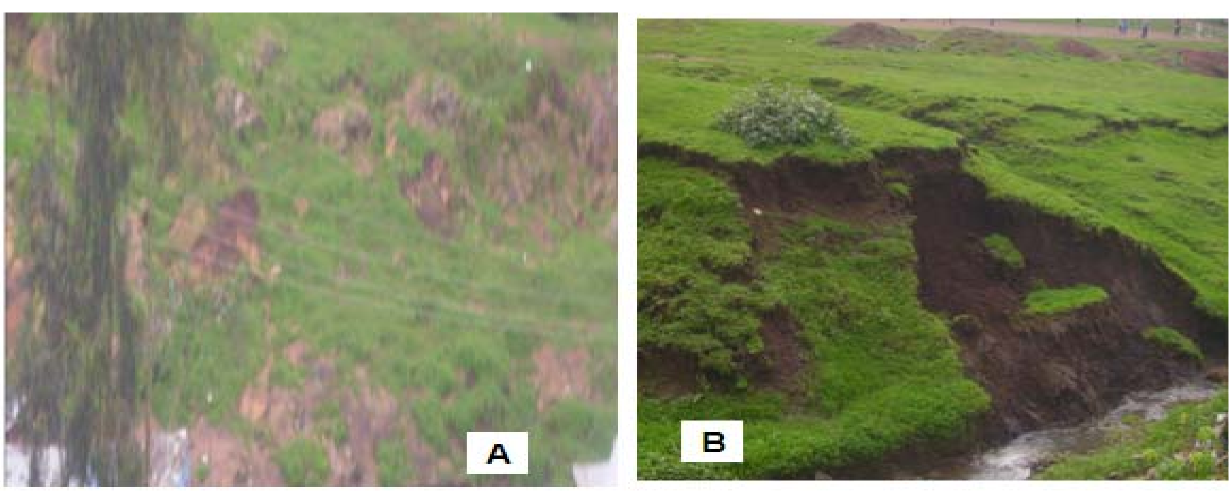

Fig-4.1 Rugged, large slope and impervious surface in Yeka sub-city (source: Field survey 2009).

ii. **Less vegetation cover on Yeka Mountain:** this is the other major challenge, particularly in the hilly parts of the sub-city. About 3,566 ha (45%) of the sub-city is reserved for green area or in other way this is not recommended for settlement, but most of the reserved areas are illegally utilized for unauthorized function/uses such as quarrying, informal settlements and farming activities and hence there is a serious problem in managing the storm water drainage system in the sub-city due to: inadequate forest/tree, inadequate soil and water conservation activities, loss of indigenous trees, lack of appropriate tree species-which can have the capacity to hold soil through their roots and improper land use that is reserved forest lands are illegally encroached for other purposes. Figure-4.2 is a notable evidence to this phenomenon.

Fig-4.2 Sparsely vegetated part of Yeka sub-city kebele01/02(source:Field survey August, 2009).

iii. **Informal settlement**: this is the biggest challenge in managing the drainage system in this sub-city, because the area reserved for forest is encroached by informal settlement. This has exacerbated the land degradation/erosion problem due to the increased flooding as a result of impermeable surfaces, illegal solid and liquid wastes disposal in to existing natural water ways and drains. Figure-4.3 is an evidence to this reality.

Fig-4.3 Ilegal settlements on Yeka mountain kebele08/15 (source:Field survey August, 2009).

iv. **Illegal quarry activity:** In a similar way the area reserved for greenery is turned in to illegal quarrying. This illegal quarrying particularly on the hilly parts of the sub-city aggravates the land degradation and flooding problem. The features of such illegal quarrying activities are depicted in Fig.4-4.

Fig-4.4 Illegal quarrying in Yeka Sub-city kebele08/15(source: Field survey August, 2009).

v. Absence of River buffers around natural water ways: Although the Addis Ababa Environmental Protection Authority has set a regulation on buffer zones of rivers to be kept 15m to 30m from the center of the river on both sides, most of the river banks/buffers are encroached by illegal settlements and/or functions. This in turn has widened the river bank through water erosion and land sliding, which then decreased the productive urban land which may be used for other productive land use functions. Figure-4.5 is a good evidence to this**.**

Fig-4.5 A river without a buffer zone (source: Field survey August, 2009).

vi. Dumping of solid wastes in to natural water ways and drainage facilities (Including demolished materials, soil, house refuses plastic materials and others):

This has been aggravated the problem of flooding. This is to mean because of dumped solid waste in to the existing natural water ways and urban drainage facilities the flood over flows and create a problem on residents and other urban infrastructure and utilities. According to the Addis Ababa sanitation and beautification agency, it is nearly 60% of the total solid waste generated from various sources has a proper management. This implies that the other 40% is dumped in to open spaces or unauthorized places including natural water ways and drains. Figure-4.6 confirms this truth.

Fig-4.6 solid waste dumped in to storm water drains (A) & rivers (B) Kebele 01/02 (source: field survey August 2009).

vii. **Discharge of liquid wastes in to existing water ways and drains**: Illegal connection of sewerage system in to existing drains and natural water ways is one of the challenges which have been observed in the sub-city. Most of the drainage lines in Yeka sub-city serve as a sewer and are blocked by liquid wastes; Figure-4.7 is one of the evidence for such illegal activities.

Fig-4.7 Natural water way full of wastes Kebele 13/14 (source: field survey May, 2009).

viii. **Low community awareness to environmental management**: community awareness is one of the best proactive measures for the sustainable urban drainage management. But, as it has been studied during the field survey about 72% (43 of 60 respondents) of the residents have no knowledge about the effect of dumping solid and liquid wastes in to existing drainage and river system, where as 28% have the knowledge but they said where shall we dispose "we have no sewerage system".

ix. **Infrastructure development (or construction sites) does not consider the existing drainage system: -** the majority of infrastructure development in the sub-city has no attention to the drainage system. For example, housing construction, road construction and upgrading, water supply lines and telephone line installation and expansion have been degrading the urban drainage system and have found that they are the major causes of land degradation and erosion. Figure-4.8 is a notable one.

Fig-4.8 Housing development that disturbs the drainage system kebele 08/15 (source: Filed survey, 2009).

4.2 The impact of Yeka Mountain on Yeka sub-city.

Yeka Mountain is relatively bare and predominantly covered by eucalyptus tree, which does not allow other shrubs and grasses to grow underneath due to its high competition to water and nutrients. Fig-4.9 is evidence to this.

Fig-4.9 Land covered by eucalyptus tree and exposed to erosion kebele01/02.

This on the other hand reduces the soil erosion prevention capacity of the land surface. Generally, the mountain discharges excessive flood into the sub-city due to the rugged and larger gradient nature of the mountain associated with its bareness. That is accelerated and concentrated run-off enters in to the sub-city during every rain event. The total amount of runoff generated from the mountain and entered in to the Sub-city was estimated using the known rational formula:

$$Q= 0.00278*C*I*A \text{ --- } (4)$$

Where, Q= run-off discharge (m^3/s)

I= rain fall intensity (mm/hr)

C= run-off coefficient

A= catchment/drainage area (m^2)

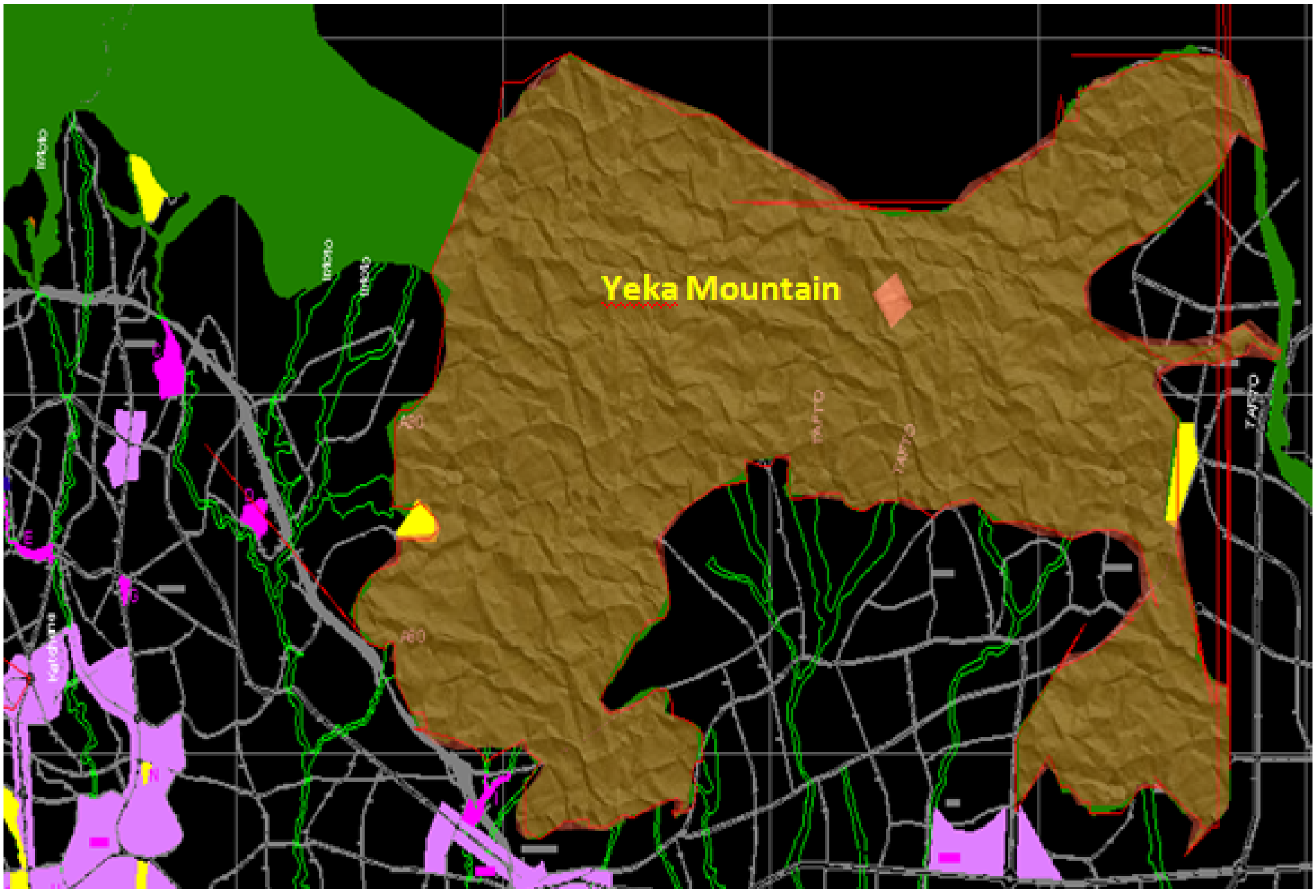

Fig-4.10 Yeka Mountain (source: AAEPA, September 2009)

The Area (A) of Yeka Mountain, which has a direct environmental impact on the Yeka sub-city as indicated in fig-4.10 is calculated (using AutoCAD and GIS soft wares) and found to be 3,566ha. This value was considered to calculate/estimate the total amount of runoff entering in to the sub-city.

The rainfall intensity (I) was calculated using the technique of linear regression from the 10 year rain fall data which has been obtained from the Addis Ababa observatory metrology station.

Table 4.1 Maximum daily rainfall data of Addis Ababa for the recent ten years.

Year	J	F	M	A	M	J	Jy	A	S	O	N	D	Annual max.
1998	32.2	8.5	14.9	16.6	43.3	26.7	27.2	28.9	24.7	78.3	0.0	0.0	78.3
1999	2.9	0.3	5.8	5.8	4.4	21.8	27.4	37.4	20.5	15.4	0.0	0.0	37.4
2000	0.0	0.0	15.2	15.3	28.5	25.9	29.3	26.4	37.1	25.1	19.6	0.0	37.1
2001	0.0	11.6	96.3	13.5	23.8	20.3	42.5	41.4	33.5	4.7	0.0	0.0	96.3
2002	4.6	14.6	23.3	25.9	29.5	20.2	29.3	25.8	25.6	0.2	0.0	11.4	29.3
2003	10.5	26.5	33.4	31.1	18.9	17.9	46.2	31.3	40.1	0.8	1.2	54.9	54.9
2004	12.7	19.7	17.1	29.6	10.5	16.4	33.2	36.5	24.3	44.2	0.0	0.0	44.2
2005	21.4	26.2	32.8	58.6	35.6	24.4	42.6	46.8	25.5	-	2.3	0.0	46.8
2006	0.7	5.2	70.9	16.0	51	42.6	40.8	30.3	61.9	27.2	0.3	3.0	70.9
2007	24.8	11.9	24.4	25.2	34.1	33.8	46.3	64.0	16.6	11.8	0.0	0.0	64
Total													559.2
Average maximum daily rainfall													~ 56
Average number of rainy days per year													145

Source: Ethiopian Meteorological Agency (Addis Ababa observatory station, 2009).

The general equation to calculate intensity is (source: Bell, 1969):

$$R^{t}{}_{T} = (0.21\ln T + 0.52)(0.54t^{\,0.25} - 0.5)R^{60}{}_{10} \quad \text{--------------------------------}(5)$$

Equation (1) is true for 2 [T [100 Years and for 10 [t[120 minute.

Where, $R^{t}{}_{T}$ = rainfall depth in mm of a 'T' years return period in 't' minute duration,

T = recurrence interval (return period) of storm in years

t = rainfall duration (minute),

$R^{60}{}_{10}$ = rainfall depth in mm of one hour duration and 10 years return period.

- The following techniques have been employed to estimate Rain fall intensity (I): *the following formula was used* to determine intensity between 10 and 60 minutes.

$R_{10}^{60} = 0.27*X*N^{0.33}$ -- (6)

where, X= Average daily max. rain fall(mm)=56

N= Average number of rainy days= 145

By substitution: $R_{10}^{60} = 0.27*X*N^{0.33}$

$= 0.27*56*145^{0.33} = 78$mm-- (7)

Substituting the value of equation (7) in to equation (5) for the selected 10 years recurrence interval and 10 to 120 minutes is calculated and summarized below:

For 10 minute------- $R_{10}^{10} = (0.21 \ln 10 + 0.52)\,(0.54(10)^{0.25} - 0.5)\ 78$

$= (0.98)\,(0.4602)78 = 35.32$

For 20 minute-------R_{10}^{20} = (0.21 In 10 + 0.52) $(0.54(20)^{0.25}$ -0.5) 78

= (0.98) (0.64)78 = 49

For 30 minute-------- R_{10}^{30} = (0.21 In 10 + 0.52)$(0.54(30)^{0.25}$ -0.5) 78

= (0.98)(0.76)78 = 58.4

For 60 minute------- R_{10}^{60} = (0.21 In 10 + 0.52)$(0.54(60)^{0.25}$ -0.5) 78

= (0.98) (1.0029)78 = 76.7

For 90 minute------- R_{10}^{90} = (0.21 In 10 + 0.52) $(0.54(90)^{0.25}$ -0.5) 78

= (0.98) (1.16)78 = 88.90

For 120minute------- R_{10}^{120} = (0.21 In 10 + 0.52) $(0.54(120)^{0.25}$ -0.5) 78

= (0.98) (1.28)78 = 98.40

The value of "I" (mm/hr) is calculated by dividing rainfall values by the corresponding minute as summarized in table.4-2.

Table 4.2: Rain fall duration-Frequency for the selected duration and return period.

Frequency \ Duration(min)		10	20	30	60	90	120
T=10 year	RF(mm)	35.3	49	58.4	76.7	88.90	98.40
	I(mm/hr)	35.32*60/10 = 212	49*60/20 = 147	58.4*60/30 = 117	76.7*60/60 = 68	88.9*60/90 = 6o	98.4*60/120 = 49

Source: own computation May, 2009.

Using the technique of linear regression "**I**" was computed as follows:

By regression: $$\mathbf{I = \frac{a}{(a + t_d)^c}} \text{ ---------------- (8)}$$

To linearize, logarithmic function has been added on both sides of the equation. This result: Y= log I,

K= log a,

a=$\log^{-1}$k,

c = regional accepted table value and for practical purposes=1

x= log (b + t_d), and take b=0.3 (regional accepted table value).

Thus, the linearized form of the above equation becomes:

Y= K- cX -- (9)

The final time of duration (t_d) is calculated and summarized in Table-4.3.

Table-4.3 Calculated value of time of duration (t_d).

	td(min)	x	x^2	y	y^2	x*y
	10	=log(0.3 + 10/60)=-0.33	0.1089	2.33	5.43	-1.79
	20	-0.19	0.0361	2.18	4.75	-0.903
	30	-0.09	0.0081	2.07	4.28	-0.39
	60	0.11	0.0121	1.83	3.35	0.37
	90	0.26	0.0676	1.78	3.17	0.82
	120	0.36	0.1296	1.69	2.86	1.03
11.88	summation 0.36	0.12	0.36	11.68	23.84	-0.86

Source: own computation, 2009.

From the regression formula, Y=K-cX, the intensity formula for ten year recurrence period is calculated and presented in equation (11).

