



Ethiopian Institute of Architecture, Building Construction, and City Development

Nature-Based Design for Stream Rehabilitation Affected by Imperviousness in Addis Ababa: The Case of Kaba River

by

Mengistu Abebe Abidie

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Author: Mengistu Abebe

Date: June 2020

Approved by Board of Examiners:

Ato Alazar Assefa (Ph.D.) _____

Advisor Signature Date

External Examiner Signature Date

Internal Examiner Signature Date

Chair Person Signature Date

DECLARATION

I, the undersigned, declare that this thesis is my own and original work and has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged, following the scientific guidelines of the Institute.

Student's Name: **Mengistu Abebe Abidie**

Signature: _____

CONFIRMATION

The thesis can be submitted for examination with my approval as an Institute's advisor.

Advisor's Name: Ato Alazar Assefa (Ph.D.)

Signature: _____

ABSTRACT

Urbanization of watersheds substantially changes the health of a stream by increasing impervious surfaces that deliver pollutants directly to waterways. The major environmental problem that Addis Ababa facing is the increasing impervious surface. Although improving the riparian zone has been attempted to restore urban stream health in Addis Ababa, that does not significantly improve it, since it is not equivalent to the scale of degradation of streams based on recent studies. The main objective of the study is to introduce an appropriate type of watershed-level nature-based design measures for the rehabilitation of urban streams affected by the higher level of imperviousness in Addis Ababa. Stream restoration can be achieved in this case by a cross-sectional study of the specific case watershed to address the issue of urban streams and river system rehabilitation at the watershed level by introducing appropriate nature-based design solutions and by upscaling the solution from the case site into the entire city river system. The study site is selected based on the density by comparing the built-up of upper catchments. The study estimates the existing level of effective impervious area for 'Kaba' river watershed and stream health improvement solution. The total impervious cover of the city and effective impervious cover of the study area are 52 and 27.8 percent respectively. The current condition of the stream will not support its intended hydro-ecological functions. Different design scenarios are proposed in the watershed to reduce the effective impervious areas to a level at which measurable improvement in the ecological indicators. Finally, the study concludes that the proportion of the effective impervious areas is a good predictor of the ecological condition of streams and it should be reduced to a level of recommended proportion to maintain stream health.

Key Words: *Hydro-ecological function, Runoff volume, Green infrastructure(GI), Retrofitting measures.*

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Table of Contents

Contents	Pages
Abstract	iii
Acknowledgment.....	iv
Table of contents.....	v
List of Figures	viii
List of Tables.....	x
Acronyms.....	xiii
Chapter One: Introduction	1
1.1 Background	1
1.2 Problem statement.....	3
1.3 Objectives of the study.....	4
1.4 Research question.....	4
1.5 Significance.....	5
1.6 Scope	5
1.7 Limitation.....	5
1.8 Organization of the paper.....	5
Chapter Two: Literature review	6
2.1 Theoretical Review	6
2.1.1 Imperviousness and stream health.....	6
2.1.2 Watershed delineation and codification for stream rehabilitation.....	13
2.1.3 Nature-based landscape design.....	17
2.1.4 Summery.....	20
2.2 Contextual Review	21
2.3 Similar study in Australia.....	22
Chapter Three: Material and. Methods	23
3.1 Study area.....	23
3.2 Variables of steam health and imperviousness of Addis Ababa.....	26
3.3 Drainage of study area.....	29
3.4 Watershed delineation, estimation, and analysis method.....	31
3.4.1 Watershed delineation technique.....	31
3.4.2 Estimation technique.....	32
3.4.3 Data analysis method and interpretation for each specific objective.....	34
3.4.4 Research design.....	35

Chapter Four: Result	36
4.1 Total impervious area of Addis Ababa.....	36
4.2 ‘Kaba’ River watershed.....	38
4.3 Existing and structure plan proposal road network of study area.....	38
4.3.1 Road area summary.....	50
4.3.2 Runoff volume and EIA estimation for the study area’s existing road based on SCS method.....	44
4.3.3 Runoff volume and EIA estimation of existing and proposed road on structure plan based on SCS method.....	44
4.4 Existing land use.....	45
4.5 Existing vegetation cover.....	49
4.6 Existing land cover classification of case area.....	52
4.7 Analysis of existing impervious cover (Effective Impervious Area).....	54
Chapter Five: Discussion	82
Chapter Six: Conclusion, and Recommendation	83
6.1 conclusion.....	54
6.2 Recommendation.....	55
6.2.1 Decreasing runoff volume to restore stream health using nature-based design of urban catchments.....	56
6.2.1.1 Options for reducing runoff volume on impervious surfaces.....	56
6.2.1.1.1 Road level nature-based landscape design.....	57
6.2.1.1.2 Block-level, Plot-level, and Watershed-level nature-based design in the watershed.....	61
6.2.1.1.2.1 Block level nature-based design.....	61
6.2.1.1.2.2 Plot level nature-based design from the selected blocks based on density.....	65
6.2.1.1.2.3 Watershed level nature-based design for all land uses.....	67
References	84
Appendices	87

Lists of figures

Figure 1.1: Relationship of imperviousness to stream health.....	2
Figure.2.1: Impervious cover model [adapted from CWP (1998).....	14
Figure.2.2: Sample of interbasin and basin subdivision using rules of 'pfafstetter' codification for delineation.	17
Figure 3.1a: Location map of case area in Addis Ababa.....	25
Figure 3.1b: Satellite image of case area.....	25
Figure 3.1c: Contour map of case area	25
Figure 3.2: Soil map and topography of Addis Ababa and case Area.....	27
Figure 3.3: Land cover of Addis Ababa in 1986, 1999, and 2011.....	28
Figure 3.4: Drainage map of Addis Ababa and the study area.....	29
Figure 3.5: Slope map of Addis Ababa and the study area.....	29
Figure 3.6: Little Akaki watershed delineation and codification.....	30
Figure 3.7: Research design and procedure.....	34
Figure-4.1a: Area proportion of land use cover of Addis Ababa.....	37
Figure 4.1b: Land cover classification of Addis Ababa in 2020.....	36
Figure 4.2: Existing and structure plan proposed road network of case area based on the road width.....	38
Figure 4.3a: Existing and proposed road network of case area based on road material.....	40
Figure-4.3b: Area proportion and road materials of existing road.....	43
Figure-4.3c: Area proportion and road materials of proposed and existing road.....	43
Figure 4.4: Existing impervious surface (buildings) of case area.....	45
Figure 4.5a: Existing land use of case area.....	46
Figure-4.5b: Proportion of land use.....	47
Figure 4.6a: Existing vegetation cover of case area.....	49
Figure 4.6b: Total area proportion of vegetation cover.....	50
Figure 4.7a: Existing land cover of case area.....	51
Figure 4.7b: Area proportion of land cover.....	52
Figure 6.1: Cross-section of landscaped swale for typical 2 meter median of 30m asphalt road.....	55
Figure 6.2: Road network with highlighted on section line of the above detail and 40m width road.....	55
Figure 6.3: Aerial view of a landscaped swale.....	56

Figure 6.4: 40m width road aerial view with proposed seating area at the median and rain garden on the walkway.....	56
Figure 6.5: Proposed Inlet points of a rain garden for 40m width road.....	56
Figure 6.6: Proposed permeable surface and seating area at the median for 40m width road ...	57
Figure 6.7: Location of a high, medium, and low-density residential block.....	58
Figure 6.8: High-density residential block: Existing and revised with nature-based landscape...	59
Figure 6.9: Medium density residential block: Existing and revised with nature-based landscape.....	60
Figure 6.10: Low-density residential block: Existing and revised with nature-based landscape.....	61
Figure 6.11: Existing and proposed high-density residential Plot.....	63
Figure 6.12: Existing and proposed medium density residential Plot.....	63
Figure 6.13: Existing and proposed low-density residential plot	64
Figure 6.14: Watershed level reduced total runoff volume in the residential plot by reducing or changing impervious surface to pervious.....	68
Figure 6.15: Watershed level reduced total runoff volume in the mixed-use plot by reducing or changing impervious surface to pervious.....	69
Figure 6.16: Watershed level reduced total runoff volume in the commercial and business plot by reducing or changing impervious surface to pervious.....	70
Figure 6.17: Watershed level reduced total runoff volume in the social service and Institute plot by reducing or changing impervious surface to pervious.....	71
Figure 6.18: Watershed level reduced total runoff volume in the Industry plot by reducing or changing impervious surface to pervious.....	72
Figure 6.19: Watershed level reduced total runoff volume in the riparian area by introducing wet pond (Retention pond) to restore stream health.....	76

Lists of tables

Table 2.1: Impervious ratios of land uses in various studies modified by the author.....	8
Table 2.2: Level of imperviousness for numerous land cover classes estimated from an aerial photo and map analysis.....	9
Table 2.3: Level of degradation and related threshold findings summary.....	12
Table 2.4: Comparison of runoff characteristics for a variety of pervious surfaces.....	13
Table 2.5: Summary of several basins and stream gauge codification schemes that have been applied over wide areas.....	16
Table 2.6: Comparison of the ability of detention ponds to clean various contaminants from stormwater.....	22
Table 3.1: Methodology.....	33
Table 4.1: Area of land use cover of Addis Ababa.....	35
Table 4.2: Types of road and area coverage on the study Area.....	39
Table 4.3: Total area of existing road material.....	41
Table 4.4: Total area of proposed road materials.....	41
Table 4.5: Existing total runoff volume and percentage of imperviousness estimated for all road cover of the watershed excluding proposed asphalt road on the structure plan.....	43
Table 4.6: Existing total runoff volume and percentage of imperviousness estimated for all road cover of the watershed including proposed asphalt road on the structure plan...	44
Table-4.7: Total area of land-use classification	46
Table 4.8: Existing total runoff volume and percentage of imperviousness estimated for all land-use of the watershed.....	47
Table-4.9: Total Area of Vegetation Cover.....	49
Table-4.10: Existing total area of forest, stream, (grass, and shrubs), bare land, and agriculture Of riparian	50
Table-4.11: Existing total runoff intensity based on average annual rainfall for the riparian zone..	50
Table 4.12: Existing total runoff volume and percentage of imperviousness estimated for all riparian of the watershed.....	50
Table-4.13: Landcover area.....	51
Table 4.14: Summary of existing total cumulative runoff volume and percentage of imperviousness estimated for all land cover of the watershed excluding proposed asphalt road on the structure plan.....	52

