IMPACT OF BUILT ENVIRONMENT ON HYDROLOGICAL REGIMES OF ADDIS ABABA

By

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Water Supply and Environmental Engineering of Addis Ababa University.

Addis Ababa University
School of Post Graduate Studies
September, 2011

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Thesis submitted to Addis Ababa University, School of Graduate studies in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Water Supply and Environmental Engineering).

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Certification

The undersigned certify that he has read and hereby recommend for the Acceptance by the Addis Ababa University a dissertation entitled: **Impact of Built Environment on Hydrological Regimes of Addis Ababa City** in partial fulfillment of the requirements for the degree of Master of Science.

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Declaration and copy right

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

Signature ……

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September, 2011

ACKNOWLEDGMENT

I would like to thank my adviser Dr.Semu Ayalew (AAU) for his valuable support in helping me set up direction, suggestion, and particularly the good and positive discussions we had to clear many doubts and to broaden my understanding about the topic. I would like to extend my sincere gratitude to the WWDSE (Water Works Design and Supervision Enterprise) for the financial support of my research and school fee as well. I would like also to thank my all families and friends especially Ato Fetene Befikadu for his big support in providing me reference materials, with strength and encouragement in times when I needed it most.

ABSTRACT

Urbanization takes place takes place in Ethiopia early 1900's. The rate is different from place to place; this is mainly due to social and economic influences. Among the big cities of Africa Addis Ababa is the one with high population low planned urbanization influence. This lack of proper settlement plan of the city influences its hydrological regimes due to influence on main streams of the city

The built environment of Addis Ababa includes Asphalt roads, paved roads, residential areas, commercial and industrial areas and other big infrastructures. The purpose of this study was to show the impact of built environment on hydrological regimes of Addis Ababa through defining hydrological parameters by using SCS (soil conservation Service) method to evaluate surface runoff generated as result of rainfall and it is impact on streams.

The study focused on the city of Addis Ababa without considering the entire Akaki watershed. Three periods of land use maps were considered in the analysis. The land use periods are 1984, 1986 and 2002, the first two maps was obtained from Ethiopian mapping agency and the 2002 one is from Addis Ababa city Administration which developed by City master plan office. The land use maps were digitized using GIS. Based on the three periods the land uses types categorized as Asphalt, Agriculture, Forest, Paved, Built and Park and Cemetery. Using parameter,curve number for each land use types surface runoff was calculated. Accordingly it was found out that since 1984 the runoff potential has changed from 0.28 in 1984to 0.45 in 2002. This is due to the expansion of the city and increasing of built environment, which was expressed by composite Curve Number and Soil Retention. The composite curve number has changed from 84.6 in 1984 to 91.1 in 2002. This change has been also observed when we delineated twelve sub catchments using ARC SWAT and GIS . Based on the analysis we found change of surface runoff was observed. The characteristics of streams which found in the delineated sub catchments also changed .The time of concentration for streams in delineated sub catchments reduced by twenty seven percent in small streams (intermittent). Therefore it is important to consider the impact of land use change in planning and design of urban infrastructure.

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Abbreviations

AAU	Addis Ababa University
AACAECS	Addis Ababa city Administration Environment Conservation Service
AIMP.	Area Impervious
AMC	Antecedent Moisture Condition
APER.	Area Pervious
AAWSA	Addis Ababa Water and Sewerage Authority
CN	Curve Number
CSA	Central Statistical Authority
ERA	Ethiopian Roads Authority
GIS	Geographical Information system
Ia	Initial Abstraction
JICA	Japan International Cooperation Agency
ORAAMP	Office for Revision of Addis Ababa Master Plan
Qu	Unit peak Discharge
Qp	Peak Discharge
S	Hydraulic Soil Retention
SCS	Soil Conservation Service
UN	United Nation
UNDP	United Nation Development Program
MOFED	Ministry of Finance and Economic Development

CHAPTER ONE

INTRODUCTION AND BACK GROUND

1.1 Back ground

Addis Ababa was founded in 1986 and since 1889 it has functioning as the seat of government and capital of Ethiopia. Since it is founded Addis Ababa has experienced rapid physical expansion in east, west, south and little in north direction. Though this has not been properly controlled by appropriate planning intervention. Almost none of the plans prepared at different times by different planners have been effective, nor have they been ever been fully implemented (ORAAMP, 1999:51). This unsuccessful planning history of the city is reflected in its development, which has largely been characterized by spontaneous growth.

The city had different land use maps which developed at different time in the history of the city, in 1936 Guidi and Valle developed a land use map by the Italian government in perspective of Italian city. The land use plan is assumed to comprise the rural districts and towns within a 40-50km radius. Air Force has taken many Arial photo graphs at different times. The 1993 aerial photo taken by Ethiopian Air Force is used as an input for the land use maps developed in recent times including master plan of the city

According to UN-Habitat, Addis Ababa, the capital of Ethiopia, with an estimated population of over 3 million has an amount of slum dwellers between 85% and almost 100 % within the districts (Sub-Cities) (UN-Habitat, 2004). But the central government has only recently given urban development issues attention as there has been a traditional focus on the agricultural sector that is still the dominate source of livelihood for most Ethiopians. The negligence of urban issues has had severe consequences for the physical, social and economic development of Addis Ababa (Solomon, 2005). Recently, the national government and the local government of Addis Ababa have formulated policies that target urban poverty reduction and slum upgrading by improving tenure security, water supply, sanitation, housing conditions etc. (AAWSA, 2004; HDPO, 2004; MOFED, 2002)

The foundation and expansion of Addis Ababa was associated with the rapid conversion of land from rural to urban uses more than anyone else in the country (Tamiru A., 2003). For the last one hundred 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 high ways), recreation areas and other manmade structures. The less controlled urbanization that includes construction of residential houses, commercial centers, and transport infrastructures, various types of industry, parks and recreational areas covered most proportion in the urban parts of Addis Ababa

According to Daniel (1977) classification of Ethiopia rain fall region, Addis Ababa is located in the region where the rainy months are closely distributed .In this region there are seven rainy months from march to September and the small rains occur from march to may .The big rains are from June to September .High concentration of rain fall occurs in July and very high concentration in august

The drainage area lies within the awash river basin which has a total drainage area of 530.14 square kilometers (Tesfaye chernet.1993).The perennial streams in the city are little Akaki, Bantiyiktu, kurtume ,kebena ,Ginfle and big Akaki .Other streams are intermittent in nature

The city of Addis Ababa has been vulnerable to flooding due to its topographic and metro-hydrological conditions. It experienced severe floods affecting nearly 8000 persons and extensive damage to property and loss of life in recent years (JICA and Region 14 Administration, 1998). Potential flood damages exist in many areas of the city adjacent to the river channels that are now occupied for house with the increase in population which is susceptible to severe damage or destruction by flooding (AACAECS 2000)

The 1986 Addis Ababa Master Plan had proposed compact urban expansion in three major directions: east (kotebe), south (Akaki and mekanisa), and west(Kerannyo). These are wider spatial units lying between the regional outlets to the east, south, southwest, and west. On the contrary, however, linear developments are observed along all the regional outlets while there are considerable vacant spaces in the proposed expansion areas (ORAAMP 2002).

Currently there is increasing of built up environment in the city mainly high rise buildings which done by private investors and housing agency Condon apartments and upgrading and building of new roads. There is also pavement works (kobil stone) done intensively on sides of main roads and within the residential areas. The construction of commercial high rise buildings dominates the main roads of the city. All these built environment increases the runoff generated from the city due to the increase in impervious area. More Agricultural lands and green areas of the city has changed to built environment due to socio –economic growth or demographic change. The expansion of built environment especially residential areas inhibited in the northern part of the city due to the topography of Intoto area

Generally Addis Ababa passes through different land use maps which are influenced by many factors. The expansion of the city has different patterns .Some part of the city is unplanned, simply illegal settlements which legalized gradually. In generalized category the built environment of the city can be categorized as well built, moderate and poor built environment

This study focuses on the impact of built environment that changes the hydrology of the city of Addis Ababa. This is achieved by evaluating different land use changes that occurred based on land use maps developed at different period. Through this study we can evaluate and make analysis of the surface runoff generated and Stream characteristics due to expansion of impervious area of the city. This will enable us to know impact of different land use changes such as built environment, roads and deforestation on flood. The sub catchments are selected from the entire Addis Ababa catchments to calculate hydraulic parameters further for surface runoff and the streams within the city.

1.2 Demography

The population growth has a significant impact on increase of built environment of Addis Ababa. Residential buildings including apartments and areas with private fences are among the indication of impact of population. Addis Ababa has high increment of population rate which is due to high birth rate and rural-urban migration

The Urban-rural distribution of population in Addis Ababa indicates that the overwhelming (greater or vast) majority of the population is living in urban areas. The population density of

Addis Ababa is 3984 persons per km2. The densities of population in urban and rural sectors of the city are 7008 and 121 persons per Km2 respectively. The highest population density is concentrated over northeast and central parts of the city (Bisrat K. 1999)

Table 1.1 Size and average annual population growth rate of Addis Ababa (1961-2010)

Year	Population Size	Annual Average Growth Rate
1961	443,328	-
1967	683,530	7.6
1978	1,167,301	4.9
1984	1,423,111	3.5
1994	2,112,737	4
2000	2,495,000	2.9
2004	2,805,000	3
2005	2,946,000	3.51
2006	3,051,000	3.56
2007	3,161,000	3.61
2009	3,398,000	3.7
2010	3,525,000	3.75

Source: CSA 1999

It is obvious that as population increases the need for residential area or housing and infrastructure. But here it is difficult to trace the relationship between the two, this is due to some increment in built environment such as roads and high rise buildings can also related to some living standard conditions and economic progresses

1.3 Statement of the Problem

Apart from rainfall characteristics such as intensity, duration and distribution, there are a number of site (or catchment) specific factors, such as soil type, land use and slope and catchment size of the watershed which have a direct bearing on the occurrence, and volume of runoff

The hydrologic response of a catchment primarily influenced by the characteristics such as the shape, size and land use distribution of the catchment. The runoff generated from the area will increase as the land use of a given area become impervious. The natural drain systems of the catchment will be altered as the increase of manmade structures due to increase of runoff generated.

All the above mentioned reasons seem obvious for urban watershed. But they need to be quantified scientifically based on hydrological models and principles in order to know percentage change relationship between land use change and surface runoff. Currently Addis Ababa is undergoing different economic and social activities. Due to economic and social influences such as population growth, the land use of the city is changing from time to time. There is an overall increment of built environment within the city. This study was conducted using SCS method to assess how hydrology of natural areas are changing as they are urbanized, how built environment affect the hydrologic regimes of Addis Ababa city? And what is the relationship between the increasing built environments to the runoff generation and Stream flow characteristics?

1.4 Objective of the study

1.3.1 General objective

The general objective of the study is to assess the historical relationships of built environment of Addis Ababa city with its hydrological regimes through derivation of hydrological parameters and to assess the characteristics of streams flow of the city that altered or modified due to built environment by relating its rainfall and runoff

1.3.2 Specific objective

1. Assessing the expansion of built environment and derivation of the hydrological parameter to define the built environment
2. Assessment of the impact of built environment on stream flow characteristics

CHAPTER TWO

LITERATURE REVIEW

2.1 Urbanization

Urban expansion has increased the exploitation of natural resources and has changed land use and land cover patterns. In 1900, only 15 percent of the world's population lived in the cities, however now more than 50% do so, with the United Nations forecasting that between 1990 and 2050, the urban population will rise to over 5 billion (Maksimovic & Tucci, 2001). Urbanization represents a modification of the natural conditions of a watershed. The main features of natural areas modified by urbanization and directly related to the quantity and rate of storm water runoff are (Jorge G. 2007): the natural surface detention, the infiltration characteristics and the drainage pattern formed by natural flow paths. The process of urbanization results in high catchment imperviousness (increased volume of runoff), fast runoff and quick catchment response to critical rainfall of reduced duration, all of which contribute to increased runoff flows. Impervious surfaces associated with urbanization alter the natural amount of water that takes each route. The consequences of this change are a decrease in the volume of water that percolates into the ground, and a resulting increase in volume and decrease in quality of surface water. These hydrological changes have significant implications for the quantity of fresh, clean water that is available for use by humans.

The effects of large urban areas on local microclimate have long been recognized and occur as a result of changes in the energy regime, air pollution, and air circulation patterns caused by building and/or transformation of land cover (J.marsalek 2006). The concentration of urban population brings about not only social and economic problems but also physical ones (see lai 1980). Among the effects of increased runoff flows and their durations are secondary effects on sediment erosion, transport, increased concentrations of suspended solids and sediment deposition (siltation) in slowly moving stream reaches. Soil erosion is intensified in urbanizing areas as a result of two factors: the stripping of natural protective vegetative covers from the soil surface during construction and increased runoff flows, which cause sheet erosion, scouring in unlined channels and transport of eroded material to the downstream areas (Horner et al., 1994). Sediment conveyed by urban runoff is deposited in receiving impoundments and lakes, where it causes similar effects as in streams, particularly with respect to siltation and increased concentrations of suspended solids in the water column. Erosion and siltation impacts can manifest themselves on various time scales; a single large rainfall/runoff event can cause significant impacts, but generally long-term impacts are more important. Ecological impacts include those related to critical species and dispersal and migration; and, practically all beneficial water uses are affected (water supply, bathing, recreation, fishing, industrial water supply and irrigation) (Lijklema etal., 1993).

As a watershed develops, many changes occur. Undeveloped areas are typically covered by grass, brush, and trees. This type of natural land cover allows a large amount of rainfall to infiltrate into the ground when a storm occurs. Undeveloped areas also tend to have many ponds and natural depressions that store water, keeping it from reaching the outlet of the watershed. The development of a watershed usually brings about an increase in impervious areas as well as a reduction in storage areas. Roads, parking lots, driveways, buildings, sidewalks, and other facilities increase the hydraulic efficiency of the land. These surfaces allow for little or no rainfall to be infiltrated into the soil. These smooth, impervious surfaces cause the majority of the rainfall to be quickly ushered to the watershed outlet. The reduction in infiltration means that a larger percentage of the total rainfall will be released from the watershed as runoff. This runoff will flow over the smooth concrete and asphalt surfaces that are typically found in developed areas and give much larger peak discharges than were previously found under undeveloped conditions. This runoff is then carried downstream by various means dependent upon the particular storm water system present. Both the increase in total volume and peak flows can cause problems downstream. One issue that occurs is increased flooding. Areas downstream often cannot handle the increased flows causing frequent flooding. In urban areas this can mean the flooding of streets, parking lots, businesses, and even houses. Another problem is the increased erosion that occurs downstream in the streams. Stream channels are forced to carry much higher peak flows more frequently than were previously carried. In addition, high flows last much longer due to the increase in the total amount of runoff. These factors can lead to instability and increased erosion in the channel as it tries to adapt to the new conditions. Also, the increased erosion means that a larger amount of sediment will be carried downstream. This can have a dramatic effect on the quality of bodies of water downstream as this sediment is deposited into larger rivers, ponds, and lakes.

Soil infiltration and surface loss of rainfall involve many different processes at different scales of observation. The most basic of the processes is the infiltration of water into an "ideal" soil, a soil of uniform properties and infinite depth. Initially, the soil is assumed to have uniform water content. The initial water content or an initial condition related to the water content must be specified for any of the methods which are used for single rainfall event analysis. At the commencement of rainfall, water is infiltrated until the rainfall exceeds the capacity of water to be absorbed by the soil. At this point, the surface becomes saturated and rainfall in excess of the soil infiltration capacity is assumed to be runoff. As the volume of infiltrated water increases, the infiltration capacity of the soil decreases to a minimum rate equal to the soils saturated hydraulic conductivity. Surface losses are categorized as being due to interception, depression, and detention storage. Interception storage results from the absorption of rainfall by surface cover such as plants and trees. Depression storage results from micro and macro relief depressions in the surface topography that store water which eventually infiltrates or evaporates. Also a function of topography, detention storage acts as mini reservoirs, increasing the retention time of overland flow and providing more opportunity for infiltration

Surface cover also increases loss rates by delaying overland flow. In addition, surface cover impacts on rainfall losses by protecting the soil surface from the impact of rainfall, preventing the formation of surface crusts that decrease the hydraulic conductivity of the soil surface. The extent to which surface conditions affect rainfall excess is a function of land use. Forested areas exhibit the greatest surface losses because of their well developed canopies and significant surface storage provided by surface litter. Range land is less effective in storing water because of sparser cover. The presence of grazing further reduces cover and increases runoff potential. Bare surface conditions in agricultural areas can potentially result in relatively high runoff rates due to crusted surfaces formed from rainfall impact. Management practices, such as contour plowing or mulching, have been employed to protect the soil or store overland flow. Urban area runoff increases in proportion to the amount of impervious area and how this area is connected to outflow points by the drainage system.

2.1.1 Expansion Trend of Addis Ababa City

The large scale implementation of slum upgrading and improvement programs is one of the biggest challenges that communities and municipalities in developing countries are facing. Such programs aim to overcome diverse problems such as poor housing conditions, access to water, sanitation, insecure tenure, hazard risks, missing access to employment opportunities. The need to address these problems is reflected by the high priority within the Millennium Declaration, Goal 7 - Target 11 that aims at the improvement of the lives of 100 million slum dwellers by 2020 (UNDP, 2003). One important prerequisite for improving conditions in slums are local intervention strategies that build on adequate and timely available information that spatially locate slum areas but also reflect their diversity in a local context. According to UN-Habitat, Addis Ababa, with an estimated population of over 3 million has an amount of slum dwellers between 85% and almost 100 % within the districts (Sub-Cities) (UN-Habitat, 2004) The negligence of urban issues has had severe consequences for the physical, social and economic development of Addis Ababa (Solomon, 2005). Recently, the national government and the local government of Addis Ababa have formulated policies that target urban poverty reduction and slum upgrading by improving tenure security, water supply, sanitation, housing conditions etc. (AAWSA, 2004; HDPO, 2004; MOFED, 2002). Main strategic decisions about slum intervention and the allocation of the budget is still done on the City level

Addis Ababa began its rise to megacity status between 1967and1975 when rural to urban migration in Ethiopia was at its peak (United Nations). The second growth wave is between1975-1987, in this period the population growth is rapid. Rural to urban migration decreased drastically during this period and most of the population boom in Addis Ababa was due to natural increase. Metropolitan Addis Ababa, sprawling at the foothill of Intoto mountain range is traversed by several small streams originating from the mountain range. The center of the city lies on an undulating topography with some flat land areas. The topography is undulating and form plateau in the northern, western and southwestern parts of the city, while gentle morphology and flat land areas characterize the southern and southeastern parts of the city. Moreover, it is not uncommon to see sharp changes in the inclination of the slope and some flat land areas in different parts of the city. On the top of the hills and ridges streams are dense and form radial drainage pattern, whereas on the slope and most parts of the study area they form denderitic features. Torrential rains which are common during the rainy season in the city, cause sudden rise in flow of these streams which bring about flood damages to settlements along the bank of these streams. Such damages have often caused losses of property. Recently a study of flood risks and measures of intervention along these streams has been carried out by the municipality and an implementation program over a 15-year period to contain flood waters within their banks have been drawn out (Kefyalew A.). Lack of explicit urbanization policy has resulted in unbalanced urban growth. The city is sharply divided by class and ethnicity with informal settlements concentrated near the center and wealthier districts to the south east and south west. There is no doubt that over the last four decades enormous urban sprawls have cropped up everywhere in general. Due to increased impervious area in the Addis Ababa water shed (12.63% in 1975 to 49.25% in 2020) precipitation responds quickly, producing higher peak flows in the drainage channels. This pattern of high flows that assumes the peak flow with a considerably reduced 'time to peak' has been illustrated in the hydrographs plotted using simulated hydrologic and meteorological time series using HECHMS hydrological modeling (Fessahatsion Z. 2008). From 1984 to 1994, 14,794 illegal/informal houses were developed in the urban peripheries accounting for 15.7% of the total housing stock (Mintesnot G.)

2.2 Approaches to Study Impact of Urbanization

There are three major approaches undertaken in many places to evaluate the hydrological impact of urbanization,

Before-After method by involving the analysis of long term stream flow records for reflection of changing trend in discharge and time lag characteristics of drainage basin undergoing urban development,

Synthetic method this involves the use of synthetic hydrographs to predict the hydrological conditions of the watershed prior to urban development.

Paired watershed method involves the comparison of different watersheds with similar basin characteristics. All the above approaches used to evaluate the effect of urbanization on hydrological conditions of the watershed. Rainfall losses are due to both surface storage and soil infiltration. In the field, the surface storage and infiltration of rainwater are dynamically interconnected. The interconnection occurs primarily via surface depression and detention storage. Detention storage increases infiltration rate by adding a small (less than an inch) pressure head to the wetting front. This additional head is insignificant when compared to the suction head which drives soil infiltration. Detention storage increases apparent infiltration by delaying surface flow and providing more catchment retention time for water to infiltrate. In general, these effects are minor when compared to the problem of estimating the magnitude of surface loss and the in-situ capacity of soils to infiltrate water. Consequently, the typical approach is to separate these two contributions to rainfall loss unless surface losses are empirically included in the loss rate method.