K_{10yr} = $(nx^2)(n\ y)-(nX)(nx*y)/(n(nX^2)-(nx)^2$ --- (10)

$= (0.36)(11.68)-(0.12)(-0.86)/6(0.36)-(0.12)^2 = 2$

Log a=k

$a = \log^{-1}(k) = \log^{-1}(2) = 101.30$

Therefore, the rainfall intensity (**I**), by substituting the value of "a", "b" and "t_d" is expressed as:

$I_{10} = 101.3/\ (0.3 + t_d)$ -- (11)

And the time of concentration, Tc, was calculated from the time that it takes the storm water to reach from the most remotest distance to the outlet. The following, Bell, formula was adopted in estimating Tc;

$Tc = 3.64\ (1.1 - c)\ L^{0.83}/\ H^{0.33}$ -- (12)

Where: Tc = Time of Concentration (hrs),

L = Flow length (km)

H = Elevation difference (m),

C = Runoff coefficient (Unitless)

That is $Tc= 3.64(1.1-0.7)\ (6565/1000)^{0.83}/(2965-2335)^{0.33}$. From contour map the value of H1=2965 m and H2= 2335m

Tc = 0.82 hr

From this the Rainfall intensity, I, was calculated using the above formula and found:

I = 101.3/ (0.3 + 0.82) = 90.5 mm/hr

Therefore, the storm water discharge, Q, was calculated as follows:

$$Q = 0.00278 * C * I * A \quad (13)$$

Let C= 0.70 (source: from a Run-off coefficient table, which is appropriate for Yeka sub-city) (FUPI, 2008).

Q= 0.00278 * 0.70 * 90.50 mm/hr * 3566 ha = 872m^3-----this amount of storm water/runoff enters in to the sub-city in every rain event.

Taking the average annual number of rainy days in Addis Ababa, the total amount of annual storm water that enters in to Yeka sub-city from Yeka mountain was calculated as follows: = Rainfall discharged in every rain event * Average annual number of rainy days

= 872 m^3 * 145 days/yr

= 126,440m^3 per year

That is, 126,440m^3 of storm water or runoff per year wastes without use. If this rain water is properly harvested and utilized 6,928 persons would get their water consumption from this source, taking 50liter average daily water consumption per person (6,928 = 126,440m^3/ 50lt/people*365dys/yr).

If this amount of rain water is properly harvested and utilized, it can be used to recharge the reliable ground water source of the city, to reduce soil & river bank erosion.

The implications of this run-off are:

i. Such amounts of rain water transports considerable amount of non-point source pollutants, particularly in to the natural water ways/rivers, with a greater impact on the down catchment environment.

ii. Such larger amount of water resource which is lost with no value would have greater importance if it were harvested or encouraged to infiltrate in to the ground.

iii. This aggravates river bank erosion and other land degradation processes.

iv. Causes degradation of road bases and other urban utilities like telephone, electric, and water supply lines.

If Yeka Mountain were fully covered by forest the value of run-off coefficient “c” would decrease (from 0.7 to 0.25)-this allows flood to infiltrate in to the soil instead of flood generation. The following comparison gives a good understanding about the effect of deforestation on Yeka Mountain. Then, the total amount of storm water entering in to the sub-city would be:

$$Q= 0.00278*0.25*90.50*3566=225m^3/day*145days/year., \text{ where } c= 0.25$$

$$Q= 32,522m^3 \text{ per year.}$$

Storm water entering in to the sub-city annually with the existing situation, as calculated above is $126,440m^3$.

The difference is $126,440m^3$ - $32,522m^3$ = $220,358$ m^3-this large volume of rain water with acceptable forest coverage of Yeka Mountain would be infiltrated in to the soil.

The implications of reduced runoff as a result of good vegetation cover on Yeka Mountain as calculated above are:

- The Ground water recharges to a reliable amount.
- The ongoing soil erosion would be reduced.
- The ever existing river bank erosion will get reduced.
- Reduced degradation on road bases and/or road surfaces and on other urban utilities like water supply lines, telephone and electric lines.
- The total amount of non-point source pollution transport would get reduced.

4.3 Major impacts of the Urban Storm Water Drainage System on existing natural water ways.

This part gives a detail description about the major pollutants which are found in the urban storm water drainage system with their impacts on existing rivers and the existing condition of natural water ways which passes through the study area.

4.3.1 Major pollutants in urban storm water drainage system in the study area.

Increased pollutant loadings and discharges are the major impact of urban storm water runoff from impervious surface and other disturbed areas.

Generally, all of the non-point source pollution contaminants have grouped in to the following major categories of non-point source pollution. These categories are:

- Sediment from improperly managed construction sites, deforested Yeka Mountain and eroding river banks from Kebena and its tributaries, Jelissa and others.
- Oil, grease and toxic chemicals from garages. For example, during field survey in kebele13/14 there was a local car wash site, which discharges its spent/washed-out wastes in to the nearby river. Figure-4.12 is representative to this reality.
- Nutrients and pesticides from Embassies, Schools and other government and non-government offices in the process of grass management and gardening.
- Viruses and bacteria from faulty septic systems or sewerage connected to a drainage system from human, livestock and pet wastes.

Fig-4.12 Car wash site that discharge its spent in to a river (source: filed survey May, 2009).

The major contributors, as studied during field survey, of the above categories of non-point source pollutants in the study area are households, government and non-government institutions, commercial centers, schools, medical centers, parks, impervious structures (Roads, roofs--), garages, and local car wash stations.

Based on the above mentioned factors, the major pollutants which are common in urban storm water drainage system were analyzed in this study. That is, a total of nine samples were collected from three rivers: Kebena, Jelissa and a river in between British embassy and Yeka Michael (=Yeka river) and from each sample rivers three samples were collected. The samples were collected before and after a rain falls. The collected samples were given to an external laboratory analysis- namely “Water works Design and Supervision Enterprise Laboratory Service”. Each samples were analyzed for Total suspended solid, Total Solids, Total dissolved solid, Nitrate, Nitrite, Phosphate, Total and Fecal coli forms.

Table-4.4 Major pollutants in the urban storm water drainage system in Yeka Sub-city.

No	Pollutant type	Sample Rivers								
		Kebena			Yeka			Jelissa		
		S_1	S_2	S3	S_1	S_2	S_3	S_1	S_2	S_3
1	Total suspended Solid (mg/ml)	334	350	340	32	44	18	492	588	458
2	Total solids (mg/ml)	584	606	596	222	254	152	624	705	616
3	Total Dissolved Solid (mg/ml)	250	256	256	190	210	134	117	132	158
4	Nitrite (mg/ml NO_2)	0.625	1.00	1.40	1.15	0.925	0.93	0.9	0.85	0.88
5	Nitrate (mg/ml NO_3)	81.50	77.5	62.3	43.9	50.5	53.31	39	41.4	43.4
6	Phosphate(mg/ml PO_4)	1.2	0.97	0.89	1.30	0.89	0.70	0.57	0.51	0.75
7	Total Coliform per 100ml	9900	9200	9400	11500	1010	11000	1400	3000	3400
8	Fecal Coliform per 100ml	5450	4800	5010	6560	6030	6470	1100	2700	2700

Source: Field survey, July-August, 2009.

Note: S_1= sample Number-1(before a rain fall)

S_2= sample Number-2 (with a rain fall)

S_3= sample number-3 (after a rain fall)

From table-4.4, total suspended, total dissolved and total solids were high during a rainfall event than before and after a rainfall event. The implication of this is that it is the runoff which contributes for greater amount of solids to be found in the rivers in the urban drainage system. Whereas, both total and Fecal coli-form are maximum before a rain event than within and after a rain event. The implication of maximum coli-form before a rainfall indicated that the river waters are highly concentrated as a result of sewerage/toilet connections, and solid waste disposals in to rivers with a reduced peak water volume. Whereas, in rainy season because of high peak flow rain water the river water gets diluted.

The implications of this laboratory analysis indicated that:

- High and concentrated pollutants present in a dry season than rainy season. Thus, the connection of sewerage lines/toilets should be prohibited or enforced not to connect and there should be an integrated solid waste management and provision of sewerage systems to residents.

- Such maximum non-point sources of pollutants are the results of deforested Yeka mountain and expansion of the urbanized area resulting in impervious surfaces leading to flood generation. If the area were covered by forest and pervious layers/surfaces the rain water that transports pollutants would get infiltrated in to the ground.

4.3.2 Sources of major pollutants in the urban drainage system and their impacts on receiving Rivers.

The pollutants in urban drainage system transported, transformed, deposited, re-suspended and biologically taken-up. According to various studies, urban drainage system carries relatively high concentrations of a variety of pollutants (Addis Ababa University, 2003). These pollutants originate from diverse sources, both natural and man-made. In addition, pollutant generating activities are considered to be more prevalent on impervious surfaces than on pervious surfaces. Generally, common sources of pollutants which have been surveyed in this study includes: accumulation of street refuse(like litter, street dirt, organic residues), accidental spills, solid waste, paper and plastic products, fallen leaves, clipping grasses, dead animals, animal excreta and urban land erosion.

The major sources of pollutants in this study are summarized and presented below:-

Solids

The most prevalent form of storm water pollution is the presence of suspended and dissolved solids that is eroded from river banks and other surfaces, and washed off paved surfaces by storm water. According to the field survey, the most sources of sediments(solids) emanates from improperly managed construction sites (building and road construction) and urban utilities installation such as telephone, electric and water supply lines, urban soil erosions particularly from river bank and bed erosion. The solids content in urban storm water measured as total solids, suspended and dissolved solids. Suspended solids increase the turbidity of receiving water, thereby reducing the penetration of light, resulting in decreased activity and growth of plants.

Bacteria (coli-forms)

Coli-forms are indicator organisms that originate from soil or *the* intestinal tract of humans and/or animals (fecal coli-form). The presence of such organisms in water indicates that the water is potentially infected with pathogenic bacteria. As it has been identified during field survey these pollutants enter the drainage system from the wash-off animal feces, organic matter from the drainage system and from illegal sanitary sewer connections.

In the study area, during field survey, it was realized that mainly the bacteria enters the urban drainage system through lateral connections of sewerage/toilet and from animal feces.

Nutrients (Nitrate and Nitrite)

Urban runoff contains significant concentration of nitrogen, phosphorus, and carbon compounds, which accelerate the nutrient enrichment and eutrophication of receiving waters. According to the field survey, the sources of nutrients in the study area was attributed to leaching of vegetation, agricultural fertilizers and residential waste water discharges. Common types of nutrients as depicted on Table-4.4 are nitrates, nitrites and phosphates.

4.3.3 The existing condition of natural water ways/rivers in the study area.

Addis Ababa is located in the uppermost catchment area of the Awash River basin. The catchment area of the Rivers in the study area is part of this river basin and is represented by the Kebena river system. Figure-4.13 depicts all the river systems in Addis Ababa and in the study area, which is enclosed within the red boundary.

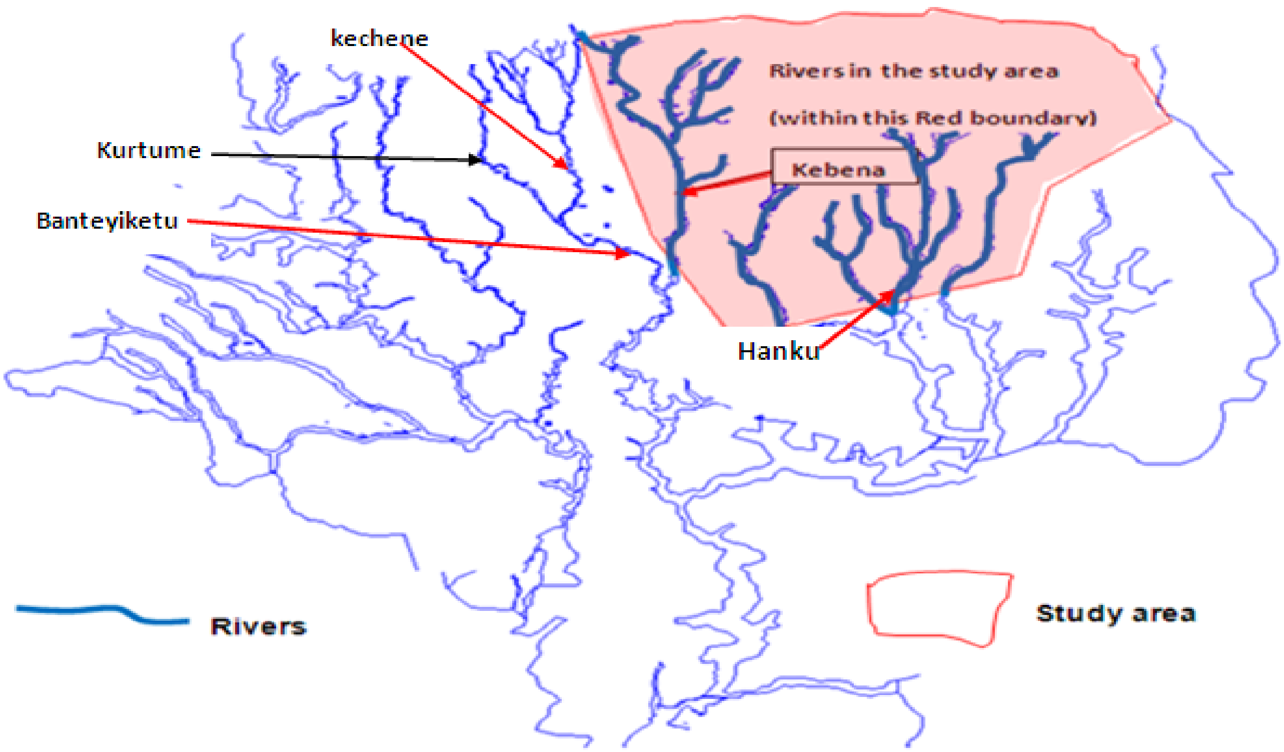

Fig-4.13 River systems in Addis Ababa and the study area(source: Addis Ababa EPA and AutoCAD analysis)

In Addis Ababa, particularly in the study area there are several rivers that emanates from the Yeka mountain and flows down catchment and joins the little and large Akaki Rivers and then joins the Awash River, but none of these rivers are valuable to the city, Addis Ababa. They serve as solid as well as liquid waste damping site. Industries, medical centers, residents, and institutions damp their wastes of various types to these rivers.

The rivers in the study area are shown in Figure-4.13. In this study area there is one big and influential river to the urban drainage system, which is Kebena River. It has about seven tributaries including Banteyiketu with its tributaries Kechene and Kurtume, which are located west of the study area (refer to Fig-4.13).

The down catchment drainage system suffers from the negative impact or environmental load of the upper catchment drainage system due to the long distance travel of the rivers. These rivers transport excessive pollutants and other loads from the upper catchment to down catchment drainage system. The Kebena river is the wider and longer river system in the study area in collecting and transporting pollutants and other unnecessary loads. It collects and transports various pollutants from all its tributaries and other unnecessary loads from illegally connected sewerage systems and untreated drainage facilities.

The other rivers which have a direct impact in transporting urban drainage pollutants in the study area comprises of Hanku & Kotebe, which are located east of the study area.
Generally, as it has been surveyed during this study regarding to the existing condition of rivers almost all of them are encroached by illegal settlements (refer Figure-4.14), solid waste damped in to rivers (refer Fig-4.15), no or inadequate buffers, liquid wastes discharged in to rivers (refer Fig-4.14), there exists a river bank erosion, and silted or blocked by solid wastes of various types.

Fig.-4.14 Encroached river by illegal settlement kebele 08/15 (source: Field survey, 2009).

Fig-4.15 Solid waste damped in to Kebena River (source: Field survey, 2009).

Generally, the width, length and buffer zone of three selected rivers in the study area have been surveyed during field work and presented in Table-4.5.

Table-4.5 The Existing condition of rivers in the study area.

River name	Average width (m)	Length (km)	Average depth(m)	Catchment coverage(km^2)	Buffer condition
Kebena	25	24.00	3.17	89.00	Generally, no buffer zone
Hanku	14	9.00	2.5	11.00	Generally, no buffer zone
Jelissa	12	6.00	1.75	8.00	Has only around "Gurd shola"

Source: Field survey and GIS analysis, 2009.

Note: - Catchment area of Kebena includes its tributaries: Banteyiketu, Kechene and Kurtume.

As shown in Table-4.5, particularly Kebena River covers larger catchment area in the study area and relatively it has longer, deeper and wider sizes and almost all rivers have no buffer zone which can prevent the direct encroachment of rivers by human activities. Besides, due to the absence of proper management the rivers and their river side do not give productive values.

On the other hand, the Addis Ababa Environmental protection Authority has one river buffer zone demonstration site, which is Jelissa river bank development project. This pilot program has changed the general existing condition of the river to become more attractive. Along with its environmental benefits, it contributes considerable values in to the surrounding community. Figure-4.16 is one of the interesting result of this river bank development on Jelissa river around Gurd Shola-adjacent to Lucy Academy or left to the way of office of Addis Ababa Environmental Protection Authority. Furthermore, to show the effect of a river with and without buffer a pictorial comparison has presented in Fig-4-16.

Fig-4.16 Comparison between a river with(**A**) and without(**B**) buffer zone (source field survey, 2009)

The implications of a river with and without buffer zone are:

i. Without buffer zone

- Residents connect toilets and liquid wastes in to rivers.
- Residents damp solid wastes in to rivers.
- Unaesthetic to the environment
- May harbor disease causing (pathogenic) organisms.

ii. With buffer zone

- Attract people to keep it from illegal activities like solid and liquid waste damping.
- Aesthetic and healthier to the environment.
- Relatively, free from disease causing organisms.
- Means to additional income generation through investment and job recreation.
- Increase the well being of citizens.