Table 4.15: Summary of total cumulative runoff volume and percentage of imperviousness estimated for all land cover of the Watershed including proposed asphalt road.....	53
Table 6.1: Reduced total runoff volume and percentage of imperviousness estimated after new proposed design of street and road in the watershed including proposed asphalt road on the structure plan.....	57
Table 6. 2: Comparison of existing and proposed impervious level for low, medium, and high-density blocks.....	62
Table 6. 3: Comparison of existing and proposed impervious level for low, medium, and high-density plots.....	64
Table 6. 4: Proportion of soil group in the study area.....	65
Table 6.5: Basic infiltration rates for various soil types.....	65
Table 6.6: Recommended rain garden (4% of catchment area) for all land uses in the watershed.....	66
Table 6.7: Total forest, grass and shrubs area of existing land uses in the watershed.....	67
Table 6.8: Average parcel area and built-up area estimation within a plot for all land uses (Estimated from the whole watershed).....	67
Table 6.9: Average forest, grass cover, paved surface, and bare land area estimation within a plot for all existing land uses. (Estimated from the entire watershed).....	67
Table 6.10: New proposed design of open space in a single plot for every land use including rain garden.....	68
Table 6.11: Watershed level reduced total runoff volume in the residential plot by reducing or converting impervious surface to pervious.....	69
Table 6.12: Watershed level reduced total runoff volume in mixed-use plots by reducing or converting impervious surface to pervious.....	70
Table 6.13: Watershed level reduced total runoff volume in commercial and business plots by reducing or converting impervious surface to pervious.....	71
Table 6.14: Watershed level reduced total runoff volume in social service and institute and business plots by reducing or converting impervious surface to pervious.....	72
Table 6.15: Watershed level reduced total runoff volume in industry plots by reducing or converting impervious surface to pervious.....	73
Table 6.16: Watershed level reduced total runoff volume in other plots by reducing or converting impervious surface to pervious.....	73
Table 6.17: New proposed design of landcover in the riparian area including rain garden.....	73

Table 6.18: Watershed level reduced total runoff volume in the riparian area by reducing or converting impervious surface to pervious.....	74
Table 6.19: Summary of proposed total cumulative runoff volume and percentage of imperviousness estimated for all land cover of the watershed including proposed asphalt road.....	77
Table 6.20: Comparison of proposed and existing total cumulative runoff volume and percentage of imperviousness estimated for all land cover and land-use of the watershed	77

Acronyms

AACG	Addis Ababa City Government
AAEPA	Addis Ababa Environmental Protection Authority
CSA	Central Statistics Agency
CWP	Center for Watershed Protection
DEM	Digital Elevation Model
DNAEE	Departamento Nacional de Aguas e Energia Eletrica
DNOS	Departamento Nacional de Obras de Saneamen to
EIA	Effective Impervious Area
EI	Effective Impervious Proportion
GIS	Geographical Information System
GPS	Global Positioning Systems
GTOPO30	Global digital elevation model with a horizontal grid spacing of 30 arc-second (approx.1km)
GRDC	Global Runoff Data Center
HUC	Hydrologic Unit Code
ICM	Impervious Cover Model
LID	Low Impact Design
NRCS	U.S.Natural Resources Conservation Service
NWIS	National Water Information System
OAAOSZIDP	The Office of Addis Ababa and the Surrounding Oromia Special Zone Integrated Development Plan
ORSTOM	Office de la Recherche Scientifiqueet Technique d'Outre- Mer(French)
SCS	Soil Conservation Service
TIA	Total Impervious Area
TSS	Total Suspended Solid
USGS	Unite States Geological Survey
WGA	Water resilient Green cities in Africa
WSUD	Water Sensitive Urban Design

CHAPTER ONE

INTRODUCTION

1.1 Background

Impervious surfaces are surfaces that do not allow water to pass through. These are mainly related to transportation (streets, highways, parking lots, sidewalks) and rooftops. Expansion of impervious surfaces is not only increasing runoff volume, but also a basic determinant of water quality of lakes and streams. If the percentage of imperviousness exceeds 10%, stream health indicators decrease (Schuelre, 1994). Arnold and Gibbons (1996) suggest that impervious surface area is directly related to the health of streams, and more generally that key environmental indicator and habitat quality or biological diversity, in urban areas is imperviousness of a watershed. Yuan and Bauer (2006) have recently reported that there is a close relationship between temperatures of land surface or the urban heat island and habitat quality in urban areas and the percentage of imperviousness. Based on Yuan and Bauer (2006) a high level of impervious surfaces, and associating phosphorous, sediment, and thermal loads can have serious negative impacts on lakes and streams and habitat for fisheries. The level of imperviousness has emerged as a key factor nowadays to explain in general watershed planning and management in urban planning and policy (Yuan and Bauer 2006).

Impervious surfaces are most visible in heavily industrialized and retail commercial areas. Although less pervasive, imperviousness is abundant in residential neighborhoods in such structures as garages, patios, and sheds (Arnold and Gibbons 1996). Heavily compacted soils, gravel areas, and water bodies can also have impervious characteristics. Imperviousness values range from 0 to 100% (Arnold and Gibbons 1996). Natural areas with well-drained permeable soils are represented at the lower end of the range, and urban areas completely covered in impervious materials are at the upper end.

The four main characters of impervious surface area explained by Arnold and Gibbons (1996) that make it a basic environmental quality indicator are: First; there is a strong connection between Imperviousness and stream health degradation, although pollution is not generated by impervious area; Second; urbanization is characterized by an impervious surface.

Third; an impervious surface prohibits percolation and prevents natural pollutant processing in the soil; and The last: impervious areas deliver pollutants into the waterways, typically through the direct stormwater pipe.

Arnold and Gibbons (1996) based on Schueler (1995) (Fig 1.1) also describe that stream health degradation starts to drop at 10 percent of impervious surface and becomes severe as becomes almost unavoidable at 30 percent. This leads to a ranking of stream health “which can be roughly characterized as ‘**protected**’ (less than 10% impervious surface) ‘**impacted**’ (10%-30% impervious surface), and ‘**degraded**’ (over 30% impervious surface).”

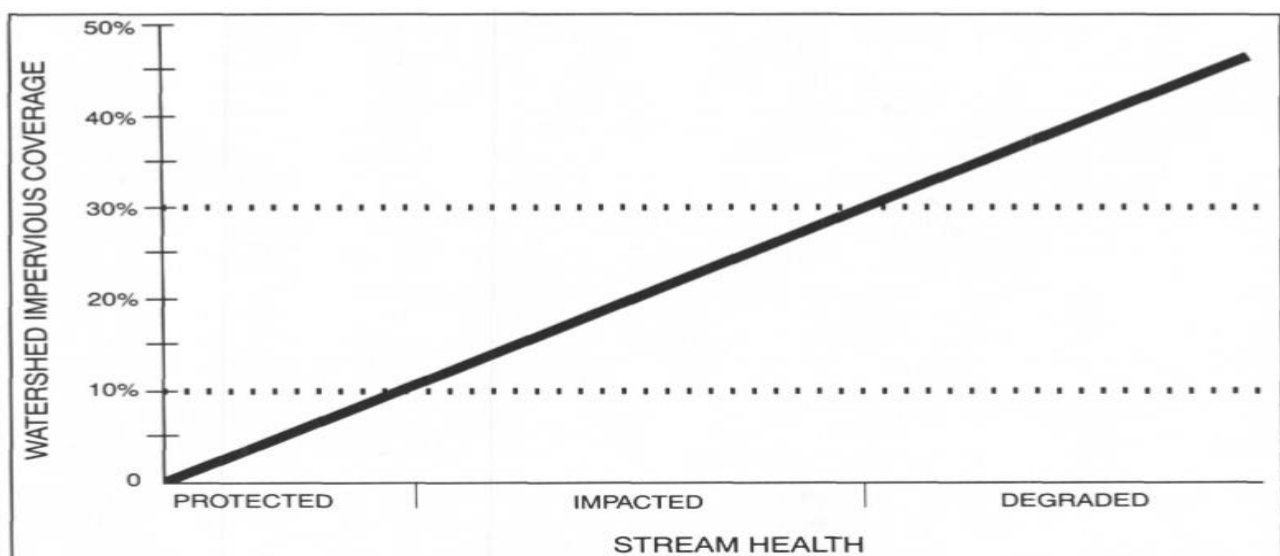


Fig-1.1 Relationship of imperviousness to stream health. Adapted from Arnold and Gibbons (1996) which is modified from Schueler 1995

Many factors contribute to the quality of a stream and how it is affected by impervious surfaces (Morisawa and LaFlure 1979). At a basic level, climate, geology, soils, land use, and vegetation are five variables that the function and hydrology of streams are reliant on. Of these variables, **land use** and **vegetation** are the only variables over which man has direct control (Morisawa and LaFlure 1979).

Stream health of Addis Ababa is affected by imperviousness according to Alemayehu et al. (2009). To reduce urban stream health degradation, the study tries to decrease impervious surfaces that are directly connected to the stream using a nature-based design to reduce urban runoff volume in the study area.