The SCS hydrologic method requires basic data similar to the Rational Method: drainage area, a runoff factor, time of concentration, and rainfall. However, the SCS approach is more sophisticated in that it also considers the time distribution of the rainfall, the initial rainfall losses due to interception and depression storage, and an infiltration rate that decreases during the course of a storm. The drainage area of a watershed is determined from topographic maps and field surveys. For large drainage areas it might be necessary to divide the area into sub-drainage areas to account for major land use changes, obtain analysis results at different points within the drainage area, combine hydrographs from different sub-basins as applicable, and/or route flows to points of interest. The SCS method applicable to based on a storm event that has a Type II time distribution. This distribution is used to distribute the 24-hour volume of rainfall for the different storm frequencies. A relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous soils and vegetative cover conditions. The SCS runoff equation is used to estimate direct runoff from 24-hour or 1-day storm rainfall. The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope. The SCS method uses a combination of soil conditions and land uses (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher the CN, the higher the runoff potential. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Based on infiltration rates, the SCS has divided soils into four hydrologic soil groups. Consideration should be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, appropriate changes should be made in the soil group selected. Also, runoff curve numbers vary with the antecedent soil moisture conditions. Average antecedent soil moisture conditions (AMC II) are recommended for most hydrologic analyses, except in the design of developments in sinkhole drainage areas where AMC III may be allowed. But for this study AMC III is used due to the selection of four rainy months of the city. Areas with high water table conditions may want to consider using AMC III antecedent soil moisture conditions. This should be considered a calibration parameter for modeling against real calibration data. Table gives recommended curve number values for a range of different land uses assuming AMC II. When a drainage area has more than one land use, a composite curve number can be calculated and used in the analysis. It should be noted that when composite curve numbers are used, the analysis does not take into account the location of the specific land uses, but sees the drainage area as a uniform land use represented by the composite curve number several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for developed areas

For example, the SCS curve number method includes surface losses directly into the method. Estimation of losses from an urban area is complicated by the presence of impervious surfaces which are not hydraulically connected to drainage systems. Typically, these areas are roof tops with downspouts that drain to flower beds or lawns. The critical part of the analysis is to determine if the pervious area can infiltrate the flow received from the unconnected impervious area. A method applied by SCS (1986) considered this problem in determining corrections for the curve number based on the percent of total and unconnected impervious areas. The corrections are only applicable for areas with up to 30 percent total impervious area. If the percent of impervious area exceeded this amount, then the assumption was that the unconnected impervious area runoff would not infiltrate because of the small retention time on pervious

CHAPTER THREE

METHOLOGY AND DATA ANALYSIS

3.1 Materials and Methods

3.1.1 Detail Study Area

Addis Ababa is located at the geographical center of Ethiopia and lies between 8º55’ north and 9º05’ north latitude and 38º40’ east and 38º50’ east longitude. Addis Ababa being at an altitude 2300-2500 meter (AAWSA, AAU, 2003). The major soil types of the city are Pellic Vertisols, Lavisols, Cambisols and Nitosols. Nitosols are found in the high land of Addis Northwest and Northeast of the catchments. Nitosols have very good potential for agriculture and have high water storage capacity. Generally the soil is classified as B and D soil group. Addis Ababa has a Subtropical highland climate (Koppen Cwb). The city possesses a complex mix of highland climate zones, with temperature differences of up to 10 °C, depending on elevation and prevailing wind patterns. The high elevation moderates temperatures year-round, and the city's position near the equator means that temperatures are very constant from month to month

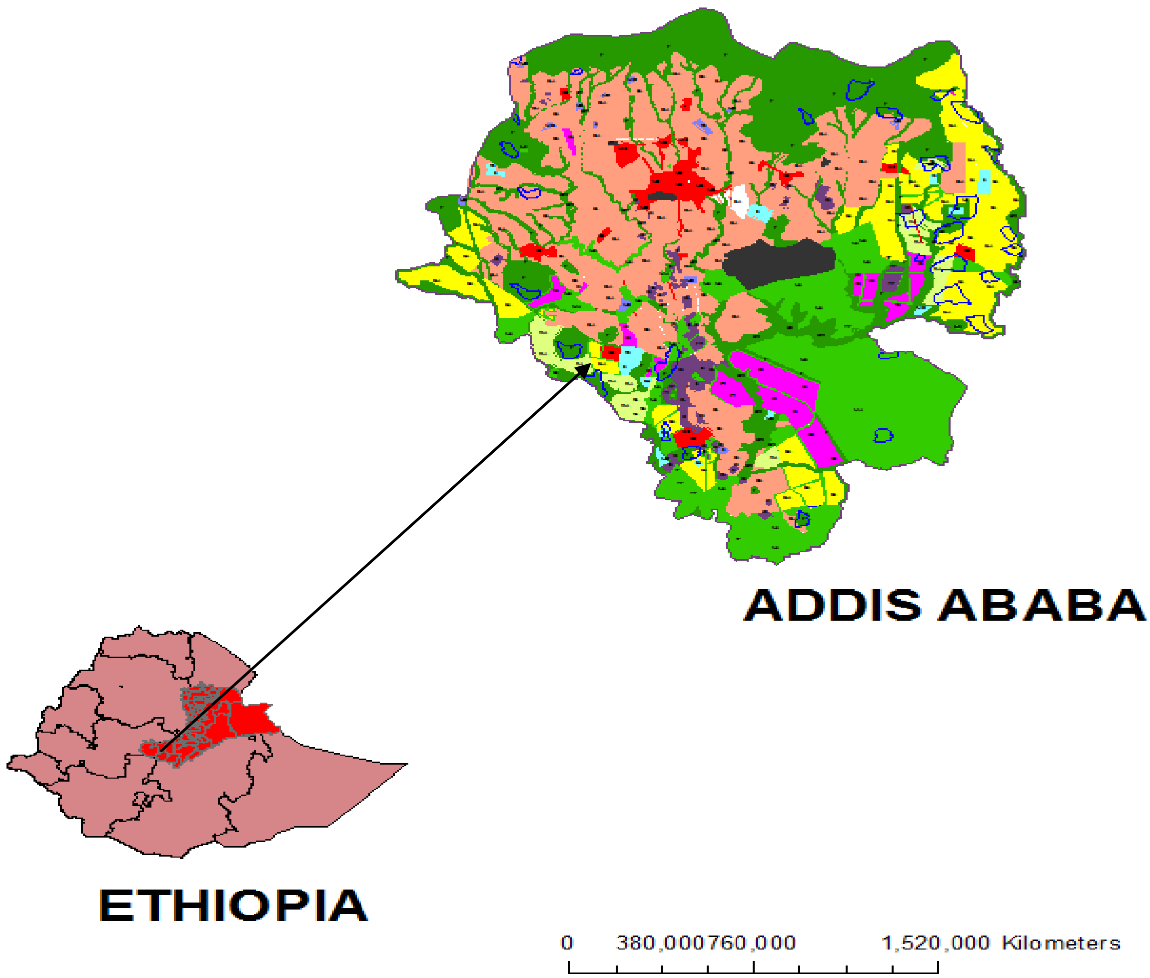

Figure 3.1 Location of Addis Ababa in Awash Catchment

3.1.2 Materials

Since establishment, the city undergo many proposed land use maps but there is no available organized documentation about the land use maps in the documentation library of the city administration. The study done on three land use maps of Addis Ababa which of one is developed by organization of Addis Ababa master plan study. The two other land use maps were developed by Ethiopian mapping agency in a year 1984 and 1986 which developed for ten years anniversary of the Derg regime and hundred year's anniversary of Addis Ababa city .Both two maps shows detail existing land uses of the city at that specific period. The hydrological data including soil type and land use data of the study area of Awash basin is obtained from Ministry of water Resources. The rainfall data required for the study area on daily basis for four meteorological stations in the city was obtained from National Meteorological Agency. GIS and Arc SWAT software were obtained from commercial software galleries

3.1.3 Methods

Land use maps are the major materials of the thesis, which were obtained in hard copy .The land use maps digitized using GIS soft ware. After digitizing each land use map, the areal coverage of each land use type is calculated in order to show the land use changes of each period. The land use grouped (classified) as Built, Asphalt, Forest, Agricultural land, Paved, parks and cemetery.

The runoff calculation was conducted using SCS (soil conservation service) method. SCS method was developed by U.S soil conservation service. The SCS approach however is more sophisticated in that it considers also the time distribution of the rainfall, the initial rainfall losses to interception and depression storage and an infiltration rate that decreases during the course of a storm. It is based on a 24 hour storm event which has a type Π time distribution. The type Π storm distribution is a typical time distribution which the SCS has prepared from rain fall records. It is applicable for interior rather than the coastal regions and should be appropriate for Ethiopia (ERA 2001). The type Π rainfall distribution will usually give a higher runoff than a type I distribution

3.1.3.1 SCS method runoff depth estimation

Excess rainfall or effective rainfall is the rainfall which is neither retained on the land surface nor infiltrated into the soil. After flowing across the watershed surface, excess rainfall becomes direct runoff. Runoff estimates are based upon the soil types, land-use practices within a basin and the influence of the antecedent soil moisture conditions for a specific storm. For many peak discharge estimation methods, the input includes variables to reflect the size of the contributing area, the amount of rainfall, the potential watershed storage, and the time-area distribution of the watershed. The volume of storm runoff can depend on a number of factors. Certainly, the volume of rainfall will be an important factor. For very large watersheds, the volume of runoff from one storm event may depend on rainfall that occurred during previous storm events. In addition to rainfall, other factors affect the volume of runoff. A common assumption in hydrologic modeling is that the rainfall available for runoff is separated into three parts: direct (or storm) runoff, initial abstraction, and losses. Factors that affect the split between losses and direct runoff include the volume of rainfall, land cover and use, soil type, and antecedent moisture conditions. Land cover and land use will determine the amount of depression and interception storage. In developing the SCS rainfall-runoff relationship, the total rainfall was separated into three components: direct runoff (Q), actual retention (F), and the initial abstraction (Ia). The SCS method applicable to a storm event that has a Type II time distribution. This distribution is used to distribute the 24-hour volume of rainfall for the different storm frequencies. The retention F was assumed to be a function of the depths of rainfall and runoff and the initial abstraction. The development of the equation yielded

$$Q = (p - Ia)^2 / (P - Ia) + S \ldots\ldots 2.3$$

Where,

P = depth of precipitation, mm (in)

Ia = initial abstraction, mm (in)

S = maximum potential retention, mm (in)

Q = depth of direct runoff, mm (in).

The retention S should be a function of the following five factors: land use, interception, infiltration, depression storage, and antecedent moisture. By using empirical relations

$$Ia = 0.2S \ldots\ldots 2.3.1$$

By combining equations 2.3.1 and 2.3 above

$$Q = (P - 0.2S)^2 / P + 0.8S \ldots\ldots 2.3.2$$

Empirical analyses were made to estimate the value of S. The studies found that S was related to soil type, land cover, and the hydrologic condition of the watershed. These are represented by the runoff curve number (CN), which is used to estimate S. The curve number CN (Appendix-B) apply for normal antecedent moisture condition (AMC II) can be estimated from the surface type and condition and the hydrologic soil group using tables developed by the NRCS (NRCS, 1972), which appear in many standard references. For dry condition (AMC I) or wet conditions (AMC III) equivalent curve numbers can be computed by

Table 2.1 Seasonal rainfall limits for AMC (Applied Hydrology Vent chow)

AMC group	Total five day antecedent rainfall (mm)	
	Dormant season	Growing season
I	Less than 13mm	Less than 36mm
II	13 to 28 mm	36 to 53mm
III	More than 28 mm	More than 53mm

$$CN(III)=23CN(II)/10+0.13CN(II) \qquad \ldots\ldots 2.3.3$$

For this study the selected months are the rainy season of Addis Ababa city, therefore wet condition (AMC III) is selected for computing direct runoff

$$S=\alpha\left((1000/CN)-10\right) \qquad \ldots\ldots 2.3.4$$

Where

CN = index that represents the combination of a hydrologic soil group and a land use and treatment class

α = unit conversion constant equal to 25.4 in SI units and 1.0 in CU units

Empirical analyses suggested that the CN was a function of three factors: soil group, the cover complex, and antecedent moisture conditions.

The study considers only the runoff generated from total area coverage of Addis Ababa city, do not follow drainage pattern of the watershed. On this paper The Addis Ababa city divided into four polygons, using area rainfall Thiessen polygons. This is used for calculating weighted hydrological parameters. The Thiessen polygons constructed using the rain fall stations in the city and its periphery. Based on these polygons, the land uses are classified and area coverage of each was calculated on respective land use period, in order to calculate the hydrological parameters and runoff depth

By using three land use maps of the city at different periods, the runoff generated was calculated by using maximum rainy months of the area which is in the months June, July, August and September. Thiessen polygon is constructed using GIS, for each rainfall station in the city, Intoto, Addis Ababa observatory, Bole and Akaki Mission. Within the area coverage of each Thiessen polygon the land use is further classified as Pervious and Impervious area in order to calculate weighted hydraulic retention of soil and composite curve number. Using these two calculated hydrological parameters based on available land use types, the runoff depth is calculated for each polygon for available land use periods of 1984, 1986 and 2002. Graphical comparison has been made between calculated runoff depths in order to made analysis between land use changes to show impact of built environment. The comparison is done by using daily rainfall of rainy months between 1984-2002 and annual runoff generated in these periods.

From the entire Area twelve sub-catchments which randomly selected and delineated using Arc SWAT in order to calculate parameters to show changing of stream flow characteristics. The time of concentration is calculated using lag time equation. The equation is selected because it can give best estimates for urban areas having curve number between 85 and 95. The discharge for each watershed is calculated and comparison made between discharge values by taking 1984 land use as base period.

3.2 Data Analysis

3.2.1 Rainfall Data

3.2.1.1 Data Availability and Statistics

Precipitation data are an important input for this study, in particular for the study of the rainfall-runoff process through which runoff results determined from a certain amount of precipitation on catchment area. Addis Ababa's rainfall data is recorded in four meteorological stations located at different parts of the city Intoto northern hilly part, Addis Ababa observatory at central part, Bole south western part and Akaki mission in southern part of the city. The annual rainfall ranges from 1233mm at Intoto to 944mm at Akaki mission. The highest rainfall season of the area is from June to September. August is the highest rainfall month in all stations. The elevation range of Addis Ababa is highest in Intoto mountain ranges and lowest in Akaki area. Due to this elevation difference the rainfall records at Intoto station are highest of all, while records at akaki mission are the lowest, since Addis Ababa is found as neighbor of rift valley in southern part. Generally the annual rainfall values decline with decrease in elevation and the effect of altitude on rainfall distribution is more clearly visible in the magnitude of rainfall record during the rainy season than the annual values.

Table 3.2 Rainfall Data Availability (Ethiopian metrology Agency)

Station Name	Record Length	Mean Annual Rainfall (mm)
A.A observatory	From 1984-2002	1227
A.A Bole	From 1984-2002	1097
Intoto	From 1984-2002	1233
Akaki Mission	From 1984-2002	944

Table 3.3 Monthly average rainfalls of four stations between 1984-2002

Station	**Jan**	**Feb**		**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	***Annual***
A.A Bole	11.8	33.0	65.0	105.9	74.6	136.4	234.8	239.0	154.0	35.1	3.1	4.2	***1097.05***
STD	17.7	39.0	53.2	76.0	53.9	75.3	54.7	55.4	69.0	40.6	6.6	9.7	
CV	1.5	1.2	0.8	0.7	0.7	0.6	0.2	0.2	0.4	1.2	2.1	2.3	
A.A Obser.	10.4	45.3	68.3	89.7	85.8	147.1	267.9	285.6	178.6	35.1	5.6	7.9	***1227.31***
STD	15.6	51.9	66.4	57.0	60.9	51.1	57.4	52.4	63.0	35.4	12.4	15.5	
CV	1.5	1.1	1.0	0.6	0.7	0.3	0.2	0.2	0.4	1.0	2.2	2.0	
Akaki Mis.	6.6	32.1	62.4	84.4	66.7	111.4	228.9	226.7	104.8	10.9	3.3	5.6	***943.86***
STD	11.9	34.4	43.8	58.9	47.6	34.6	45.7	54.2	49.1	14.0	7.5	13.5	
CV	1.8	1.1	0.7	0.7	0.7	0.3	0.2	0.2	0.5	1.3	2.3	2.4	
Intoto	11.3	46.4	57.3	84.6	64.6	133.0	296.6	326.3	170.1	24.7	7.9	10.2	***1232.85***
STD	13.5	51.2	50.3	52.6	40.6	41.5	55.5	74.3	66.5	23.7	21.9	13.7	
CV	1.2	1.1	0.9	0.6	0.6	0.3	0.2	0.2	0.4	1.0	2.8	1.3	

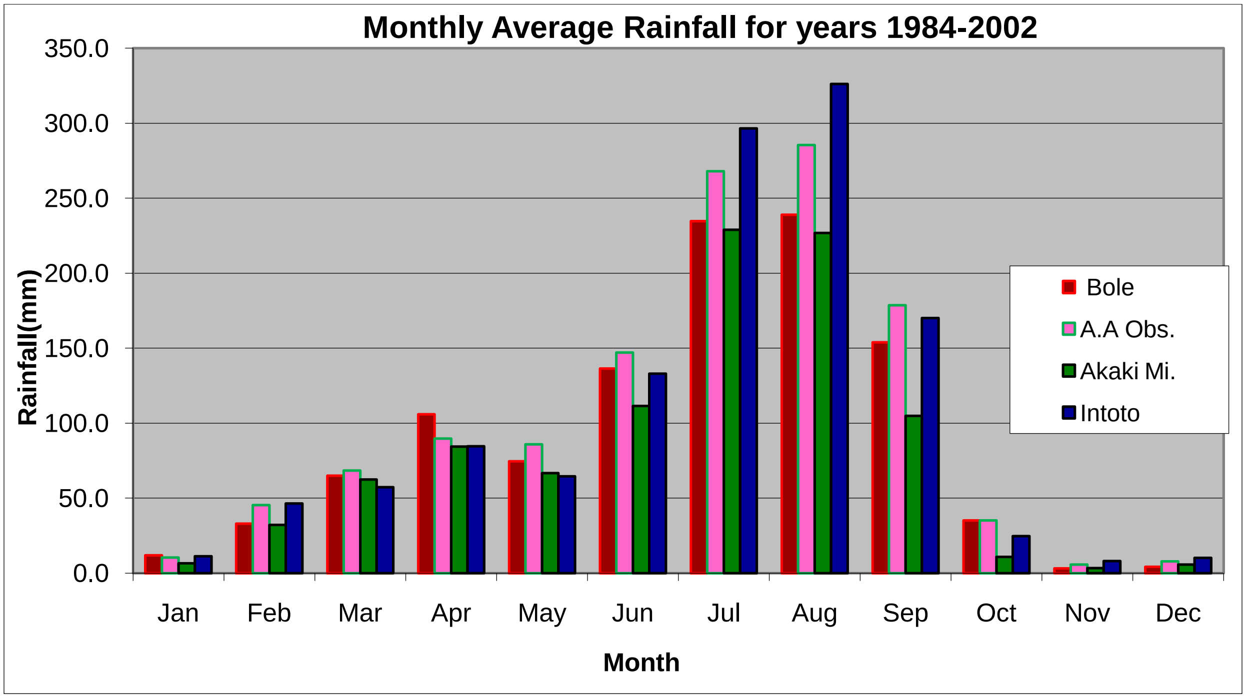

Figure 3.2 Monthly average rainfalls at four rainfall stations in Addis Ababa

3.2.1.2 Areal Rainfall Using Thiessen Polygon

Thiessen polygon is constructed by connecting rainfall stations, including those just outside the area. The connecting lines are bisected perpendicularly to form a polygon around each station. This Thiessen polygon is aimed rainfall as input to runoff generation under the land use change. For this study six meteorological stations located in the city and its neighborhood is used for the construction of the polygon. The four meteorological stations which are located in the city of Addis Ababa observatory, Bole, Akaki mission and Intoto. The Thiessen polygon selected rather than delineating catchments because the parameter curve number is the same in both cases. The data from two stations namely sebeta and sendafa is not used in the study since the study considers only Addis Ababa area. The four thiessen polygons of the city are differing in the magnitude of rainfall distribution and area coverage. The difference in magnitude of rainfall is due topographic distribution of the polygon and area coverage of each polygon is different from one another. Bole station Thiessen polygon has greater area coverage than the rest of stations and Intoto station polygon covers lower area. To determine the mean the rainfall amount, each station is multiplied by the area of its polygon and the sum of the products divided by the total area

Table 3.4 Areal Rainfall of four stations from 1984-2002

Name of Thiessen polygon	Rainfall (MAR) (mm)	Area (km^2)	% of total area for polygon	Area weighted Rainfall (mm)
A.A observatory	1227.31	123.830	23.911	293.46
A.A Bole	1097.05	227.437	43.918	481.80
Akaki Mission	943.86	106.244	20.516	193.64
Intoto	1232.85	60.359	11.655	143.69
Total		***517.87***	***100***	***1112.6***

Therefore from the table we conclude that the areal rainfall for Addis Ababa from 1984 to 2002 using the Thiessen polygon weighted average is 1112.6mm

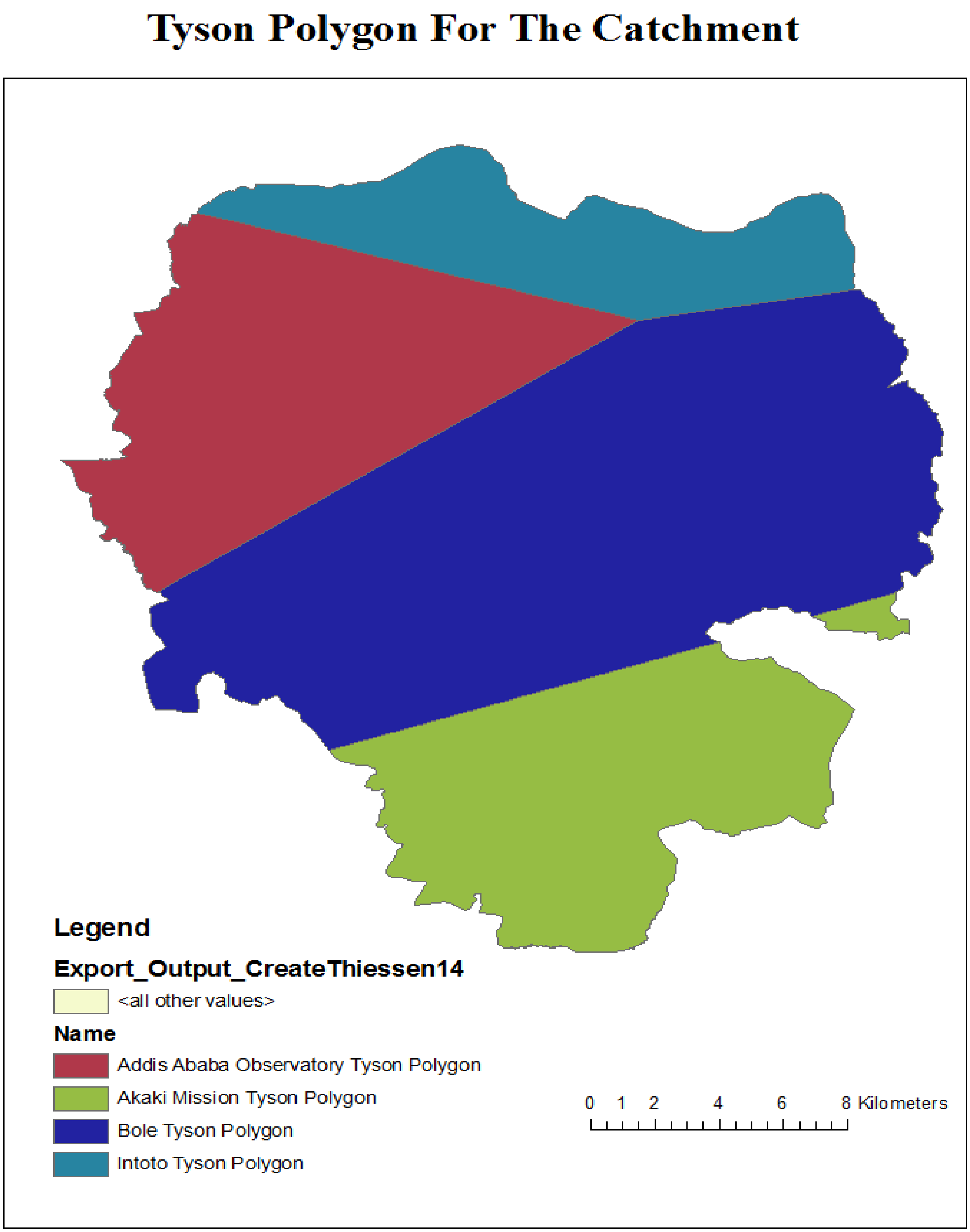

Figure 3.3 Thiessen polygon for Rainfall stations in the City

Thiessen Polygon constructed using rainfall stations located in the city and its periphery such as sendafa and Sebeta meteorological stations

3.2.2 Land Use Type and Area Coverage

3.2.2.1 Land use map of 1984

The 1984 land use map was developed using aerial photograph captured pre-1984. All the land use type which was mentioned in previous sessions cleared described and area coverage of each land use type is obtained by digitizing the map using GIS. In the map most of the built environment is found in Thiessen polygon of Addis Ababa observatory and Bole station. The rest two Thiessen polygons Intoto with small built environment and Akaki mission with null built environment in this period. In order to calculate run off generated for 1984 map the land use is classified as shown in table 3.5

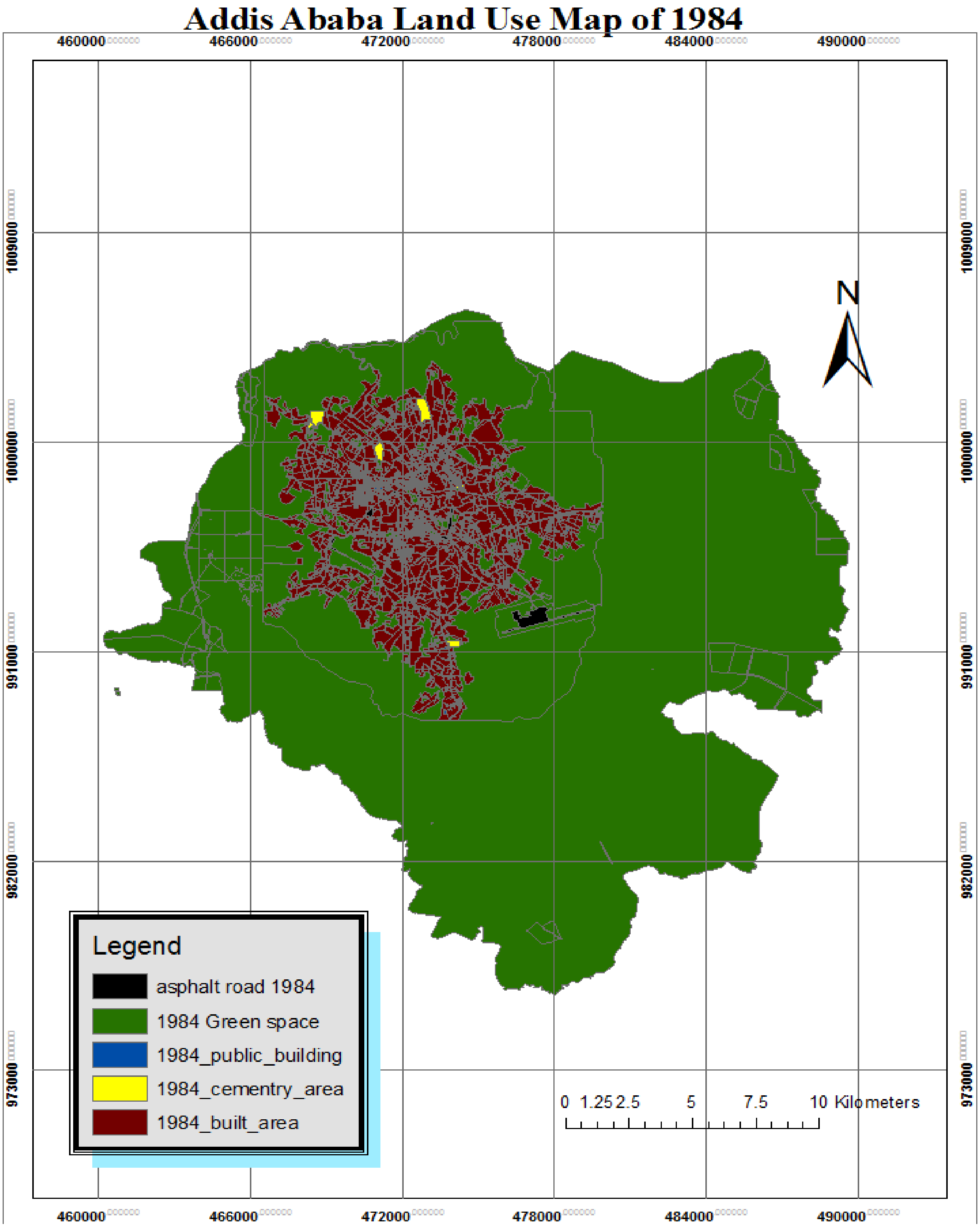

Figure 3.4 Land use map of 1984

3.2.2.2 Land use map of 1986

As similar to the land use map of 1984, the 1986 land use map has similar land use patterns with significant expansion of built environment in some parts of Addis Ababa. The land use map was developed by Ethiopian mapping agency for hundreds year anniversary of Addis Ababa city. The land use classification with areal coverage of the map is as shown in the table 3.5. In order to calculate run off generated for 1986 period map the weighted hydraulic parameters (CN and S) is determined using the classified Thiessen polygons together land use types.