4.4 The level of integration between Road and Urban Storm Water Drainage infrastructure

Provision of Road and USWD infrastructure are indispensible, particularly, in an urban center for safe and easy reachability from one area to another and to protect flood damage on urban infrastructure and utilities as a result of pavement or imperviousness.

There is a need to integrate Road and USWD infrastructure 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 generated as a result of pavement of structures. But, during field survey it was observed that most of the roads surface and base have been degraded, water supply lines have exposed for external weathering as a result of erosion. These and the other related issues have been discussed in detail in following sections.

4.4.1 The existing condition and coverage of urban storm water drains in the study area.

With the help of a base map and check list the existing condition and coverage of the urban storm water drainage infrastructure have been surveyed one by one for the three sample kebeles to study whether the flood generated in the drainage system of the study area are safely discharged in to the final receiving natural water ways or not. Accordingly, the existing condition and coverage of the storm water drains for the three kebeles have presented from Table-4.6 to Table-4.9.

All the conditions of roads and urban storm water drainage infrastructure deterioration scales here after in this research work has been studied on the basis of the indicators presented in Table-4.5.

Table-4.5 Road and Drainage lines infrastructure deterioration scales/indicators.

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

Source: GTZ, 2006.

Table-4.6 Length and condition of drainage lines in kebele 01/02.

Drain shape	pavement	segme nts	total length(m)	existing condition	length, m.	percentage
Trapezoidal	masonry	5	2,318.21	Good	-	-
				Light	979.88	42.27%
				Severe	1338.33	57.73%
			Percentage from total		26.97%	
Rectangular		30	6,277.65	Good	139.9	2.23%
				Light	1108.20	17.65%
				Severe	5029.55	80.12%
			Percentage from total		73.03%	
Total		35	8,595.86~ 8.6km		100.00%	

Source: Field survey and own GIS analysis, 2009.

Table-4.6 reveals that, of the total urban storm water drainage lines found in kebele01/02 26.97% is trapezoidal and 73.03% is rectangular in shape. From the total drains about 74% (6367.88/8595.86) is severely degraded. This is due to inadequate attention to this infrastructure, there is no scheduled maintenance program or infrastructure inventory to maintain damaged drains before they became out of use.

In summary, in kebele 01/02 the flood generated due to urbanization cannot safely be discharged in to the final receiving natural water ways but flows over the surface of roads and stagnated on open surfaces. During the event of rain fall it is common to see flood flowing over the surface of roads (Fig.-4.18), which is a big obstacle to vehicles and pedestrians. Both pedestrians and vehicles stand and wait until the flood stops.

Table-4.7 Length and condition of Drainage lines in kebele 08/15.

Drain shape	pavement	segments	total length(m)	condition	length(m)	Percentage
Trapezoidal	masonry	4	1681.06	Good	-	-
				Light	1,254.25	74.61%
				Severe	426.81	25.39%
			Percentage from total		38.37%	
Circular /pipe		3	120.73	Good	120.73	100%
				Light	-	-
				Severe	-	-
			Percentage from total		2.76%	
Rectangular		10	2579.21	Good	-	-
				Light	1,309.69	50.78%
				Severe	1,269.52	49.22%
			Percentage from total		58.87 %	
Total		17	4381.00 m ~4.38 km		100.00%	

Source: Field survey and GIS analysis, 2009.

From Table-4.7, it is clear that of the total drains 38.37% is trapezoidal, 2.76% circular and 58.87% is rectangular in shape. In this kebele, from the total drains about 38.72% is severely degraded. This shows that the flood generated within this kebele cannot safely be discharged in to the nearby river. On the other hand this will stagnate on open surfaces, overflow over road surfaces and may be a cause of flood hazards in this kebele.

Generally, the problem gets pronounced because kebele 08/15 is situated at the base of mount Yeka. During field survey it was evidenced that due to excessive flood, in some parts of the kebele larger open drains have been constructed, with a depth and width of 1.00m and 1.47m respectively, to tackle the excessive flood that enters in to the kebele.

Table-4.8 Length and condition of Drainage lines in kebele 13/14.

Drain shape	pavement	segments	total length(m)	condition	Length(m)	Percentage
Trapezoidal	masonry	10	3,117.50	Good	183.02	5.87%
				Light	1,992.16	63.90%
				Severe	942.32	30.23%
			Percentage from total		37.14%	
Circular/pipe		4	1,268.47	Good	1,268.47	100%
				Light	-	-
				Severe	-	-
			Percentage from total		15.11%	
Rectangular		29	4,008.41	Good	867.688	21.65%
				Light	1,419.33	35.40%
				Severe	1,721.40	42.95%
			Percentage from total		47.75%	
Total		33	8,394.39~8.4km		100.00%	

Source: Field survey and GIS analysis, 2009.

As depicted in Table-4.8, 37.14% is trapezoidal, 15.11% circular and 47.75% is rectangular in shape. In this kebele of the total drains 31.73% is severely degraded.

In summary, the problem gets increased because kebele 13/14 receives the flood generated both from Kebele 01/02 and kebele 08/15, which is located at the down catchment of the former kebeles.

Table-4.9 Summary of Urban storm water drainage lines in the study area.

Drainage line type	Surface Condition				Kebele
	Good (m)	Light (m)	Severe(m)	Total (m)	
Trapezoidal	-	979.88	1338.33	2,318.21	01/02
Rectangular	139.90	1108.23	5029.55	6,277.65	
Circular	-	-	-	-	
Sub-total	139.90	2088.11	6367.88	8595.89	
Trapezoidal	-	1254.25	426.81	1,681.06	08/15
Rectangular	-	1,309.69	1,269.52	2,579.21	
Circular	120.73	-	-	120.73	
Sub-total	120.73	3563.94	696.33	4,381.00	
Trapezoidal	183.02	1,992.16	942.32	3117.50	13/14
Rectangular	867.69	1,419.33	1,721.40	4,008.42	
Circular	1,268.47	-	-	1,268.47	
Sub-total	2319.18	3411.49	2663.72	8,394.39	
Grand total	2,579.81	9,063.54	9,727.93	21,371.28	
Percentage from total	12.07%	42.41%	45.52%	100.00%	

Source: Field survey and GIS analysis, 2009.

From Table-4.9, of the total drains in the three sample kebeles about 45.52% is severely degraded, which has resulted in degradation of road and other urban utilities as evidenced by Fig.4-17.

Fig-4.17 Severely degraded storm water drainage lines kebele o1/02(source: Field survey, 2009)

The implications of Table-4.9 are summarized below:

- Relatively, in kebele 01/02 flood generated as a result of urbanization could safely be discharged in to final receiving natural water ways. This enables other urban utilities to give the expected service as per their designed period.
- On the other hand, particularly in kebele 08/15 the flood generated could not safely be discharged in to the final receiving water ways. This results in degradation of urban utilities including road infrastructure, inundation on open surfaces.
- The municipality may allocate additional money for maintaining the degraded utilities.
- The productive urban land gets shrink due to land degradation and erosion.
- The water supply lines could be exposed for disease causing organisms.

Generally, in the sub-city the flood generated during the rainy season could not safely be discharged in to the final receiving natural water ways. That is why, during field survey (in the time of rain event) it was common to observe runoff (flood) that flows over the surface of roads and other urban utilities-this is evidenced by Figure-4.18.

Fig-4.18 Flood over flowing on road surfaces kebele13/14 (source: Field survey, 2009).

4.4.2 The existing condition and coverage of Road infrastructure and its performance

The existing condition and coverage of Road infrastructure have been fully surveyed and studied in the three sample kebeles to study whether the Road infrastructure in the study area are in a good performance or not, because Roads adequately integrated with storm water drains have a good performance with longer service life than those without storm water drains. The bases as well as surface degradation of roads will get down when there is a proper integration between road and urban storm water drains.

Accordingly the existing condition and coverage of the Road infrastructure with their surface types for the three kebeles have been summarized and depicted in Table-4.10.

Table-4.10 Summary of road surface type and existing surface condition.

Kebele	Road surface type	Existing Surface condition (meters, m)					Total
		segments	V.good	Good	Light	Severe	
01/02	Asphalt	6	-	2,785.69	829.11	-	3,614.80
	Stone surfaced	86	-	4,728.44	8,206.00	1,904.29	14,838.73
	Gravel	28	-	395.75	4,925.70	295.06	5,616.51
	Red ash	9	-	-	1,149.17	405.46	1,554.63
	Sub-total	129	-	7,909.88	15,109.98	2,604.81	25,624.67
	Percent proportion			31%	59%	10%	100.00%
08/15	Asphalt	13	-	1,684.42	1,010.53	673.47	3,368.42
	Stone surfaced	100	-	4,132.20	9917.27	2,479.32	16,528.79
	Gravel	11	-	-	2709.90	968.73	3,678.33
	Red ash	2	-	-	183.03	-	183.03
	Sub-total	126	-	5,816.62	13,820.73	4,121.52	23,758.57
	Percent proportion		-	24.5%	58.2%	17.3%	100.00%
13/14	Asphalt	12	2,503.0	2,694.57	1,077.65	718.43	6,993.65
	Stone surfaced	18	-	-	2171.71	1,001.25	3,172.96
	Gravel	96	-	1,692.65	7,988.06	7,860.30	17,541.01
	Sub-total	126	2,503.0	4,387.22	11,238.42	9,579.98	27,707.62
			9.0%	15.8%	40.6%	34.6%	100.00%
Grand total			2,503.00	11,114.70	40,169.13	16,306.31	77,090.56
Percent proportion			3.24%	14.44%	52.17%	21.15%	100.00%

Source: Field survey and GIS analysis, 2009.

From Table-4.10 it has evidenced that, in kebele 01/02, of the total road surface condition 30.87% is good, 58.97% is light and 10.16% is severe and in kebele 08/15, 24.48% is good, 58.17% light and 17.35% is severe and in kebele 13/14, 15.83% is good, 40.56% light and 34.57% is severe.

Generally, of the total roads in the three sample kebeles 14.44% is good, 52.17% is light and 21.15% is severe. Light and severely degraded roads together comprises of 73.26%. As it was critically studied during field survey almost 90% of the deteriorated and degraded and/or eroded roads have occurred due to the absence of adequate urban storm water drainage infrastructure that discharges the flood generated safely in to the final receiving systems. Figure-4.19 “A” and “B” are notable examples to this truth.

Fig-4.19 Highly eroded (A)and flooded road(B) surfaces (source: Field survey August, 2009).

From the field survey it was evidenced that water supply lines, telephone lines, bases of residences’ foundation and other buildings have seriously degraded due to the inadequate urban storm water drainage provision and management. For example in kebele 08/15 water supply lines and road bases have seriously degraded-as depicted in Figure-4.20.

fig-4.20 Degraded water supply lines (source: Field survey, 2009).

In many parts of the study area flood over flows on the surface of roads during rainy events. For example, in kebele 13/14 it was observed that accelerated and concentrated flood was flowing over the surface of a road, which is evidenced by Figure-4.21.

Fig-4.21 Flood flowing over the surface of roads (source: Field survey August, 2009).

4.4.3 Integration of Road and Urban storm water drainage lines.

The integration of Road and Urban drainage lines has a greater significance in alleviating otherwise reducing the flood hazards which may occur as a result of reduced infiltration due to surface payments, constructions and deforestation. Urban storm water drainage and road infrastructure should well be integrated so as to remove floods, which is generated within urban centers or coming from an external source, safely or with a minimum risk to the final receiving natural water ways. By so doing, the aesthetic (environmental situation), the condition of urban utilities (road bases, buildings, water supply lines, telephone lines, electric lines, railway bases) and quality of life of city residents will get improved. But, in the study area, due to inadequate integration of road and urban storm water drains the following major problems have been observed: road base and road surface degradation, widening of river banks, erosion on road bases and road surfaces, degradation of Urban utilities, blockage of urban drainage lines, inundation of rain water on vacant surfaces which may breed and/or harbor disease causing organisms.

The existing integration of road and urban storm water drainage infrastructure is discussed here under:

i. Kebele 01/02

$$\text{Urban storm water drainage (USWD) density} = \frac{\text{Total drainage lines}}{\text{Kebele built up area}} * 100 \text{ -------- (14)}$$

$$= \frac{8.6\text{ km}}{238.8\text{ ha}} * 100$$

= 0.036 km of USWD line per hectare of area or 3.6%

$$\text{Drainage line and Road integration} = \frac{8.6\text{ km}}{25.6\text{ km}} = 0.3359$$

= 336 meters

Built-up area( ) =37689073.90m² ( )) non-built up(green) area =43,911708.61m²
total=81,600,782.51m².

Fig-4.22 Shows the built-up and non-built up area of Yeka sub-city (source: own analysis)

That is, for every kilometer of road there is only 336 meters of drains, which means only 33.59% of the road have drains. The rest 66.41% has no drain that safely discharges the flood generated within the kebele.

ii. Kebele 08/15

$$\text{Urban storm water drainage (USWD) density} = \frac{\text{Total drainage lines}}{\text{Built up area}} * 100 \text{ ------- (15)}$$

$$= \frac{4.38 \text{ km}}{648\text{ha}} * 100$$

$$= 0.00676\text{km} \sim 6.70\text{m of drain per hectare of area.}$$

$$\text{Or } 0.67\%$$

$$\text{Road to Drainage line integration in kebele 08/15} = \frac{4.38 \text{ km}}{23.76 \text{ km}} = 0.1843 \text{ km}$$

$$= 184 \text{ meters}$$

That is, for every kilometer of road there is only 184 meters of drains, which means only 18.43% of the road have drains. The other 81.57% have no drainage lines.

iii. Kebele 13/14

$$\text{Urban storm water drainage (USWD) density} = \frac{\text{Total drainage lines}}{\text{Built up area}} * 100 \text{ -------- } (16)$$

$$= \frac{8.39 \text{ km}}{145 \text{ ha}} * 100$$

$$= 0.0578 \sim 5.7\text{m per hectare of area or } 5.7\%.$$

$$\text{Road to Drainage line integration in kebele13/14} = \frac{8.39 \text{ km}}{27.71 \text{ km}} = 0.3027 \text{ km} = 303\text{m}$$

From this, for every kilometer of road there is only 303 meters of drains, which means only 30.27% of the road have drains. The other 69.73% have no drainage lines.

The summary of the drainage density and the integration between road and urban storm water drainage infrastructure in the study area have presented in Table-4.11.

Table 4-11 Summary of USWD density and Road and USWD integration in the study area.

No.	Keble	USWD density (%)	Road and USWD integration(m)
1	01/02	3.6	336
2	08/15	0.67	184
3	13/14	5.7	303
4	Average of Yeka Sub-city	3.23	271.33
5	Addis Ababa Average	15.01	Not known
6	World average	18	Not known

Source: field survey and GIS analysis, 2009 but Addis Ababa average from literatures.

As depicted in Table-4.11, average USWD density and Road to USWD integration at Yeka sub-city was found 3.23 % and 271meteres respectively. That is, the urban storm water drainage density of the study area is less than by 78.47% from that of the Addis Ababa average.

Generally, the implications of the above discussions regarding the integration between road and urban storm drainage lines integration in the study area are:

- The flood generated within the study area could not safely be discharged in to the final receiving system.
- The problem of flood gets increased to excessive amount leading to environmental degradation like erosion and water pollution.
- The degradation of urban utilities and road increases to a larger amount.
- Inundation of storm water on vacant surfaces, which decreases the aesthetic value of the areas.

This study clearly showed that:

- the environmental impact of the drainage system has resulted in:
    - accelerated and concentrated runoff.
    - degradation of soil and water resources.
    - the productive urban land shrinks due to erosion.
    - stagnation and/or inundation of rain water on vacant spaces.
    - river bank degradation.
- there is a serious flood problem in Yeka sub-city because of deforestation of Yeka mountain and inadequate integration between road and storm water drains.
- urban utilities are vulnerable to degradation and may have shorter service life than expected.

4.5 Urban storm water drainage net-work design options

To safely remove flood generated in an urban center and to discharge it to final receiving system there should be a well planned, designed and adequate urban storm water drainage net-work infrastructure.

In light of this, based on the information gathered during field survey and challenges observed in the study area the following urban storm water drainage net-work option has planned and designed to properly manage the urban drainage system in the study area.

Some of the major components which have been considered and followed steps in planning and designing the aforementioned net-work includes:

i. rainfall intensity.
ii. catchment/draining area of each drainage line.
iii. time of concentration.

iv. elevation difference or slope of each specific drainage line.
v. flow speed of the flood in each drains.
vi. runoff coefficient or surface condition of the total drainage area.
vii. surface condition of the drainage lines, that is the manning's coefficient)
viii. drainage line length.

Based on this information, the drainage lines have been designed with three alternative drainage line shapes namely: Trapezoidal, Rectangular and Circular. The basic reasons to design for these three drain shapes is to let the municipality or any other concerned body to use one of them depending on their budget availability and soil types.

Thus, the selection of these drainage lines shapes depends on: Soil types, environmental considerations and available finance. For example, if the sub-city has sufficient finance it is advisable to use the Trapezoidal drainage line type and to prevent connection of toilets to drains, to prevent air pollution and other unnecessary smells it is better to use the circular one. Finally, if the sub-city has not sufficient budget but stable soil structure the Rectangular one can be used as a third option. Generally, from environmental point of view the circular (buried) type of urban storm water drainage line is selected for the study area-there by air pollution and respiratory disease causing agents will be discouraged.