1.2 Problem Statement

Stormwater runoff increase is one of the environmental problems that Addis Ababa city is facing, which resulting in stream health degradation and others such as damage to infrastructure and properties and hindering traffic movement (Alemayehu et al. 2009). In urbanization, the natural landscape is replaced by impervious material and resulting in higher stormwater runoff flows and lower base flows in a stream (Cengiz, B. 2013). Thus, most of the rainy season rainfall water containing all sorts of wastes, including solid organic waste, sediments, and nutrients, ends in the rivers. Alemayehu et al. (2009) noted that the dominance of impervious surfaces, coupled with the altitude difference between upper and lower reaches, increased the discharge of rivers in Addis Ababa. The average TSS concentration is high throughout the study sites of rivers in Addis Ababa with a moderate increase in the lower reaches (Solomon et al.,2011). Surface runoff from impervious surfaces and erosion from riparian areas contributed to the high TSS recorded in the study sites (Solomon et al.,2011).

The other problem of imperviousness is reducing groundwater recharge. Cengiz. B noted that before urbanization and deforestation in natural situations, nearly half of all stream flows are provided by groundwater and this percentage can be increased to a much higher level during drought periods. This is also the other problem of streams of Addis Ababa (Solomon et al. 2011). The urban rivers are adversely affected by these impermeable surfaces of hardscapes as they do not absorb stormwater (Cengiz, B. 2013). According to Arnold and Gibbons imperviousness also affect stream stability, degrade terrestrial and aquatic habitat, and increase pollutant loads to surface and groundwater resource. Even though urbanization causes watersheds to be degraded due to imperviousness, there is no documented study on literature that describes the quantitative relationship between land use and its impact on hydrology or the environment in Addis Ababa. Therefore even land-use policies have a contribution to the problem of stream health by allowing a high percentage of imperviousness.

A general report by WGA (2015) stated that the little Akaki river catchment covers one-third of Addis Ababa that consists of 63 weredas. The report noted that although, there are substantial green spaces mainly in the upper catchment such as Gullele botanical garden...etc; construction of new highways to Ambo, Sebeta, and Bishoftu boosted construction of a building, investment, and settlement expansion through the conversion

of green space and farmland in the catchment. This activity contributes to several tributary rivers joining little Akaki to be degraded (WGA 2015).

1.3 Objectives of the Study

General objective

To measure the total imperviousness of Addis Ababa and identifying the appropriate type of watershed-level nature-based design solution for the rehabilitation of the Kaba river.

Specific objectives

1. To map out and measure the built-up area of Addis Ababa to identify city-level total imperviousness.
2. To delineate local watersheds and compare built-up areas to identify highly degraded watersheds in the upper catchment of the little Akaki River system.
3. To develop a nature-based solution as green infrastructure for the affected watershed of 'Kaba' river.

1.4 Research question

Main question

What proportion of the city is covered with a high level of total imperviousness and needs improvement for stream health of kaba river at the watershed level using nature-based design solution?

Specific question

1. To what extent the built-up area of Addis Ababa covers the natural landscape?
2. How much area and which watershed is more affected by a high level of imperviousness in the upper catchment of the little Akaki river?
3. How to improve stream health using nature-based design measures of the more degraded watershed of the 'Kaba' river?

1.5 Significance

Government, nongovernment, researchers, planners, and the public at large can use the study to get a different insight into managing watershed planning even to the site-specific level and easy way to implement and helpful for alleviating the problem sustainably. In addition to that, the study will be used as a reference document and start-up for a similar study.

1.6. Scope

The spatial scope of the study covers a general study on the imperviousness of the city and a detailed investigation of the selected watershed area locally known as 'Kaba'river watershed including individual plot level. The thematic scope of the study focuses on land use, built-up area, and vegetation cover from the basic factors of stream hydrology and function.

1.7. Limitation

The study is limited on recommendations rather than experimental (Similar studies had tested in Australia) and it is purposive since the area that the study focused on has adequate information on related studies. Although; Merkato, Teklehimanot, Piassa, Aratkillu areas are highly affected by imperviousness in Addis Ababa, there is no adequate information on related studies on imperviousness of the area. Other limitations of the study are the inaccessibility of recent line maps and high-resolution satellite images.

1.8 Organization of the paper

This paper is structured into six parts. The introductory part consisting of the objective of the study, research questions, scope and limitations of the study as well as the significance of the study make up the first section. The second section discusses a literature review of imperviousness and stream health using various theories along with an overview of Addis Ababa planning regulations towards watershed areas. Selected case areas along major streams and methods are used to investigate the subject matter are discussed in the third section. Results take up the fourth section. The discussion will be explained in the fifth section leading to the sixth and last section which points out the conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

By reviewing and analyzing existing literature in the field, this article covers a theoretical and contextual review of imperviousness. The first part develops an understanding of imperviousness and stream health. Besides the article reviewed in the first part an articulated impervious cover model (Schueler et al. 2009) that strengthened the original model to reveal modern science and make it straightforward for policymakers and watershed managers than the first proposed impervious cover model by Schueler (1995) (Fig 1.1) reviewed. In the next section of part one nature-based delineation of watershed-based on topographic control and arrangement of nodes of the river network, to identify a high level of imperviousness are reviewed. Nature-based design and type of nature-based design for stream rehabilitation will also be reviewed. Finally, a contextual review and similar experimental studies in Australia are covered in the second and the third part by reviewing and analyzing existing literature in the field.

2.1 Theoretical Review

2.1.1 Imperviousness and stream health

In the planning viewpoints, the essential arithmetic quantification of the effect of impervious surface on stream health is the level at which water quality degradation starts (Arnold and Gibbons 1996). In defining the level of imperviousness a specific study associates to a level of degradation. (1) The methods for defining impervious surface, (2) TIA versus EIA, and (3) The measures of impacts on stream (4) Reformulated conceptual impervious cover model are issues that will be reviewed in the next Sections.

2.1.1.1 Method of defining the level of impervious surface for different land uses

In the early research, imperviousness was estimated in four methods (1) Isolating impervious surface from aerial photography and measure area using a planimeter (Booth and Jackson 1994); (2) Overlaying a grid on an aerial photograph and counting covered land uses or impervious types (Hammer 1972); (3) Supervised classification of remotely

sensed images (Miltner 1997), and (4) Equating the percentage of urbanization in a region with the percentage of imperviousness (Limberg and Schmidt 1990).

The majority of current studies depend on the above original methods and consequent studies that correlated the level of imperviousness to land use by using estimates of the percentage of imperviousness within each class (Table 2.1) that have revealed a substantial correlation of total imperviousness and demographic variables. Much of the effort of early research has been focused on assembling the percentage of imperviousness in specific land-use classes to estimate the proportion of impervious surfaces (Table 2.2). There are three major problems with this approach (Brabec et al. 2002). First, the previous data revealed significant imperviousness deviation in the same land-use class, showing that these classes were too general to provide accurate results when applying these ratios at the watershed level. Second, imperviousness has been shown considerably with use density. In a specific land use like the residential, increasing size of parcel associated with reducing impervious surface at a particular site level. However, imperviousness per capita increases due to the extra roadway mainly to provide access for the larger plot. Third, the previous studies that are adapted for the current studies concentrated mainly on urban areas, even though the current land use pattern and demography have altered noticeably from the time of the earlier study (Jones and Clark 1987).

Table 2.1. Impervious area of land use in various studies modified by the author

Author and date (Study)	Purpose (EIA/EIA)	Method	Sample (Number of Land Use class)	Measurement
Hammer (1972)	TIA	Aerial photos and field survey	17	Direct Measure
Alley and Veenhuis (1983)			6	
Krug and Goddard (1986)	EIA	Measured from topographic maps	6	
Booth and Jackson (1994)	TIA	Typical impervious area ratios	-	Estimates
Klein (1979)		County land use maps and coefficients from Soil Conservation Service (1975) and Graham et al. (1974)	-	
Limberg and Schmidt (1990)	% Urbanization	U.S. Geological Survey land use classification	-	Urbanization
Miltner (1997)		Satellite imagery	-	
Yoder et al. (1999)			-	
Miltner (1997)	Housing density	Census data	-	Other measures
Jones and Clark (1987)	Population density		-	

NOTE: TIA= total impervious area; EIA= effective impervious area. source: Brabec et al. (2002).

Table 2.2. Level of imperviousness for numerous land cover classes estimated from an aerial photo and map analysis.

Land Cover Class	Notes	Mean	Range	Studies
Single-family residential	< 0.25 acre lots	39	30-49	Alley and Veenhuis (1983)
	0.25-0.5 acre lots	26	22-31	Alley and Veenhuis (1983)
	0.5-1.0 acre lots	15	13-16	Alley and Veenhuis (1983)
	Includes multi-family residential	30	22-44	Sullivan et al. (1978)
Multiple-family residential		66	53-64	Alley and Veenhuis (1983)
Commercial		88	66-98	Alley and Veenhuis (1983)
		81	52-90	Sullivan et al. (1978)
Industria		60	-	Alley and Veenhuis (1983)
		40	11-57	Sullivan et al. (1978)
Open		5	1-14	Sullivan et al. (1978)

(Source: Brabec et al. (2002)).

2.1.1.2 Effective Impervious Area (EIA) and Total Impervious Area (TIA)

Previous studies (Beard and Chang 1979; Driver and Troutman 1989) show that TIA, although correlating with changes in runoff, does not affect runoff as much as the proportion of imperviousness which is linked right to the stream (EIA). The difference of both relies on direct linkage to the stream network: Total impervious area includes all non-infiltrating surfaces, whereas effective imperviousness includes only those impervious areas that drain into a piped storm sewer and discharge into a stream network. There on for EIA, practically 100 percent of urban runoff water will reach the surface-water body. TIA, on the other hand, includes both EIA and “ineffective impervious areas” that drain to

the permeable surface (such as roadway into a meadow) (Alley and Veenhuis 1983). The non-effective impervious areas will infiltrate all or part of runoff water based on soil, grade, and character of ground cover.

Most studies do not identify the difference between TIA and EIA on their threshold level. TIA is generally calculated based on the weighted percentage of each land use in the watershed to estimate the total proportion of impervious area for the watershed (Brabec et al. 2002). Using TIA instead of EIA or not differentiating both will result in listed problems in the study of imperviousness: (1) Overestimation of runoff volumes and peak flows, (2) If TIA is considered the simulated difference in runoff as a result of increasing the amount of land use can be reduced. and (3) Overestimation of the infiltration rate (Alley and Veenhuis, 1983).