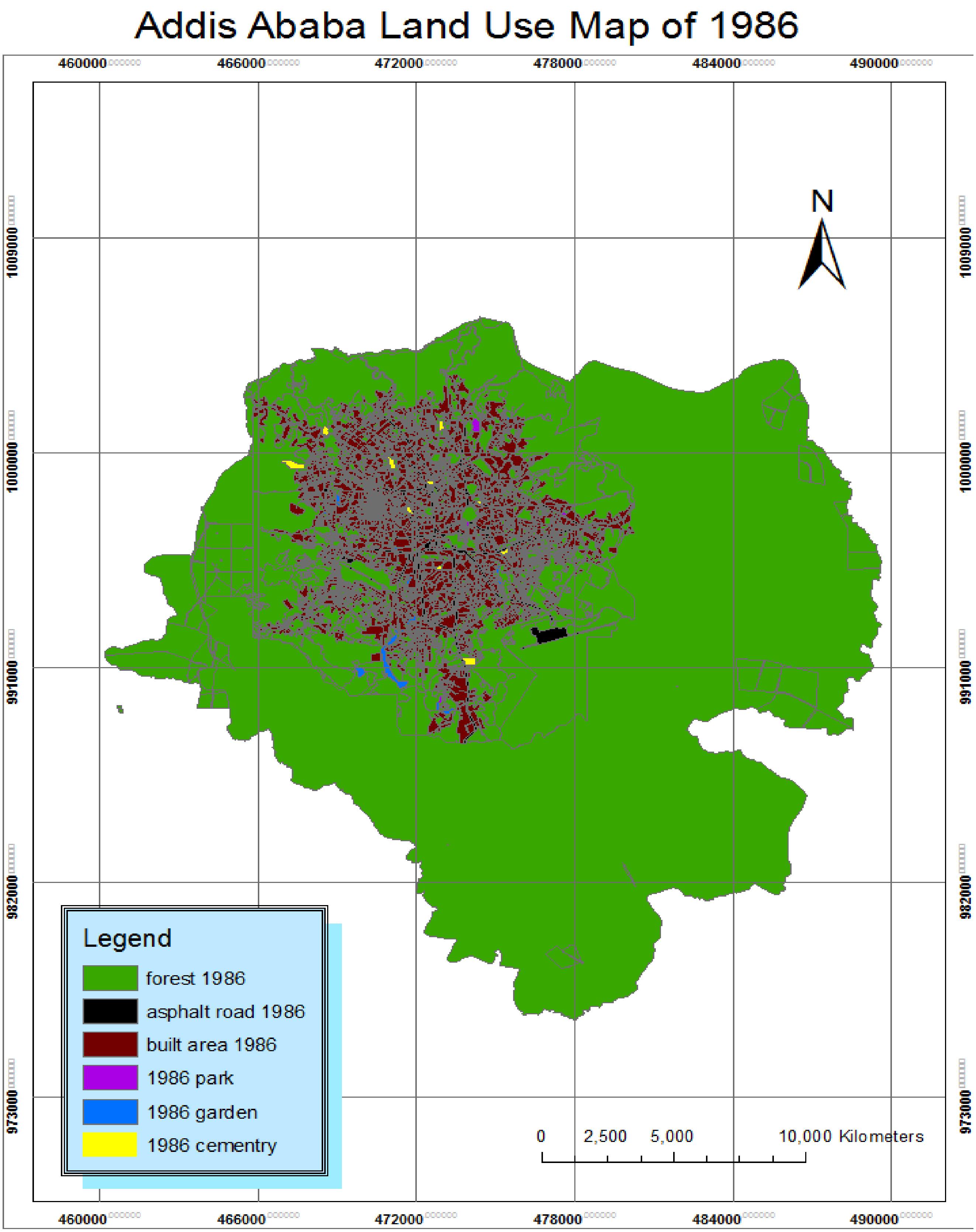

Figure 3.5 Land use map of 1986

3.2.2.3 Land use map of 2002

This map was developed by office of revision of Addis Ababa master plan. Since the year gap between1984-1986 is smaller than the gap between1986-2002, the 2002 land use map shows larger built environment than the other maps. All parts of the city shows high increasing trend of built environment. Between the mentioned years the city undergoes many land use changes due to its unplanned as well as planned rapid urbanization.

Mostly the southern part of the city shows dramatically increments of built environment this is mainly due to expansion of industrialization. This shows that many Agricultural lands changed to urban areas. Generally the land use change in the 2002 land use map is due to expansion of residential area, industrialization and paved road. The overall land use changes of the map with its areal coverage shown on table 3.5

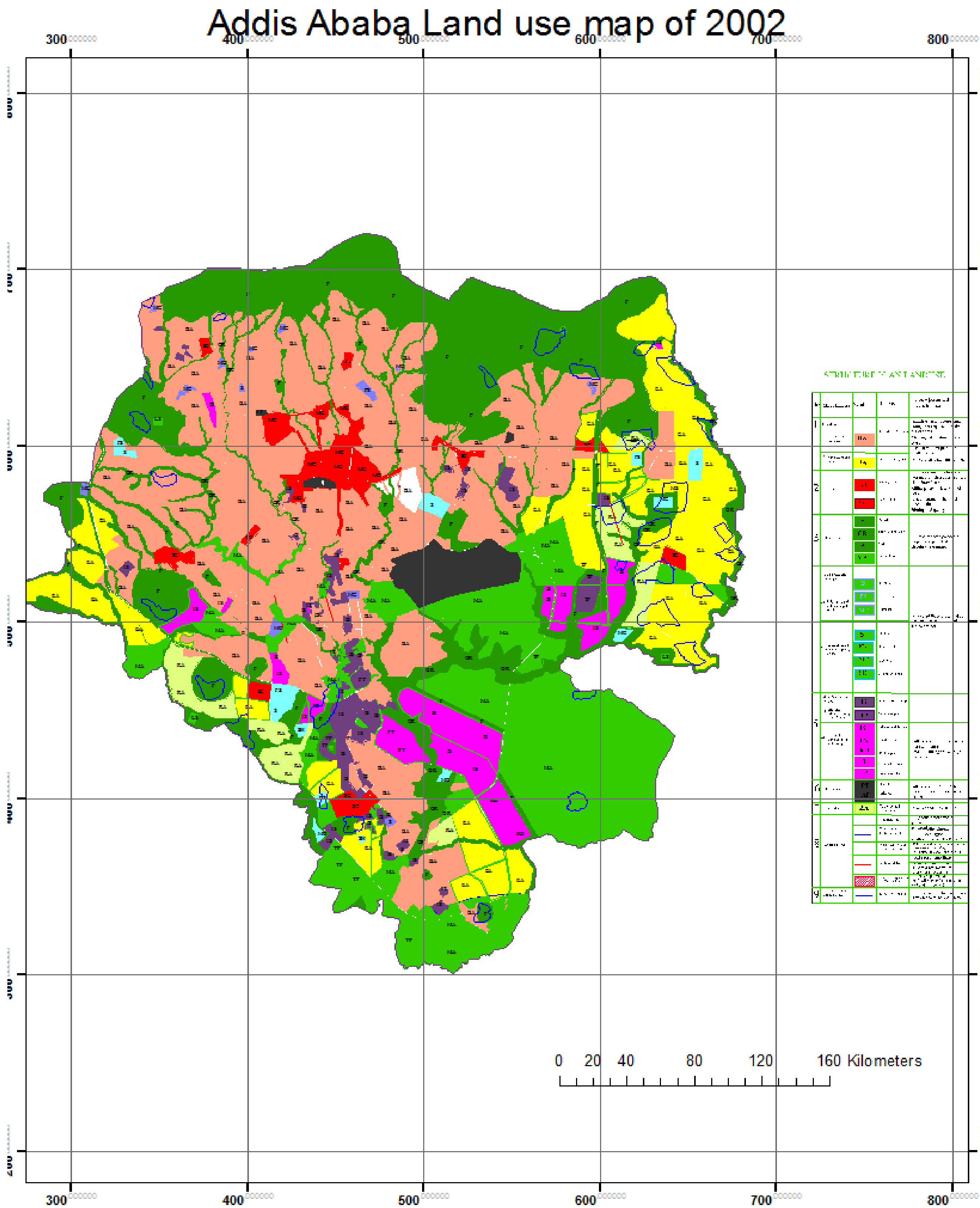

Figure 3.6 Land use map of 2002

Table 3.5 Land use type and Total Area coverage of each three periods

Year	Total Area (km^2)	Land use Type					
		Impervious Area			Pervious Area		
		Asphalt (km^2)	Paved (km^2)	Built (km^2)	Forest (km^2).	Agriculture (km^2)	Cemetery and park (km^2)
1984	517.87	4.72	11.16	60.15	139.023	301.7	1.09
1986	517.87	10.734	12.864	80.173	98.062	314.67	1.38
2002	517.87	27.704	57.358	212.733	68.717	142.87	8.43

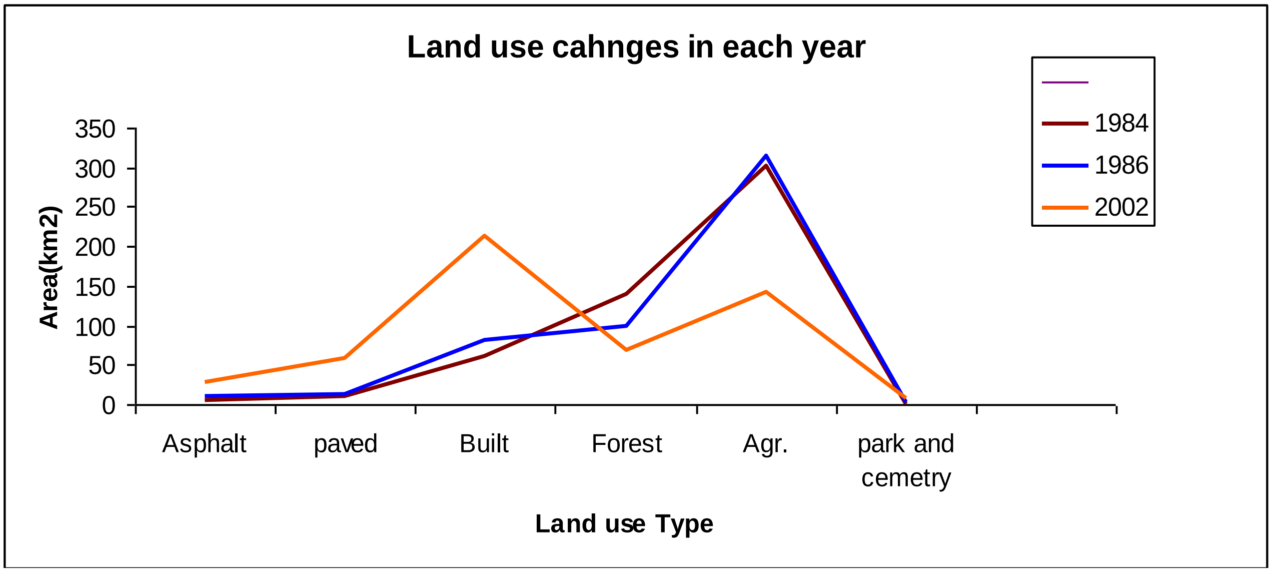

Figure 3.7 Land use Type and Area coverage at different periods

Generally to establish relationship between the amounts of runoff generated for the land use change from pervious to impervious, the runoff generated using 1984, 1986 and 2002 land use maps for rainfall periods between 1984 to 2002 is presented as follow. The average runoff values indicated in the table is the weighted value using Thiessen polygon.

Table 3.5.1 pervious and impervious area of each period and Runoff generated

Year	Pervious area(km2)	Impervious area(km2)	Average runoff generated(mm)
1984	441.8115	76.01711	221.4
1986	414.1018	103.7693	239
2002	220.0118	297.6941	358.4

To relate percentage of land use change to the amount of rainfall converted into runoff, the percentage coverage of each land use type in a given land use period was necessary to calculate weighted hydraulic parameters such as curve number.

Table 3.5.2 land use coverage in percent of total area in 1984

Land use type	Asphalt	Paved	Built	Forest	Agriculture	Cemetery and park
Area(km2)	5.716	11.155	60.146	138.023	301.7	1.09
Area (%)	1.104	2.15	11.61	26.652	58.26	0.22

Table 3.5.3 land use coverage in percent of total area in 1986

Land use type	Asphalt	Paved	Built	Forest	Agriculture	Cemetery and park
Area(km2)	10.734	12.864	87.173	93.062	312.666	1.375
Area (%)	2.07	2.48	16.833	17.97	60.38	0.27

Table 3.5.4 land use coverage in percent of total area in 2002

Land use type	Asphalt	Paved	Built	Forest	Agriculture	Cemetery and park
Area(km2)	27.704	57.358	212.733	68.717	142.870	8.425
Area (%)	5.35	11.08	41.08	13.27	27.60	1.63

From the entire above tables conclusion can be made about increment of built environment of Addis Ababa city. Among land use changes, change due to residential buildings is higher than other impervious land use changes. The large percentage of agricultural land also changed to built environment.

Table 3.5.5 Difference in land use change area in percentage

Year	Land use Types and Area coverage in Percent					
	Asphalt	Paved	Built	Forest	Agriculture	Cemetery and park
1984	1.104	2.15	11.61	26.65	58.26	0.22
1986	2.07	2.48	16.833	17.97	60.38	0.27
2002	5.35	11.08	41.08	13.27	27.60	1.63
Difference (1984-1986)	***0.97***	***0.33***	***5.22***	***-8.68***	***2.12***	***0.05***
Difference (1986-2002)	***3.28***	***8.60***	***24.25***	***-4.70***	***-32.78***	***1.36***

It is possible to develop linear relationship between homogenous land use changes and rainfall-runoff transformation from the above changes in land use area coverage and runoff generated, since different land uses has different rainfall-runoff transformation

3.2.3 Soil Data Analysis

Consideration should be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, appropriate changes should be made in the soil group selected. Also, runoff curve numbers vary with the antecedent soil moisture conditions. Empirical analyses suggested that the CN was a function of three factors: soil group, the cover complex, and antecedent moisture conditions.

SCS developed a soil classification system that consists of four groups, which are identified by the letters A, B, C, and D. Soil characteristics that are associated with each group are as follows

Group A: Soils having low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.

Group B: Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Soils having a moderately high runoff potential due to slope infiltration rate. These soils consist primarily of soils in which a layer exist near the surface that impede the downward movement of water of soils with moderately fine to fine texture.

Group D: Soils have a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a clay pan or clay layer at or near the surface, and shallow soil over nearly impervious parent material.

Generally the soil classification of Addis Ababa categorized as B and D soil group. The soil group D mainly dominant type in south and south western part of Addis Ababa

Table 3.6 Hydrologic Classification of the Addis Ababa Watershed Soils (ERA 2002)

Soil Symbol	Soil Type	Hydrological soil group
Bc	Chromic cambisols	B
By	Vertic cambisols	B
Lc	Chromic lavisols	B
Ne	Eutric Nitrosols	B
Vc	Chromic vertisols	D
Vp	Pelic Vertisols	D
Xk	Caloic Xerosols	B
Zo	Orthic Solonchaes	B

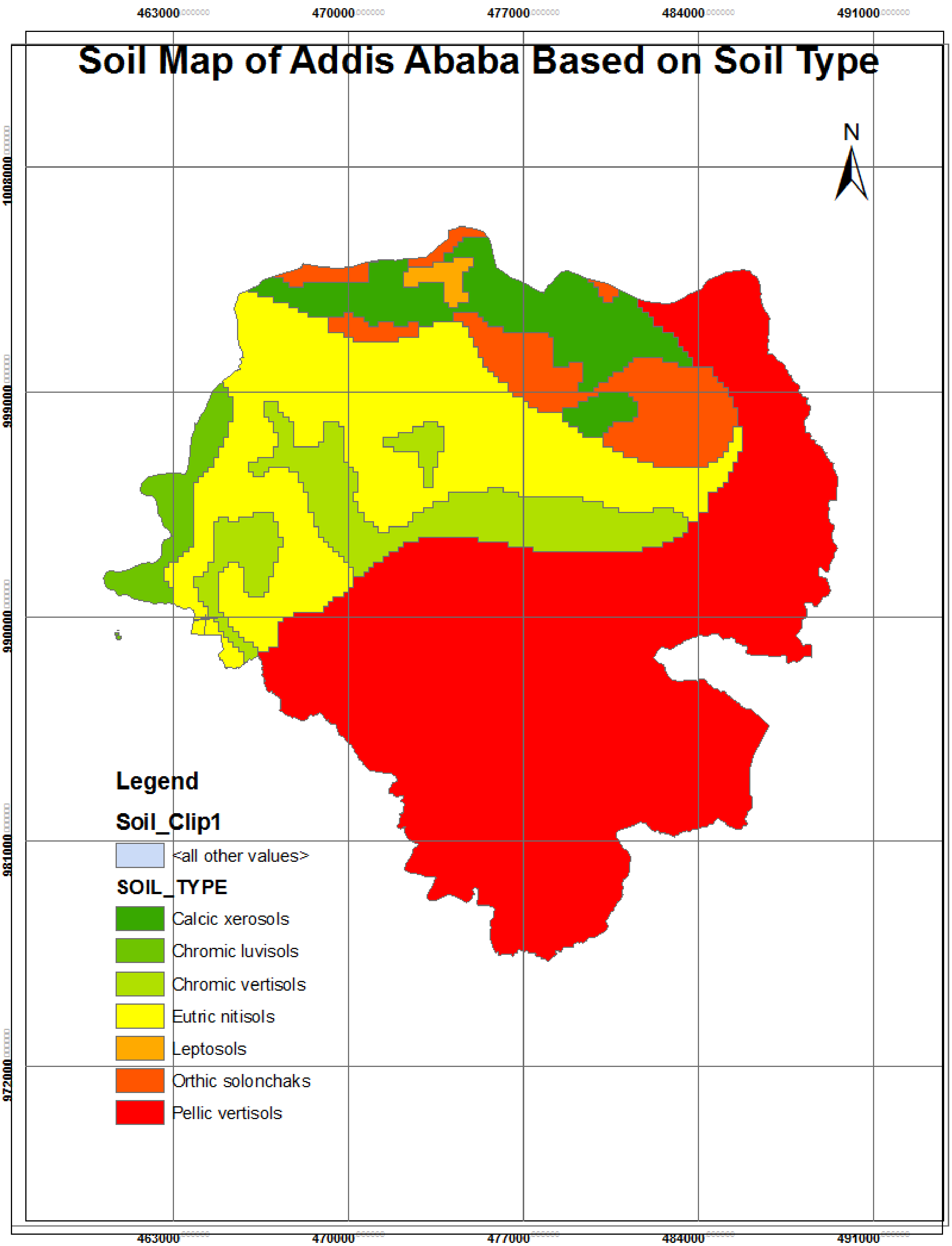

Figure 3.8 Soil classification of Addis Ababa based on soil type

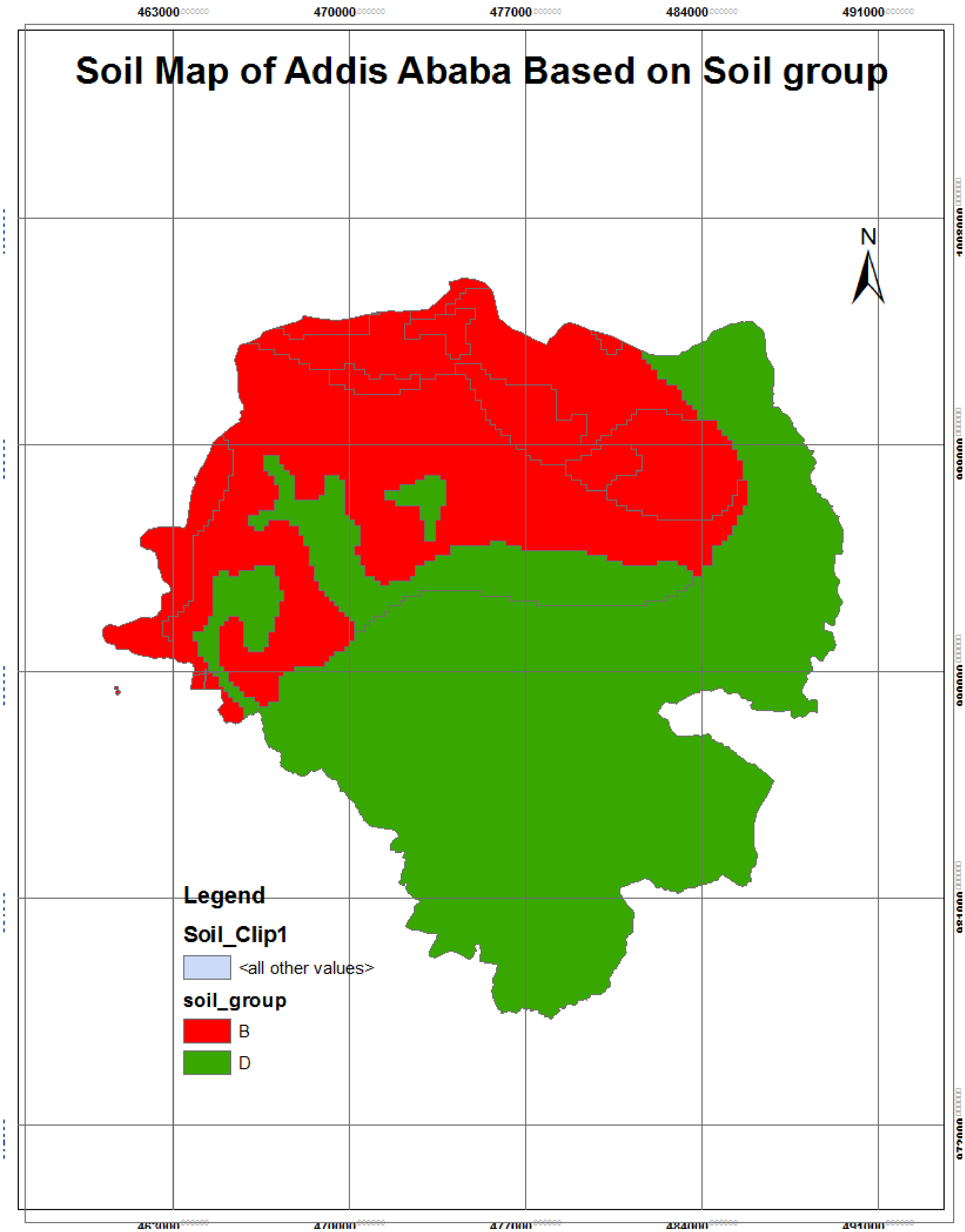

Figure 3.9 Soil classification of Addis Ababa based on soil group

3.2.4 CN (curve number) values Based on Tyson polygon

The curve number (CN) is a parameter which used to describe the degree of urbanization or impervious area, the higher the curves number the higher the runoff. This curve number valued is obtained from references based on AMCII. Based on AMCII values AMCIII was calculated for runoff generation. For all Thiessen polygon areas the weighted curve number was calculated. Since each polygon contain different percentage coverage of pervious and impervious area