The following procedures have been employed in preparing the drainage net-work design:

I. **Hydrological Analysis** for the selected two recurrence periods (Year Ten and Five for collector and individual/single drains respectively).

$$R_{10}^{60} = 0.27*X*N^{0.33} \text{ -- } (17)$$

$$R_t^T = (0.21*\ln T + 0.52) * (0.54*t^{0.25} - 0.52)*R_{10}^{60} \text{ -- } (18)$$

By substituting the values of X= 56 and N= 145 in to equation-(16): $R_{10}^{60} = 0.27*X*N^{0.33}$ yields 78mm. The corresponding values of "t" for 10, 20, 30, 45, 60, 90 and 120 minutes have given in Table-4.12.

Table-4.12 value of R_{10}^{60} for year 5 (i.e. T=5) R_t^T

0.21	1.6094	0.52	0.54	10	0.25	0.5	78	30.802
0.21	1.6094	0.52	0.54	20	0.25	0.5	78	42.961
0.21	1.6094	0.52	0.54	30	0.25	0.5	78	51.114
0.21	1.6094	0.52	0.54	45	0.25	0.5	78	60.137
0.21	1.6094	0.52	0.54	60	0.25	0.5	78	67.116
0.21	1.6094	0.52	0.54	90	0.25	0.5	78	77.846
0.21	1.6094	0.52	0.54	120	0.25	0.5	78	86.146

Table-4.12 value of R_{10}^{60} for Year 10 (i.e. T=10) R_t^T

0.21	2.3026	0.52	0.54	10	0.25	0.5	78	36.905
0.21	2.3026	0.52	0.54	20	0.25	0.5	78	51.077
0.21	2.3026	0.52	0.54	30	0.25	0.5	78	60.579
0.21	2.3026	0.52	0.54	45	0.25	0.5	78	71.095
0.21	2.3026	0.52	0.54	60	0.25	0.5	78	79.23
0.21	2.3026	0.52	0.54	90	0.25	0.5	78	91.736
0.21	2.3026	0.52	0.54	120	0.25	0.5	78	101.41

II. Frequency and Intensity Analysis

Table-4.13 Value of Intensity for the given duration of time

Duration/frequency			10min	20min	30min	45min	60min	90min	120min
T=5yr		RF(mm)	30.80	42.96	51.11	60.14	67.12	77.85	86.15
		I(mm/hr)	184.81	128.88	102.23	80.18	67.12	51.90	43.07
T=10yr		RF(mm)	36.90	51.08	60.58	71.10	79.23	91.74	101.41
		I(mm/hr)	221.43	153.23	121.16	94.79	79.23	61.16	50.71

III. The process/techniques of Linear regression for the given periods of time has depicted on following tables-4.14 and 4.15, below.

Table-4.14 For year 5

Td(min)	X	X2	Y	Y2	X*Y
10	-0.33	0.11	2.27	5.14	-0.75
20	-0.20	0.04	2.11	4.45	-0.42
30	-0.10	0.01	2.01	4.04	-0.19
45	0.02	0.0004	1.90	3.63	0.04
60	0.11	0.01	1.83	3.34	0.21
90	0.26	0.07	1.72	2.94	0.44
120	0.36	0.13	1.63	2.67	0.59
Summ.	0.13	0.37	13.47	26.20	-0.09

Table-4.15 for year 10

Td(min)	X	X2	Y	Y2	X*Y
10	-0.33	0.11	2.35	5.50	-0.78
20	-0.20	0.04	2.19	4.78	-0.43
30	-0.10	0.01	2.08	4.34	-0.20
45	0.02	0.0004	1.98	3.91	0.04
60	0.11	0.01	1.90	3.61	0.22
90	0.26	0.07	1.79	3.19	0.46
120	0.36	0.13	1.71	2.91	0.62
summ.	0.13	0.37	13.98	28.23	-0.08

Determination of the value of K;

$K_5 = (\sum x^2)*(\sum Y) - (\sum X)*(\sum X * \sum Y)/n*(\sum X^2) - (\sum X)^2$ ----------------------------- (19)

By inserting values from table-4.14 in to equation (17) the value of 'K_5' and 'a_5' was computed and presented in equation (18) and (19) respectively.

K_5=1.9**,** K5= log (a_5)

Then, $a_5 = \log^{-1}(1.94)$, a_5= 87.1

$k_5 = (\sum x^2)*(\sum Y) - (\sum X)*(\sum X * \sum Y) / n*(\sum X^2) - (\sum X)^2$

In a similar analogy the value of 'k_{10}' and 'a_{10}' have presented as follows:

k_{10}= 2.0058

Then, $a_{10}= \log^{-1}(2.0058)$, a_{10}= 101.3

By substituting these values in to the general Rain fall intensity(I) formula given in equation(8) the rain fall intensity formula for year five and ten is represented by equation (20) and (21) respectively:

$I_5 = 87.1/(0.3 + t_d)$ -- (20)

$I_{10} = 101.3/(0.3 + t_d)$ -- (21)

The following major methods were employed in designing the Urban Storm Water Drainage net-work. The methods adopted in preparing the design are:

Rain fall intensity (I): this was calculated with the help of equation-(8), and equation-(20) and–(21) have been employed to estimate the rain fall intensity for individual and collector drainage lines respectively.

The channel slope = ((terminal – initial) elevation / channel or drain length**)***100--- (22)

Discharge, Q (m^3/s) = CIA**,** where C=run-off coefficient, I (mm/hr) =Run-off intensity and A (m^2)=the corresponding catchment area that drains in to a corresponding drainage line.

Diameter of pipe, Dp= $(3.2*n*Q/S^{1/2})^{0.375}$ -- (23) where, n=manning's coefficient which is a standard table value, Q=discharge, S (%) = slope of a drainage line.

To make the design manipulations easier and appropriate the dimensions of the three alternative drainage line shapes were related with the pipe diameter(Dp) with the following techniques, the relations have done by trial and error to get the maximum allowable amount (source: FUPI, 2008).

- **Bottom Base of Trapezoidal drain,** B=0.80*Dp -------------------------------------- (29)
- **Upper Base of Trapezoid drain,** T= 2*B --- (30)
- **Depth of a Trapezoid drain,** Y=0.866*Dp+ free board----------------------------- (31)
  The free board is taken as 0.20 and 0.30 when the catchment area is less than and greater than 50hectares respectively.
- **Base of a Rectangular drain,** Br=1.25*Dp --- (32)
- **Depth of a Rectangular drain**, Yr=0.5*Dp+ free board ----------------------------- (33)
  The free board is added based on the size of the catchment area of each corresponding drainage line(drain) which is same to the case of depth of a trapezoidal drain.
- **Diameter of a Circular drain**, D=Dp+ free board -------------------------------------- (34)
  The free board is added in a way similar to that of the depth of Rectangular and Trapezoidal drain.
- **Area of pipe/circular drain**, $Ap=3.14*Dp^2/4$ --- (33)
- **Speed of flood or storm water** (V)= 0.77* Q/A_p -- (34)
  where 0.77 is used to compensate or balance the effect of retarding materials like weeds, sediments and the like when storm water travels within a drain.

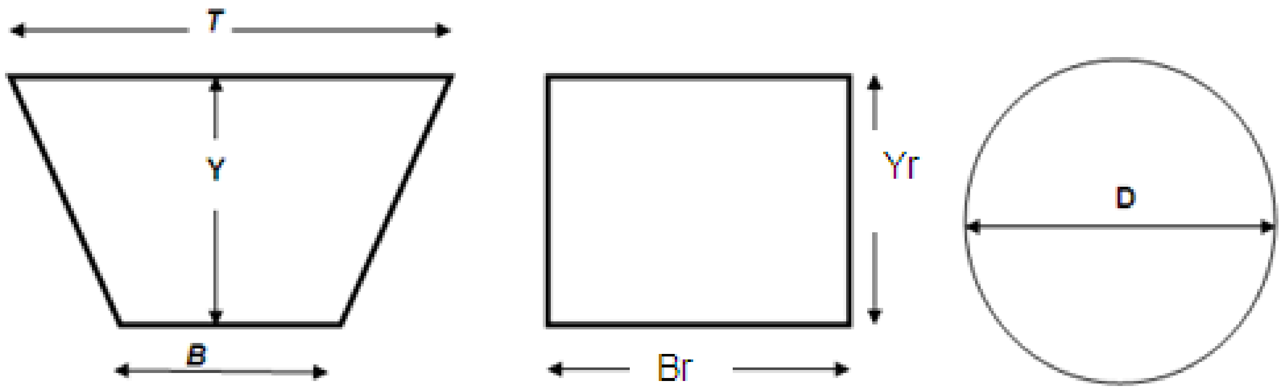

Fig-4.30 The three alternative urban storm water drainage line shapes with their dimension designations.

Because of its excessiveness part of the data have presented in Table-4.16, where as the full design sheet is given in Appendex-1.

Table-4.16 Part of the urban storm water drainage net-work design sheet.

code	elevation		channel length	channel slope(%)	T_{pipe} (min	Tc (hr)	I (mm/hr	each area (m^2)	cum_area (m^2)	Q (m^3)	Dp (m)	Alternative drain shapes(m)						Ap (m^2	V (m/s
	initia	term										Trapezoidal (m)			Rectangular(		Circular		
												B	Y	T	B	Y	D		
D1	2515	2473	309	13.6		0.16	189.34	50908	50908	1.87	0.69	0.55	0.80	1.11	0.86	0.55	0.89	0.38	3.84
D2	2512	2483	121	24.0		0.17	186.64	3464	3464	0.13	0.23	0.18	0.40	0.36	0.28	0.31	0.43	0.04	2.42
D3	2505	2480	140	17.9		0.17	186.64	8725	8725	0.32	0.34	0.27	0.49	0.54	0.42	0.37	0.54	0.09	2.73
D4	2481	2477	156	2.6		0.20	175.20	12550	12550	0.43	0.54	0.43	0.67	0.87	0.68	0.47	0.74	0.23	1.42
D4.1	2481	2473	95	8.4	0.02	0.22	196.43	6105	21170	0.81	0.55	0.44	0.68	0.88	0.69	0.48	0.75	0.24	2.60
D5	2478	2457	107	19.6		0.17	186.64	7770	7770	0.28	0.32	0.25	0.47	0.51	0.40	0.36	0.52	0.08	2.75
D6	2488	2477	112	9.8		0.11	213.88	2515	2515	0.10	0.25	0.20	0.42	0.40	0.31	0.32	0.45	0.05	1.65
D7	2488	2478	225	4.4		0.20	175.09	22479	22479	0.77	0.61	0.49	0.73	0.98	0.76	0.50	0.81	0.29	2.02
D7.1	2478	2472	91	6.6	0.01	0.21	198.64	2634	25113	0.97	0.62	0.50	0.74	0.99	0.77	0.51	0.82	0.30	2.48
D7.2	2478	2472	135	4.4	0.02	0.23	192.93	5645	30758	1.15	0.71	0.57	0.82	1.14	0.89	0.56	0.91	0.40	2.24
D8	2463	2459	74	5.4		0.17	186.64	3933	3933	0.14	0.31	0.25	0.47	0.50	0.39	0.36	0.51	0.08	1.43
D9	2459	2455	47	8.5	0.01	0.18	212.90	1999	5932	0.25	0.35	0.28	0.51	0.56	0.44	0.38	0.55	0.10	1.94
D10	2458	2434	434	5.5		0.26	156.89	37814	37814	1.15	0.68	0.55	0.79	1.09	0.85	0.54	0.88	0.37	2.43
D11	2440	2418	238	9.2		0.17	186.64	253025	253025	9.18	1.35	1.08	1.37	2.16	1.69	0.87	1.55	1.43	4.95
D11.1	2600	2430	395	43.0		0.17	186.64	46575	46575	1.69	0.54	0.43	0.66	0.86	0.67	0.47	0.74	0.23	5.77
D12	2600	2430	378	45.0		0.17	186.64	4624	4624	0.17	0.22	0.18	0.39	0.36	0.28	0.31	0.42	0.04	3.29
D13	2449	2430	155	12.3		0.17	186.64	4161	4161	0.15	0.27	0.22	0.44	0.44	0.34	0.34	0.47	0.06	1.97
D13.1	2430	2421	93	9.7	0.01	0.18	211.14	2418	6579	0.27	0.36	0.29	0.51	0.57	0.45	0.38	0.56	0.10	2.08
D13.2	2421	2414	80	8.8	0.01	0.19	206.55	2773	16640	0.67	0.51	0.41	0.64	0.82	0.64	0.46	0.71	0.20	2.52
D14	2449	2432	153	11.1		0.17	186.64	7179	19249	0.70	0.50	0.40	0.63	0.79	0.62	0.45	0.70	0.19	2.78

Source: own design sheet (November, 2009).

Note: - T_{pipe}= time taken for a flood to flow within a drainage line. Ap = area of pipe, Initia = initial elevation, Term = terminal elevation, Dp = diameter of pipe. For simplicity each drainage lines are coded with specific codes for example D1 means Drainage number1.

Three of the alternative drainage shape is designed with a sufficient free board to prevent any unexpected or excess flood other than the designed one.

According to the above alternative design option the integration between road and urban drainage infrastructure has improved when compared to the existing integration. The summary of this is presented in Table-4.17.

Table-4.17 comparison between the new designed and existing urban drainage lines.

Kebele	Length of newly designed USWD line	Existing			Existing USWD line and Road integration	New USWD and Road integration	Improved by
		USWD lines	Road	Built-up area			
01/02	16.6km	8.6km	25.60km	238.8ha	1:0.336	1:0.648	48%
08/15	15.2km	4.38km	23.76km	648ha	1:0.184	1:0.639	71%
13/14	18.1km	8.4km	27.71km	145ha	1:0.303	1:0.653	54%

Source: own analysis (November, 2009)

From Table-4.17, the integration of urban drainage line and road in Kebele 01/02 has improved by 48%. This is to mean for every kilometer of road there will be 648meter of a drainage line or nearly 65% of the roads will have drainage lines. In a similar analysis about 64% and 65% of the roads in kebele 08/15 and 13/14 respectively will have drainage lines. The implication of this, generally, is to safely discharge the flood generated within each kebeles in to the final receiving systems thereby reducing the damages that occurs on urban utilities and degradation of the scarce urban land. That is, specifically the existing condition of the urban drainage and the environment system as a whole will be improved.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This study has been carried out with the help of base map and checklists to study the overall drainage system, the impact of Yeka mountain, the integration between road and urban drainage infrastructure, the existing condition of natural water ways and related issues in Yeka sub-city, particularly in kebele 01/02, kebele 08/15 and kebele 13/14. These kebeles were selected due to the fact that they are representative to address the objectives of this research study.

The data collected with the help of base map and checklists were transferred in to AutoCAD and then to GIS software. The existing road infrastructure was digitized to analyze the existing condition, and pavement of roads. Whereas Shape files were created on the ArcCatalog and then the collected data concerning the urban storm water drainage lines along with their conditions, types and pavements were transferred into ArcMap for a simplified analysis. This is because the drainage lines were not present on the base map and hence to make the analysis easier.

The urban drainage design option was carried out with the help of Microsoft excel to properly plan and design the urban drainage net-work with all necessary techniques.

Generally, the following major points have drawn as conclusions in line with the objectives of this study:

- Topography and geological formations are the major challenges in managing the urban drainage system by aggravating the problem of flood through reduced infiltration capacity of the land and these features are barrier to afforestation due to the fact that they do not allow planted seedlings to survive at a maximum rate.
- Due to deforestation on Yeka Mountain the environmental degradation is serious and the flood washes non-point source pollutants which then pollutes the existing urban environment. It is because of this the productive urban land shrinks. The eroded soil has blocked the existing drainage lines and natural water ways thereby

reduces the effective carrying capacity of these structures. This on the other hand has led to over topping of flood on infrastructure.

- Informal settlement and quarrying degraded the general environment by reducing the productive urban land and by making the place to generate additional flood through concentrated, accelerated and peak run-off.
- Most of the natural water ways have no buffer zones and serves as sewerage lines and most residents connect their toilets to natural water ways and drainage lines. It is these situations that worsen the conditions of natural water ways unmanageable.
- Most of the construction sites including housing construction, water supply lines, electric lines and telephone lines installation do not consider the effect of such infrastructure and utility development on the general environment.
- Yeka Mountain is relatively bare and predominantly covered by eucalyptus tree, which does not allow other shrubs and grasses to grow underneath due to its high competition to water and nutrients through its allelopathic effect.

- Taking the average annual number of rainy days in Addis Ababa the total amount of annual storm water that enters in to Yeka sub-city from Yeka Mountain is estimated to be 126,440m^3 per year. That is, this amount of water wastes with no use. If this rain water were properly harvested and utilized 6,928 persons would get their water consumption from this source, taking 50liter average daily water consumption per person (6,928 = 126,440m^3/ 50lt/people*365dys/yr).

- If Yeka mountain were fully covered by forest the value of run-off coefficient “c” would decrease(from 0.7 to 0.25) and this allows flood to infiltrate in to the soil instead of flood generation thereby decreasing the total amount of flood generated as a result of infiltration. This will improve the reliable ground water source by recharging itself.
- The major pollutants which are common in most urban storm water drainage system were analyzed from a sample of three kebeles and three sample rivers which passes through the study area.