2.1.1.3. The measures of impacts on stream health

2.1.1.3.1. Impacts of imperviousness surface on stream health

There are a variety of measures for stream quality since stream quality is a combination of the physical, chemical, and biological health of a stream. These are categorized into two: biotic and abiotic measures (Brabec et al. 2002). Many of the studies reviewed define a percentage of impervious surface at which a factor of stream quality is measurably degraded (Table.2.3). In some studies, the threshold of biotic degradation is defined by various means.

The most common standard index is (IBI) (Karr 1987) to measure aquatic species' richness and composition, local indicator species, trophic composition, fish abundance, and fish diversity.

Individual variables usually define abiotic parameters threshold whether it is physical or chemical, for instance, water volume increases. sedimentation and solids (Wydzga1997; Griffinetal.1980; May et al. 1997; Horner et al. 1997), channelization and stream bank erosion(BoothandJackson1997; Mayetal. 1997), habitat (Horner et al. 1997) temperature (Galli 1990), the volume of base flow (Tennant 1975), dissolved oxygen (May et al. 1997), nutrients (Griffinetal. 1980; Mayetal.1997), and heavy metals (Horner et al. 1997).

Table 2.3. Level of degradation and related threshold findings summary (Brabec et al. 2002)

Impact Measurement		Percentage Impervious Threshold for Degradation	Study	
Parameter type	Parameter			
Biotic	Benthic invertebrates	< 10 humans per hectare	Jones and Clark (1987)	
		8	Horner et al. (1997)	
	Fish diversity	15	Klein (1979)	
		10 urbanized	Limberg and Schmidt (1990)	
		12	Klein (1979)	
		8	Miltner (1997)	
		3.6	Booth and Jackson (1994)	
		10	Wang et al. (forthcoming)	
	IBI	8 urban land use	Yoder et al. (n.d.)	
	Macroinvertebrate diversity	8 to 15	Shaver et al. (1994)	
8		Miltner (1997)		
Species diversity	10 to 15	Booth and Reinelt (1993)		
Abiotic and biotic	IBI, habitat quality	10 to 20 urban land use	Wang et al. (1997)	
	Mean event water-level fluctuation/ indicator species	10 TIA, 14 EIA	Taylor (1993)	
	Variation of water depth and indicator species	15 to 21	Chin (1996)	
Abiotic—physical	Temperature for cold-water biota	12	Galli (1990)	
	Base flow	45	Klein (1979)	
	Stream flow	> 21	Horner et al. (1997)	
		Not defined	Krug and Goddard (1986)	
	Peak flows	4.6	Booth and Jackson (1994)	
	Channel enlargement and streambank erosion	Not given	Hammer (1972)	
		34 urbanization	MacRae (1997)	
	Habitat assessment	8 to 10	Booth and Reinelt (1993)	
		30	May et al. (1997)	
	Large woody debris	10	Booth and Jackson (1994)	
		4 to 9 impervious surface and 30 to 50 forest	Hicks and Larson (1997)	
	Abiotic—chemical	Sediment	9	Horner et al. (1997)
			20	Wydzga (1997)
Nutrients		50	Horner et al. (1997)	
		Not defined	Krug and Goddard (1986)	
Phosphorous		43	Griffin et al. (1980)	
		45	May et al. (1997)	
Threshold of eutrophication based on TSS and TP		42	Griffin et al. (1980)	
		45	May et al. (1997)	
Chemical water quality		30	Todd et al. (1989)	
		45	May et al. (1997)	
Oxygen	10	May et al. (1997)		
	7.5 urbanized	Limburg and Schmidt (1990)		
	43	Griffin (1980)		
Metals	50	Horner et al. (1997)		
Zinc	40	Horner et al. (1997)		

NOTE: IBI=Index of Biotic Integrity; TIA=total impervious area; EIA=effective impervious area; TSS=total suspended solids; TP= total phosphorus.

2.1.1.3.2 Impacts of the Pervious Cover

Various types of pervious cover can also have considerable impacts on stream quality even though the data indicate that the impervious surface is the dominant determinant of stream quality (Ross and Dillaha 1993). Related sediment concentrations, nutrients, and runoff from six different previous areas in a simulated rainfall event (Table 2.4). The results showed a great difference in the runoff characteristics among different types of pervious surfaces (Ross and Dillaha 1993).

Table 2.4. Comparison of runoff characteristics for a variety of pervious surfaces (after Schueler 1995)

Surface	RV Soluble			
	(Runoff)	Nitrate	P	TSS
Gravel driveway	0.51	0.03	0.06	692
Bare soil	0.33	0.32	0.79	1,935
Cold-season sodded grass,	0.05	0.31	1.12	29
Warm-season turf	0.03	0.44	0.33	43
Mulched landscape	0.00	None	None	None
Meadow	0.00	None	None	None

NOTE: RV=run off volume; P=phosphorus; TSS=total suspended solids.

2.1.1.4. Modified impervious cover model (ICM)

The ICM stream health indicators start to decline at around 10% of total IC in the smallest (i.e., 5 to 50 km²) sub-watersheds based on the Center for Watershed Protection (CWP 2003). The ICM defines urban stream into four classes related to how much IC exists in their contributing sub-watershed: sensitive, impacted, non-supporting, and urban drainage (Fig. 2.1) ICM model by (CWP 2003), modified from (Schueler 1994).

The overall predictions of the ICM are: streams with less than 10% subwatershed IC considered as sensitive streams, and generally able to retain their hydrologic function and support well to excellent aquatic diversity (Schueler et al. 2009).

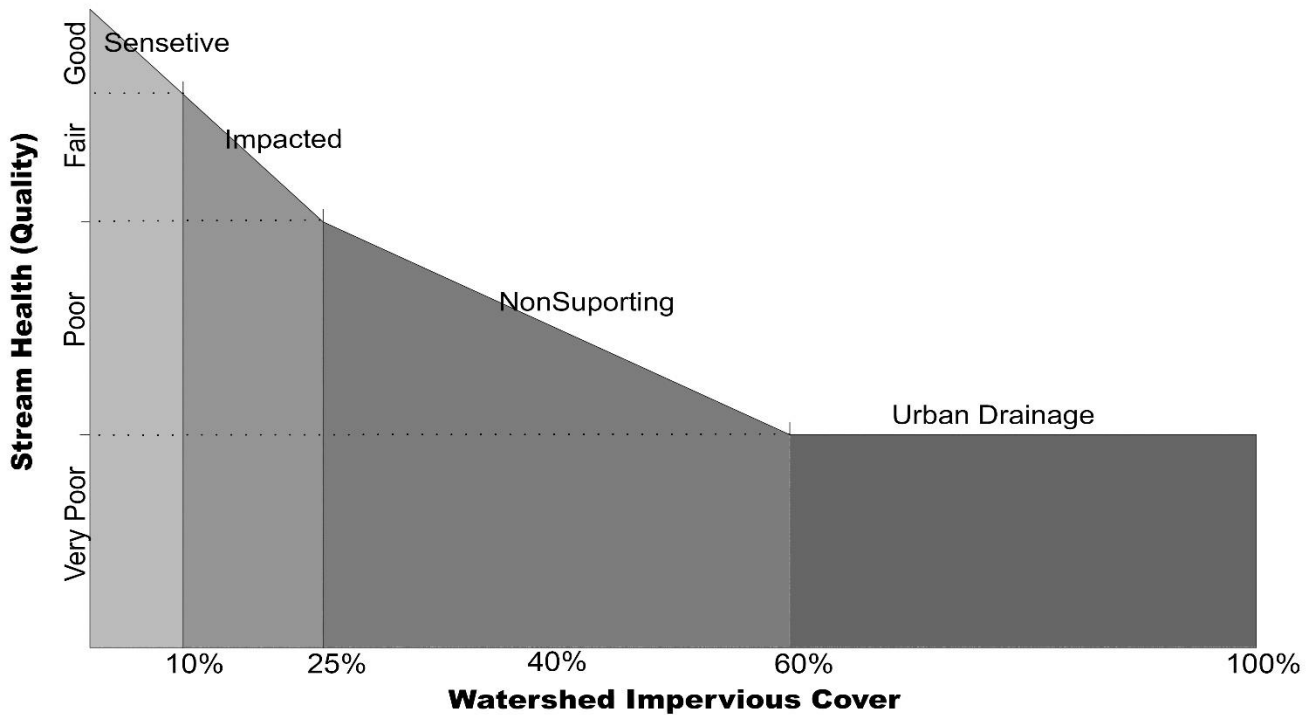


Fig.2.1. Impervious cover model [adapted from CWP (1998) which is modified from Schueler (1994)]

Streams with sub-watershed IC 10 to 25% considered as impacted and behaves as declining stream health. Most indicators of stream health are categorized in the fair range (Schueler et al. 2009). Streams with sub-watershed IC 25 to 60% are known as non-supporting, they will not support their desired uses based on hydrology, channel stability, habitat, stream health, or biological diversity (Schueler et al. 2009). They are so degraded and they may not be fully recovered to expected uses. Sub watersheds streams surpassing 60% IC are often so extensively modified that they merely function as a conduit for floodwaters (Schueler et al. 2009). These streams are characterized as urban drainage and they have degraded stream health, highly unstable channels, and very poor habitat and biodiversity (Schueler et al. 2009).

2.1.2 Watershed delineation and codification for stream rehabilitation

For river basin planning, delineation is a vital step in GIS tools. To identify uniquely simple and international applications based on the nature of the hydrographic basin is needed and codification of basins based on topography and drainage network topology is described in various studies (Verdin, K. and Verdin, J. (1999)).