Table 3.7 Thiessen polygon area coverage of 1984 land use map

Thiessen polygon	Impervious Area (km2)	pervious Area (km2)	Total area (km2)	CN pervious	Remark for pervious. area
A.A observatory	42.228	81.602	123.830	83	Grass land with crop land
A.A bole	28.341	199.097	227.437	85	Crop land with shrub land
Intoto	5.222	55.138	60.359	66	Tropical plantation
Akaki Mission	0	106.244	106.244	85	Grass land with crop land

Table 3.7.1 Thiessen polygon area coverage of 1986 land use map

Thiessen polygon	Imper. Area (km2)	Perv. Area(km2)	Total area(km2)	CN pervious	Remark for pervious. area
A.A observatory	53.078	70.753	123.830	83	Grass Land with crop land
A.A bole	45.160	182.277	227.437	85	Crop Land with shrub land
Intoto	5.532	54.828	60.359	66	Tropical plantation
Akaki Mission	0	106.244	106.244	85	Grass Land with crop land

Table 3.7.2 Thiessen polygon area coverage of 2002 land use map

Thiessen polygon	Imperv. Area(km2)	Perv. Area(km2)	Total area(km2)	CN pervious	Remarkfor pervious area
A.A observatory	97.405	25.261	123.830	83	Grass land with crop land
A.A bole	117.708	109.729	227.437	85	Crop land with shrub land
Intoto	31.64	28.719	60.359	66	Tropical plantation
Akaki Mission	49.942	56.303	106.244	85	Grass land with crop land

Based on the above tables weighted hydraulic parameters were calculated for each period considering pervious and impervious area coverage of each polygon. In order to get representative curve number, soil group and land use type of each period has been considered.

CHAPTER FOUR

RESULTS AND DISSCUSION

4.1 Runoff Estimation

4.1.1 Composite Curve Number (CN) Values

Curve number is a hydraulic parameter used to know the extent of impervious area. To calculate runoff generated from each land use map for a watershed that consists of several soil types and land uses first composite curve number calculated using pervious and impervious area. The calculation can be done by grouping land use into pervious and impervious area. Higher curve number shows that imperviousness of the watershed area. Assumptions are as follows. Impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. When a drainage area has more than one land use, a composite curve number can be calculated and used in the analysis a composite CN was calculated as:

$$CN_{composite}=(98*Aimp)+(CN_{per.}*A_{per.})/(A_{imp.}+A_{per.}) \qquad \text{……………..4.1}$$

Where;

$A_{imp.}$ =Area of impervious

$A_{per.}$ =Area of pervious

Table 4.1 Weighted curve number for three periods at each polygon

Name of polygon	Composite Curve number (CN)		
	1984	1986	2002
A.A Observatory	88.12	89.43	94.02
A.A Bole	86.62	87.58	91.73
Intoto	68.77	68.93	82.77
Akaki Mission	85	85	91.11
weighted	***84.57***	***85.32***	***91.11***

4.1.2 Hydraulic Soil Retention

Several soil hydraulic parameters including soil hydraulic conductivity, infiltration rate, water holding capacity and water table depth, are required for various water management activities including selection and design of drainage systems, supply infrastructure planning and catchment management. Soil retention, a measure of the ability of a watershed to abstract and retain storm precipitation, until the accumulated rainfall exceeds the initial abstraction. Since the city undergoes different land use changes the hydraulic retention of soil also changed. As the impervious area increases the hydraulic retention of soil decreases as a result quick runoff will occur. For all the three periods both curve number and hydraulic retention which have inverse relationship changes significantly.

To calculate hydraulic retention

$$S=\alpha\,((1000/CN)-10) \qquad \alpha=25.4 \text{ in SI unit}$$

Based on the above equation the hydraulic retention of soil was calculated for each Thiessen polygon. The weighted soil retention is obtained for the land use periods

Table 4.2 Weighted Hydraulic Retention for three periods at each Thiessen polygon

Name of polygon	Hydraulic Retention (S)		
	1984	1986	2002
A.A observatory	34.24	30.02	16.16
A.A bole	39.24	36.02	22.90
Intoto	115.35	114.45	52.86
Akaki Mission	44.82	44.82	24.78
weighted	**48.04**	**45.53**	**25.16**

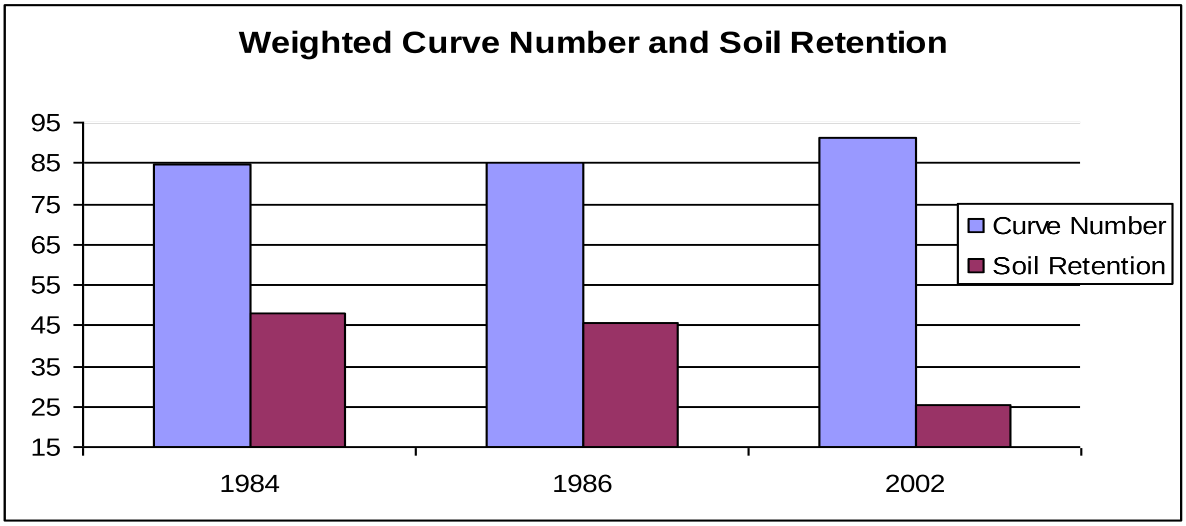

Figure 4.1 Weighted Soil retention and Curve number of three periods

4.2 Surface Runoff Estimation from Addis Ababa City

The rainy months of the city from June to September is assumed to be representative rainy season of the area. In order to check impact of built environment on the hydrology, the period between1984-2002 is considered. Generally eighty two rainy months of nineteen years is considered.

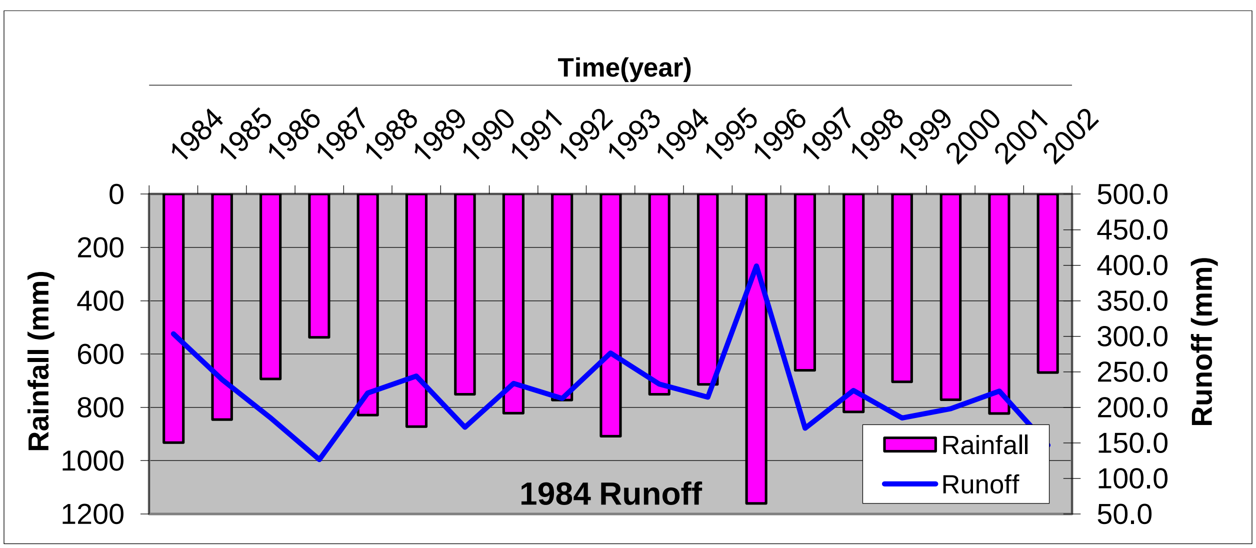

Figure 4.2 Runoff and Precipitation for 1984 land use

Based curve number 1984 land use map has lower curve number than 1986.Due to this there is a runoff difference between the two periods.

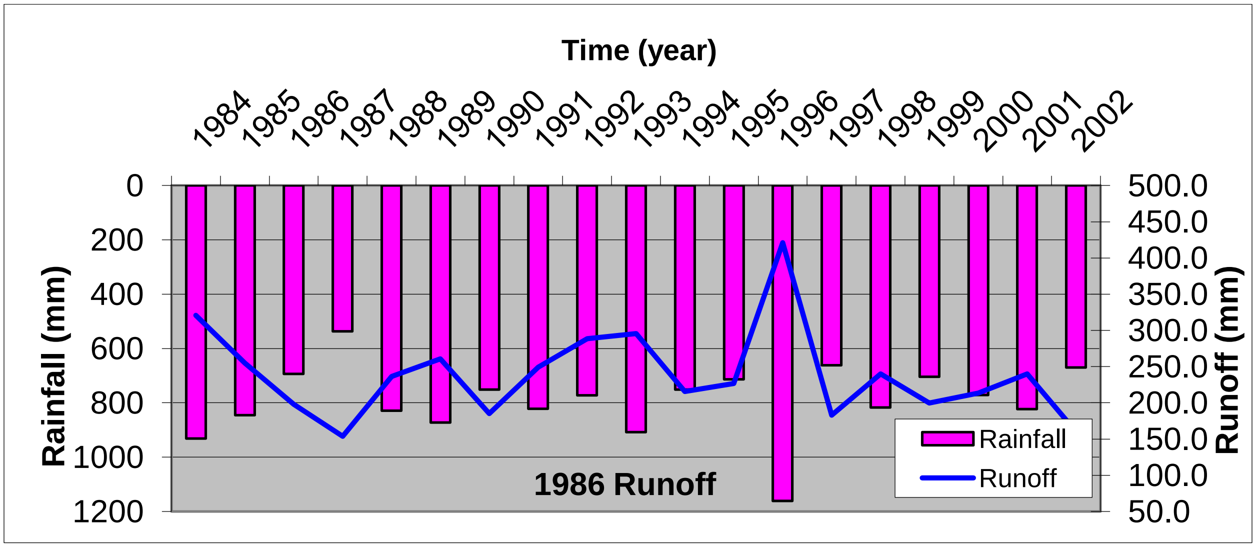

Figure 4.3 Runoff and Precipitation for 1986 land use

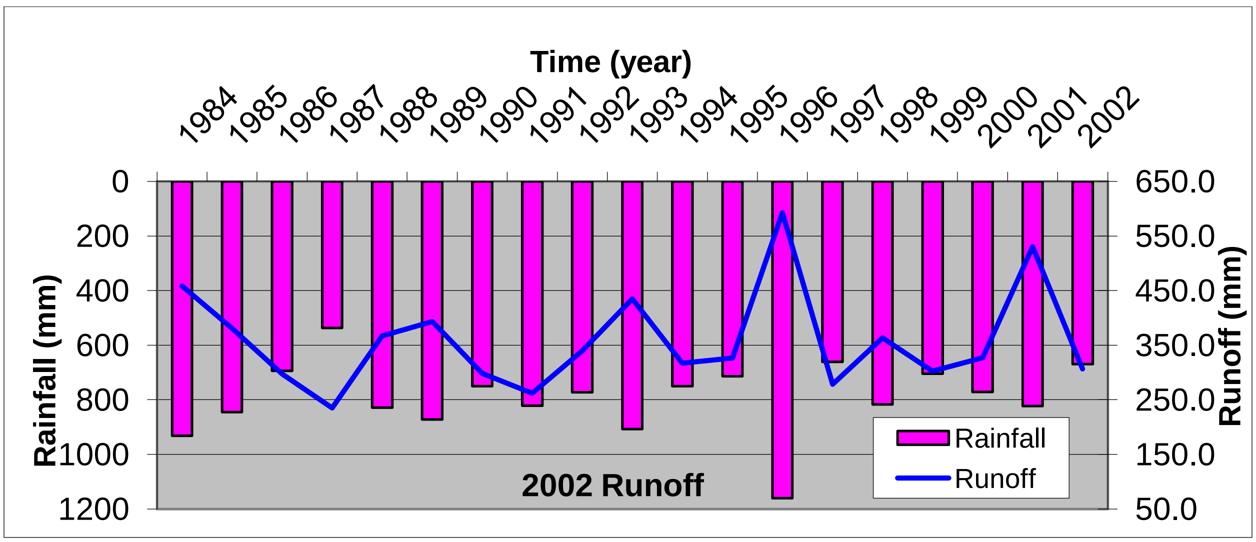

Figure 4.4 Runoff and Precipitation for 2002 land use

4.3 Comparison of the three periods Runoff

The runoff depth was calculated based on land use type and by using parameters (curve numbers and hydraulic retention) of each period. For the selected four rainy months (June, July, August and September) and rainfall station polygon the runoff depth computed using SCS method

Generally to show the impacts of built environment on the hydrological regimes in each period it is necessary to show the graph of each period in a combined form for the rainfall-runoff transformation. The overall runoff generated from the city is the sum of the runoff generated from the sub catchments within it. The graphical comparison give us by how the amount of runoff generated in each period changes.

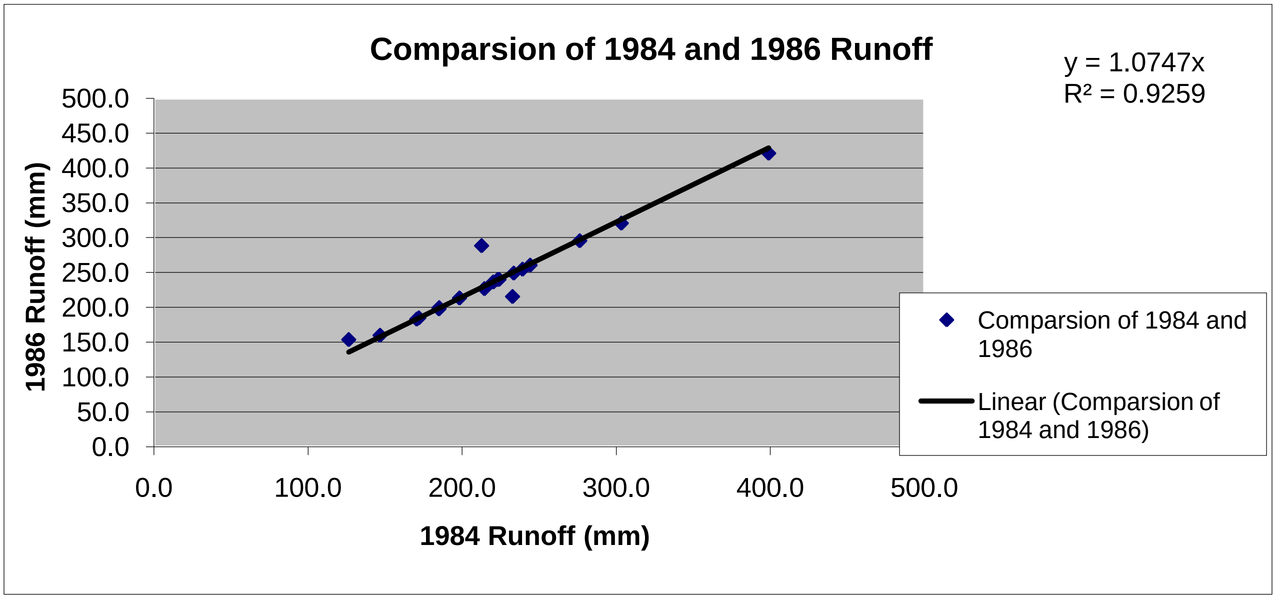

Figure 4.5 Comparing1984 and 1986 runoff

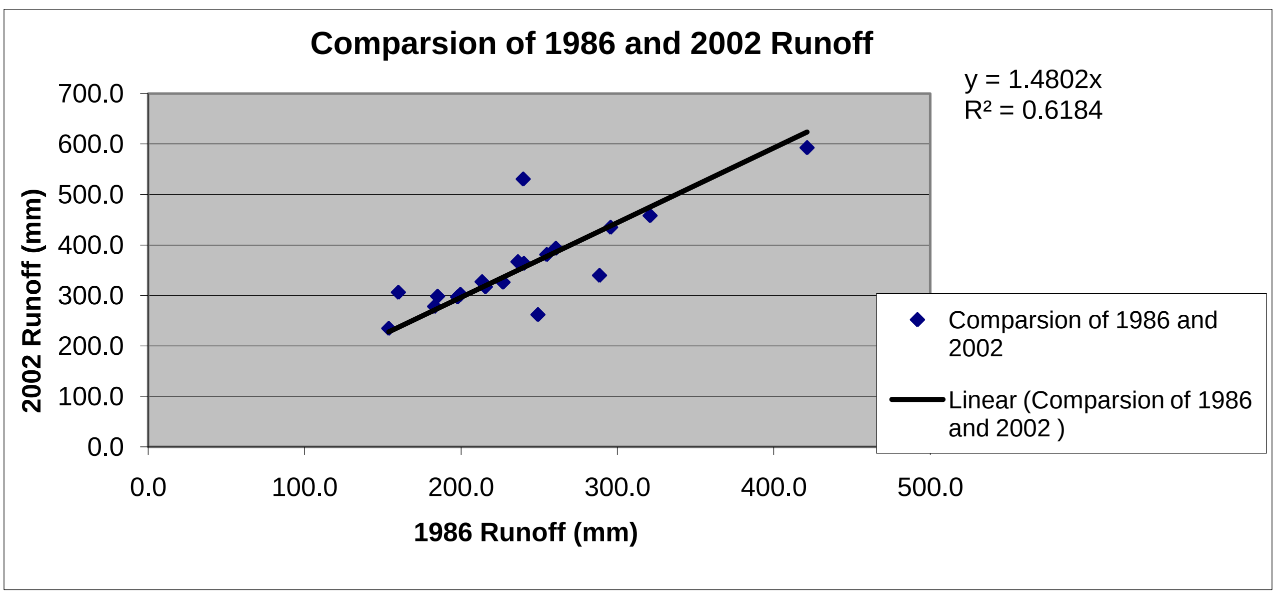

Figure 4.6 Comparing 1986 and 2002 runoff

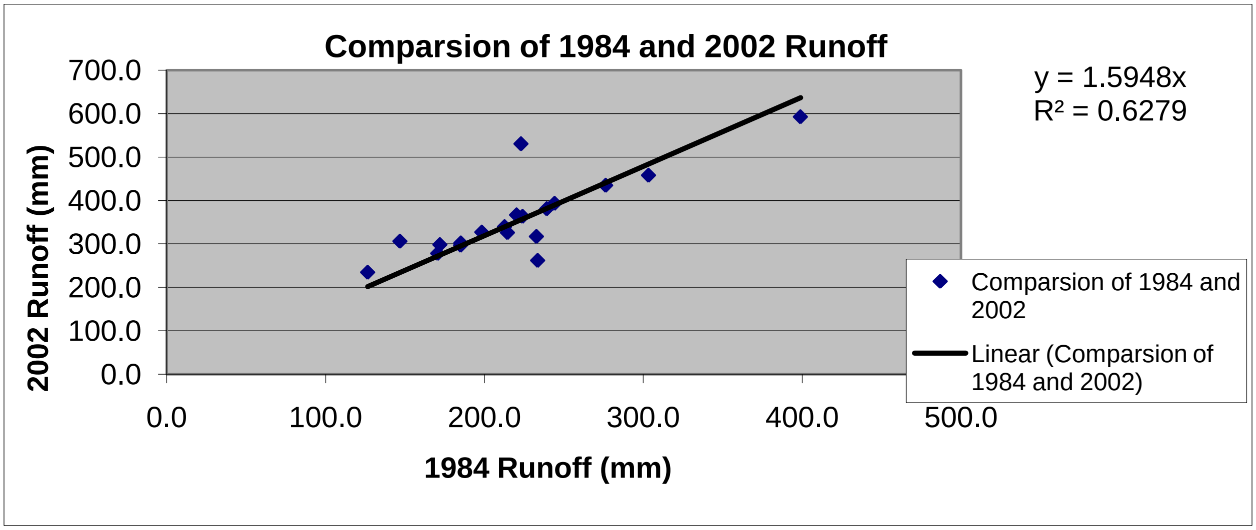

Figure 4.7 Comparing 1984 and 2002 runoff

As shown in the figures above there is a visible runoff increment between each period of land use maps. The runoff change is due to increasing of built environment in the city. Based on the above figures the land use changes influence the rainfall runoff transformation or changes the hydrological regimes. Comparing the 1984 and 1986 land use periods, generally there was small land use changes. But there is high deforestation which shows eight percent reduction. The built environment in this period increased by four percent. From the above changes we can conclude that the runoff change in 1986 is mainly due to deforestation and increasing of built environment. Because built environment has larger rainfall runoff transformation potential. Overall from period 1984 to 1986 the surface runoff of Addis Ababa city increased by seven and half percent. The increasing of land use changes both in type and area coverage is more visible in 2002 land use map. There was since sixteen years gap between the 1986 and 2002 land use maps, the land use changes was also very visible. Between the two periods there was high transformation of agricultural land to built environment. In 2002 both there were increasing residential and industrial sites in southern parts of the city. This agricultural land decrement coincides with this part of urbanization. There is also increasing of high runoff producing impervious areas such as asphalt and paved roads. The deforestation process is also one of the major land use transformation of this period. Generally in 2002 land use period the increments of impervious area was very high, mainly transformation of agricultural and forest land to built environment of type residential and industrial districts. For all the above mentioned reasons there was surface runoff increment by forty eight percent from that of 1986 period. Overall Addis Ababa's impervious area is increasing time to time

Abstractions may also be accounted for by means of runoff coefficients. The most common definition of a runoff coefficient is that it is the ratio of runoff to rainfall over a given time period. The runoff coefficient of each period of land use map was calculated using average rainfall of the nineteen years and average runoff generated in this period

Table 4.3 Runoff generated and Runoff coefficient of each period

Land use period	Wet season Annual Average Rainfall (mm) from(1984-2002	Annual Average Runoff (mm)	Runoff Coefficient
1984	791	221.4	0.28
1986	791	239	0.30
2002	791	358.4	0.45

4.4 Runoff Generation Comparison between homogenous land uses

Different land use types have different rainfall runoff transformation characteristics due to coefficient of runoff. In all three periods of land use maps there are commonly known land use types such as Asphalt, Agriculture, Forest and Built. To compare and relate runoff generated from these homogenous land use types, from 1986 land use map Addis Ababa observatory areal Thiessen polygon is selected to relate amount of runoff generated from these homogenous land uses. From (Annex-B) the table the curve number for each land use type was selected based on AMCII and AMCIII is calculated. To develop empirical relationship the surface runoff was calculated for each land use period and compared.