These common pollutants were analyzed under three conditions:

i. before a rain felled.
ii. in between the rainy period.
iii. after the rain stopped

- The following pollutants which were analyzed in the laboratory have included: Total suspended solids, Total Solids, Total dissolved solids, Nitrate, Nitrite, Phosphate, Total and Fecal coli forms. The analyses were carried out externally by the “Water works Design and Supervision Enterprise Laboratory Service”. The result of this analysis showed that:
  - total suspended, total dissolved and total solids were high during a rainfall event than before and after a rainfall event. This was because runoff contributes for greater amount of solids to be washed and joined the rivers.
  - both total and Fecal coli-form are maximum before a rain event than within and after a rain event. The presence of maximum coli-form before a rainfall indicated that the river waters are highly concentrated as a result of toilet connections, and solid waste disposals in to rivers with a reduced peak water volume. Whereas, in rainy season because of high peak flow rain water the river water gets diluted.
- Effective drainage is the key to longer lasting roads. Neglected urban drainage infrastructure lead to the deterioration of the entire road structure. Simple clearing of the drains and culverts can prolong the life of urban drainage lines as well as roads as a proactive measure before the beginning of every rainy season.
- Road and urban drainage infrastructure provision are indispensible in an urban center for safe and easy reachability from one area to another and to protect flood damage on urban infrastructure and utilities as a result of pavement or imperviousness.

- The integration of road and urban drainage lines have critically surveyed for the three sample kebeles and found that there is inadequate integration between road and urban drainage lines. As evidence, in kebele 01/02 it is only 3.6%, in kebele 08/15, 0.67% and in kebele13/14, 5.7 % of the roads have urban drainage infrastructure. Correspondingly, the greater proportions of roads in both kebeles have no drains-this on the other hand aggravates the problem of flooding.

- The emphasis to keep the overall drainage system is very minimal or generally ignored in the study area.
- The challenges to handle the problems of the drainage system are manmade and are possible to manage at the coordinated effort of the community and concerned bodies.
- The existing urban drainage lines or infrastructure could not accommodate or safely discharge in to the final receiving system.
- To curb the existing inadequate integration of road and urban storm water drainage infrastructure an alternative and appropriate drainage infrastructure have been planned and designed with the help of ArcGIS with a full consideration of hydrology and rainfall intensity analysis. This will reduce and then avoid the existing environmental degradation problems if implemented as the original plan and design.

5.2 RECOMMENDATIONS

- Sustainable urban storm water drainage management through:
  - introducing fast growing indigenous trees, shrubs and grasses to increase the forest coverage of Yeka mountain so that flooding problem and environmental degradation on the lower catchment areas will get minimized.
  - grassing and use of permeable structures on gardens, vacant areas, river and road sides to increase infiltration and reduce flooding hazards like the one which has been experienced by the AAEPA on Jelissa river around Gurd shola.
- Integrated solid waste management:
  - through the coordination effort of various stake holders and line ministries as solid waste management will not be effective only by a single body.
  - by providing adequate transfer sites equitably to each locality to encourage solid wastes to be damped only in to authorized places.
  - through awareness creation not to damp solid wastes and other toxic chemicals in to unauthorized places like rivers, vacant areas and drainage lines.
- The buffer zones of rivers set by the AAEPA should be implemented for the sustainable urban drainage management of rivers thereby to reduce and then avoid the ever existing pollution problem on them. This should be done through consensus.

- River buffer zone and bank development through the participation of private sectors will facilitate the sustainable development of rivers and will increase their aestheticity.
- Provision of appropriate sewerage system to safely discharge the liquid wastes and to properly manage and use the urban drainage lines as per their primary design objectives.
- Provision of communal or community toilets to discourage open defecation there by non-point source pollution will be reduced through such an integrated effort.
- Development of storm water drainage system is not possible in isolation from other infrastructure and environmental sectors. Thus, Coordination is necessary between, different; departments, government, NGOs and other stakeholders.
- Use of gabion retaining walls to prevent river bank erosion instead of paved retaining walls to allow root penetration and soil trapping.
- Through discussion and consensus prohibiting illegal quarrying activities which are the major cause of flooding.
- The use of rain water harvesting technologies should highly be encouraged to reduce flooding hazards, to recharge the ground water, to keep soil moisture, to reduce natural resource degradation, to solve the problem of water shortage for planted seedlings and other water requiring activities
- Indigenous trees should be utilized for afforestation programs on Yeka Mountain and other greeneries followed by various physical conservation activities to reduce soil erosion.
- Roof water harvesting should be introduced for rain water harvesting which can be employed for domestic uses, gardening and related activities. In doing so it will reduce the peak runoff discharge and the problem of environmental degradation.
- The newly designed urban drainage infrastructure shall be implemented so that the flood generated within each kebele can safely be discharged in to the final receiving systems.

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APPENDIX-1: Alternative urban storm water drainage net-work design sheet

i. **Kebele 01/02.**

code	flow direction	channel length	Channel slope (%)	Tc (hr)	I (mm/hr)	area (m^2)	Q (m^3)	Alternative drainage shapes: Trapezoidal			R e c t an g u l a r(m)		Circular	V (m/s)
								B	Y	T	Br	Yr	D(m)	
D1	D1-D7.1	309	13.6	0.16	189.34	50908	1.87	0.55	0.80	1.11	0.86	0.55	0.89	3.84
D2	D2-outlet	121	24.0	0.17	186.64	3464	0.13	0.18	0.40	0.36	0.28	0.31	0.43	2.42
D3	D3-outlet	140	17.9	0.17	186.64	8725	0.32	0.27	0.49	0.54	0.42	0.37	0.54	2.73
D4	D4-D4.1	156	2.6	0.20	175.20	12550	0.43	0.43	0.67	0.87	0.68	0.47	0.74	1.42
D4.1	D4.1-D7.2	95	8.4	0.22	196.43	21170	0.81	0.44	0.68	0.88	0.69	0.48	0.75	2.60
D5	D5-outlet	107	19.6	0.17	186.64	7770	0.28	0.25	0.47	0.51	0.40	0.36	0.52	2.75
D6	D6-D4.1	112	9.8	0.11	213.88	2515	0.10	0.20	0.42	0.40	0.31	0.32	0.45	1.65
D7	D7-D7.1	225	4.4	0.20	175.09	22479	0.77	0.49	0.73	0.98	0.76	0.50	0.81	2.02
D7.1	D7.1-D7.2	91	6.6	0.21	198.64	25113	0.97	0.50	0.74	0.99	0.77	0.51	0.82	2.48
D7.2	D7.2-D9	135	4.4	0.23	192.93	30758	1.15	0.57	0.82	1.14	0.89	0.56	0.91	2.24
D8	D8-D9	74	5.4	0.17	186.64	3933	0.14	0.25	0.47	0.50	0.39	0.36	0.51	1.43
D9	D9-outlet	47	8.5	0.18	212.90	5932	0.25	0.28	0.51	0.56	0.44	0.38	0.55	1.94
D10	D10-outllet	434	5.5	0.26	156.89	37814	1.15	0.55	0.79	1.09	0.85	0.54	0.88	2.43

D11	D11-outlet	238	9.2	0.17	186.64	3E+05	9.18	1.08	1.37	2.16	1.69	0.87	1.55	4.95
D11.1	D11.1-D13.1	395	43.0	0.17	186.64	46575	1.69	0.43	0.66	0.86	0.67	0.47	0.74	5.77
D12	D12-D13.1	378	45.0	0.17	186.64	4624	0.17	0.18	0.39	0.36	0.28	0.31	0.42	3.29
D13	D13-D13.1	155	12.3	0.17	186.64	4161	0.15	0.22	0.44	0.44	0.34	0.34	0.47	1.97
D13.1	D13.1-D13.2	93	9.7	0.18	211.14	6579	0.27	0.29	0.51	0.57	0.45	0.38	0.56	2.08
D13.2	D13.2-D17	80	8.8	0.19	206.55	16640	0.67	0.41	0.64	0.82	0.64	0.46	0.71	2.52
D14	D14-outlet	153	11.1	0.17	186.64	19249	0.70	0.40	0.63	0.79	0.62	0.45	0.70	2.78
D14.1	D14.1-D17	174	10.3	0.17	186.64	46310	1.68	0.56	0.81	1.12	0.87	0.55	0.90	3.38
D15	D15-D13.2	75	2.7	0.17	186.64	7288	0.26	0.36	0.59	0.72	0.56	0.43	0.65	1.28
D16	D16-D17	385	2.1	0.33	137.83	35490	0.95	0.61	0.86	1.22	0.95	0.58	0.96	1.60
D17	D17-D18	225	3.1	0.37	150.99	2E+05	6.30	1.15	1.44	2.30	1.80	0.92	1.64	2.99
D18	D18-D19	108	0.9	0.38	148.76	2E+05	6.81	1.49	1.81	2.97	2.32	1.13	2.06	1.94
D19	D19-D20	198	1.0	0.41	142.81	3E+05	7.14	1.49	1.81	2.98	2.32	1.13	2.06	2.03
D20	D20-D21	205	2.9	0.44	137.37	3E+05	7.29	1.23	1.53	2.46	1.92	0.97	1.74	3.03
D21	D21-D22	66	6.1	0.03	303.15	3E+05	16.7	1.46	1.78	2.92	2.28	1.11	2.03	4.90
D22	D22-outlet	85	4.7	0.17	217.07	4E+05	15.2	1.48	1.80	2.96	2.31	1.12	2.05	4.35
D23	D23-D18	93	8.6	0.17	186.64	9704	0.35	0.32	0.55	0.64	0.50	0.40	0.60	2.13
D24	D24-D19	69	8.7	0.17	186.64	7759	0.28	0.30	0.52	0.59	0.46	0.38	0.57	2.02
D25	D25-D26	291	2.7	0.26	154.67	15866	0.48	0.45	0.68	0.89	0.70	0.48	0.76	1.50

D26	D26-D20	288	6.3	0.32	164.32	49719	1.59	0.60	0.85	1.20	0.94	0.58	0.95	2.76
D27	D27-D28	180	6.7	0.17	187.07	4415	0.16	0.25	0.47	0.50	0.39	0.36	0.51	1.59
D28	D28-D29	138	8.7	0.19	206.42	9127	0.37	0.33	0.55	0.65	0.51	0.40	0.61	2.16
D29	D29-D21	232	7.3	0.22	194.59	7676	0.29	0.31	0.53	0.62	0.48	0.39	0.59	1.91
D30	D30-D31	205	8.8	0.17	186.64	13907	0.50	0.37	0.60	0.73	0.57	0.43	0.66	2.35
D31	D31-D21	178	6.7	0.19	207.71	26315	1.06	0.51	0.75	1.02	0.80	0.52	0.84	2.56
D32	D32-D31	187	7.0	0.17	186.64	6684	0.24	0.29	0.52	0.58	0.46	0.38	0.56	1.79
D33	D33-D35	87	5.7	0.17	186.64	9843	0.36	0.35	0.58	0.70	0.55	0.42	0.64	1.84
D34	D34-D35	123	7.3	0.17	186.64	3575	0.13	0.23	0.45	0.46	0.36	0.34	0.49	1.56
D35	D35-D36	111	9.9	0.19	208.27	23485	0.95	0.46	0.69	0.91	0.71	0.48	0.77	2.88
D36	D36-D37	231	6.5	0.21	199.15	44082	1.71	0.61	0.86	1.23	0.96	0.58	0.97	2.85
D37	D37-D22	72	15.3	0.22	196.43	46783	1.79	0.53	0.78	1.06	0.83	0.53	0.86	3.97
D38	D38-D22	499	5.8	0.27	153.04	20392	0.61	0.43	0.66	0.85	0.66	0.47	0.73	2.11
D39	D39-D37	69	8.7	0.17	186.64	4165	0.15	0.23	0.45	0.47	0.37	0.35	0.49	1.73
D40	D40-D36	131	1.5	0.21	169.33	7940	0.26	0.40	0.63	0.80	0.62	0.45	0.70	1.03
D41	D41-D41.1	55	3.6	0.17	186.64	18931	0.69	0.49	0.73	0.97	0.76	0.50	0.81	1.82
D41.1	D41.1-D41.2	87	1.1	0.20	202.60	40713	1.60	0.83	1.10	1.66	1.30	0.72	1.24	1.46
D41.2	D41.2-D41.3	54	3.7	0.21	198.53	49073	1.89	0.71	0.97	1.42	1.11	0.64	1.09	2.37
D41.3	D41.3-D41.4	86	3.5	0.22	194.68	68255	2.58	0.81	1.07	1.61	1.26	0.70	1.21	2.50

D41.4	D41.4-out	45	4.4	0.23	192.83	72344	2.71	0.78	1.05	1.57	1.22	0.69	1.18	2.77
D42	D42-D16	166	9.6	0.17	186.64	15777	0.57	0.38	0.61	0.76	0.59	0.44	0.67	2.51
D43	D43-D43.1	193	12.4	0.17	186.64	52461	1.90	0.57	0.81	1.13	0.88	0.55	0.91	3.73
D43.1	D43.1-D43.2	113	0.9	0.25	184.72	76725	2.76	1.07	1.36	2.13	1.67	0.87	1.53	1.52
D43.2	D43.2-D25	174	3.4	0.19	207.24	91693	3.69	0.92	1.20	1.85	1.44	0.78	1.35	2.72
D44	D44-D43.1	224	14.7	0.17	186.64	15389	0.56	0.35	0.57	0.69	0.54	0.42	0.63	2.93
D45	D45-D43	283	16.3	0.17	186.64	19324	0.70	0.37	0.60	0.74	0.58	0.43	0.66	3.21
D46	D46-D14	188	80.9	0.17	186.64	12070	0.44	0.23	0.45	0.46	0.36	0.34	0.49	5.21
D47	D47-D49	176	9.1	0.17	186.64	20081	0.73	0.42	0.65	0.84	0.65	0.46	0.72	2.61
D48	D48-D49	132	3.0	0.17	184.68	5437	0.20	0.31	0.54	0.63	0.49	0.40	0.59	1.24
D49	D49-D14.1	75	4.0	0.19	207.43	28482	1.15	0.58	0.83	1.16	0.91	0.56	0.92	2.15
D50	D50-D52	118	8.5	0.17	186.64	6209	0.23	0.27	0.50	0.55	0.43	0.37	0.54	1.90
D51	D51-D52	32	25.0	0.17	186.64	1846	0.07	0.14	0.35	0.28	0.22	0.29	0.38	2.10
D52	D52-D41	226	14.2	0.20	204.00	15753	0.62	0.36	0.59	0.73	0.57	0.43	0.65	2.97
D53	D53-D41.1	197	10.7	0.17	186.64	7280	0.26	0.28	0.50	0.56	0.43	0.37	0.55	2.15
D54	D54-D41.2	171	22.2	0.17	186.64	5463	0.20	0.22	0.44	0.43	0.34	0.34	0.47	2.64
D55	D55-D41.3	228	11.0	0.17	186.64	11750	0.43	0.33	0.56	0.66	0.52	0.41	0.61	2.45
D56	D56-D41.1	127	14.2	0.17	186.64	4089	0.15	0.21	0.43	0.42	0.33	0.33	0.47	2.07
D57	D57-OUT	354	10.2	0.19	178.31	19314	0.67	0.40	0.63	0.79	0.62	0.45	0.70	2.66

D58	D58-OUT	279	10.8	0.17	186.64	13482	0.49	0.35	0.58	0.70	0.55	0.42	0.64	2.52
D59	D59-OUT	277	10.8	0.17	186.64	6786	0.25	0.27	0.49	0.54	0.42	0.37	0.54	2.12
D60	D60-OUT	269	8.2	0.18	182.77	29397	1.04	0.49	0.73	0.98	0.76	0.51	0.81	2.74
D61	D61-D62	143	0.7	0.29	147.68	3275	0.09	0.31	0.54	0.63	0.49	0.40	0.59	0.60
D62	D62-D63.1	77	20.8	0.33	161.93	4984	0.16	0.20	0.42	0.40	0.32	0.33	0.45	2.42
D63	D63-D63.1	48	4.2	0.17	186.64	1123	0.04	0.16	0.38	0.33	0.26	0.30	0.41	0.95
D63.1	D63.1-D63.2	91	5.5	0.19	205.33	11500	0.46	0.39	0.62	0.77	0.60	0.44	0.68	1.92
D63.2	D63.2-D63.3	56	17.9	0.20	202.02	16821	0.66	0.36	0.58	0.71	0.56	0.42	0.64	3.28
D63.3	D63.3-OUT	67	20.9	0.21	199.76	27861	1.08	0.42	0.65	0.83	0.65	0.46	0.72	3.94
D64	D64-D63.2	68	7.4	0.17	186.64	3668	0.13	0.23	0.45	0.46	0.36	0.34	0.49	1.58
D65	D65-D63.3	204	10.8	0.17	186.64	8205	0.30	0.29	0.51	0.58	0.45	0.38	0.56	2.22
D66	D66-OUT	525	13.7	0.21	171.47	26040	0.87	0.41	0.65	0.83	0.65	0.46	0.72	3.18
D67	D67-D67.1	101	6.9	0.17	186.64	6520	0.24	0.29	0.51	0.58	0.45	0.38	0.56	1.78
D67.1	D67.1-D67.2	56	1.8	0.18	213.08	10968	0.45	0.48	0.72	0.95	0.74	0.50	0.79	1.26
D67.2	D67.2-OUT	50	4.0	0.17	217.07	11893	0.50	0.42	0.66	0.85	0.66	0.47	0.73	1.75
D68	D68-D67.1	56	21.4	0.17	186.64	2259	0.08	0.16	0.37	0.31	0.25	0.30	0.40	2.08
D69	D69-D69.1	73	17.8	0.17	186.64	4824	0.18	0.22	0.43	0.43	0.34	0.34	0.47	2.35
D69.1	D69.1-D69.2	55	12.7	0.18	211.04	13665	0.56	0.36	0.59	0.71	0.56	0.42	0.65	2.77
D69.2	D69.2-D67.2	65	18.5	0.18	211.04	18390	0.75	0.37	0.60	0.74	0.58	0.43	0.66	3.43