2.1.2.1 Delineation and Codification Systems

Several codification systems for basins and stream gauges have been developed over the years by organizations with a need to organize hydrologic data. Basin codification schemes directly address the need for numbering natural landscape units that are the focus of river basin management. (Verdin, K. and Verdin, J. (1999))

The water resources division of the US Geological Survey (USGS) has its Hydrologic Unit System (HUC) (Seaber et al.1987). A Hydrologic Unit Code (HUC) is an eight-digit number that has two digits each to indicate region, sub-region, accounting unit, and cataloging unit. The hydrologic units delineate all river basins with a drainage area of at least 700 mi² (1800 km²), approximate mean areas of regions, sub-regions, accounting units, and cataloging units are, respectively, 500 000, 50 000, 25 000, and 4000 km².

NWIS is the repository for USGS surface-water records (Wahl, 1995). NWIS includes a system of stream gauge station identification numbers. These are 8-digit numbers whose ordinal values increase in a downstream sense. However, the main stem and tributary are not differentiated by numbers on the typology of the stream network. The major river basin is designated by the first two digits and the downstream order is labeled by the next six digits. ORSTOM uses a nine-digit method in the stations in Africa, South America, Europe, and Oceania (Roche, 1968). The first digit identifies the continent, the second and third identify the country, and the fourth and fifth a continental river basin. The location of the gauging station is identified by sixth and seventh digits and the specifying station is carried by given the data gathered by the previous digits identified by eighth and ninth digits (Verdin, K. and Verdin, J. (1999)). In Brazil, the hydroelectric power agency, Department to Nacional de Aguas e Energia Eletrica (DNAEE), has defined a codification scheme for gauging stations that somewhat resembles the NWIS system. Basins and sub-basins are represented by the first two digits (Fernandes, 1987) later on station numbers from upstream to downstream are assigned by the next three digits, third, fourth, and fifth. Digits six, seven, and eight are provided to accommodate stations added in the future (Fernandes, 1987).

(GRDC) federal institute of hydrology in Koblenz in Germany operates the world meteorological organization and publishes analysis and data (Global Runoff Data Center (GRDC), 1996). Inspection of a GRDC stream gauge index list reveals that it uses a system with seven-digit identification numbers for the thousands of stations around the world for

which it archives and disseminates streamflow data. The first digit indicates the continent, the second country, the third and fourth together identify a continental basin, and digits five, six, and seven are for the station itself. When there are more than nine countries on a continent, values 1–9 are used over again for the second digit, and digits three and four, indicating basin, are depended upon to prevent confusion. (Table 2.5) summarizes the codifications discussed above (Verdin, K. and Verdin, J. (1999)).

Table 2.5 Summary of several basins and stream gauge codification schemes that have been applied

over wide areas (after Verdin, K. and Verdin, J. (1999))

Organization/system	Country	Basis	Extent	No. digits
USGS/HUCS	USA	Basin	National	8
USGS/NWIS	USA	Gauge	National	8
ORSTOM	France	Gauge	Continental	9
DNAEE	Brazil	Gauge	National	8
GRDC	United Nations	Gauge	Global	7

2.1.2.2 Delineation and codification systems based on topological characteristics

The late Otto Pfafstetter an engineer with (DNOS), founded the first system for delineation and codification of river basins using topological characteristics. It is nature-based on topographic control of areas of surface water and topology of the stream network. Pfafstetter system is intended to use the base 10 numbering system to reflect the basin characteristics (Pfafstetter, 1989) (Verdin, K. and Verdin, J. (1999)). One important outcome of this strategy is the efficient use of digits. Compared to the systems described in the previous section, the Pfafstetter system uses significantly fewer digits to uniquely code a population of basins.

The system Identify the main stem and tributary from mouth to source by considering a river on a map. The main stem is considered as the stream it drains the greater area and the tributary drains the lesser area by the Pfafstetter system. Basin is the area drained by a tributary, whereas interbasin is the area directly drained by the extent of the main stem between the two tributaries.

Margins between interbasin are created by starting at a point on the bank of the main stem directly reverse the outlet of a basin and outlining uphill, orthogonal to the topographic slope until come across a basin margin.

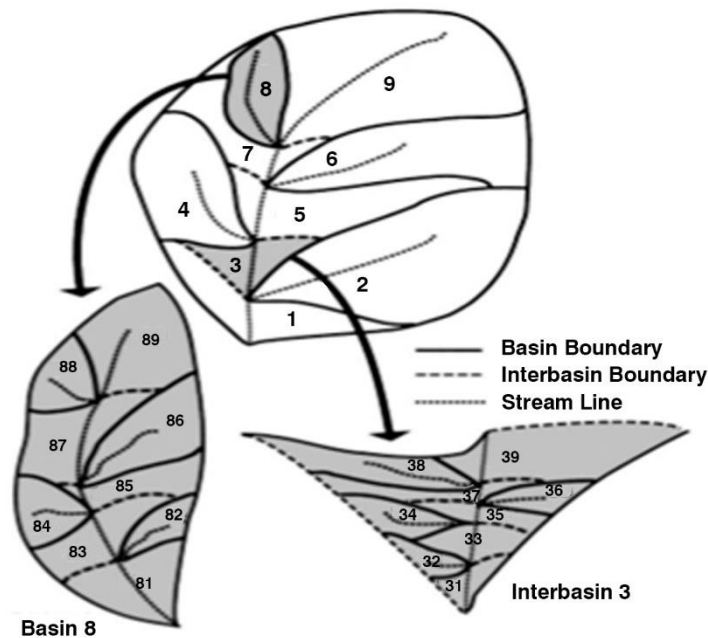


Fig. 2.2. Sample of interbasin and basin subdivisions using rules of Pfafstetter codification for delineation. (Adapted from Verdin, K. and Verdin, J. (1999))

Subdivision of basins and interbasin area using code by assigning digits in such a way that ordinal values and party. Odd digits are assigned to interbasin and even digits for basins from downstream to upstream, internal closed drainage is assigned by zero digits. Five values (1,3,5,7,9) are for interbasin and four values(2,4,6,8) for basins in the subdivision of the main basin.

According to Pfafstetter the catchment area on the main stem between the exit of basin 2 and the mouth of the main stem is interbasin 1. The catchment area on the main stem between the exit of basin 2 and 4 is interbasin 3. The catchment area on the main stem between the exit of basin 4 and 6 is interbasin 5, and the catchment area on the main stem between the exit of basin 6 and 8 is interbasin 7. Interbasin 9 drains a larger area on the main stem, and it comprises of the headwater area by definition, number zero is assigned If closed basins have come across. Subdivision of coded basins and interbasin are shown on an ideal river basin (Fig. 2.3). The same rule can be applied for any basin subdivision of its internal area. First, the four tributaries (2, 4, 6, and 8) of the largest catchment area from downstream to upstream are identified within each interbasin or basins. As shown in

(Fig. 2.3.), basin 82, 84, 86, and 88, and interbasin 81, 83, 85, 87, and 89 are further subdivisions of basin 8. And basin 32, 34, 36, and 38 and interbasin 31, 33, 35, 37, and 39 are a further subdivision of interbasin 3.

2.1.3 Nature-based landscape design

Nature-based design reduces landscape maintenance costs, fixes erosion problems, improves water quality, enhances aesthetic conditions, and/or reduces flooding (Dennis W. D. 2008). Watershed managers are increasingly recommending large-scale nature-based designs to enhance the beneficial uses of urban and suburban water bodies and are selling the retrofit concept on aesthetic and cost-saving grounds (Pursglov, 1988).

There are growing awareness and appreciation of an alternative urban design ethic that incorporates “natural” elements into developed properties. This alternative ethic is based on both ecologic and aesthetic considerations (Dennis W. D. 2008). Central to this ethic is the belief that it is both possible and desirable to mix natural areas and materials with developed landscapes. Elements of this ethic include the use of native plants for landscaping, preserving or restoring natural buffers at the edges of developments, and incorporating native ecosystems — grassland, wetlands, and woodlands — into development site designs (Pursglov, 1988)

2.1.3.1 Types of Nature-based design

The nature-based design includes a range of activities. In other contexts, some of these activities might be termed rehabilitation, restoration, or renovation (Dennis W. D. 2008). Regardless of terminology, the nature-based design is assumed to involve a substantive, long-term change to an existing facility or landscape resulting in demonstrable improvements to water quality and aquatic ecosystems. Some of the nature-based design types are:

- Converting conventional turf landscapes to native vegetation,
- Restoring eroding and/or channelized stream and rivers,
- Nature-based design stormwater detention basins, and
- Converting, or “daylighting,” storm sewers to open drainage ways

(i) Converting turf to natural landscapes

Natural landscaping applies to an array of landscaping techniques that incorporate native vegetation, particularly prairie, wetland, and woodland plants. Natural landscaping also includes natural drainage techniques, such as swales and vegetated filter strips, instead of storm sewers and artificial drainage channels (Northeastern Illinois Planning Commission, 1997). The benefits of natural landscaping are the broadest ranging of any of the nature-based design techniques. In addition to water quality benefits, they include flood reduction, habitat enhancement, improved air quality (climatological benefits) aesthetic enhancement, and cost-savings (Sear, 1994).

Water quality benefits are derived in two ways. First, unlike conventional landscapes of turfgrass and ornamental plants, native plants do not usually require chemical additives after their initial establishment. Fewer applications mean greatly reduced runoff of fertilizers, pesticides, and herbicides. Second, natural landscapes, particularly with the deep root zones of many native plants, can effectively soak up, filter, and transform contaminated stormwater runoff from roadways and parking lots, greatly reducing the pollutant loads discharged to the “receiving stream” (Pursglov, 1988).

(ii) Restoring stream and rivers

Uncontrolled development of upstream watersheds has led to severe flooding, streambank erosion, and water quality degradation (Dreher 1998). Nature-based design is used to describe stabilization or limited rehabilitation of the physical characteristics of the channel and its riparian zone. The nature-based design includes the stabilization of eroding banks, enhancement of instream habitat, and restoration of the near-stream riparian zone (Sear, 1994).