Table 4.4 Curve number of homogenous land use and runoff generated

Land use type	Curve Number(CN)	Soil Retention(S) (mm)	Runoff (mm)	Rainfall (mm)	Soil group
Asphalt	98	5.2	550.9	871.7	B
Agriculture	72	98.8	93.3	871.7	B
Forest	66	130.8	56.3	871.7	B
Built area	85	44.82	248.1	871.7	B

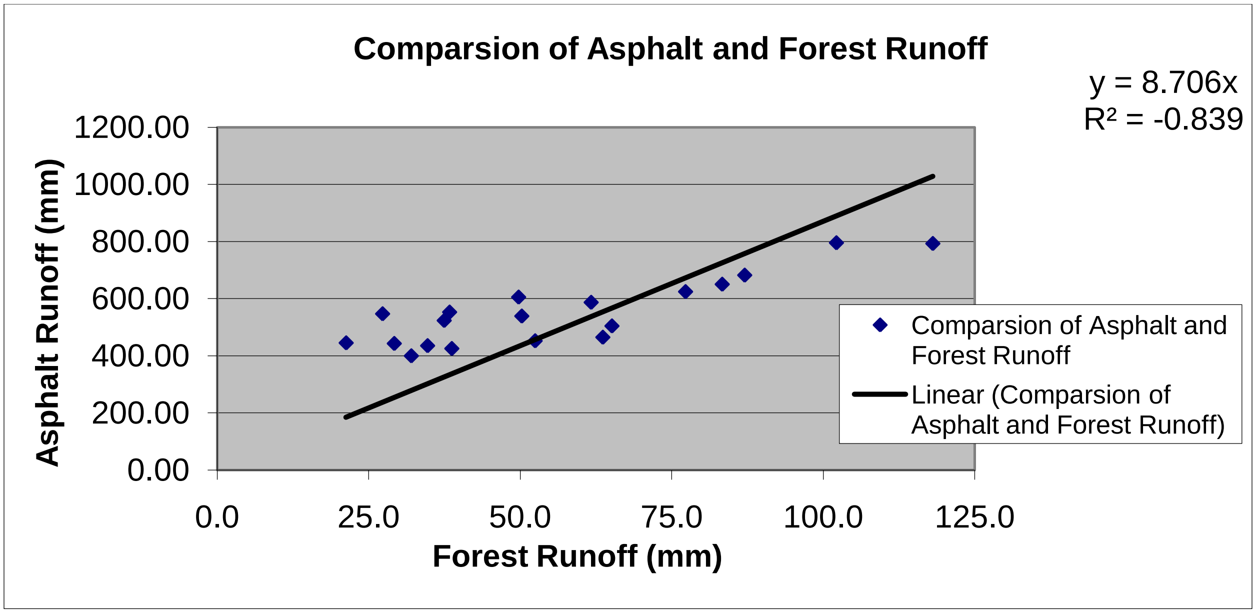

Figure 4.8 Comparison of runoff generated on Asphalt and Forest

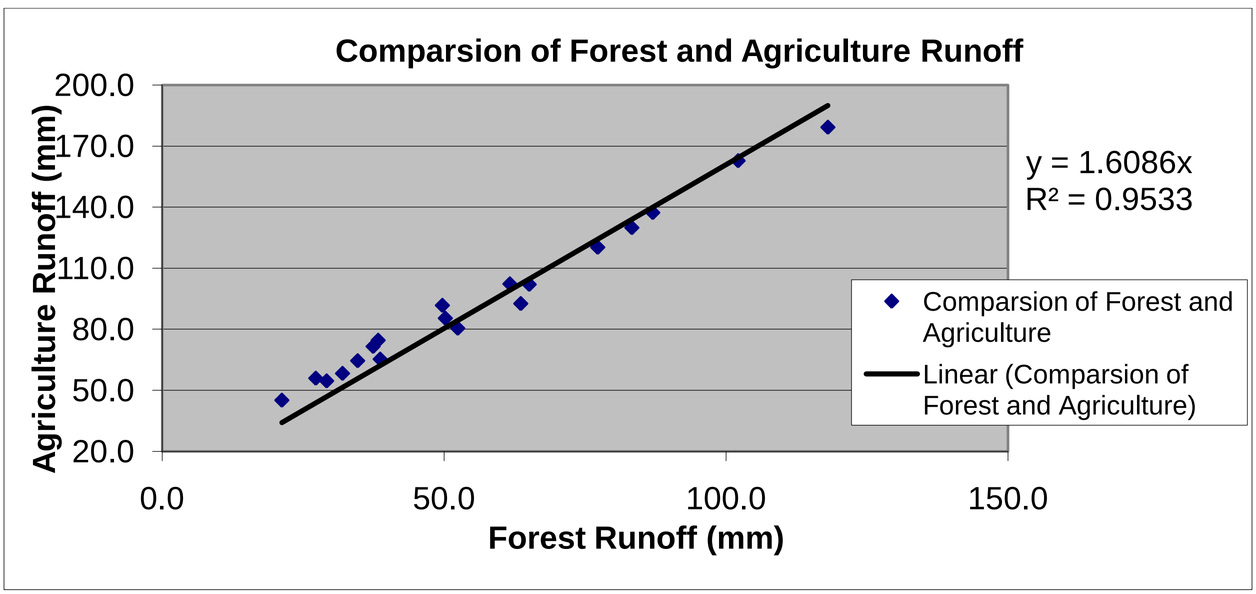

Figure 4.9 Comparison of runoff generated on Agricultural land and Forest

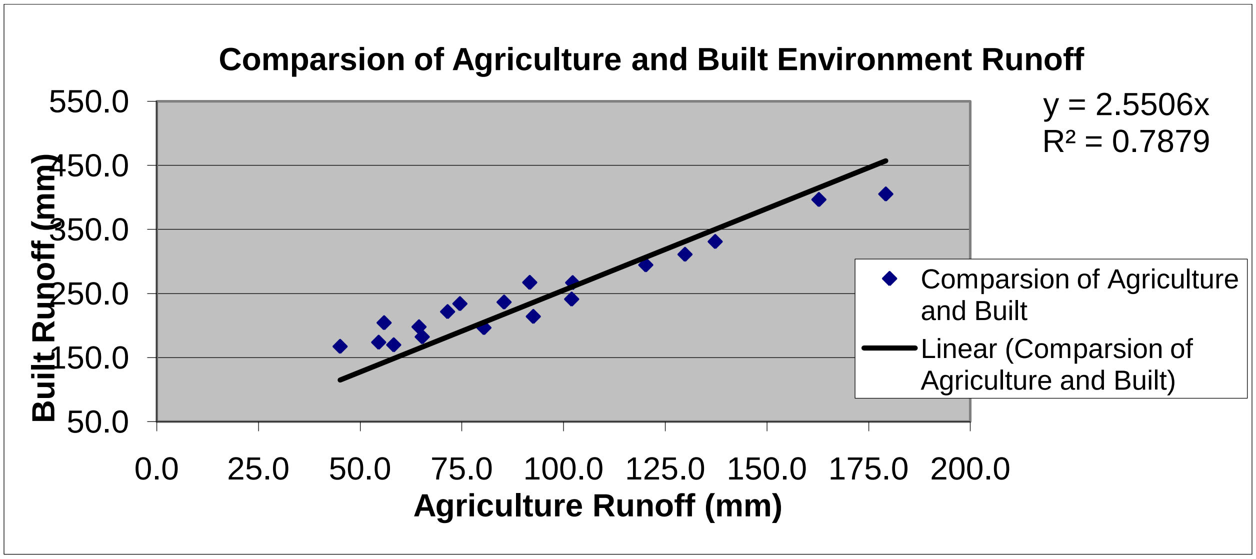

Figure 4.10 Comparison of runoff generated on Agriculture land and built environment

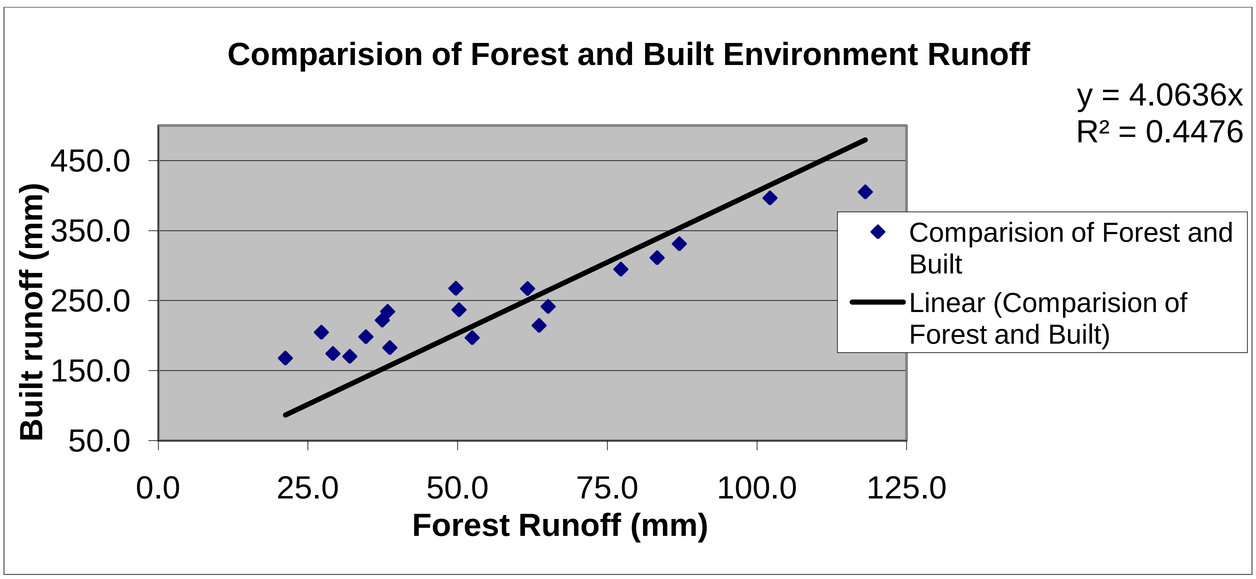

Figure 4.11 Comparison of runoff generated on Forest and built environment

By observing the figures one can conclude about how land use changes affects amount of surface runoff generated. The homogenous land uses has different area coverage in the city. Each land use has its own runoff contribution for the same rainfall depth. Comparing the four land use types Asphalt, Built, Agriculture and Forest, Asphalt has the largest contribution of all land use types. The changing of Agricultural land to residential areas, deforestation for agricultural land and built environment, upgrading and construction of new roads all are the major issues for increasing of surface runoff. When we refer to expansion history of Addis Ababa it was associated with conversion of land from rural to urban uses. From the above figures changing of land use from forest to Agriculture or to built environment will change significantly the surface runoff depth of the city. Once the pervious area such as Agricultural land transformed into residential areas is not mean that there is only built environment but there will be also developing of Asphalt roads which highly increases the runoff due to necessity of infrastructure. Therefore transformation of natural land uses to impervious area will cause high surface runoff generation which results in flooding risks of the area. Currently Addis Ababa has undergoing upgrading of existing roads and constructing of new roads this will highly influence the runoff volume of the city. So mitigation measures should be considered in accommodation of incoming surface runoff.

4.5 Developing scenarios for future Land use Change

The scenarios have been developed considering two conditions of land use changes and considering the same rainfall data of previous periods. The first scenario considers When the agricultural land in period of 2002 reduced to 10% and forest land reduced to 5% and assuming all pervious (agricultural and forest) land uses changed to built environment. The second scenario (extreme scenario) considers when all agricultural land transformed into Built environment and Asphalt road. In this scenario most of southern parts of Addis Ababa will become impervious area, since major parts of south and south-western parts of the city dominated by Agricultural lands. This scenario can express the current situation of Addis Ababa because there is construction of new and upgrading of existing roads

Table 4.5 land use changes for the two scenarios

Year	Total Area (km^2)	Land use Type					
		Impervious Area			Pervious Area		
		Asphalt (km^2)	Paved (km^2)	Built (km^2)	Forest (km^2)	Agriculture (km^2)	Cemetery and park (km^2)
Scenario 1	517.87	27.704	57.358	346.63	25.890	91.08	8.43
Ext. Scenario	517.87	53.594	57.358	372.52	25.890	0	8.43

Observing the two possible scenarios, the runoff coefficient of the city will increase from 0.56 to 0.70. Possibly these two scenarios can indicate the current condition of the city. From the two scenarios conclusion can be made that, surface runoff potential of the city can be greater than the scenario values if the progress of built environment rate increases

Table 4.6 Runoff coefficient for the two scenarios

		2002	Scenario 1	Extreme Scenario
Year	Rainfall(mm)	Runoff Depth (mm)	Runoff Depth (mm)	Runoff Depth (mm)
1984	931.8	458.01	558.73	680.46
1985	845.7	380.94	474.35	595.25
1986	693.9	297.02	376.54	478.06
1987	536.9	234.86	296.42	375.69
1988	828.6	366.79	464.43	587.59
1989	872.3	393.35	491.39	616.26
1990	750.9	298.46	385.58	496.89
1991	821.8	262.09	464.46	582.76
1992	772.9	339.71	426.70	532.93
1993	907.9	434.89	538.41	654.86
1994	750.9	317.20	395.71	491.48
1995	713.7	326.11	402.38	502.75
1996	1160.8	592.48	711.78	871.25
1997	661.3	278.24	352.50	450.75
1998	816.7	363.46	458.48	565.01
1999	704.3	302.21	387.12	483.96
2000	771.4	327.15	417.14	524.68
2001	823.5	530.38	457.79	574.48
2002	669.7	306.23	390.74	492.02
Avr.	791.3	358.40	444.77	555.64
C		**0.45**	***0.56***	***0.70***

Based on the values indicated in the table above and considering the two scenarios we can make analysis on land use influences. The increasing of runoff coefficient is an indication of change in hydrological regimes due to change in surface runoff. Therefore the two scenarios can indicate or give direction of Addis Ababa land use changes.

CHAPTER FIVE

SUB CATCHMENT CONTRIBUTING FLOW

5.1 Selected sub-catchments from entire watershed

The watershed, or catchment, is the area of land draining into a stream at a given location. It is known that Built environment will change the stream flow characteristics to certain extent. Addis Ababa has visible slope variation from place to place in all directions and different streams from perennial to intermittent. The city has also different expansion trends in all directions which mean different land use at different rate in different direction. To describe how the various surface water processes vary through time during a storm the following twelve sub catchments are selected from the entire Addis Ababa catchments. The sub-watersheds selected randomly in order to make representative to evaluate impact of built environment on streams. To consider impact of built environment on hydrological regimes of Addis Ababa the sub catchments hydraulic parameters were calculated. Change in characteristics of streams within the city also assessed by calculating time of concentration. The selection was done randomly through consideration of perennial and intermittent streams since Addis Ababa's topography is not uniform.

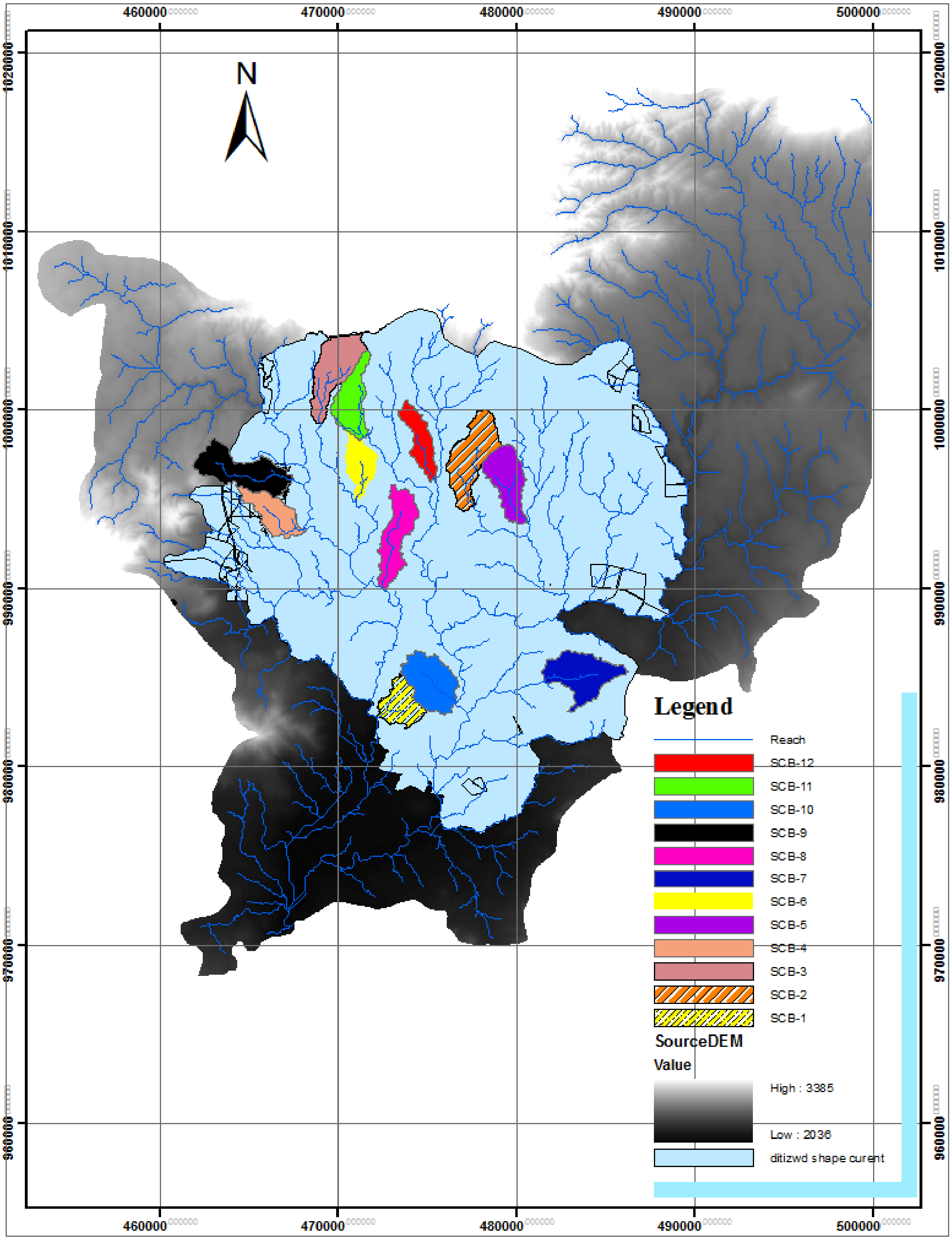

Figure 5.1 Sub Catchments contributing Flow

The sub catchments delineated using SWAT and GIS. The curve numbers assigned referring (Annex-B). The sub catchments have different land use types and slope. Due to this the surface runoff results also different.

Table 5.1 sub catchments with its curve number and land use description

Sub-catchment	1984	Remark	1986	Remark	2002	Remark
SC- 1	85	Agriculture	85	Agriculture	90.2	Built and Agriculture.
SC- 2	85.3	Forest and built	85.3	Forest and built	88.6	Forest and built
SC -3	72	Forest and built	72	Forest and built	77	Forest and built
SC- 4	73.2	Agriculture and built	75.7	Agriculture and built	83.7	Agriculture and built
SC-5	87	Agriculture and built	88	Agriculture and built	90.7	Agriculture and built
SC-6	93.7	Asphalt & built	94.8	Asphalt & built	94.8	Asphalt & built
SC-7	85	Agriculture	85	Agriculture	85	Agriculture
SC-8	93	Built, Asphalt and Green area	94.2	Built, Asphalt and Green area	94.6	Built, Asphalt and Green area
SC-9	72	Agriculture	72	Agriculture	79.6	Agriculture and built
SC-10	85	Agriculture	85	Agriculture	92.5	Agriculture and built
SC-11	79.3	Forest, Built and asphalt	85.2	Forest, Built and asphalt	86.3	Forest, Built and asphalt
SC-12	85.2	Built, Asphalt and Green area	85.6	Built, Asphalt and Green area	85.6	Built, Asphalt and Green area

In order to make assessments of impact of built environment on stream flow characteristics, it is necessary to estimate parameters such as time of concentration (Tc). Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. Tc is the time it takes for water to travel from the most hydraulically distant point in a watershed to its outlet. By considering the land use changes of the three periods and taking 1984 as base period Tc was estimated using SCS lag equation. The lag equation is selected because it estimates Tc by considering land use change

$$\mathbf{Tc=100L^{0.8}[(1000/CN)-9]0.7/\ (1900S0.5)} \qquad \mathbf{5.1}$$

Where:

Tc; time of concentration

L; hydraulic length of watershed (longest flow path)

CN; SCS runoff curve number

S; average watershed slope (%)

Table 5.2 Sub catchments time of concentration at different periods

Sub-catchments	Slope (%)	length(ft)	CN 1984	CN 2002	Tc-84 (min)	Tc-2002 (min)
SC 1	6.73	6246.72	85	90.2	45.0	36.9
SC 2	12.14	13454.72	85.3	88.6	61.2	54.2
SC 3	14.70	14783.46	72	77	90.3	78.3
SC 4	10.48	11965.22	73.2	83.7	87.4	63.4
SC 5	8.59	11646.98	87	90.7	61.0	52.7
SC 6	6.97	8887.80	93.7	94.8	41.2	39.0
SC 7	5.06	11587.93	85	85	85.1	85.1
SC 8	6.54	19406.17	93	94.6	82.1	76.0
SC 9	12.95	18211.94	72	79.6	113.7	91.1
SC 10	7.14	10298.56	85	92.5	65.1	48.4
SC 11	8.29	12454.07	79.3	86.3	84.8	67.2
SC 12	8.01	10967.85	85.2	85.6	64.2	63.3

All the sub catchments selected within the city boundary has different topography and land use trends. To assess level of Impervious the surface runoff generated for twenty four hour was calculated for each sub catchments. Taking 1984 land use map as base period, graphically comparisons made between base period and 2002 for each sub catchments.