D70	D70-D69.1	108	0.9	0.23	164.48	4741	0.15	0.36	0.59	0.71	0.56	0.42	0.65	0.75
D71	D71-D69.2	67	1.5	0.17	186.64	3085	0.11	0.29	0.52	0.58	0.45	0.38	0.56	0.83
D72	D72-OUT	111	12.6	0.17	186.64	4580	0.17	0.23	0.44	0.45	0.35	0.34	0.48	2.04
D73	D73-OUT	167	9.0	0.17	186.64	5826	0.21	0.26	0.49	0.53	0.41	0.36	0.53	1.91
D74	D74-OUT	202	4.0	0.19	176.19	10057	0.34	0.37	0.60	0.74	0.58	0.43	0.66	1.58
D75	D75-D17	659	2.0	0.44	117.42	2E+05	3.73	1.03	1.31	2.06	1.61	0.84	1.49	2.21
D76	D76-D77	129	7.0	0.17	186.64	5531	0.20	0.27	0.49	0.54	0.42	0.37	0.54	1.71
D77	D77-OUT	326	11.3	0.22	194.97	22413	0.85	0.43	0.66	0.85	0.66	0.47	0.73	2.95
D78	D78-OUT	103	11.7	0.17	186.64	1202	0.04	0.14	0.35	0.28	0.22	0.29	0.37	1.42
D79	D79-OUT	46	15.2	0.17	186.64	11846	0.43	0.31	0.54	0.62	0.49	0.39	0.59	2.77
D79.1	D79.1-D80	210	3.3	0.21	170.86	3743	0.12	0.26	0.48	0.52	0.41	0.36	0.53	1.15
D79.2	D79.2-OUT	23	8.7	0.17	186.64	3366	0.12	0.22	0.43	0.43	0.34	0.34	0.47	1.64
D80	D80-D81	230	6.1	0.18	181.47	11292	0.40	0.36	0.59	0.72	0.56	0.42	0.65	1.93
D81	D81-D82	191	1.6	0.21	199.63	25541	0.99	0.65	0.91	1.31	1.02	0.61	1.02	1.46
D82	D82-OUT	60	5.0	0.22	195.23	37066	1.41	0.60	0.85	1.20	0.94	0.57	0.95	2.46
D83	D83-D82	149	6.0	0.17	186.64	9683	0.35	0.34	0.57	0.69	0.54	0.41	0.63	1.87
D84	D84-OUT	99	8.1	0.17	186.64	3806	0.14	0.23	0.45	0.46	0.36	0.34	0.49	1.65
D85	D85-D88	117	2.6	0.17	185.03	8717	0.31	0.39	0.62	0.77	0.60	0.44	0.68	1.31
D86	D86-D87	89	30.3	0.17	186.64	23758	0.86	0.36	0.59	0.71	0.56	0.42	0.64	4.28

D87	D87-D88	145	16.6	0.18	212.78	3818	0.16	0.21	0.43	0.42	0.33	0.33	0.46	2.23
D88	D88-OUT	114	3.5	0.19	206.61	18999	0.76	0.51	0.75	1.02	0.80	0.52	0.84	1.85
D89	D89-D87	194	0.5	0.37	129.37	10578	0.27	0.49	0.73	0.98	0.77	0.51	0.81	0.69
D90	D90-D87	66	4.5	0.17	186.64	10888	0.40	0.38	0.61	0.76	0.59	0.44	0.67	1.73
D91	D91-D90	91	31.9	0.17	186.64	4326	0.16	0.19	0.40	0.37	0.29	0.32	0.43	2.85
D92	D92-OUT	145	2.1	0.20	172.81	20178	0.68	0.54	0.78	1.08	0.84	0.54	0.87	1.47
D93	D93-D94	182	8.2	0.17	186.64	7869	0.29	0.30	0.52	0.60	0.47	0.39	0.58	1.99
D94	D94-D95	53	1.9	0.18	211.04	14394	0.59	0.52	0.76	1.04	0.81	0.52	0.85	1.37
D95	D95-D97	313	1.3	0.24	186.45	52417	1.90	0.87	1.14	1.73	1.35	0.74	1.28	1.59
D96	D96-D95	199	17.6	0.17	186.64	8772	0.32	0.27	0.49	0.54	0.42	0.37	0.54	2.72
D97	D97-OUT	189	1.6	0.25	157.16	27023	0.83	0.61	0.86	1.22	0.95	0.58	0.96	1.40
D98	D98-D99	276	6.5	0.19	176.78	23261	0.80	0.46	0.70	0.92	0.72	0.49	0.78	2.36
D99	D99-D99.1	129	0.8	0.21	199.45	99349	3.85	1.24	1.54	2.48	1.94	0.98	1.75	1.57
D99.1	D99.1-D96	253	12.3	0.17	217.07	1E+05	5.13	0.82	1.09	1.65	1.29	0.71	1.23	4.76
D100	D100-D99	439	10.5	0.21	171.52	68995	2.30	0.63	0.88	1.25	0.98	0.59	0.98	3.67
D101	D101-D99.1	81	22.2	0.17	186.64	6309	0.23	0.23	0.45	0.46	0.36	0.34	0.49	2.73
D102	D102-D103	93	32.3	0.17	186.64	4519	0.16	0.19	0.40	0.38	0.29	0.32	0.44	2.89
D103	D103-D104	26	19.2	0.17	215.92	40543	1.70	0.50	0.74	1.00	0.78	0.51	0.83	4.27
D104	D104-OUT	233	17.2	0.18	209.16	66193	2.69	0.61	0.86	1.21	0.95	0.58	0.96	4.59

D105	**D105-D103**	**302**	**0.7**	**0.43**	**119.52**	**24185**	**0.56**	**0.62**	**0.87**	**1.24**	**0.97**	**0.59**	**0.98**	**0.92**
D106	**D106-D104**	**306**	**0.7**	**0.43**	**118.75**	**10664**	**0.25**	**0.46**	**0.69**	**0.91**	**0.71**	**0.49**	**0.77**	**0.74**
ii.	**Kebele 08/15**													
								Bt	Yt	T	Br	Yr	D(m)	
D1	D1-OUT	134	12.7	0.17	186.64	34977	1.27	0.48	0.72	0.97	0.76	0.50	0.81	3.40
D2	D2-OUT	143	10.5	0.17	186.64	12857	0.47	0.34	0.57	0.69	0.54	0.42	0.63	2.46
D3	D3-D1	229	2.6	0.24	162.15	20381	0.64	0.50	0.75	1.01	0.79	0.52	0.83	1.59
D4	D4-D2	43	7.0	0.17	186.64	7551	0.27	0.30	0.53	0.61	0.48	0.39	0.58	1.85
D5	D5-OUT	153	6.5	0.17	186.64	15905	0.58	0.41	0.64	0.82	0.64	0.46	0.71	2.18
D6	D6-D5	140	7.9	0.17	186.64	15608	0.57	0.39	0.62	0.78	0.61	0.44	0.69	2.32
D7	D7-D9	123	0.8	0.26	156.73	7995	0.24	0.44	0.67	0.87	0.68	0.47	0.75	0.80
D8	D8-D9	66	7.6	0.17	186.64	5145	0.19	0.26	0.48	0.52	0.41	0.36	0.53	1.73
D9	D9-D11	131	6.9	0.19	207.73	17642	0.71	0.44	0.67	0.88	0.68	0.47	0.75	2.34
D10	D10-D11	126	0.8	0.26	155.29	23598	0.71	0.66	0.91	1.31	1.02	0.61	1.02	1.04
D11	D11-OUT	61	3.3	0.28	175.51	46181	1.58	0.68	0.93	1.35	1.06	0.62	1.05	2.16
D12	D12-D10	212	6.1	0.17	184.40	8430	0.30	0.32	0.55	0.65	0.51	0.40	0.61	1.81
D13	D13-D10	130	1.5	0.21	169.78	5043	0.17	0.34	0.56	0.67	0.52	0.41	0.62	0.93
D14	D14-D14.1	91	8.8	0.17	186.64	14986	0.54	0.38	0.61	0.76	0.59	0.44	0.67	2.40
D14.1	D14.1-D14.2	80	6.3	0.18	212.84	72449	3.00	0.76	1.03	1.53	1.19	0.68	1.15	3.23

D14.2	D14.2-D14.3	90	6.7	0.19	206.73	99982	4.02	0.84	1.11	1.68	1.32	0.73	1.25	3.56
D14.3	D14.3-D19	64	6.3	0.17	217.07	1E+05	5.47	0.96	1.24	1.91	1.49	0.80	1.40	3.75
D15	D15-D16	285	2.5	0.27	152.73	22014	0.65	0.51	0.76	1.03	0.80	0.52	0.84	1.55
D16	D16-OUT	64	9.4	0.28	174.14	28849	0.98	0.46	0.70	0.93	0.73	0.49	0.78	2.84
D17	D17-D18.1	218	2.3	0.24	160.77	5123	0.16	0.31	0.53	0.61	0.48	0.39	0.58	1.07
D18	D18-D18.1	115	6.1	0.17	186.64	10990	0.40	0.36	0.59	0.72	0.56	0.43	0.65	1.93
D18.1	D18.1-OUT	61	4.9	0.18	213.07	19870	0.82	0.49	0.73	0.98	0.77	0.51	0.81	2.14
D19	D19-OUT	57	3.5	0.17	217.07	1E+05	5.53	1.07	1.36	2.14	1.67	0.87	1.54	3.03
D20	D20-D20.1	82	2.4	0.17	217.07	10802	0.46	0.45	0.69	0.90	0.70	0.48	0.76	1.42
D20.1	D20.1-OUT	266	2.6	0.31	165.29	49309	1.58	0.71	0.97	1.41	1.10	0.64	1.08	1.99
D21	D21-D20.1	206	4.4	0.19	177.75	10841	0.37	0.37	0.61	0.75	0.58	0.43	0.67	1.68
D22	D22-OUT	189	4.8	0.18	182.64	54716	1.94	0.68	0.94	1.37	1.07	0.63	1.05	2.62
D23	D23-OUT	164	4.9	0.16	187.93	40298	1.47	0.61	0.86	1.23	0.96	0.58	0.97	2.46
D24	D24-OUT	100	3.0	0.17	186.64	1E+05	4.80	1.05	1.33	2.09	1.63	0.85	1.51	2.76
D25	D25-D25.1	285	2.5	0.27	152.73	13088	0.39	0.42	0.66	0.85	0.66	0.46	0.73	1.37
D25.1	D25.1-D14.1	71	4.2	0.28	173.25	54718	1.84	0.68	0.94	1.37	1.07	0.63	1.06	2.47
D26	D26-D14.2	368	3.0	0.29	148.17	22195	0.64	0.49	0.73	0.98	0.77	0.51	0.81	1.66
D27	D27-D14.3	392	0.5	0.53	104.64	23431	0.48	0.61	0.86	1.23	0.96	0.58	0.97	0.80
D28	D28-D28.1	207	7.7	0.16	190.27	14047	0.52	0.38	0.61	0.76	0.59	0.44	0.68	2.26

D28.1	D28.1-D28.2	56	3.6	0.17	217.07	54012	2.28	0.77	1.03	1.53	1.20	0.68	1.16	2.44
D28.2	D28.2-D24	138	10.1	0.19	206.73	1E+05	4.87	0.84	1.11	1.67	1.31	0.72	1.25	4.37
D29	D29-OUT	426	4.5	0.27	152.44	10096	0.30	0.34	0.57	0.69	0.54	0.41	0.63	1.60
D29.1	D29.1-D28.2	164	6.1	0.17	186.64	55770	2.02	0.66	0.92	1.32	1.03	0.61	1.03	2.90
D30	D30-D28.1	382	8.9	0.20	172.62	36490	1.22	0.51	0.75	1.02	0.80	0.52	0.84	2.95
D31	D31-D23	150	3.3	0.18	182.49	5004	0.18	0.30	0.52	0.60	0.47	0.39	0.57	1.26
D32	D32-D22	556	2.5	0.37	129.15	32937	0.83	0.56	0.80	1.12	0.87	0.55	0.90	1.66
D33	D33-D34	74	16.2	0.17	186.64	3690	0.13	0.20	0.42	0.40	0.31	0.32	0.45	2.12
D34	D34-D25.1	51	11.8	0.18	211.04	39139	1.61	0.54	0.78	1.07	0.84	0.54	0.87	3.50
D35	D35-D23	89	4.5	0.17	186.64	15509	0.56	0.43	0.67	0.87	0.68	0.47	0.74	1.88
D36	D36-D42.2	255	7.5	0.18	182.50	18482	0.66	0.42	0.65	0.84	0.65	0.46	0.72	2.36
D37	D37-D42.3	395	6.8	0.23	165.28	11784	0.38	0.35	0.57	0.69	0.54	0.42	0.63	1.99
D38	D38-OUT	200	8.5	0.17	186.64	8183	0.30	0.30	0.53	0.61	0.47	0.39	0.58	2.03
D39	D39-OUT	135	6.7	0.25	183.05	32964	1.17	0.53	0.77	1.06	0.83	0.53	0.86	2.62
D40	D40-D39	514	8.8	0.24	161.71	21821	0.69	0.41	0.65	0.82	0.64	0.46	0.72	2.53
D41	D41-D42.1	209	4.8	0.19	179.32	8554	0.30	0.34	0.57	0.68	0.53	0.41	0.62	1.64
D42	D42-D42.1	119	9.2	0.17	186.64	66319	2.41	0.65	0.91	1.31	1.02	0.61	1.02	3.54
D42.1	D42.1-D42.2	444	11.3	0.20	200.95	91851	3.59	0.73	0.99	1.46	1.14	0.66	1.11	4.21
D42.2	D42.2-D42.3	105	6.7	0.21	198.23	1E+05	4.74	0.90	1.17	1.79	1.40	0.76	1.32	3.71

D42.3	D42.3-OUT	175	10.9	0.22	193.28	1E+05	4.94	0.83	1.10	1.66	1.30	0.72	1.24	4.50
D43	D43-D43.1	277	9.0	0.17	183.98	17098	0.61	0.39	0.63	0.79	0.61	0.45	0.69	2.49
D43.1	D43.1-D43.2	38	10.5	0.17	217.07	33381	1.41	0.52	0.76	1.04	0.81	0.53	0.85	3.25
D43.2	D43.2-D43.3	187	11.8	0.19	206.73	47314	1.90	0.57	0.82	1.14	0.89	0.56	0.91	3.65
D43.3	D43.3-D43.4	30	13.3	0.17	217.07	61424	2.59	0.63	0.88	1.25	0.98	0.59	0.98	4.14
D43.4	D43.4-D43.5	53	11.3	0.17	217.07	72420	3.06	0.69	0.94	1.38	1.07	0.63	1.06	4.05
D43.5	D43.5-D43.6	63	4.8	0.17	217.07	91764	3.87	0.88	1.16	1.77	1.38	0.75	1.31	3.11
D43.6	D43.6-D43.7	53	13.2	0.17	217.07	1E+05	5.32	0.82	1.09	1.65	1.29	0.71	1.23	4.93
D43.7	D43.7-OUT	106	10.4	0.18	211.04	1E+05	5.82	0.89	1.16	1.78	1.39	0.76	1.31	4.61
D44	D44-D46	418	6.0	0.24	160.11	19833	0.62	0.43	0.66	0.85	0.66	0.47	0.73	2.14
D45	D45-D46	102	8.8	0.17	186.64	39724	1.44	0.54	0.79	1.09	0.85	0.54	0.88	3.06
D46	D46-D42	74	9.5	0.18	211.04	62571	2.57	0.67	0.92	1.33	1.04	0.62	1.03	3.63
D47	D47-D43.1	199	19.1	0.17	217.07	10368	0.44	0.30	0.53	0.60	0.47	0.39	0.58	3.03
D48	D48-D43.2	116	12.9	0.17	217.07	5790	0.24	0.26	0.48	0.52	0.41	0.36	0.53	2.27
D49	D49-D43.3	144	18.1	0.17	217.07	11896	0.50	0.32	0.55	0.64	0.50	0.40	0.60	3.08
D50	D50-D43.4	204	18.1	0.17	217.07	6415	0.27	0.25	0.47	0.51	0.40	0.36	0.52	2.64
D51	D51-D43.5	330	11.2	0.18	212.72	14358	0.59	0.37	0.60	0.75	0.58	0.43	0.67	2.68
D52	D52-D43	253	2.8	0.24	185.93	88892	3.21	0.91	1.19	1.83	1.43	0.77	1.34	2.42
D53	D53-D34	428	4.2	0.28	175.46	33078	1.13	0.57	0.82	1.14	0.89	0.56	0.91	2.18