Potential benefits include bank stabilization, improved water quality, improved habitat, and enhanced aesthetics (Dreher 1998). Water quality improvement can be accomplished by several nature-based design techniques (Barmuta et.al, 1992). One way to improve water quality is to restore the natural pollutant filtering capability of the riparian zone and floodplain (Horner et al. 1997). This is most readily accomplished by re-planting streambanks and riparian buffers with native vegetation, particularly indigenous wetland,

prairie, and woodland plants that were common before settlement (Horner et al. 1997). Another way to improve water quality is to stabilize stream temperatures (Brookes 1988). Often, degraded streams suffer from over-heated conditions during the summer due to a loss of shading in combination with overly wide, shallow channels (Barmuta et.al, 1992). Establishing native vegetation, particularly along sensitive headwater streams, can result in substantial improvements.

(iii) Nature-based design stormwater detention basins

Various studies have assessed the pollutant removal ability of various mitigation strategies. Because allowing for runoff to sit before rejoining the hydrologic system is important to achieving removal (Horner et al. 1997), detention basin is important for the cleaning process as noted in (Comings et al. 2000), studies for removal of both soluble reactive phosphorous and total phosphorous using detention basin are commonly falling below 50 percent, even if the result of the study varies (Comings et al. 2000). (table 2.6)

TABLE 2.6. Comparison of the ability of detention ponds to clean various contaminants from Stormwater.

Contaminant	Maristany (1993)	Stanley (1996)	USEPA (1983)	Kantrowtiz and Woodham (1995)
Total suspended solids	95.4	71	93	7
Turbidity	86.6	—	—	—
Total chromium	77.5	—	—	25
Total copper	72	26	64	52
Total lead	91.3	55	84	>60
Total nickel	68	—	—	—
Total zinc	84.9	26	51	48
Total organic carbon	24.3	10	—	—
Chemical oxygen demand	14	—	44	16
Biochemical oxygen demand	20.3	—	51	49
Total nitrogen	31.3	26	—	—
Ammonia	54.5	9	—	40
Total Kjeldahl nitrogen	28.8	—	38	—
Nitrate	60	-2	44	—
Total phosphorus	64	14	64	40
Orthophosphate	-50	26	—	52

NOTE: USEPA= U. S. Environmental Protection Agency. Source (Brabec et al. (2002)

Detention basins can be targeted to a range of objectives (Horner et al. 1997). These include improved pollutant removal, improved flow control, reduced maintenance, and enhanced aesthetics (Horner et al. 1997).

One of the nature-based design techniques to improve pollutant removal is to revegetate basin bottoms with wetland plants in place of turf (Comings et al. 2000). If paved low-flow channels exist, they can be replaced with vegetated swales (Comings et al. 2000). Pollutant removal also can be enhanced by excavating settling basins at the inlets and/or outlets of the existing basin (Dreher 1998). Settling basins can greatly enhance the removal of suspended solids and attached pollutants (Dreher 1998). Outlet structures also can be modified to increase detention times for small-to-moderate-sized storms, thereby enhancing pollutant settling (Horner et al. 1997). Finally, pollutant removal can be enhanced in basins where inlets and outlets are located nearby, causing short-circuiting (Horner et al. 1997). This is accomplished by lengthening flow paths through the construction of low berms (Horner et al. 1997).

(iv) Converting, or “Daylighting,” Storm Sewers

The term “daylighting” refers to the elimination of a storm sewer or culvert and its replacement with open channel flow (Horner et al. 1997). On the principle that open drainage systems provide certain natural and aesthetic functions not provided by artificial, underground systems (Horner et al. 1997).

There are several potential benefits of converting closed pipes to open channels (Dreher 1998). These include improved water quality and hydrologic functions as well as aesthetic benefits. These benefits are optimized when the open channel is designed as a natural, unlined swale or stream (Dreher 1998). Several water quality benefits are likely to result from storm sewer daylighting (Horner et al. 1997). By running stormwater through an open, vegetated channel, runoff pollutants can be filtered and transformed by a combination of physical and biological processes (Horner et al. 1997). These processes, similar to those occurring in the natural swale and stream systems, are constrained in closed pipes by inadequate light and the absence of natural substrates (Horner et al. 1997).

2.1.4 Summery

The particular studies about the level of imperviousness and degree of degradation of stream health associate the methods for defining impervious surfaces, effective impervious area (EIA), and total impervious area (TIA), and the measures of impacts of imperviousness and pervious surface on stream.

Among several codification and delineation systems for river basins, The Pfafstetter system based on topological characteristics is the One with efficient use of digits, Compared to the other systems described in the previous section. The system Identify the main stem and tributary from mouth to source by considering a river on a map.

There are growing awareness and appreciation of an alternative urban design ethic that incorporates “natural” elements into developed properties based on both ecologic and aesthetic considerations for nature-based design. The nature-based design includes a range of activities. In other contexts, it might be termed as rehabilitation, restoration, or renovation.

2.2. Contextual Review

In Addis Ababa, rivers and riversides are among the natural resources that are negatively affected by the rapid watershed urbanization (Tesfaye, 2015; AACSPPO, 2017; Yohannes, and Elias, 2017; Alemayehu, 2001). Land-use change and deforestation in Addis Ababa have resulted in a high level of river water pollution, which has become a threat to human health and native biodiversity causing habitat loss and fragmentation (AACSPPO, 2017; Beyene et al. 2009).

Settlements along riversides

The research made on Addis Ababa shows more than 90% of the city’s riversides are occupied by residents who settled either illegally or permits granted by Kebele authorities. To take one example, many immigrants have settled around Akaki River without obtaining a legal permit from the government (MUDC, 2004; Seyoum M. et al,2007; Hayal et al. 2011).

Riverside Greenways of Addis Ababa

In Addis Ababa, there are no greenways along riverbanks. According to Tesfaye, M.(2015). the reason for the lack of greenways in the city is that rivers are places for evil spirits and sources of nuisance. Because of this, it is impossible to find greenways along the rivers of Addis Ababa. Currently, OAAOSZIDP is planning to study regarding greenways of Addis Ababa (Tesfaye, M.,2015).

Proposed Measures by AAEPA

According to Tesfaye, M.(2015). the interview conducted with Ato Masersha, who is working in AAEPA, explained that to reduce river pollution, the office developed a regulation base, economic base, information-based instrument, and color rating. Each of the instruments was explained in the interview.

Planning Implication to water pollution mitigation in Addis Ababa

According to Asnake, M.et al.,(2020) Addis Ababa City Structure Plan confirmed that high pollution of river waters emanates from domestic and industrial wastewater discharges as well as storm runoff, thus, suggested various ways to prevent pollution of rives (Addis Ababa City Administration Structure Plan Project Office,2017). The structure plan delineated a river buffer zone around the rivers of Addis Ababa with the width of 10-30m to be covered with indigenous trees and shrubs, the structure plan also forwarded a way of considering the slope of the buffer zone and various ways of developing the sloped riversides (Addis Ababa City Administration Structure Plan Project Office,2017). However, this river water pollution prevention methods lack a watershed level perspective that will contribute to the fragmented and site-specific river management gaps of the study area. Watershed planning, therefore, becomes one of the vital tools to addresses water quality problems in a holistic manner (Ding et al., 2015; Arnold and Gibbons, 1996).

2.3 Similar study in Australia

A feasibility study analogous to this paper were undertaken in Australia with a similar principle to examine options to reduce the area of impervious surfaces that are directly connected to waterways by efficient drainage systems (Ladson et.al. 2006). These options include rainwater tanks; permeable pavements that reduce runoff from roads; and swale drains and bioretention systems along roads, rather than piped drainage direct to streams. Models of the relationship between effective imperviousness and a range of ecological indicators, from previous studies, are used to assess the likely effect of these options on stream health (Ladson et.al. 2006). The study achieved the reduction of effective imperviousness from 45% to 0% using varying degrees of interception at the house block scale, and from 26% to 4% using further treatment at the streetscape scale.

CHAPTER THREE

MATERIAL AND METHODS

3.1 Study Area

Addis Ababa is the capital of Ethiopia and is also known as the capital of Africa (Tamiru et al, 2005). The city is situated in the plateau of central Ethiopia in the North-South oriented mountain systems neighboring the great rift-valley (Fig3.1) (Abiye et al, 2009). It is located between the geographical coordinates of 09°02'N latitude and 38°44'E longitude, the city is located in the geographic center of the country which makes it easily accessible from any direction in the country and its high altitude makes a very pleasant climate (Tamiru et al, 2005). The city is the key economic, social, and political center of Ethiopia and is situated between 2000 and 3000 meters above sea level, and with faster population growth (Abiye et al, 2009). Compared to other cities in the country, some factors contribute to rapid urbanization in the city. Facilities, infrastructures, and industries are among the factors (Tamiru et al, 2005). The specific location of the study area is situated in Kolfekeranio sub-city, in wereda 04, 05, 06, and 07 (Fig-3.1a-c)