Table 5.3 Wet season average (June-September) discharge flows for sub-catchment 1 and 2

	SC-1			SC-2		
	1984	1986	2002	1984	1986	2002
Period	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)
1984	1.22	1.22	2.36	3.40	3.40	4.73
1985	1.58	1.58	2.88	1.34	1.34	2.23
1986	0.67	0.67	1.45	1.39	1.39	2.26
1987	0.96	0.96	1.73	0.35	0.35	0.66
1988	1.20	1.20	2.50	1.34	1.34	2.29
1989	0.73	0.73	1.65	1.58	1.58	2.55
1990	0.72	0.72	1.57	0.77	0.77	1.41
1991	0.99	0.99	1.98	2.15	2.15	3.21
1992	0.80	0.80	1.69	1.73	1.73	2.66
1993	1.01	1.01	1.90	6.49	6.49	7.71
1994	0.91	0.91	1.68	1.41	1.41	2.25
1995	1.05	1.05	2.04	0.81	0.81	1.69
1996	1.92	1.92	3.60	3.73	3.73	5.58
1997	0.52	0.52	1.18	1.36	1.36	2.20
1998	0.66	0.66	1.35	1.90	1.90	2.98
1999	0.26	0.26	0.74	1.62	1.62	2.65
2000	0.55	0.55	1.28	1.06	1.06	1.83
2001	0.68	0.68	1.46	1.04	1.04	1.88
2002	0.29	0.29	0.85	0.71	0.71	1.40

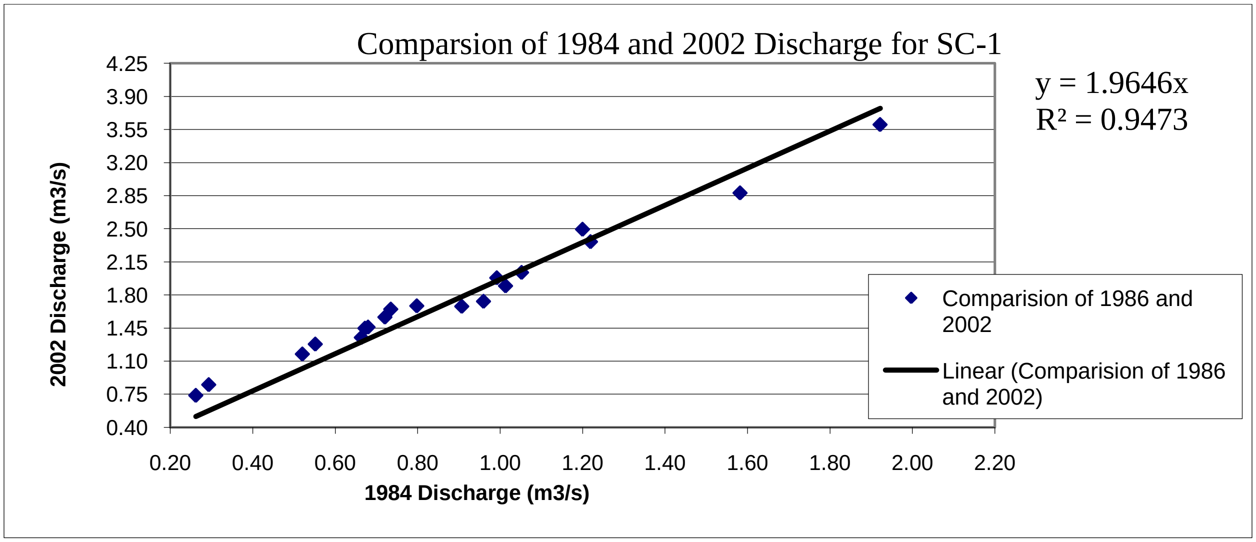

Figure 5.2 Comparing SC-1 discharges

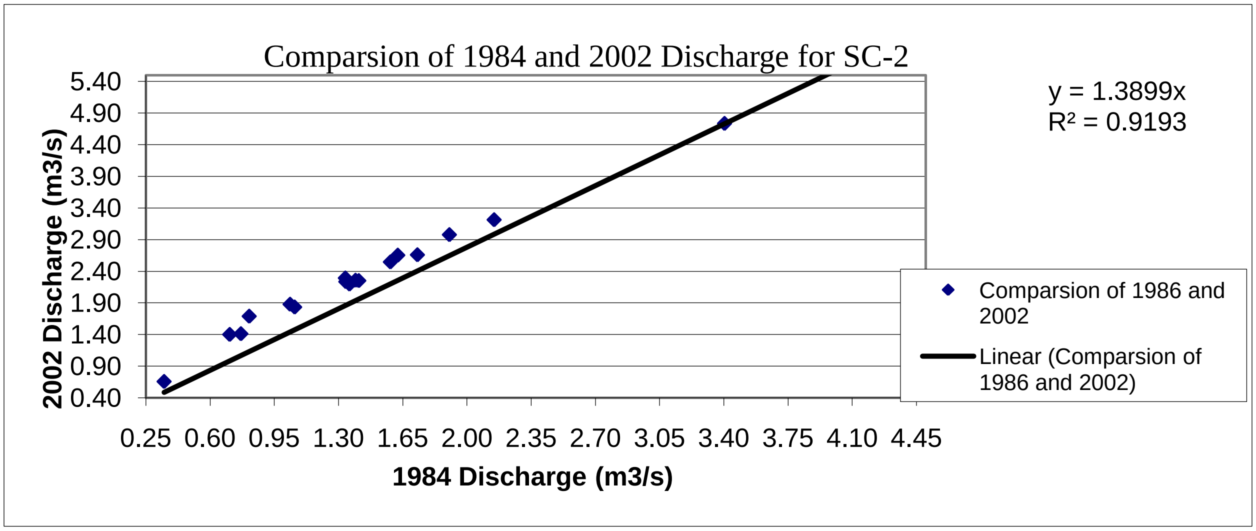

Figure 5.3 Comparing SC-2 discharges

Table 5.4 Wet season average (june-september) discharge flows for sub-catchment 3 and 4

	SC-3			SC-4		
	1984	1986	2002	1984	1986	2002
Period	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)
1984	0.89	0.89	1.50	0.40	0.55	1.38
1985	0.26	0.26	0.60	0.26	0.36	1.14
1986	0.36	0.36	0.68	0.27	0.37	0.93
1987	0.16	0.16	0.38	0.04	0.06	0.27
1988	0.22	0.22	0.40	0.06	0.11	0.57
1989	0.89	0.89	1.50	0.41	0.57	1.49
1990	0.87	0.87	1.52	0.09	0.14	0.58
1991	0.28	0.28	0.65	0.08	0.16	0.75
1992	0.32	0.32	0.63	0.21	0.31	0.94
1993	0.26	0.26	0.60	0.50	0.68	1.85
1994	0.65	0.65	1.04	0.31	0.44	1.17
1995	0.16	0.16	0.38	0.44	0.54	1.09
1996	0.86	0.86	1.55	0.63	0.85	2.09
1997	0.04	0.04	0.17	0.15	0.23	0.72
1998	0.44	0.44	0.99	0.08	0.15	0.77
1999	0.16	0.16	0.41	0.11	0.17	0.71
2000	0.55	0.55	0.95	0.12	0.22	0.98
2001	0.50	0.50	0.86	0.41	0.58	1.57
2002	0.12	0.12	0.34	0.04	0.08	0.45

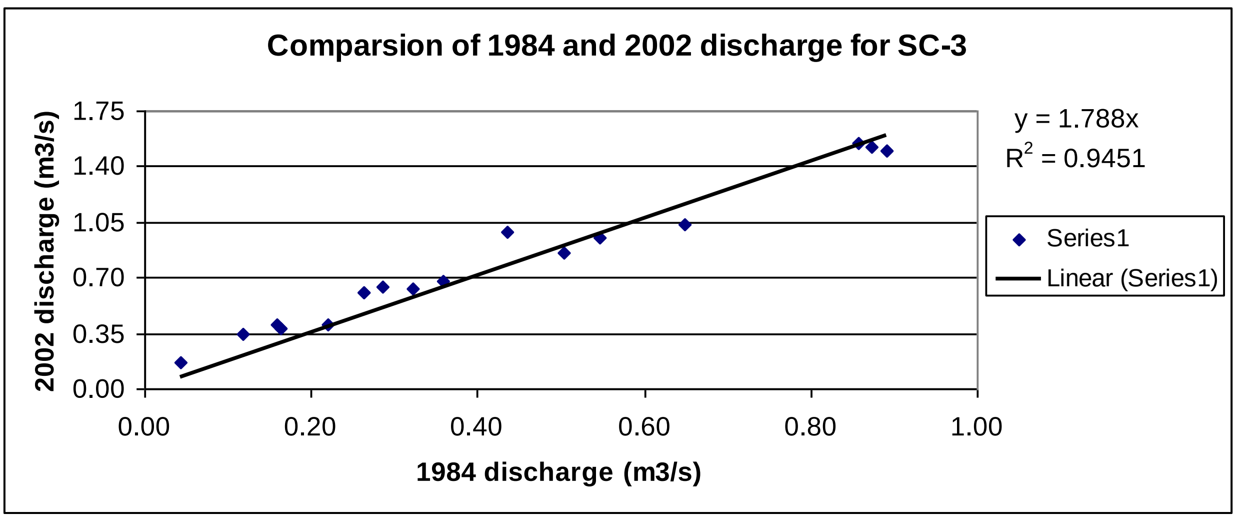

Figure 5.4 Comparing SC-3 discharges

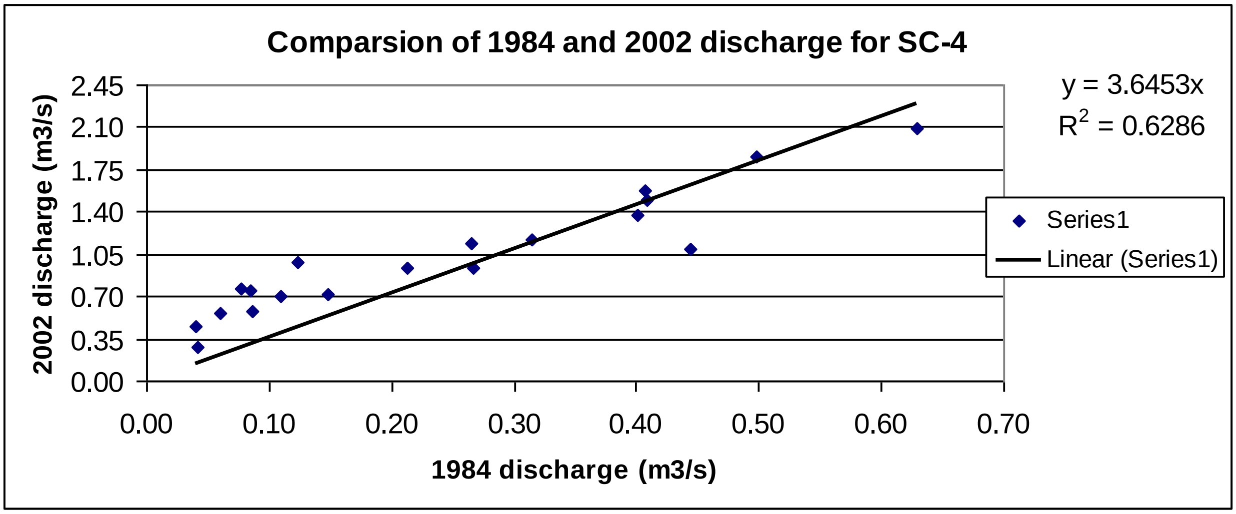

Figure 5.5 Comparing SC-4 discharges

Table 5.5 Wet season average (june-september) discharge flows for sub-catchment 5 and 6

	SC-5			SC-6		
	1984	1986	2002	1984	1986	2002
Period	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)
1984	3.05	3.48	4.29	4.01	4.61	4.61
1985	1.33	1.62	2.21	3.65	4.23	4.23
1986	1.36	1.64	2.18	2.70	3.14	3.14
1987	0.37	0.47	0.69	1.22	1.46	1.46
1988	1.35	1.66	2.28	2.91	3.50	3.50
1989	1.54	1.86	2.47	4.22	4.83	4.83
1990	0.80	1.02	1.46	2.44	2.90	2.90
1991	2.00	2.35	3.03	3.08	3.62	3.62
1992	1.64	1.94	2.52	3.26	3.80	3.80
1993	2.90	3.22	3.85	5.36	6.12	6.12
1994	1.36	1.64	2.17	3.27	3.74	3.74
1995	1.02	1.23	1.65	2.91	3.35	3.35
1996	3.49	4.09	5.20	5.45	6.17	6.17
1997	1.32	1.60	2.13	2.52	2.96	2.96
1998	1.82	2.17	2.84	3.26	3.83	3.83
1999	1.60	1.93	2.57	2.75	3.25	3.25
2000	1.07	1.33	1.84	3.68	4.30	4.30
2001	1.08	1.36	1.92	4.48	5.13	5.13
2002	0.78	1.01	1.48	2.37	2.85	2.85

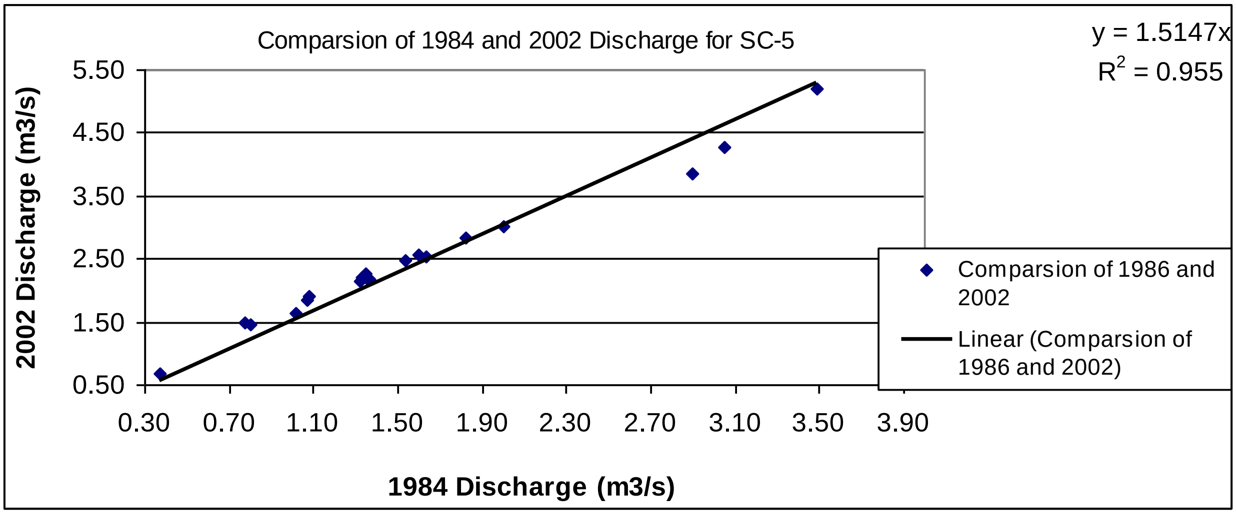

Figure 5.6 ComparingSC-5 discharges

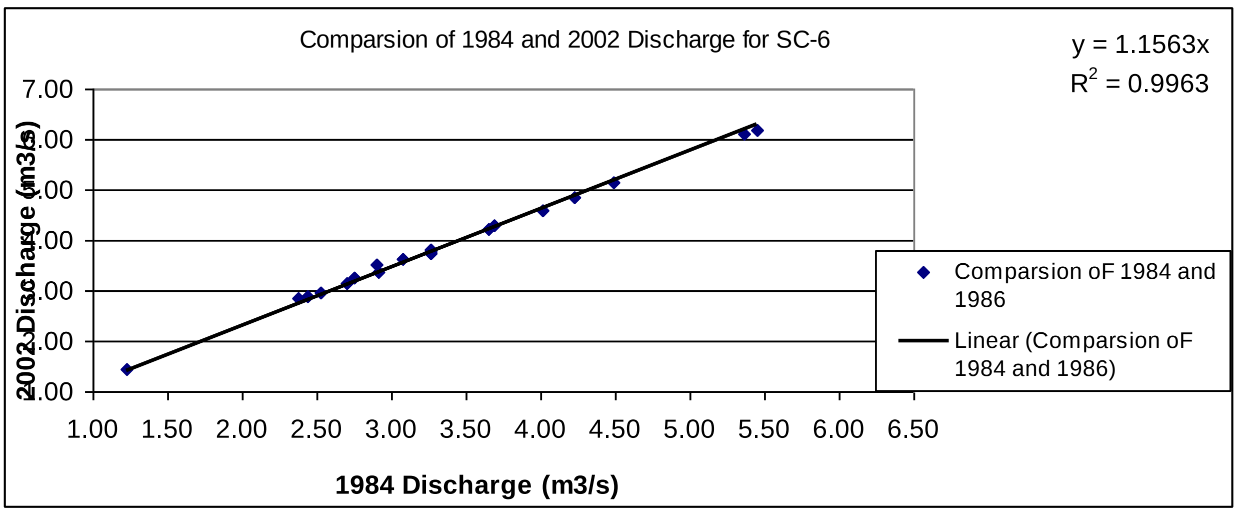

Figure 5.7 Comparing SC-6 discharges

Table 5.6 Wet season average (june-september) discharge flows for sub-catchment 7 and 8

	SC-7			SC-8		
	1984	1986	2002	1984	1986	2002
Period	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)
1984	2.09	2.09	2.09	6.14	7.06	7.46
1985	2.72	2.72	2.72	3.58	4.32	4.66
1986	1.15	1.15	1.15	3.42	4.08	4.37
1987	1.65	1.65	1.65	1.23	1.55	1.70
1988	2.06	2.06	2.06	3.70	4.47	4.81
1989	1.26	1.26	1.26	3.92	4.70	5.05
1990	1.24	1.24	1.24	2.58	3.22	3.51
1991	1.70	1.70	1.70	4.56	5.36	5.72
1992	1.37	1.37	1.37	3.85	4.53	4.84
1993	1.74	1.74	1.74	5.37	6.13	6.47
1994	1.56	1.56	1.56	3.39	4.02	4.31
1995	1.81	1.81	1.81	2.64	3.20	3.45
1996	3.30	3.30	3.30	7.68	8.91	9.44
1997	0.89	0.89	0.89	3.36	4.01	4.30
1998	1.14	1.14	1.14	4.40	5.22	5.58
1999	0.45	0.45	0.45	4.02	4.77	5.10
2000	0.95	0.95	0.95	3.04	3.70	4.00
2001	1.17	1.17	1.17	3.28	4.05	4.40
2002	0.50	0.50	0.50	2.59	3.22	3.51

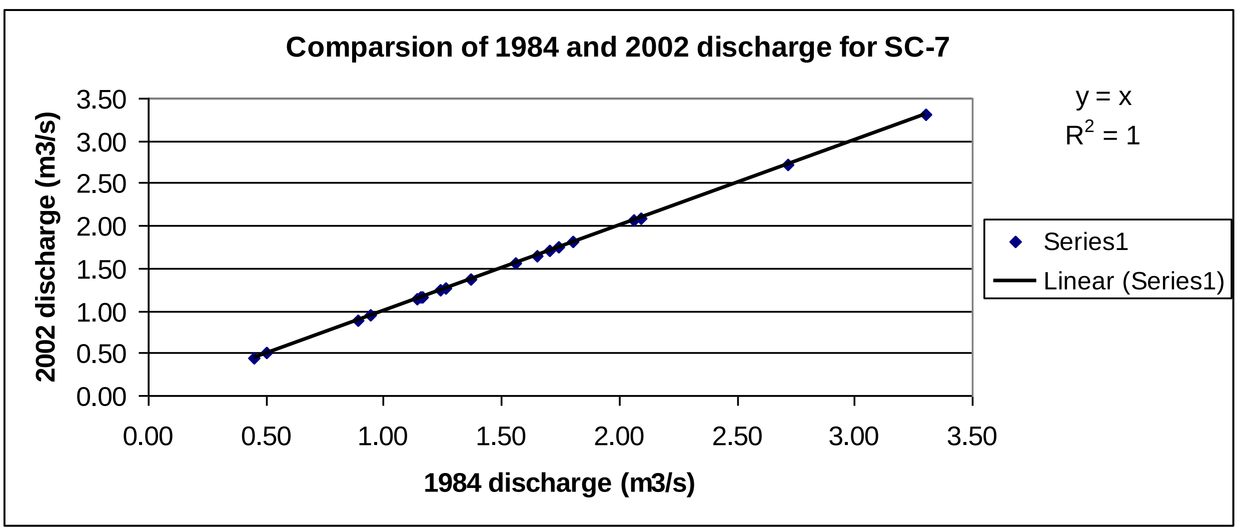

Figure 5.8 Comparing SC-7 discharges

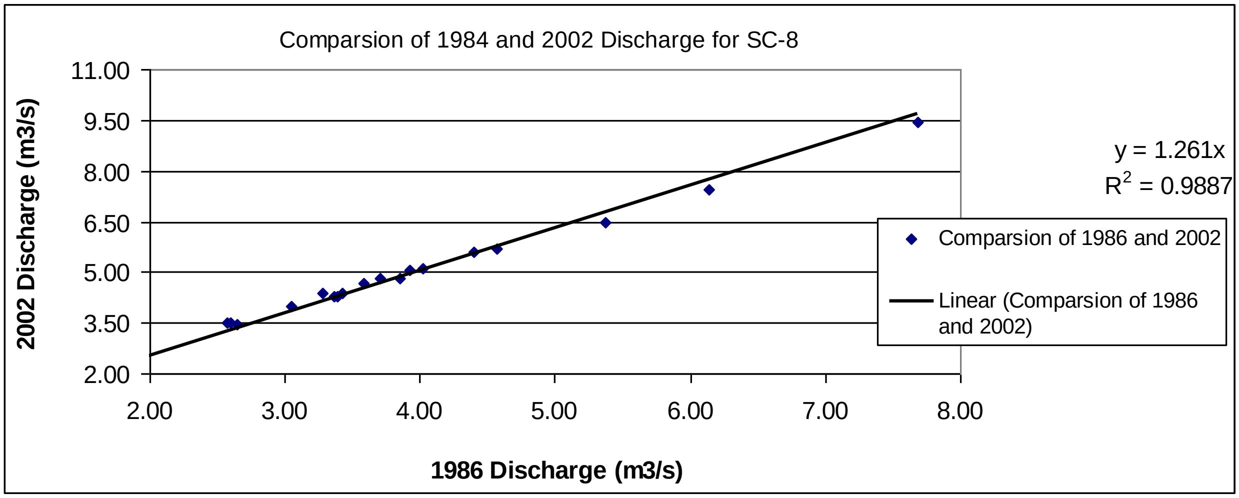

Figure 5.9 Comparing SC-8 discharges

Table 5.7 Wet season average (june-september) discharge flows for sub-catchment 9 and 10

	SC-9			SC-10		
	1984	1986	2002	1984	1986	2002
Period	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)
1984	0.61	0.61	1.54	1.98	1.98	5.24
1985	0.35	0.35	1.16	2.57	2.57	6.26
1986	0.40	0.40	1.04	1.09	1.09	3.38
1987	0.06	0.06	0.23	1.56	1.56	3.79
1988	0.08	0.08	0.45	1.95	1.95	5.69
1989	0.62	0.62	1.64	1.19	1.19	3.95
1990	0.12	0.12	0.51	1.17	1.17	3.66
1991	0.11	0.11	0.64	1.61	1.61	4.52
1992	0.32	0.32	0.95	1.29	1.29	3.89
1993	0.76	0.76	1.99	1.64	1.64	4.21
1994	0.47	0.47	1.28	1.47	1.47	3.73
1995	0.72	0.72	1.33	1.71	1.71	4.51
1996	0.96	0.96	2.36	3.12	3.12	7.89
1997	0.21	0.21	0.73	0.84	0.84	2.81
1998	0.10	0.10	0.64	1.08	1.08	3.11
1999	0.15	0.15	0.62	0.42	0.42	1.88
2000	0.16	0.16	0.87	0.89	0.89	3.09
2001	0.61	0.61	1.70	1.10	1.10	3.39
2002	0.05	0.05	0.34	0.47	0.47	2.18