D54	D54-D58	155	3.2	0.18	210.09	17982	0.73	0.51	0.75	1.02	0.80	0.52	0.84	1.77
D55	D55-OUT	319	11.3	0.17	214.22	13046	0.54	0.36	0.59	0.72	0.56	0.43	0.65	2.63
D56	D56-D58.1	107	0.9	0.23	191.93	7036	0.26	0.44	0.67	0.87	0.68	0.47	0.75	0.86
D57	D57-OUT	281	17.1	0.17	217.07	21847	0.92	0.41	0.64	0.81	0.63	0.45	0.71	3.51
D58	D58-D58.1	137	2.2	0.19	204.80	28640	1.14	0.65	0.90	1.29	1.01	0.60	1.01	1.71
D58.1	D58.1-D57	88	1.1	0.20	202.60	9938	0.39	0.49	0.73	0.98	0.77	0.51	0.81	1.02
D59	D59-D52	479	4.4	0.29	147.78	69392	1.99	0.70	0.96	1.40	1.09	0.64	1.08	2.55
D60	D60-D43.6	590	4.4	0.32	140.34	30796	0.84	0.51	0.75	1.01	0.79	0.52	0.83	2.06
D61	D61-D63	129	7.8	0.17	186.64	3944	0.14	0.23	0.45	0.47	0.37	0.35	0.49	1.64
D62	D62-D63	170	21.8	0.17	186.64	8335	0.30	0.26	0.48	0.51	0.40	0.36	0.52	2.91
D63	D63-OUT	510	5.5	0.22	194.81	32473	1.23	0.56	0.81	1.12	0.88	0.55	0.90	2.46
D64	D64-D43.7	140	1.4	0.23	165.43	7607	0.24	0.39	0.63	0.79	0.61	0.45	0.69	0.99
D65	D65-OUT	222	9.0	0.16	191.28	24289	0.90	0.45	0.69	0.91	0.71	0.48	0.77	2.74
D66	D66-D59	371	3.5	0.27	151.68	34979	1.03	0.57	0.82	1.14	0.89	0.56	0.91	1.99
iii.	**Kebele 13/14**													
D1	D1-D2	261	4.2	0.22	168.66	9922	0.33	0.36	0.59	0.71	0.56	0.42	0.65	1.60
D2	D2-D3	218	0.5	0.41	122.46	24488	0.58	0.67	0.93	1.35	1.05	0.62	1.04	0.81
D3	D3-D4	161	1.2	0.47	132.11	43387	1.11	0.71	0.97	1.43	1.11	0.65	1.09	1.38
D4	D4-OUT	64	1.6	0.48	129.93	49469	1.25	0.71	0.97	1.43	1.11	0.65	1.09	1.54

D5	D5-OUT	499	0.6	0.57	116.57	10895	0.25	0.46	0.70	0.93	0.73	0.49	0.78	0.72
D6	D6-D3	198	5.1	0.18	212.11	6415	0.26	0.32	0.55	0.64	0.50	0.40	0.60	1.62
D7	D7-D3	199	5.0	0.18	211.78	7045	0.29	0.33	0.56	0.66	0.52	0.41	0.61	1.66
D8	D8-OUT	177	6.2	0.16	221.76	6842	0.30	0.32	0.55	0.64	0.50	0.40	0.60	1.80
D9	D9-OUT	117	3.4	0.16	222.51	3755	0.16	0.29	0.51	0.57	0.45	0.38	0.56	1.24
D10	D10-D4	202	4.5	0.19	208.03	4074	0.16	0.27	0.50	0.55	0.43	0.37	0.54	1.38
D11	D11-OUT	280	4.3	0.22	193.72	11461	0.43	0.40	0.63	0.79	0.62	0.45	0.70	1.73
D12	D12-OUT	136	7.4	0.17	217.07	10887	0.46	0.37	0.60	0.73	0.57	0.43	0.66	2.15
D13	D13-D24	110	0.9	0.30	168.07	19816	0.65	0.62	0.87	1.23	0.96	0.59	0.97	1.07
D13.1	D13.1-D13.2	129	1.6	0.28	173.75	21792	0.74	0.59	0.83	1.17	0.91	0.57	0.93	1.35
D13.2	D13.2-OUT	116	1.7	0.31	166.91	56247	1.83	0.81	1.07	1.61	1.26	0.70	1.21	1.76
D14	D14-OUT	71	8.5	0.17	186.86	3327	0.12	0.22	0.43	0.43	0.34	0.34	0.47	1.62
D15	D15-D13.2	285	3.9	0.23	163.66	17782	0.57	0.45	0.68	0.89	0.70	0.48	0.76	1.78
D16	D16-D13.2	275	4.0	0.23	165.77	29268	0.94	0.54	0.78	1.08	0.84	0.54	0.87	2.05
D17	D17-D13.1	420	4.8	0.26	154.69	16315	0.49	0.41	0.64	0.82	0.64	0.45	0.71	1.85
D18	D18-D18.1	66	7.6	0.17	186.86	8358	0.30	0.31	0.54	0.62	0.49	0.40	0.59	1.96
D18.1	D18.1-D18.2	80	5.0	0.18	211.92	11575	0.48	0.40	0.63	0.80	0.62	0.45	0.70	1.88
D18.2	D18.2-D18.3	24	4.2	0.17	217.07	15784	0.67	0.47	0.71	0.94	0.73	0.49	0.79	1.90
D18.3	D18.3-D18.4	25	4.0	0.17	217.07	18237	0.77	0.50	0.74	1.00	0.78	0.51	0.82	1.94

D18.4	D18.4-D13.1	230	3.9	0.20	202.79	28470	1.12	0.58	0.82	1.15	0.90	0.56	0.92	2.12
D19	D19-D18.2	90	4.4	0.17	186.64	3360	0.12	0.24	0.47	0.49	0.38	0.35	0.51	1.28
D20	D20-D18.3	91	2.2	0.16	190.00	1443	0.05	0.20	0.42	0.41	0.32	0.33	0.46	0.80
D21	D21-D18.4	88	2.3	0.17	186.64	1355	0.05	0.20	0.41	0.40	0.31	0.32	0.45	0.79
D22	D22-D13	461	4.3	0.28	148.91	14254	0.41	0.39	0.62	0.78	0.61	0.44	0.69	1.72
D23	D23-D23.1	111	4.5	0.17	186.64	5863	0.21	0.30	0.53	0.60	0.47	0.39	0.58	1.47
D23.1	D23.1-D23.2	36	2.8	0.18	211.04	14329	0.59	0.48	0.72	0.96	0.75	0.50	0.80	1.59
D23.2	D23.2-D23.3	126	5.6	0.20	201.76	21530	0.84	0.49	0.73	0.97	0.76	0.50	0.81	2.25
D23.3	D23.3-D13	190	3.2	0.23	192.76	28760	1.08	0.59	0.84	1.18	0.92	0.57	0.94	1.94
D24	D24-D29	79	2.5	0.18	209.82	23491	0.96	0.59	0.84	1.18	0.92	0.57	0.94	1.73
D25	D25-D18.1	92	2.2	0.16	189.40	6436	0.24	0.36	0.59	0.72	0.56	0.42	0.65	1.15
D26	D26-D23.2	109	0.9	0.23	163.93	2025	0.06	0.26	0.48	0.52	0.41	0.36	0.52	0.60
D26.1	D26.1-D23.1	108	0.9	0.23	164.48	6753	0.22	0.41	0.64	0.81	0.64	0.45	0.71	0.82
D27	D27-D24	103	2.9	0.17	186.64	8186	0.30	0.37	0.60	0.74	0.58	0.43	0.66	1.36
D28	D28-D24	512	6.3	0.27	153.84	11635	0.35	0.34	0.57	0.68	0.53	0.41	0.63	1.89
D29	D29-D30	69	4.3	0.17	186.64	70986	2.58	0.77	1.04	1.54	1.21	0.68	1.16	2.71
D30	D30-OUT	132	3.0	0.18	210.96	85985	3.53	0.93	1.21	1.86	1.45	0.78	1.36	2.56
D31	D31-D32	152	5.3	0.17	186.64	8330	0.30	0.33	0.56	0.67	0.52	0.41	0.62	1.71
D32	D32-D33	121	5.8	0.19	208.28	54375	2.20	0.69	0.95	1.38	1.08	0.63	1.06	2.90

D33	D33-D29	240	4.2	0.21	199.28	66391	2.57	0.78	1.04	1.56	1.22	0.69	1.17	2.67
D34	D34-D33	151	4.6	0.16	189.54	6724	0.25	0.32	0.54	0.63	0.50	0.40	0.60	1.55
D35	D35-D40.1	149	2.0	0.21	171.23	5290	0.18	0.33	0.55	0.65	0.51	0.40	0.61	1.04
D36	D36-D38	154	8.4	0.17	186.64	10094	0.37	0.33	0.56	0.66	0.51	0.41	0.61	2.14
D36.1	D36.1-D38	154	8.4	0.17	186.64	4729	0.17	0.25	0.47	0.49	0.39	0.35	0.51	1.77
D37	D37-D38	207	5.3	0.19	206.33	11789	0.47	0.39	0.63	0.79	0.62	0.45	0.69	1.92
D38	D38-D32	225	0.9	0.22	193.47	44466	1.67	0.88	1.16	1.77	1.38	0.75	1.31	1.34
D39	D39-OUT	475	6.7	0.25	158.33	7069	0.22	0.28	0.50	0.56	0.44	0.38	0.55	1.72
D40	D40-D40.1	119	10.1	0.17	186.64	2613	0.09	0.19	0.41	0.38	0.30	0.32	0.44	1.63
D40.1	D40.1-D40.2	155	2.6	0.20	204.20	6697	0.27	0.36	0.59	0.73	0.57	0.43	0.65	1.26
D40.2	D40.2-OUT	138	5.8	0.23	192.44	14023	0.52	0.40	0.64	0.81	0.63	0.45	0.70	2.03
D41	D41-D30	212	4.2	0.19	176.11	7078	0.24	0.32	0.55	0.64	0.50	0.40	0.60	1.49
D42	D42-D40.2	46	10.9	0.17	186.64	4664	0.17	0.23	0.45	0.47	0.37	0.35	0.49	1.94
D43	D43-D43.1	54	3.7	0.17	186.64	9074	0.33	0.37	0.60	0.74	0.57	0.43	0.66	1.53
D43.1	D43.1-D43.2	57	7.0	0.18	212.36	7763	0.32	0.32	0.55	0.65	0.50	0.40	0.60	1.93
D43.2	D43.2-D43.3	50	6.0	0.19	206.73	16523	0.66	0.44	0.67	0.87	0.68	0.47	0.75	2.18
D43.3	D43.3-D49	117	6.8	0.20	200.64	18643	0.73	0.44	0.68	0.88	0.69	0.48	0.75	2.34
D43.4	D43.4-D43.5	102	8.8	0.17	186.64	1698	0.06	0.17	0.38	0.33	0.26	0.30	0.41	1.39
D43.5	D43.5-OUT	121	7.4	0.19	206.39	3197	0.13	0.23	0.45	0.45	0.35	0.34	0.48	1.57

D44	D44-OUT	331	3.3	0.26	154.54	16512	0.50	0.44	0.67	0.88	0.68	0.47	0.75	1.63
D45	D45-OUT	496	0.4	0.65	91.95	28155	0.50	0.65	0.91	1.31	1.02	0.61	1.02	0.74
D46	D46-D43.2	125	0.8	0.26	155.76	3480	0.11	0.32	0.55	0.64	0.50	0.40	0.60	0.65
D47	D47-D48	126	2.4	0.18	180.87	3709	0.13	0.28	0.51	0.56	0.44	0.38	0.55	1.03
D48	D48-D44	45	4.4	0.25	182.55	10719	0.38	0.38	0.61	0.75	0.59	0.43	0.67	1.70
D49	D49-D50.1	149	0.7	0.30	168.88	29061	0.95	0.76	1.02	1.51	1.18	0.67	1.14	1.05
D50	D50-D50.1	346	1.7	0.33	137.37	31764	0.85	0.60	0.85	1.21	0.94	0.58	0.96	1.46
D50.1	D50.1-D45	289	5.5	0.21	199.36	79850	3.10	0.79	1.06	1.58	1.23	0.69	1.19	3.11
D51	D51-D43	99	5.1	0.17	186.64	3883	0.14	0.25	0.47	0.50	0.39	0.36	0.52	1.39
D52	D52-D53.1	110	3.6	0.17	186.64	3700	0.13	0.26	0.49	0.53	0.41	0.36	0.53	1.21
D52.1	D52-1-D53.1	107	3.7	0.17	186.64	4035	0.15	0.27	0.49	0.54	0.42	0.37	0.54	1.25
D53	D53-D53.1	108	0.9	0.23	164.48	6495	0.21	0.40	0.63	0.80	0.63	0.45	0.70	0.81
D53.1	D53.1-D37	224	4.9	0.31	167.05	38224	1.24	0.57	0.82	1.15	0.90	0.56	0.92	2.37
D53.2	D53.2-D48	316	3.8	0.25	159.39	9047	0.28	0.34	0.57	0.69	0.54	0.42	0.63	1.48
D53.3	D53.3-D49	96	4.2	0.17	186.64	4634	0.17	0.28	0.50	0.56	0.44	0.37	0.55	1.35
D54	D54-OUT	1543	3.4	0.56	100.93	93452	1.83	0.71	0.97	1.42	1.11	0.64	1.09	2.28
D54.1	D54.1-D54.2	435	5.3	0.26	155.74	11672	0.35	0.35	0.58	0.71	0.55	0.42	0.64	1.78
D54.2	D54.2-D54.3	172	6.4	0.29	172.82	40024	1.34	0.56	0.81	1.13	0.88	0.55	0.90	2.67
D54.3	D54.3-OUT	904	2.2	0.50	126.90	1E+05	2.49	0.87	1.14	1.73	1.35	0.74	1.28	2.09

D55	D55-D54.2	332	3.3	0.26	154.36	20539	0.62	0.48	0.71	0.95	0.74	0.50	0.79	1.71
D56	D56-D56.1	148	2.0	0.21	171.62	8203	0.27	0.38	0.62	0.77	0.60	0.44	0.68	1.16
D56.1	D56.1-D56.2	64	4.7	0.22	193.77	31275	1.18	0.57	0.81	1.14	0.89	0.55	0.91	2.30
D56.2	D56.2-OUT	224	5.8	0.25	184.22	37780	1.35	0.57	0.82	1.15	0.90	0.56	0.92	2.57
D57	D57-D56.1	336	0.9	0.41	122.71	21700	0.52	0.57	0.82	1.14	0.89	0.56	0.91	1.00
D57.1	D57.1-D54.3	362	0.8	0.44	118.35	15683	0.36	0.50	0.75	1.01	0.79	0.52	0.83	0.89
D58	D58-D58.2	190	5.8	0.17	186.79	9420	0.34	0.34	0.57	0.69	0.54	0.41	0.63	1.82
D58.1	D58.1-D58.2	193	5.7	0.17	185.93	17278	0.62	0.43	0.67	0.86	0.67	0.47	0.74	2.11
D58.2	D58.2-OUT	268	0.4	0.20	201.08	41915	1.64	1.03	1.32	2.07	1.61	0.85	1.49	0.97
D59	D59-OUT	373	1.9	0.34	136.54	31721	0.84	0.59	0.84	1.19	0.93	0.57	0.94	1.50
D60	D60-D60.2	123	4.9	0.17	186.64	3815	0.14	0.25	0.47	0.50	0.39	0.36	0.52	1.36
D60.1	D60.1-D60.2	125	4.8	0.17	186.64	24358	0.88	0.51	0.75	1.01	0.79	0.52	0.83	2.16
D60.2	D60.2-D61.1	68	2.9	0.18	213.07	31912	1.32	0.65	0.90	1.29	1.01	0.60	1.01	1.98
D61	D61-D61.1	101	2.0	0.17	184.24	5036	0.18	0.33	0.56	0.66	0.52	0.41	0.61	1.04
D61.1	D61.1-OUT	168	3.0	0.22	195.69	12278	0.47	0.44	0.67	0.87	0.68	0.47	0.75	1.54
D62	D62-OUT	219	3.2	0.22	168.41	9011	0.30	0.36	0.59	0.73	0.57	0.43	0.65	1.41
D63	D63-D64.1	239	2.9	0.23	163.25	19479	0.62	0.49	0.73	0.97	0.76	0.50	0.81	1.64
D64	D64-D64.1	87	3.4	0.17	186.64	8424	0.31	0.36	0.59	0.73	0.57	0.43	0.65	1.46
D64.1	D64.1-D65.1	119	3.4	0.16	221.44	31398	1.35	0.64	0.89	1.27	0.99	0.60	1.00	2.10