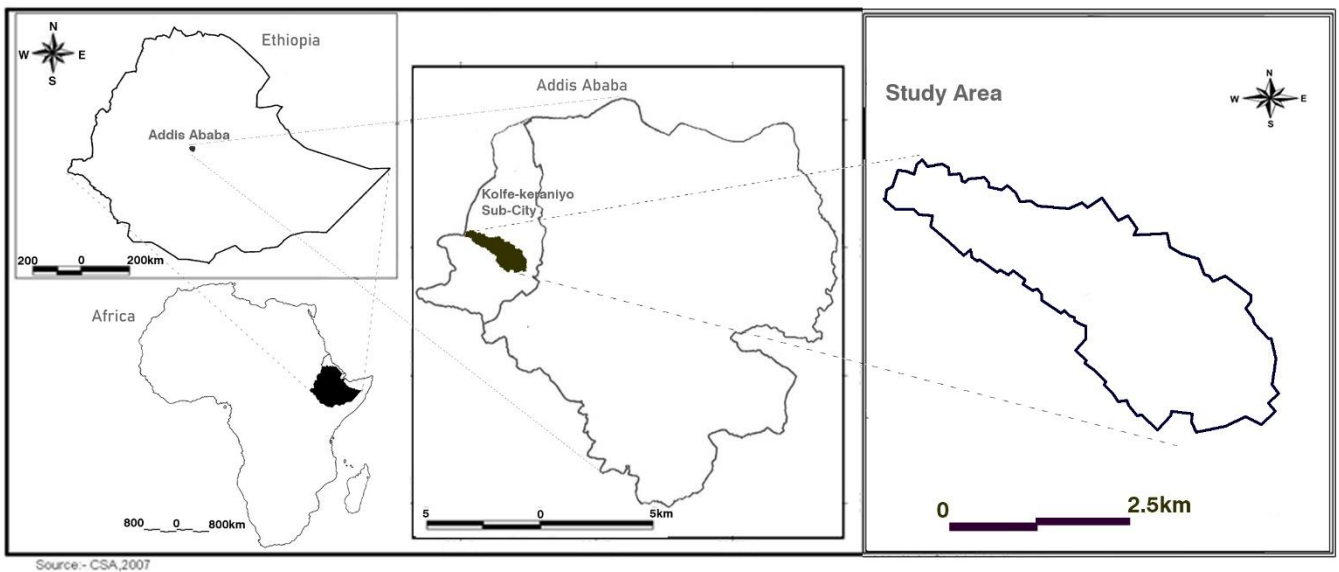


Fig-3.1a Location Map of Addis Ababa and sub-city of case area



Fig-3.1b Satellite image of case area

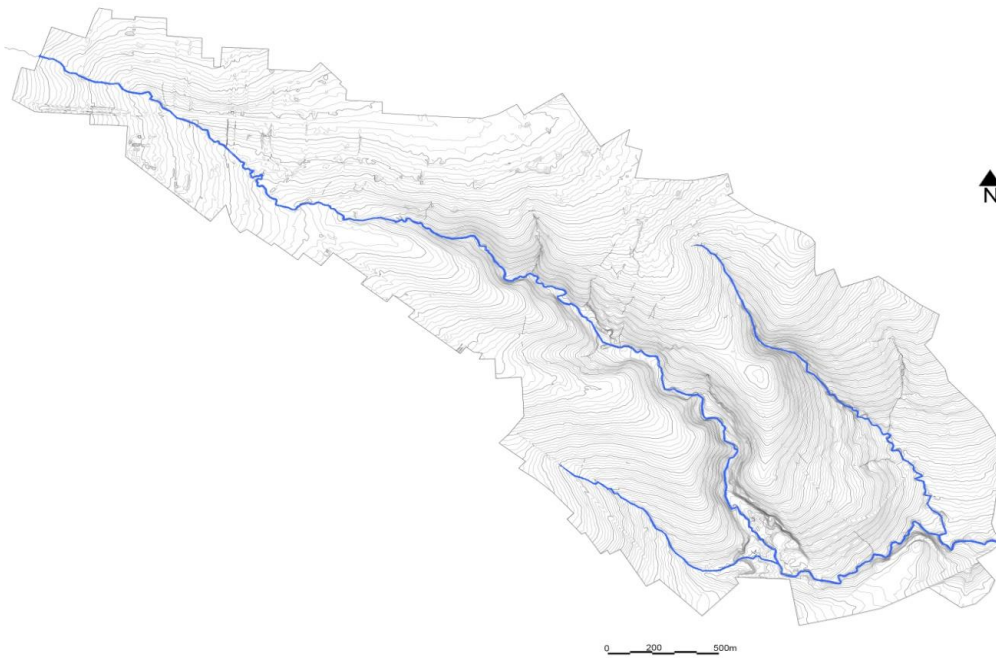


Fig-3.1c Contour map of case area

3.2 Variables of steam health and imperviousness of Addis Ababa

According to the meteorological data of Addis Ababa show that the average annual rainfall about 1127mm, with the major rainfall occurring between July and September (Akalu et al 2011). The minimum mean monthly temperature of the region ranges between 8°C to 12°C, while the maximum mean monthly temperature varies between 20°C to 25°C, throughout the year (AACG, 2010; CSA, 2010).

Initially, Addis Ababa was founded on the southern edge of the 'Entoto' ridge (3139 m. a. s. l.) and expanded in all directions (Tamiru et al, 2005). Another noticeable volcanic topography adjoining the city is in the west 'Wochecha' mountain (3385m.a.s.l), in the southwest 'Furi' mountain (2839m.a.s.l), in the southeast 'Yerer' mountain (3100m.a.s.l) (Abiye et al,2009). This volcanic topography is mostly made up of acidic and lava flows. The topography slopes down from the 'Entoto' mountain in the north to the southern border of the city (Fig-3.2), with several steep-sided valleys, rivers, and streams. The center of the city lies in an undulating topography with some flat land areas (Akalu et al 2011).

In the north, west, and southwestern area of Addis Ababa form highland (Tamiru et al, 2005). However, the southwest and 'Bole' area are considered by moderate morphology and level land area (Akalu et al 2011). Due to this, the stream flows to the south direction from 'Entoto' ridge; towards the southeast from 'Wechecha' mountain and 'Furi' mountain towards the southwest direction from 'Yerer' mountain and other eastern border highland areas of the city.

As surveyed by the Ministry of Water and Energy in 2004, the soil classes in Addis Ababa are Classic Xerosols, Chromic Luvisols, Eutric Nitisols, Leptosols, OrthicSolonchaks, and Pelvic Vertisols(fig 2.3) (Abiye et al,2009). The dominant soil of the region is Pelvic Vertisol (277.23 km²) which is found in the Southern and northeast parts of the city (Akalu et al 2011). Eutric Nitisol (111.55 km²) is the second most dominant soil found in the central and northwest parts of the region. Vertisol is composed of greater than 60 percent clay soil with a character of fine texture (Tamiru et al, 2005). Accordingly, that makes any material difficult to pass through, due to the very fine porosity of the soil. Hence, the perviousness of Vertisol is very low and the character of Leptosol is shallow depth featured by hard rock and less developed soil. Slightly coarse-textured soil and more permeable. (Gizachew

Kabite: GIS and remote sensing-based solid waste landfill site selection: A case of Addis Ababa city, Unpublished).

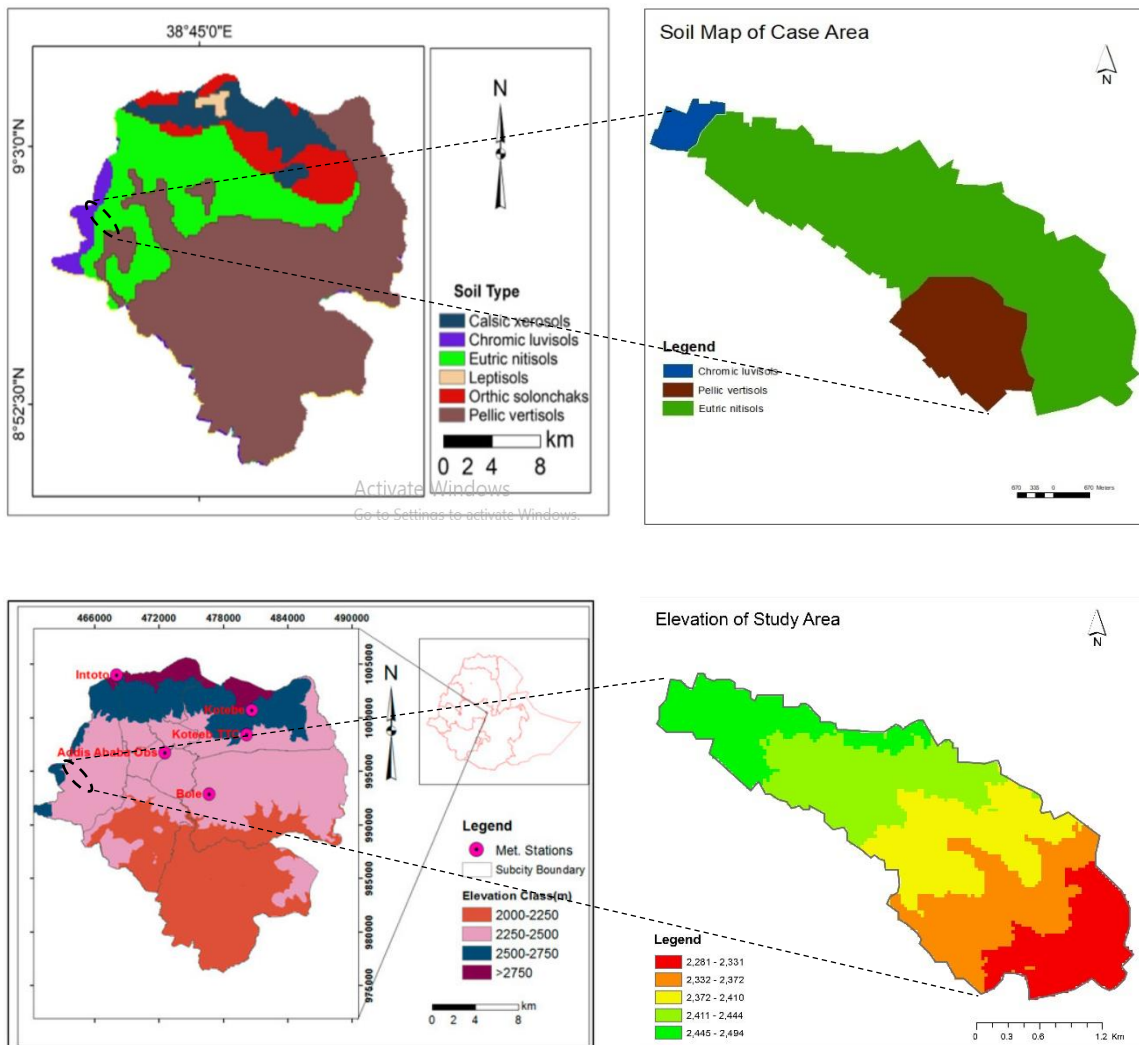


Fig 3.2 Soil map and topography of Addis Ababa and case area

The catchment areas of the rivers crossing Addis Ababa are on the one hand characterized by the large urban area of Addis Ababa (Abiye et al,2009). On the other hand, cultivated areas, woodland, and grassland are found on the banks of the rivers. The eastern part ('Hanku' river basin) is mostly covered with grassland (Tamiru et al, 2005). The northern part (Little 'Akaki', 'Kechene', and 'Kebena' river basins) is more or less covered with woodland but a certain part is an intensively cultivated land and the urbanization is closed to the basin boundary and expands further (Tamiru et al, 2005). Due to the enormous population growth, deforestation became a serious problem in the last two decades (Abiye et al,2009). Besides, mismanagement of the forest resources and failure in reforestation

programs resulted in deforested hills in the mountainous region of the 'Intoto' (EPAAA, 2010).