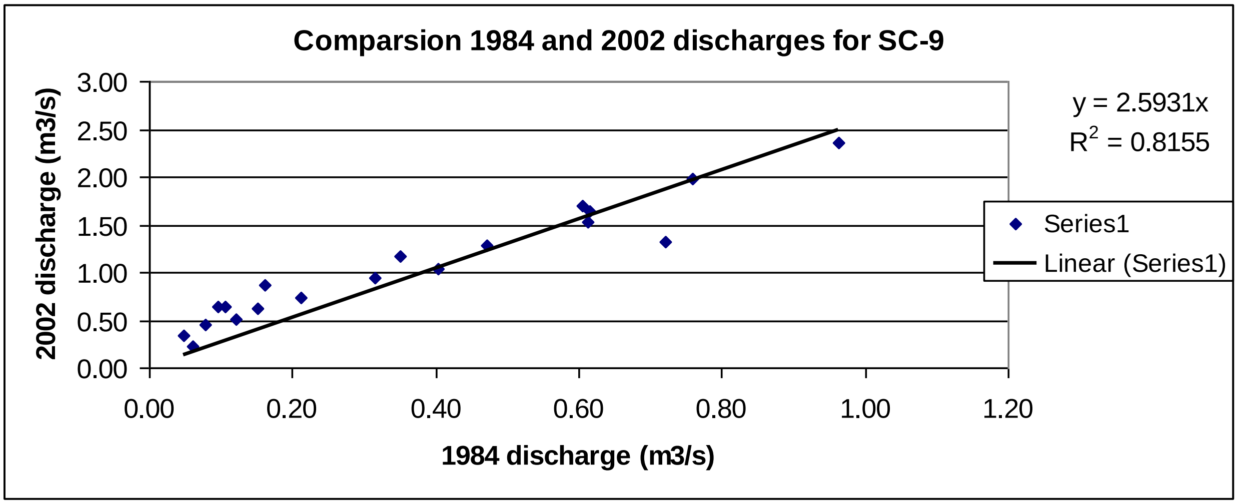

Figure 5.10 Comparing Sc-9 discharges

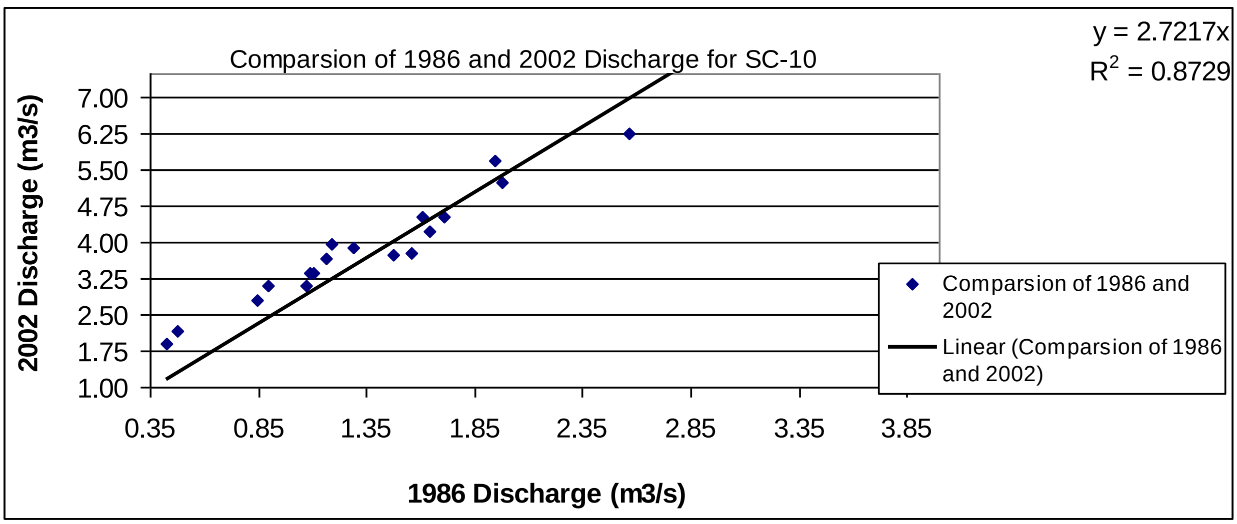

Figure 5.11 Comparing Sc-10 discharges

Table 5.8 Wet season average (june-september) discharge flows for sub-catchment 11 and 12

	SC-11			SC-12		
	1984	1986	2002	1984	1986	2002
Period	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)	Q(m3/s)
1984	0.97	1.90	2.19	1.39	1.47	1.47
1985	0.73	1.61	1.88	1.18	1.26	1.26
1986	0.66	1.28	1.46	0.93	0.99	0.99
1987	0.14	0.41	0.50	0.30	0.32	0.32
1988	0.28	0.86	1.07	0.63	0.69	0.69
1989	1.03	2.06	2.36	1.51	1.59	1.59
1990	0.32	0.85	1.03	0.62	0.67	0.67
1991	0.39	1.11	1.34	0.82	0.88	0.88
1992	0.59	1.34	1.58	0.98	1.05	1.05
1993	1.25	2.57	2.97	1.88	2.00	2.00
1994	0.80	1.62	1.85	1.18	1.25	1.25
1995	0.84	1.47	1.67	1.08	1.15	1.15
1996	1.49	2.85	3.24	2.08	2.20	2.20
1997	0.46	1.03	1.21	0.75	0.80	0.80
1998	0.39	1.16	1.41	0.85	0.92	0.92
1999	0.38	1.01	1.21	0.74	0.79	0.79
2000	0.54	1.43	1.71	1.05	1.13	1.13
2001	1.07	2.17	2.50	1.59	1.68	1.68
2002	0.21	0.70	0.87	0.51	0.56	0.56

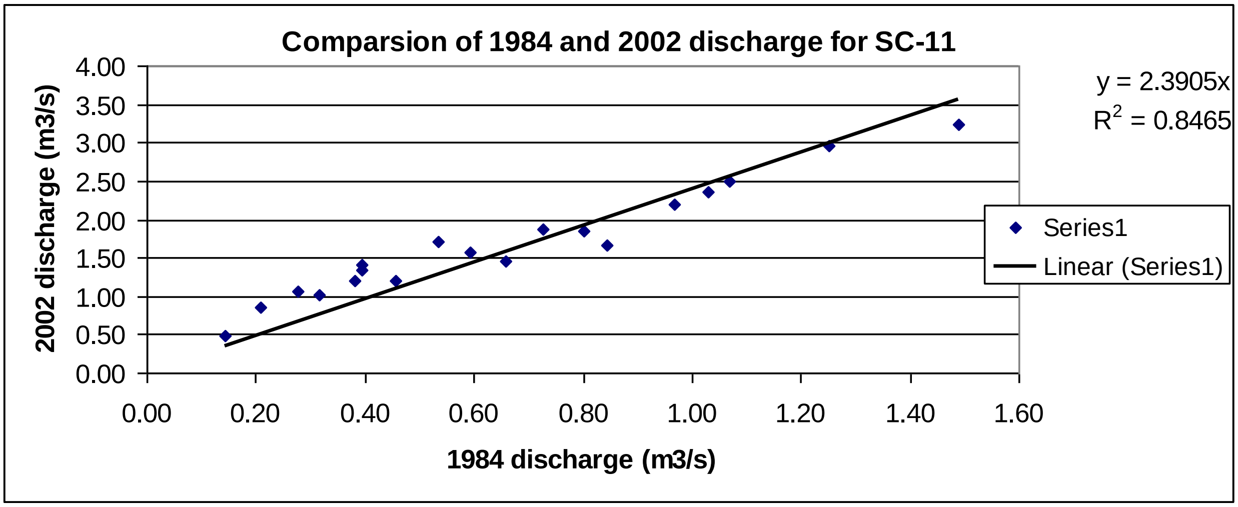

Figure 5.12 Comparing Sc-11 discharges

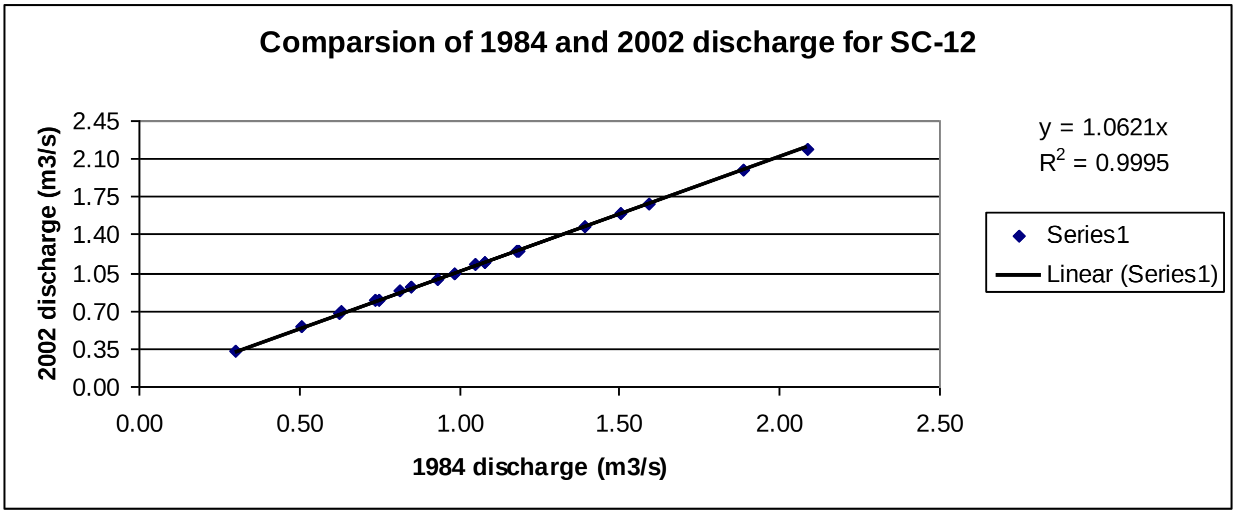

Figure 5.13 Comparing Sc-12 discharges

The sub catchments selected are located at different sub cities under different topography and land use types. The degree of urbanization differs from one sub city to another significantly. Some shows high urbanization others less. So the sub catchments delineated within particular sub cities shows the level of imperviousness of the area.

Table 5.9 Delineated sub catchments location

Sub-Catchments	Location in Sub Cities
SC-7, SC-1 and SC-10	Akaki kality
SC-3	Gulele
SC-4 and SC-9	Kolfe keraniyo
SC-6	Lideta
SC-8	Cherkos and Nifas silk-lafto
SC-12	Arada
SC-5 and SC-2	Bole and Yeka
SC-11	Addis ketema and Gulele

The volume of water available for runoff increases because of the increased impervious cover provided by different land use types which reduce the amount of infiltration. Among the sub catchments selected some shows significant land use changes and others shows little land use changes. SC-4 which is located in kolfe keraniyo sub city shows significant change than other delineated sub catchments its curve number changes from 73.2 in 1984 to 83.7 in 2002. The SC-11, SC-9 and SC-10 which located in kolfe keraniyo,akaki kality and Gulele sub cities also shows land use changes. Only SC-12 is characterized by little land use from 1984 to 2002 because it's located in Arada sub city which is already developed part of Addis Ababa. Due to high slopes, Sub catchments found within Gulele, Kolfe keraniyo and yeka sub cities shows high runoff change for small change in impervious area

Generally from the selected twelve sub catchments majority of them shows significant land use change in the city. Sub catchments which are selected from sub cities located at the periphery of the city shows significant land use change and sub cities located at the center of the city such as Arada has less land use change since it is already developed area. The discharges of the sub catchments are increased from period to period. Even if the sub catchments selected does not shows the land use changes is not mean that there is no increase of discharge because it is influenced by neighboring sub catchments. The time of concentration of streams found within the sub catchments is also changed. Generally from comparisons made of discharges of each sub catchment with the base period land uses, the runoff generated from Addis Ababa is increased and Keeps on increasing. So flood mitigation measures considering streams of the city should be followed

5.2 Characteristics of streams in the sub catchments

It is frequently presumed that urbanization reduces ground water recharge because increasing impervious surface area reduces infiltration and increases storm water runoff. Urban development modifies the production and delivery of runoff to streams and the resulting rate, volume, and timing of stream flow. Currently, the characterization of urban watersheds and their differences with respect to natural basins is based on the description of the infiltration and storage capacity. Increased stream stage and discharge variability are common responses to urbanization. Changes in land cover associated with urbanization alter surface and sub surface flow paths and transport of water to stream channels which in turn can alter the channels geomorphology. As the urban landscape was built out, the runoff increased due to greater impervious area, urban channels tends to widen as a result of increased peak flows

The small streams of the city which found in the delineated sub catchments shows change in time of concentration decreased by twenty seven percent from base period 1984. Streams such as Buhe,Banteykitu,kebena,kotebe and kechene were among the streams there Time of concentration has changed due to increase in impervious area. Generally urban streams behave in more flashy fashion than their natural counter parts and behave a greater occurrence of extreme flow events. Changes in peak flows due to urbanization vary with the degree of urban development, recurrence interval of the peak flow and location within the watershed. All streams contributes their flow to big akaki or little akaki, since Addis Ababa is located in Akaki Catchment the overall increasing of impervious area of the city will affect the downstream part of the area. Streams which located in high sloppy sub catchments such as SC-2 and SC-3 will have scouring effect of the natural channel which results in damaging banks. Therefore in order to make safe the environment from flood hazards in low lying areas and stream bank damages in sloppy areas, it is necessary to make stream banks stable through physical and biological measures. Emphasis should also given to waste disposal sites to keep not to reduce channel capacity

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Generally Addis Ababa city undergoes rapid urbanization with both planned and unplanned. Due to rapid urbanization the land use of the city has significantly changed and keeps on changing. These land use changes are due to economic growth, need for better living condition and the majority of increasing urbanization is due to rapid population growth of the city. The urbanization favors the land use changes of the city of Addis Ababa. These land use changes are commonly from Agricultural land to built environment (residential, industries…), up grading and construction of new roads, deforestation and changing of slum city areas into high rise commercial and recreation buildings

Urbanization increases the size and frequency of surface runoff generated and may expose communities to increasing flood hazards. The result from this study shows that the built environment has significant impact on the amount of flood (runoff) generated from the city of given precipitation and the time to peak, in term of runoff generation.

- Expansion of Addis Ababa city has changed the hydrological regime of Addis Ababa. The average runoff potential has changed from the runoff coefficient of 0.28 to 0.45
- Based on the two scenarios developed considering Agricultural and forest land use change the current runoff coefficient of the city will be very high
- It has also been demonstrated that conversion of the any land use type to Asphalt produces the highest runoff of all land use change. Conversion of forest area to Built environment produces more runoff than conversion of forest to Agricultural land; forest land has the lowest rainfall- runoff transformation of all land use types
- From the twelve sub catchments delineated the entire study area as per the result obtained from the analysis of discharge obtained from each sub catchments shows some parts of the city shows significant land use change. If further study is done at this time the runoff could have been greater

- Both perennial and intermittent streams of the city were affected by the increasing of impervious area. Some small streams shows reduction of Tc up to twenty seven percent from base period

Conclusions can be made regarding the impact of built environment on hydrological regimes of Addis Ababa. Due to continuous changing of pervious land use to built environment, the area coverage of pervious area such as forest, Agricultural land is highly decreased. The increasing of impervious area in the Addis Ababa watershed influences the rainfall-runoff transformation, which producing high surface runoff depth and higher peak flows in the streams of the city .As a result the time of concentration and the time to peak is reduced in sub- catchments and main streams of the city

6.2 Recommendation

The impact of built environment on the hydrological regimes in the study area can be solved with a combination of proper urban planning and protection of main stream banks from illegal housing, storm water drainage system and solid waste disposal system in the commercial and business areas of the city, forestation and other natural resource conservation activities on the upper sub catchments. The city also should have proper and periodical land use plans and greater emphasis must be given to capture surface runoff

In this study result most important measures to be carried out are

- Developing periodically land use maps of the city considering current and future expansion and population growth of the city
- Prevention of illegal settlements on the river banks and Soil and water conservation measures should be done on the upstream areas of the city
- Surveying current carrying or conveying capacity of main and small streams of the city especially for those found in commercial districts of the city due to occurrence of capacity reduction as a result of illegal solid waste disposal
- Facilitating water harvesting programs for domestic use and urban agriculture to reduce peak runoff
- Preventing land use changes from forest to built environment especially at the periphery of the city which will increase the runoff four times than previous one
- Preventing storm inlets from damage due high surface runoff generation on asphalt road

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Appendix-A

Station Addis Ababa observatory

Year	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1984	0	8	8.8	8.4	127.8	220.8	296.1	295.6	142.4	0	4.4	16.3	1128.6
1985	14.2	0	17.5	96.3	83.7	112.2	270.4	327.7	205.9	58	3.3	1.2	1190.4
1986	0	35.7	88	197.6	125.4	179.5	180.1	264.2	127.8	36.1	0	0	1234.4
1987	0.5	63.4	248.9	82.4	241.3	92.9	196.5	254.4	115.2	21.3	0.8	0.3	1317.9
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	229.7	59.9	0	0	1202.6
1989	0.8	75.9	75.7	154.4	0.5	120.9	357.7	325.3	187.7	14.8	0	7.6	1321.3
1990	0.8	155.9	59.2	106.4	20	88.8	218.7	268.6	184	16.2	12	0	1130.6
1991	0	149	106.6	34.7	55.3	191.1	248.9	262.6	126.4	3.4	0	50	1228
1992	20.2	33.7	20.2	41	52	109.1	248.5	294.7	209.4	69.7	0	2.9	1101.4
1993	10.8	67.2	16.1	157.9	97.2	208.3	274	426.5	243.3	62.1	0	4.5	1567.9
1994	0	0	82.4	82.3	63.3	123.4	308.9	225	284	0.5	14.7	0	1184.5
1995	0	138	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0	0	48.4	1214.6
1996	28.1	5.2	106.8	128.2	122	258.5	266.4	338.7	294.2	0.2	0.2	0	1548.5
1997	39.2	0	24.5	51.3	38.5	104	272.6	194.3	113.8	62.4	50.3	1.5	952.4
1998	55.2	20.5	49	97	154.2	124.4	285.4	260	213.6	126.9	0	0	1386.2
1999	2.9	0.3	28.8	16.3	23.8	119.6	268.6	305.3	88.4	75.4	0	0	929.4
2000	0	0	17.6	49.9	110	144.5	244.8	306.2	250.6	46.4	21.1	0	1191.1
2001	0	12.2	210.8	25	168	216.2	428	246.4	131.7	13.7	0	0	1452
2002	14.7	42	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0	16.5	1037.1

Station Intoto

Year	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1984	0	0	62.2	56	91	98.2	409.5	323.4	293.4	28.7	0	0	1362.4
1985	12.8	64.9	156.2	37.5	39	123.3	266.1	407.6	183.2	5	0.2	22.7	1318.5
1986	15.8	6.3	34.9	25.4	37	179.5	180.1	264.2	127.8	5	0.2	22.7	898.9
1987	0	96.3	29.7	186.1	83.7	98	297	222.1	133.7	28.7	0	0	1175.3
1988	0	156.6	42.8	117.9	17.6	124.4	285.4	260	213.6	28.9	0	0	1247.2
1989	4	76	105.4	133.3	5.8	98.2	409.5	323.4	293.4	11.7	0	14.5	1475.2
1990	0	156.6	42.8	117.9	17.6	100.5	324.5	499.7	180.8	2.3	1.5	0	1444.2
1991	12.8	64.9	156.2	37.5	39	171.2	258.5	395.2	146.7	1.4	0	44.2	1327.6
1992	52.7	31.5	14.6	42.7	84.6	131.6	247.8	387	188.4	42.4	0.7	8.1	1232.1
1993	15.3	44.6	5.7	147.5	49	123.3	266.1	407.6	183.2	28.7	0	0	1271
1994	0	0	62.2	56	91	154.8	336.3	307.2	142.5	0.3	24.4	0	1174.7
1995	0	96.3	29.7	186.1	83.7	98	297	222.1	133.7	5	0.2	22.7	1174.5
1996	0	0	5.2	108	91.4	258.5	266.4	338.7	294.2	10.7	0	28	1401.1
1997	21.2	0	18.6	77.3	27.4	77.2	256.3	240.8	89.3	88.3	90	0.2	986.6
1998	25.3	25.3	45.2	47	149.5	149.2	369	376.3	204.8	44.5	0	0	1436.1
1999	15.8	6.3	34.9	25.4	37	127.1	283.1	280.3	105	58	0.2	0	973.1
2000	0	0	5.2	108	91.4	110.7	303.8	359.1	132.8	17.2	33.5	1.7	1163.4
2001	20.6	5.5	147.5	29.8	141.7	164.3	285.6	321.4	92.5	52.4	0	1.8	1263.1
2002	17.9	50.4	88.8	67.4	49.2	138.7	293.1	262.9	92.1	10.7	0	28	1099.2

Station Bole

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1984	0	0.4	11.6	11.6	135	334.2	317.9	180.4	98.8	0	0	7	1096.9
1985	35.1	0	49.1	132.3	92.8	110.9	209.8	260.8	168.6	29.8	0	0.4	1089.6
1986	0	37.6	56.2	216.6	37.7	175.2	167.9	222.3	107.4	31.6	0	2.5	1055
1987	0	49.1	180.1	85.7	154.6	71.9	155.9	98.1	114	16.6	0	0.4	926.4
1988	4.7	33.4	6.7	157.9	34.7	93.2	181.4	265.3	187.3	57.3	0	0	1021.9
1989	3.4	33.7	58.4	143.3	0	88.1	218.1	318.6	300	36.8	0	7.9	1208.3
1990	3.2	161.1	60.4	289	25.2	48.3	194.2	293.6	143	46.1	2.1	0	1266.2
1991	0.2	29.6	134.1	30	7.7	107.5	279.4	287.9	123.1	4.4	2.1	0	1006
1992	14.5	56	35	58.6	55	82.2	254.8	223.3	314	64.4	2.2	0.4	1160.4
1993	11.7	52.1	11.6	168.3	91.5	157.2	209.5	291.7	190.1	24.1	0	0	1207.8
1994	0	0	52.9	70	29	112.4	242.3	199.3	99.4	0.5	22	0	827.8
1995	0	81.3	73.1	133.3	95.9	77.4	165.5	256.9	194	0	0	29.3	1106.7
1996	20.5	15.8	134.4	192	124.6	290.2	346.3	312.7	211.4	0.2	0.4	0	1648.5
1997	29.1	0	22.1	66.8	44.8	128	257	160.7	94.7	58.6	15.3	0	877.1
1998	66.6	40	43.8	99.8	197.7	111.6	270.7	236.8	173.4	139.4	0	0	1379.8
1999	4.4	0	35	17.8	30.5	104.6	294	270.5	62.8	127.1	0	0	946.7
2000	0	0	17.6	87.8	95.2	102.1	192.9	221.9	157.5	19.6	15	0	909.6
2001	0	10.3	174.3	14.8	116.7	166	289.4	207.3	113.3	10.6	0	0	1102.7
2002	30.6	25.9	79.4	36.6	49.6	231	213.9	233.6	72.6	0.5	0	32.8	1006.5