D65	D65-D65.1	110	3.6	0.17	186.64	7481	0.27	0.34	0.57	0.69	0.54	0.41	0.63	1.45
D65.1	D65.1-OUT	163	1.2	0.26	181.87	48506	1.72	0.84	1.11	1.68	1.31	0.73	1.25	1.53
D66	D66-OUT	168	4.2	0.17	183.64	20995	0.75	0.49	0.73	0.98	0.77	0.51	0.81	1.96
D67	D67-OUT	199	2.5	0.22	166.17	7541	0.24	0.35	0.58	0.71	0.55	0.42	0.64	1.23
D68	D68-D68.1	157	3.2	0.18	179.91	4615	0.16	0.29	0.51	0.58	0.45	0.38	0.56	1.21
D68.1	D68.1-D68.2	298	4.0	0.23	189.43	10156	0.37	0.38	0.61	0.76	0.59	0.44	0.67	1.63
D68.2	D68.2-D69.5	114	2.6	0.25	182.78	15407	0.55	0.47	0.71	0.95	0.74	0.50	0.79	1.53
D69.3	D69.3-D69.6	193	3.1	0.21	172.21	5924	0.20	0.31	0.54	0.63	0.49	0.40	0.59	1.26
D69.4	D69.4-D69.5	171	2.9	0.20	175.02	19403	0.66	0.50	0.74	1.00	0.78	0.51	0.82	1.66
D69.5	D69.5-OUT	136	2.9	0.22	194.68	64157	2.43	0.81	1.08	1.63	1.27	0.71	1.22	2.31
D69.6	D69.6-D69.5	374	3.7	0.27	152.96	20949	0.62	0.47	0.70	0.93	0.73	0.49	0.78	1.80
D70	D70-D69.6	125	3.2	0.16	187.70	15020	0.55	0.46	0.70	0.92	0.72	0.49	0.77	1.64
D70.1	D70.1-D70.2	156	5.1	0.16	190.66	6537	0.24	0.31	0.53	0.62	0.48	0.39	0.59	1.60
D70.2	D70.2-D70.3	95	13.7	0.17	214.01	24668	1.03	0.44	0.68	0.88	0.69	0.48	0.75	3.31
D70.3	D70.3-D69.4	168	3.0	0.19	204.74	85131	3.39	0.92	1.19	1.84	1.44	0.77	1.35	2.52
D71	D71-OUT	132	3.0	0.17	184.68	9846	0.35	0.39	0.62	0.78	0.61	0.45	0.69	1.44
D72	D72-OUT	110	10.9	0.17	186.64	30085	1.09	0.47	0.71	0.94	0.74	0.49	0.79	3.09
D73	D73-D69.4	215	3.3	0.21	169.49	5150	0.17	0.29	0.52	0.59	0.46	0.38	0.57	1.23
D74	D74-D70.2	137	2.9	0.18	182.60	11991	0.43	0.42	0.66	0.85	0.66	0.46	0.73	1.49

D75	D75-D76.1	146	0.7	0.29	146.43	9137	0.26	0.46	0.70	0.92	0.72	0.49	0.78	0.76
D76	D76-D76.1	266	1.9	0.29	148.84	19924	0.58	0.52	0.76	1.03	0.81	0.52	0.84	1.36
D76.1	D76.1-D77	96	4.2	0.30	167.50	33301	1.08	0.56	0.81	1.13	0.88	0.55	0.90	2.15
D77	D77-D70.3	155	1.3	0.25	185.37	52830	1.90	0.87	1.14	1.73	1.35	0.74	1.28	1.60
D78	D78-D77	359	2.8	0.29	147.38	27661	0.79	0.54	0.78	1.08	0.84	0.54	0.87	1.71
D78.1	D78.1-D77	363	2.8	0.29	146.71	21829	0.62	0.49	0.73	0.99	0.77	0.51	0.82	1.60
D79	D79-OUT	220	1.8	0.26	154.92	16164	0.49	0.49	0.73	0.97	0.76	0.50	0.81	1.29
D80	D80-D80.1	48	2.1	0.17	186.64	6509	0.24	0.36	0.59	0.72	0.57	0.43	0.65	1.13
D80.1	D80.1-OUT	79	5.1	0.19	208.42	26857	1.09	0.54	0.79	1.09	0.85	0.54	0.88	2.32
D81	D81-D80.1	204	3.9	0.20	175.62	8358	0.29	0.34	0.57	0.69	0.54	0.42	0.63	1.51
D81.1	D81.1-D80.1	205	3.9	0.20	175.34	9258	0.32	0.36	0.59	0.72	0.56	0.42	0.65	1.54
D82	D82-D82.1	2001	0.2	1.52	47.79	12394	0.12	0.41	0.65	0.82	0.64	0.46	0.71	0.43
D82.1	D82.1-OUT	218	4.6	0.19	205.75	40911	1.64	0.64	0.90	1.29	1.01	0.60	1.01	2.47
D83	D83-D82.1	156	4.5	0.16	187.76	8772	0.32	0.35	0.58	0.70	0.55	0.42	0.64	1.63
D83.1	D83.1-D83.2	95	4.2	0.17	186.64	2150	0.08	0.21	0.43	0.42	0.33	0.33	0.46	1.12
D83.2	D83.2-D82.1	65	4.6	0.18	209.81	13947	0.57	0.43	0.67	0.87	0.68	0.47	0.74	1.90
D84	D84-D83.2	234	0.4	0.44	118.32	10237	0.24	0.49	0.73	0.97	0.76	0.50	0.81	0.63
D85	D85-D43.1	127	1.6	0.21	171.15	6017	0.20	0.36	0.59	0.72	0.56	0.42	0.65	0.98
D85.1	D85.1-OUT	129	5.4	0.17	186.64	2575	0.09	0.21	0.43	0.43	0.33	0.33	0.47	1.29

NOTE: The value of C (Run-off coefficient) = 0.70 (standard table value).
The value n (manning's roughness coefficient) = 0.023 (standard table value for a masonry bed channel).
The dimensions of circular drainage lines should be approximately equal to the nearest available market size.
The code column contains the specific codes of the corresponding drainage lines. For example D1 means drainage line No.1.

APPENDIX-2: Location map of the study area

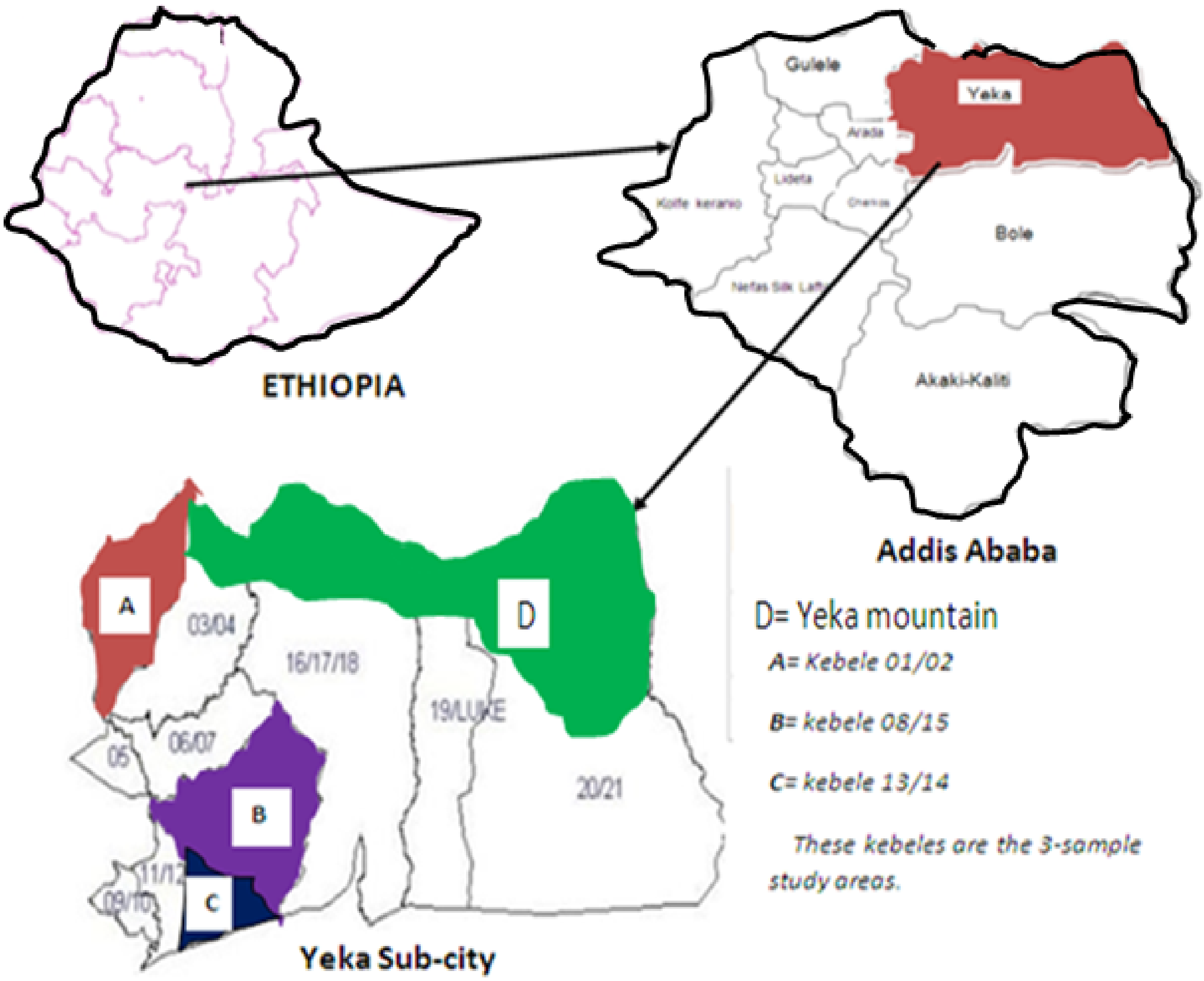
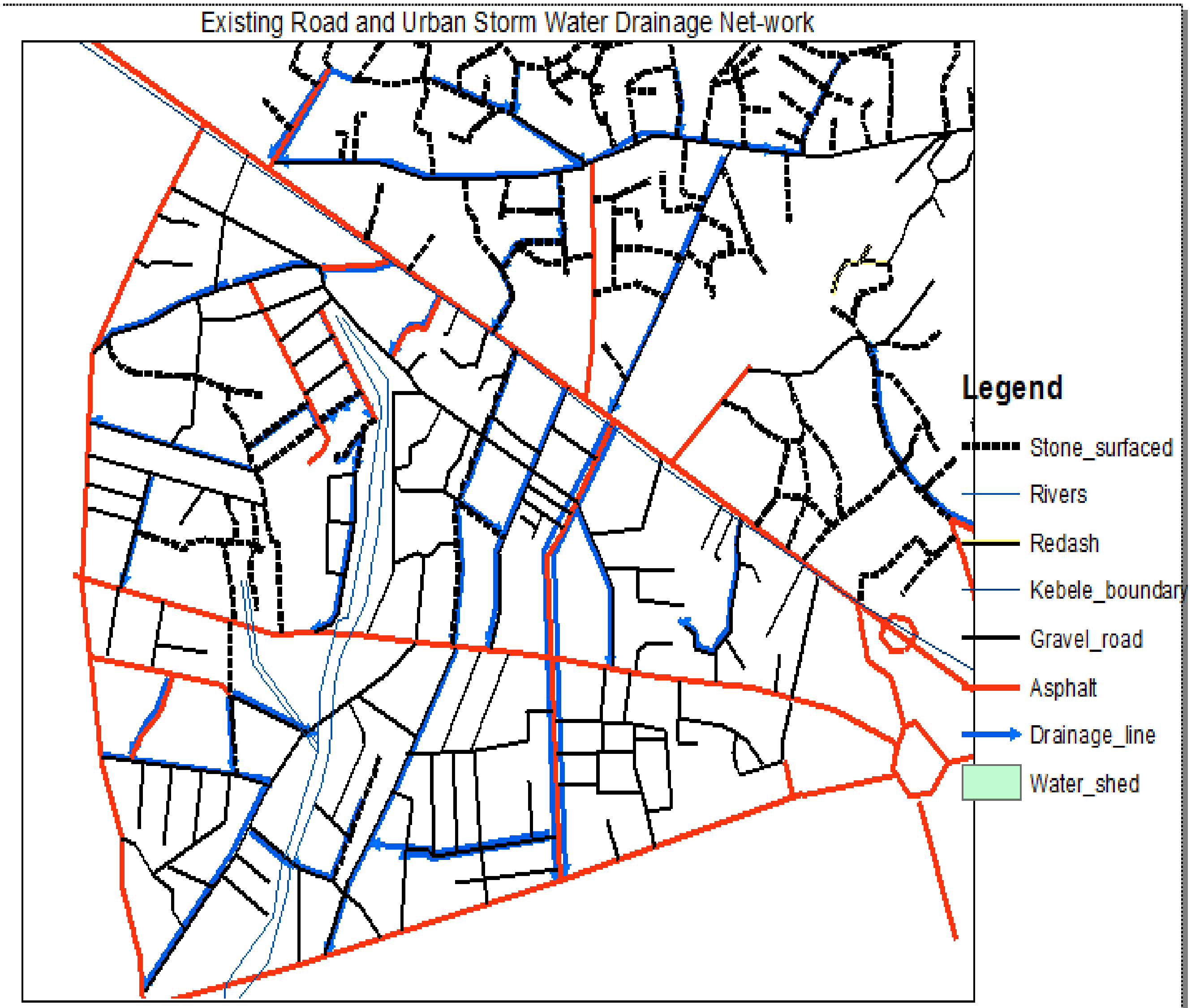


Fig. Location map of the study area (source: Addis Ababa City Administration and AutoCAD analysis, 2009)

APPENDIX-3: Existing Urban Storm Water Drainage and Road Net-Work.



APPENDIX-4: QUESTIONAIRES

- **Instructions**: tick or give reliable answers for the questions presented here with.

Address: Sex: male------female-------Age------Profession-------degree--------diploma----------

Are you expert/engineer-----------------or Administrative staff ---------------------------------

1. Total land area of Yeka sub-city----------ha. Green area in Yeka sub-city--------ha
2. Does flooding a major problem in your sub-city? yes----------------No -----------------
3. If your answer is yes, how do you rate the extent: very serious-------serious---------not serious---.
4. Which specific sites are most prone to flooding and why: use the table below:

Name of local site	kebele	rank	Reason of flooding (why?)

5. What do you think is the major causes of flood problem in Yeka sub-city?
   i. Absence of urban storm water drainage infrastructure -----------------------
   ii. Inadequate urban storm water drainage infrastructure------------------------
   iii. Blockage of urban storm water drainage structures---------------------------
   iv. Deforestation of Yeka mountain-------------rugged topography--------------
   v. If others specify---
6. What temporary solutions have ever been taken to flood problems?
   a. Cleaning drainage channels-------------d. Earth embankments---------------
   b. Sand bags ------------------------------ e. Afforestation --------------------------.
   c. Constructing new urban storm water drainage facilities-----------------------.
   f. Specify, if any--.

7. What permanent solutions have ever been taken to flood problems?
   i. Cleaning drainage channels---------------- ii. Earth embankments-----------.
   iii. Sand bags --.
   iv. Constructing new urban storm water drainage facilities-----------------------.
   v. Specify, if any--.
8. What are the major challenges in the provision of integrated road and urban storm water drainage infrastructure: finance-----------plan---------------profession------------lack of awareness-----------------.
9. Do you plan to provide urban storm water drainage infrastructure in Yeka sub-city? yes------no------If so, for what purpose:--.
10. What major impacts the drainage system has on rivers in Yeka sub-city?---------------- What impacts do rivers have on Yeka sub-city?--
11. What solutions you suggest to handle such problems on existing rivers ------------------
12. What do you suggest to manage the problem of flooding in Yeka sub-city?--------------
13. who is the responsible body or organization in urban storm water drainage provision in Yeka sub-city?--
14. What are the major challenges in handling urban storm water drainage system in Yeka sub-city? ---.
15. Is the flood from Yeka mountain a major problem to the sub-city? yes------- no-----if yes how could it be reduced/solved?---.
16. General comments/suggestions in handling the impact of the urban drainage system on Yeka sub-city?---.

Thank you.

APPENDIX-5: CHECK LISTS

1. Total built up area of the sub-city-------ha or-----------km^2. Green area------------ha.
2. Road coverage in the study area--km
3. USWD lines in the built up area--km
4. The general existing condition of natural water ways in the study area:

   4.1 Average width--------------- 4.3 Condition: Good-------light---------severe---------

   4.2 Average depth-------------- 4.4 Average length in the study area-------------------

5 General problems in the natural water ways/rivers:

5.1 Encroached by residents-------------5.2 Blocked by solid wastes-------------------

5.2 Connection of Sewerages--------5.4 No recommended buffer------&------meter

6 Road and USWD lines deterioration scales/indicators.

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

Source: GTZ, 2006.

7 The road and USWD pavement condition and type.

	Road						Urban storm water drains			
condition	Asphalt, km		Red ash(km)		Earth(km)		masonry		Earth	
Good										
Fair										
Poor										
Total										

5. Road classification

   I. High way __________ km III. Collector ____________ km

   II. Arterial ___________ km IV. Local______________ km

6. Urban storm water drainage facilities:

No.	**Type of drains**	Length (km)	Shape of drains (km)		
			Trapezoidal	circular	rectangular
1	Concrete/masonry lines				
2	Earth lines				
	total				

7. The technique of road and USWD provision/contracting: separately-------------together------------and reasons---

8. integration between road and USWD lines

No.	Road surface type	Total length of road(km)	Drain length(km)					
			Trapezoidal		Rectangular		Circular	
			M	E	M	E	M	E
1	Asphalt							
2	Red ash							
4	Gravel surfaced							
	Total							

Note: M= masonry drain, E= earth drain, It is by default known that a circular drain is closed type.

9. Dimensions of existing USWD

No.	construction material	Shape of drain					
		Trapezoidal			rectangular		circular
		L	H	B	B	H	R
1	Masonry						
1	Earth						

Where: L= length, B= base, H= height, R= radius

10. Most flood prone sites/area in the study area.

Specific sites	Causes of flooding	Ranks from observation