Station Akaki Mission

Year	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1984	0	0	40.4	5.1	130	215.3	277.9	227.1	71.7	0	0	1.9	969.4
1985	3.6	0	32.4	71.8	96.6	96.5	303	324.1	164.3	1.6	0	0	1093.9
1986	0	95.4	67.7	148.7	83.2	143.4	189.4	216.5	86.1	9.4	0	0	1039.8
1987	0	65.6	181.9	81.2	187.7	69.3	202	246.9	82.5	4.4	0	0	1121.5
1988	0	44.5	0	96	23.8	124.6	255.9	278.1	253.5	35.4	0	0	1111.8
1989	2.1	63.8	53.8	226.3	7.1	58.6	264.2	301	170.9	37.9	0	0	1185.7
1990	7.7	120.6	48.4	159.1	37.3	78.9	280.7	222.9	107.3	5.8	1.2	0	1069.9
1991	0	37.6	62.4	11.6	45.6	90.4	263.7	308.5	113.3	4.4	0	56.5	994
1992	33.5	24.2	30.5	15.5	25.6	100.4	218.4	276	86.7	43.3	0.2	0	854.3
1993	1.2	53.9	5.6	118.4	54.6	116.5	218	251.5	118.3	20.5	0	0	958.5
1994	0	0	62.7	72.2	20.2	131.2	219.3	181	94.5	0	11	0	792.1
1995	0	25.4	62.7	102.1	20.9	95.7	279	242.3	79.5	0	0	4.8	912.4
1996	15.6	15.8	61.4	154.5	15.4	95.2	150.3	189.1	80.9	4.8	3.4	0.7	787.1
1997	0	0	29.1	93	64.9	100.1	188.9	210	124.1	17.2	23.4	3.8	854.5
1998	0	20.7	121.2	23.6	118	142.6	257.5	145	64.9	2.2	0	0	895.7
1999	31.1	10.5	87.8	53.9	76.6	108	167.1	166.3	52.3	0	0	17.7	771.3
2000	0	0	29.1	93	64.9	100.1	188.9	210	124.1	17.2	23.4	3.8	854.5
2001	0	20.7	121.2	23.6	118	142.6	257.5	145	64.9	2.2	0	0	895.7
2002	31.1	10.5	87.8	53.9	76.6	108	167.1	166.3	52.3	0	0	17.7	771.3

Appendix-B

Curve numbers for Urban and Agricultural land uses

Table -B1 Curve number for urban land uses

Classification of Curve number for urban land uses

Land use description		Curve number for hydrologic Soil group			
		A	B	C	D
Fully developed urban areas (vegetation established)					
Lawns, open spaces, parks, golf courses, cemeteries, etc					
Good condition; grass cover on 75% or more of the area		39	61	74	80
Fair condition; grass cover on 50 to 75% of the area		49	69	79	84
Poor condition; grass cover on 50% or less of the area		68	79	86	89
Paved parking lots, roofs, driveways, etc. (excl. right-of-way)					
Streets and roads		98	98	98	98
Paved with curbs andstorm sewers (excl. right-of-way)		98	98	98	98
Gravel (incl. right-of-way)		76	85	89	91
Dirt (inexcl. right-of-way)		72	82	87	89
Paved with open ditches (incl. right-of-way)		83	89	92	93
Average % impervious					
Commercial and business areas	85	89	92	94	95
Industrial districts	72	81	88	91	93
Row houses, town houses, and residential	65	77	85	90	92

with lot sizes 0.05 ha (1/8 ac) or less				
Residential: average lot size				
0.10 ha (1/4 ac) 38	61	75	83	87
0.14 ha (1/3 ac) 30	57	72	81	86
0.20 ha (1/2 ac) 25	54	70	80	85
0.40ha (1 ac) 20				
0.81 ha (2 ac) 12				
Developing urban areas (no vegetation established)				
Newly graded area	77	86	91	94
Cultivated agricultural land				
Fallow				
Straight row or bare soil	77	86	91	94
Conservation tillage Poor	76	85	90	93
Conservation tillage Good	74	83	88	90

Table-B2 Curve number for Agricultural lands

Classification of soils curve number based on ministry of Agriculture classification

Land cover description	Curve Number for hydrological soil group			
	A	B	C	D
Cultivated Land; Rain fed; Cereal Land Cover System lightly stocked	58	72	81	85
Cultivated Land; Rain fed; Cereal Land Cover System moderately Stocked	30	55	70	71
Woodland; Open (20-50% tree Cover	49	69	79	84
Forest; Montane broadleaf; Open (20-50% crown cove	55	69	78	83
Grassland; lightly stocked	32	65	82	86
Forest; Plantation forest; Closed (>80% crown cove	45	58	72	79
Urban	46	65	77	82
Forest; Plantation forest; Open (20-50% crown cove	45	66	77	83
Wetland; Open water	100	100	100	100

Appendix-C

Sub catchments discharge generated for land use map periods

Table- C1 discharges for SC 1

SC-1								
		1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q(m3/s)	Time (sec)
1984	4609550	60.67	3.24	60.67	3.24	66.37	3.54	86400
1985	4609550	65.52	3.50	65.52	3.50	75.17	4.01	86400
1986	4609550	51.93	2.77	51.93	2.77	49.94	2.66	86400
1987	4609550	61.46	3.28	61.46	3.28	58.31	3.11	86400
1988	4609550	55.15	2.94	55.15	2.94	65.94	3.52	86400
1989	4609550	44.64	2.38	44.64	2.38	48.64	2.59	86400
1990	4609550	49.75	2.65	49.75	2.65	49.58	2.65	86400
1991	4609550	53.66	2.86	53.66	2.86	57.47	3.07	86400
1992	4609550	54.23	2.89	54.23	2.89	54.75	2.92	86400
1993	4609550	43.75	2.33	43.75	2.33	46.54	2.48	86400
1994	4609550	57.71	3.08	57.71	3.08	55.12	2.94	86400
1995	4609550	60.28	3.22	60.28	3.22	61.75	3.29	86400
1996	4609550	59.19	3.16	59.19	3.16	79.69	4.25	86400
1997	4609550	45.19	2.41	45.19	2.41	41.14	2.19	86400
1998	4609550	49.76	2.65	49.76	2.65	45.63	2.43	86400
1999	4609550	45.72	2.44	45.72	2.44	36.55	1.95	86400
2000	4609550	44.57	2.38	44.57	2.38	42.59	2.27	86400
2001	4609550	49.15	2.62	49.15	2.62	47.04	2.51	86400
2002	4609550	44.26	2.36	44.26	2.36	37.51	2.00	86400

Table-C2 discharges for SC 2

	SC-2	1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	8559127	63.74	6.31	63.74	6.31	67.92	6.73	86400
1985	8559127	42.99	4.26	42.99	4.26	42.42	4.20	86400
1986	8559127	48.13	4.77	48.13	4.77	45.91	4.55	86400
1987	8559127	52.36	5.19	52.36	5.19	44.01	4.36	86400
1988	8559127	47.15	4.67	47.15	4.67	46.74	4.63	86400
1989	8559127	72.37	7.17	72.37	7.17	75.05	7.44	86400
1990	8559127	36.13	3.58	36.13	3.58	33.03	3.27	86400
1991	8559127	53.13	5.26	53.13	5.26	54.20	5.37	86400
1992	8559127	77.83	7.71	77.83	7.71	79.03	7.83	86400
1993	8559127	48.81	4.84	48.81	4.84	51.29	5.08	86400
1994	8559127	49.50	4.90	49.50	4.90	46.82	4.64	86400
1995	8559127	59.49	5.89	59.49	5.89	56.94	5.64	86400
1996	8559127	59.80	5.92	59.80	5.92	70.90	7.02	86400
1997	8559127	50.64	5.02	50.64	5.02	47.96	4.75	86400
1998	8559127	50.68	5.02	50.68	5.02	51.69	5.12	86400
1999	8559127	50.51	5.00	50.51	5.00	50.28	4.98	86400
2000	8559127	42.55	4.22	42.55	4.22	39.97	3.96	86400
2001	8559127	36.61	3.63	36.61	3.63	36.27	3.59	86400
2002	8559127	58.65	5.81	58.65	5.81	57.29	5.68	86400

Table-C3 discharges for SC 3

SC-3								
		1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	7789935	86.94	7.84	86.94	7.84	70.09	6.32	86400
1985	7789935	79.68	7.18	79.68	7.18	58.56	5.28	86400
1986	7789935	97.14	8.76	97.14	8.76	72.34	6.52	86400
1987	7789935	94.27	8.50	94.27	8.50	69.36	6.25	86400
1988	7789935	84.72	7.64	84.72	7.64	62.07	5.60	86400
1989	7789935	86.94	7.84	86.94	7.84	70.09	6.32	86400
1990	7789935	87.25	7.87	87.25	7.87	69.92	6.30	86400
1991	7789935	82.83	7.47	82.83	7.47	62.04	5.59	86400
1992	7789935	81.22	7.32	81.22	7.32	59.61	5.37	86400
1993	7789935	79.68	7.18	79.68	7.18	58.56	5.28	86400
1994	7789935	89.04	8.03	89.04	8.03	67.78	6.11	86400
1995	7789935	94.27	8.50	94.27	8.50	69.36	6.25	86400
1996	7789935	85.88	7.74	85.88	7.74	69.95	6.31	86400
1997	7789935	89.19	8.04	89.19	8.04	63.68	5.74	86400
1998	7789935	79.66	7.18	79.66	7.18	62.66	5.65	86400
1999	7789935	89.98	8.11	89.98	8.11	65.85	5.94	86400
2000	7789935	85.87	7.74	85.87	7.74	64.56	5.82	86400
2001	7789935	90.32	8.14	90.32	8.14	67.88	6.12	86400
2002	7789935	87.59	7.90	87.59	7.90	63.88	5.76	86400

Table-C4 discharges for SC 4

SC-4		1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	4920401	84.30	4.80	74.01	4.21	56.71	3.23	86400
1985	4920401	82.42	4.69	71.64	4.08	52.50	2.99	86400
1986	4920401	90.66	5.16	78.24	4.46	51.81	2.95	86400
1987	4920401	74.72	4.26	64.01	3.65	38.35	2.18	86400
1988	4920401	70.21	4.00	58.55	3.33	36.41	2.07	86400
1989	4920401	82.77	4.71	72.86	4.15	57.14	3.25	86400
1990	4920401	83.39	4.75	70.69	4.03	43.60	2.48	86400
1991	4920401	83.37	4.75	71.67	4.08	48.96	2.79	86400
1992	4920401	83.24	4.74	71.80	4.09	49.95	2.84	86400
1993	4920401	78.80	4.49	70.70	4.03	62.75	3.57	86400
1994	4920401	109.08	6.21	99.05	5.64	81.18	4.62	86400
1995	4920401	96.62	5.50	84.31	4.80	58.08	3.31	86400
1996	4920401	81.30	4.63	73.27	4.17	65.28	3.72	86400
1997	4920401	94.80	5.40	82.02	4.67	54.21	3.09	86400
1998	4920401	78.67	4.48	67.31	3.83	46.17	2.63	86400
1999	4920401	85.15	4.85	72.91	4.15	47.77	2.72	86400
2000	4920401	77.41	4.41	66.75	3.80	48.54	2.76	86400
2001	4920401	82.41	4.69	72.91	4.15	59.00	3.36	86400
2002	4920401	82.53	4.70	69.76	3.97	42.57	2.42	86400

Tables –C5 discharges for SC 5

SC-5		1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	6441049	65.11	4.85	67.41	5.03	74.67	5.57	86400
1985	6441049	41.87	3.12	42.25	3.15	45.87	3.42	86400
1986	6441049	46.19	3.44	45.87	3.42	47.95	3.57	86400
1987	6441049	40.76	3.04	37.27	2.78	32.93	2.46	86400
1988	6441049	46.11	3.44	46.55	3.47	50.27	3.75	86400
1989	6441049	45.26	3.37	45.99	3.43	50.29	3.75	86400
1990	6441049	33.69	2.51	33.03	2.46	34.67	2.58	86400
1991	6441049	52.88	3.94	53.91	4.02	58.72	4.38	86400
1992	6441049	48.32	3.60	48.39	3.61	51.23	3.82	86400
1993	6441049	89.57	6.68	91.00	6.78	95.23	7.10	86400
1994	6441049	47.33	3.53	46.81	3.49	48.46	3.61	86400
1995	6441049	42.13	3.14	40.83	3.04	40.98	3.05	86400
1996	6441049	64.69	4.82	69.87	5.21	82.97	6.19	86400
1997	6441049	48.47	3.61	47.95	3.57	49.60	3.70	86400
1998	6441049	50.38	3.76	51.40	3.83	56.22	4.19	86400
1999	6441049	49.59	3.70	50.08	3.73	53.82	4.01	86400
2000	6441049	40.40	3.01	39.95	2.98	41.86	3.12	86400
2001	6441049	35.57	2.65	36.07	2.69	40.07	2.99	86400
2002	6441049	37.61	2.80	36.76	2.74	37.96	2.83	86400

Table-C6 discharges for SC 6

	SC-6	1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	4186681	90.59	4.38	101.26	4.90	101.26	4.90	86400
1985	4186681	83.12	4.02	93.35	4.52	93.35	4.52	86400
1986	4186681	64.19	3.11	71.46	3.46	71.46	3.46	86400
1987	4186681	34.21	1.65	37.40	1.81	37.40	1.81	86400
1988	4186681	65.87	3.19	76.82	3.72	76.82	3.72	86400
1989	4186681	94.33	4.57	105.48	5.11	105.48	5.11	86400
1990	4186681	57.62	2.79	65.50	3.17	65.50	3.17	86400
1991	4186681	72.94	3.53	82.24	3.98	82.24	3.98	86400
1992	4186681	74.93	3.63	84.36	4.08	84.36	4.08	86400
1993	4186681	117.96	5.71	131.85	6.38	131.85	6.38	86400
1994	4186681	106.52	5.16	115.12	5.57	115.12	5.57	86400
1995	4186681	69.99	3.39	77.03	3.73	77.03	3.73	86400
1996	4186681	118.64	5.74	132.13	6.40	132.13	6.40	86400
1997	4186681	63.54	3.07	70.15	3.39	70.15	3.39	86400
1998	4186681	74.59	3.61	84.72	4.10	84.72	4.10	86400
1999	4186681	65.72	3.18	74.07	3.58	74.07	3.58	86400
2000	4186681	83.25	4.03	94.30	4.56	94.30	4.56	86400
2001	4186681	100.15	4.85	111.85	5.42	111.85	5.42	86400
2002	4186681	57.48	2.78	65.61	3.17	65.61	3.17	86400

Table-C7 discharges for SC 7

	SC-7	1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	7917822	60.67	5.56	60.67	5.56	60.67	5.56	86400
1985	7917822	65.52	6.00	65.52	6.00	65.52	6.00	86400
1986	7917822	51.93	4.76	51.93	4.76	51.93	4.76	86400
1987	7917822	61.46	5.63	61.46	5.63	61.46	5.63	86400
1988	7917822	55.15	5.05	55.15	5.05	55.15	5.05	86400
1989	7917822	44.64	4.09	44.64	4.09	44.64	4.09	86400
1990	7917822	49.75	4.56	49.75	4.56	49.75	4.56	86400
1991	7917822	53.66	4.92	53.66	4.92	53.66	4.92	86400
1992	7917822	54.23	4.97	54.23	4.97	54.23	4.97	86400
1993	7917822	56.72	5.20	56.72	5.20	56.72	5.20	86400
1994	7917822	57.71	5.29	57.71	5.29	57.71	5.29	86400
1995	7917822	60.28	5.52	60.28	5.52	60.28	5.52	86400
1996	7917822	59.19	5.42	59.19	5.42	59.19	5.42	86400
1997	7917822	45.19	4.14	45.19	4.14	45.19	4.14	86400
1998	7917822	49.76	4.56	49.76	4.56	49.76	4.56	86400
1999	7917822	45.72	4.19	45.72	4.19	45.72	4.19	86400
2000	7917822	44.57	4.08	44.57	4.08	44.57	4.08	86400
2001	7917822	49.15	4.50	49.15	4.50	49.15	4.50	86400
2002	7917822	44.26	4.06	44.26	4.06	44.26	4.06	86400

Table-C8 discharges for SC 8

SC-8								
		1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	6814443	88.24	6.96	97.83	7.72	102.23	8.06	86400
1985	6814443	55.19	4.35	62.53	4.93	66.03	5.21	86400
1986	6814443	54.98	4.34	60.85	4.80	63.69	5.02	86400
1987	6814443	31.56	2.49	32.56	2.57	33.33	2.63	86400
1988	6814443	59.61	4.70	66.89	5.28	70.34	5.55	86400
1989	6814443	60.44	4.77	68.24	5.38	71.93	5.67	86400
1990	6814443	41.60	3.28	47.71	3.76	50.71	4.00	86400
1991	6814443	69.29	5.46	77.22	6.09	80.94	6.38	86400
1992	6814443	59.20	4.67	65.59	5.17	68.65	5.41	86400
1993	6814443	102.84	8.11	108.11	8.53	110.51	8.72	86400
1994	6814443	54.86	4.33	60.33	4.76	63.00	4.97	86400
1995	6814443	45.57	3.59	50.11	3.95	52.40	4.13	86400
1996	6814443	104.15	8.21	118.09	9.31	124.32	9.80	86400
1997	6814443	55.99	4.42	61.44	4.85	64.09	5.05	86400
1998	6814443	66.86	5.27	74.84	5.90	78.58	6.20	86400
1999	6814443	62.96	4.97	70.02	5.52	73.35	5.79	86400
2000	6814443	48.90	3.86	54.90	4.33	57.82	4.56	86400
2001	6814443	50.18	3.96	58.15	4.59	61.96	4.89	86400
2002	6814443	44.18	3.48	49.76	3.92	52.51	4.14	86400

Table-C9 discharges for SC 9

	SC-9							
		1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	8716886	89.87	9.07	89.87	9.07	62.23	6.28	86400
1985	8716886	88.21	8.90	88.21	8.90	59.01	5.95	86400
1986	8716886	97.14	9.80	97.14	9.80	62.48	6.30	86400
1987	8716886	80.19	8.09	80.19	8.09	49.61	5.01	86400
1988	8716886	76.40	7.71	76.40	7.71	44.45	4.48	86400
1989	8716886	88.17	8.90	88.17	8.90	61.78	6.23	86400
1990	8716886	90.01	9.08	90.01	9.08	54.54	5.50	86400
1991	8716886	89.56	9.04	89.56	9.04	57.42	5.79	86400
1992	8716886	89.31	9.01	89.31	9.01	57.97	5.85	86400
1993	8716886	83.43	8.42	83.43	8.42	63.01	6.36	86400
1994	8716886	114.48	11.55	114.48	11.55	87.32	8.81	86400
1995	8716886	103.04	10.40	103.04	10.40	68.68	6.93	86400
1996	8716886	85.88	8.66	85.88	8.66	65.63	6.62	86400
1997	8716886	101.44	10.23	101.44	10.23	65.63	6.62	86400
1998	8716886	84.72	8.55	84.72	8.55	53.72	5.42	86400
1999	8716886	91.57	9.24	91.57	9.24	57.62	5.81	86400
2000	8716886	83.15	8.39	83.15	8.39	54.46	5.49	86400
2001	8716886	87.63	8.84	87.63	8.84	62.62	6.32	86400
2002	8716886	89.19	9.00	89.19	9.00	53.52	5.40	86400

Table-C10 discharges for SC 10

	SC-10							
		1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	7473483	60.67	5.25	60.67	5.25	76.09	6.58	86400
1985	7473483	65.52	5.67	65.52	5.67	87.22	7.54	86400
1986	7473483	51.93	4.49	51.93	4.49	55.28	4.78	86400
1987	7473483	61.46	5.32	61.46	5.32	62.51	5.41	86400
1988	7473483	55.15	4.77	55.15	4.77	79.19	6.85	86400
1989	7473483	44.64	3.86	44.64	3.86	58.16	5.03	86400
1990	7473483	49.75	4.30	49.75	4.30	56.12	4.85	86400
1991	7473483	53.66	4.64	53.66	4.64	66.44	5.75	86400
1992	7473483	54.23	4.69	54.23	4.69	61.58	5.33	86400
1993	7473483	56.72	4.91	56.72	4.91	64.08	5.54	86400
1994	7473483	57.71	4.99	57.71	4.99	59.79	5.17	86400
1995	7473483	60.28	5.21	60.28	5.21	68.81	5.95	86400
1996	7473483	59.19	5.12	59.19	5.12	98.69	8.54	86400
1997	7473483	45.19	3.91	45.19	3.91	45.43	3.93	86400
1998	7473483	49.76	4.30	49.76	4.30	49.59	4.29	86400
1999	7473483	45.72	3.95	45.72	3.95	37.63	3.26	86400
2000	7473483	44.57	3.86	44.57	3.86	48.24	4.17	86400
2001	7473483	49.15	4.25	49.15	4.25	52.31	4.52	86400
2002	7473483	44.26	3.83	44.26	3.83	40.21	3.48	86400

Table-C11 discharges for SC 11

	SC-11	1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	5713863	63.01	4.17	56.68	3.75	57.57	3.81	86400
1985	5713863	59.87	3.96	52.08	3.44	52.64	3.48	86400
1986	5713863	63.64	4.21	49.55	3.28	48.49	3.21	86400
1987	5713863	50.72	3.35	35.25	2.33	33.25	2.20	86400
1988	5713863	45.44	3.00	35.47	2.35	35.64	2.36	86400
1989	5713863	62.50	4.13	57.50	3.80	58.70	3.88	86400
1990	5713863	55.73	3.69	41.31	2.73	40.26	2.66	86400
1991	5713863	58.43	3.86	47.74	3.16	47.63	3.15	86400
1992	5713863	58.94	3.90	48.89	3.23	48.90	3.23	86400
1993	5713863	63.40	4.19	65.01	4.30	67.86	4.49	86400
1994	5713863	88.12	5.83	80.68	5.34	81.06	5.36	86400
1995	5713863	69.83	4.62	55.82	3.69	54.76	3.62	86400
1996	5713863	66.03	4.37	67.44	4.46	70.19	4.64	86400
1997	5713863	66.84	4.42	51.64	3.41	50.32	3.33	86400
1998	5713863	54.67	3.62	45.37	3.00	45.62	3.02	86400
1999	5713863	58.73	3.88	45.94	3.04	45.29	2.99	86400
2000	5713863	55.28	3.66	48.43	3.20	49.28	3.26	86400
2001	5713863	63.26	4.18	59.79	3.95	61.37	4.06	86400
2002	5713863	54.72	3.62	40.30	2.67	39.29	2.60	86400

Table-C12 discharges for SC 12

SC-12								
		1984		1986		2002		
Period	Area (m2)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Runoff (mm)	Q (m3/s)	Time (sec)
1984	4182947	56.69	2.74	56.94	2.76	56.94	2.76	86400
1985	4182947	52.09	2.52	52.21	2.53	52.21	2.53	86400
1986	4182947	49.51	2.40	49.03	2.37	49.03	2.37	86400
1987	4182947	35.19	1.70	34.38	1.66	34.38	1.66	86400
1988	4182947	35.46	1.72	35.43	1.72	35.43	1.72	86400
1989	4182947	57.52	2.78	57.88	2.80	57.88	2.80	86400
1990	4182947	41.27	2.00	40.80	1.98	40.80	1.98	86400
1991	4182947	47.73	2.31	47.60	2.30	47.60	2.30	86400
1992	4182947	48.88	2.37	48.79	2.36	48.79	2.36	86400
1993	4182947	65.07	3.15	66.05	3.20	66.05	3.20	86400
1994	4182947	80.68	3.91	80.75	3.91	80.75	3.91	86400
1995	4182947	55.79	2.70	55.31	2.68	55.31	2.68	86400
1996	4182947	67.50	3.27	68.44	3.31	68.44	3.31	86400
1997	4182947	51.60	2.50	51.02	2.47	51.02	2.47	86400
1998	4182947	45.36	2.20	45.37	2.20	45.37	2.20	86400
1999	4182947	45.91	2.22	45.58	2.21	45.58	2.21	86400
2000	4182947	48.44	2.35	48.67	2.36	48.67	2.36	86400
2001	4182947	59.82	2.90	60.32	2.92	60.32	2.92	86400
2002	4182947	40.27	1.95	39.80	1.93	39.80	1.93	86400

Appendix-D Photo graphs show built environment of the city

Slum areas developed near stream banks

Upgraded Asphalt road