It is estimated that 22,000 hectares are dedicated to the green belt from a total of 54,000 hectares of land (Akalu et al 2011). Only 7,900 hectares of land are estimated that have been covered by forest from 22,000 hectares of land (fig-2.4) (Abiye et al,2009). According to the revised master plan of Addis Ababa, 12500 hectares are to be covered with forests (AACG, 2010; CSA, 2010).

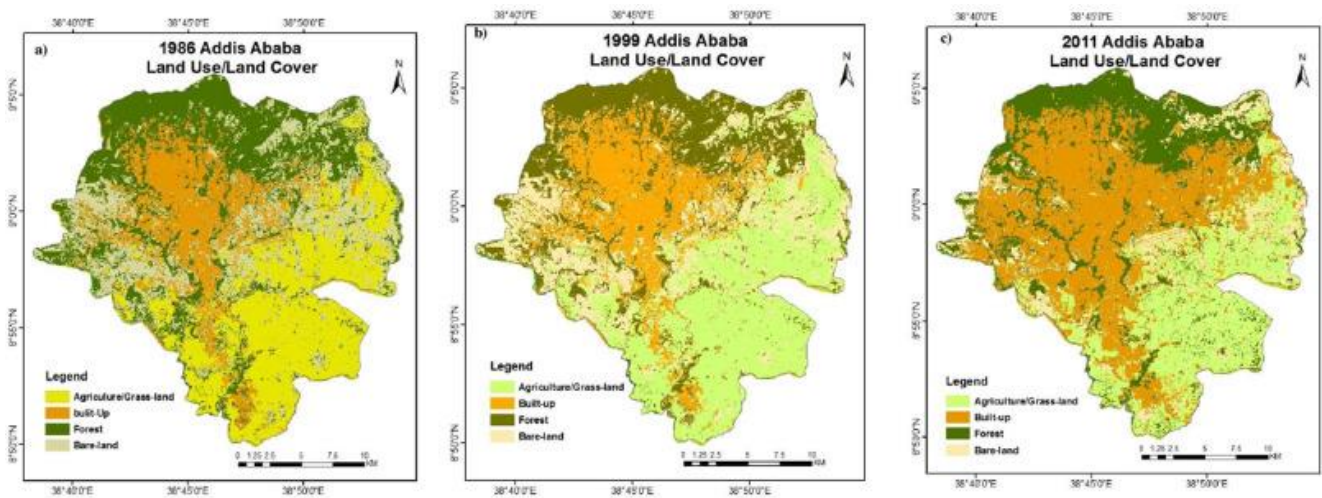


Fig-3.3 Land cover of Addis Ababa in 1986, 1999, and 2011 Source: Tamiru et al, (2005).

3.3 Drainage

The region is also characterized by permanent and perennial rivers (Akalu et al 2011). On the tops of the hills and ridges, streams are dense and form radial drainage patterns, whereas on the lowest part they form a dendritic pattern (Abiye et al,2009). The major perennial rivers of Addis Ababa are 'Kebena', Little 'Akaki', Big 'Akaki', 'Kotebe', 'Ginfile', 'Kechene', and 'Kera' (Fig-3.4). There are also several intermittent rivers in the area.

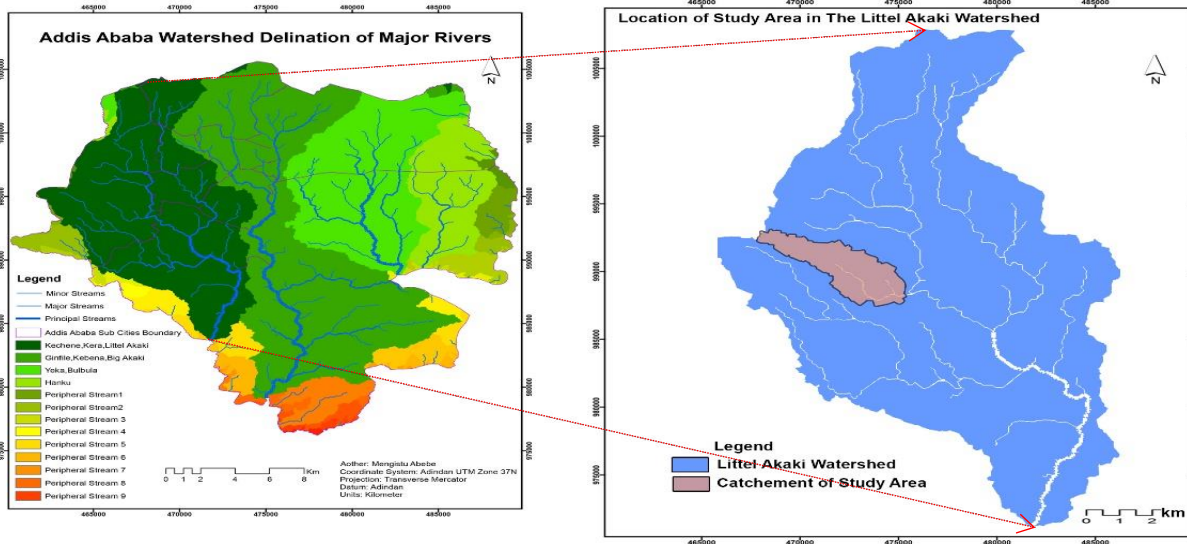


Fig-3.4 Drainage Map of Addis Ababa and the Case Area

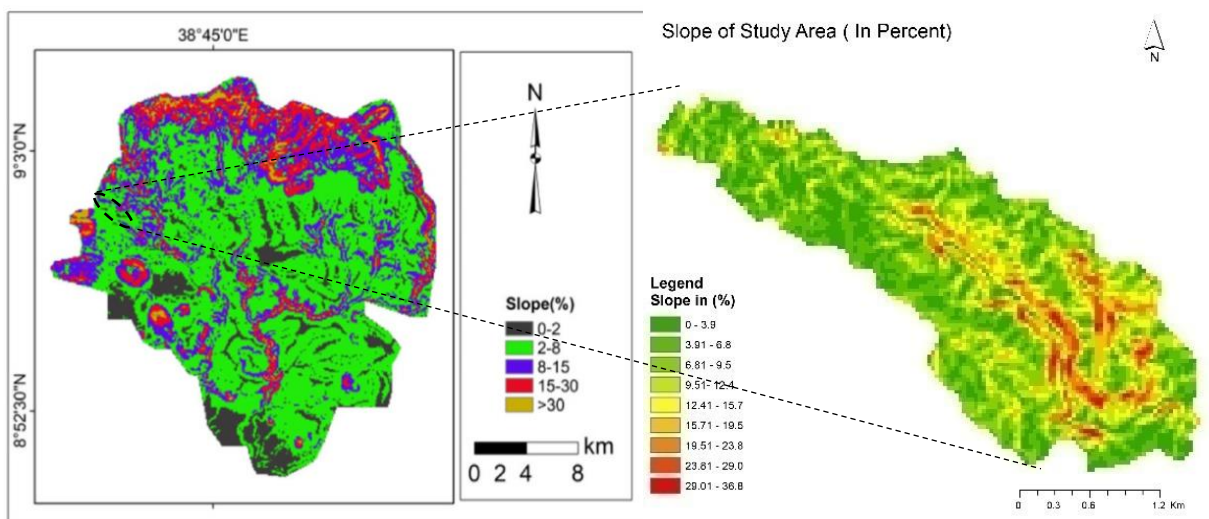


Fig-3.5 Slope Map of Addis Ababa and the Case Area

3.4 Watershed delineation and Selection, Estimation, and Analysis method

3.4.1 Watershed Delineation, Comparison, and Selection Technique

The researcher applied purposive sampling techniques since, the researcher had chosen a case study area based on well-defined characteristics, to Achieve Representativeness or Comparability. The technique enables the researcher to select a purposeful sampling that represents a broader group of cases as closely as possible. That is why the study had chosen the case area based on land use, exposure to degradation, water quality

Based on the 'Pfafstetter' method, considering 'little Akaki river' in Addis Ababa from its mouth to its source (Fig 3.4) the tributary and the main stem have to be identified. The major stem is considered as the greater catchment area that is interbasin and the tributary is the smaller catchment area which is known as a basin. To identify the major stem and the tributary the study applies the 'Pfafstetter' rule. Basin is the area drained by a tributary, whereas interbasin is the area directly drained by the extent of the main stem between the two tributaries. Odd digits are assigned to interbasin and even digits for basins from downstream to upstream. (Fig-3.4) for internal subdivision of five values (1, 3, 5, 7, 9) are for interbasin and four values (2,4,6,8) for basins in the subdivision of the little 'Akaki' river 'Interbasin9 of the parent little 'Akaki' watershed is further subdivided into basins 92, 94, 96, and 98, of interbasin9 and interbasin 91, 93, 95, 97, and 99 of interbasin9. (Fig-3.6). Since interbasin 9 is upstream of the parent watershed, the study area focused specifically on **basin 92** due to the high built-up area in the upstream (Locally known as 'Kaba' river watershed)(Fig-3.6a,3.6b and Table 3.1)

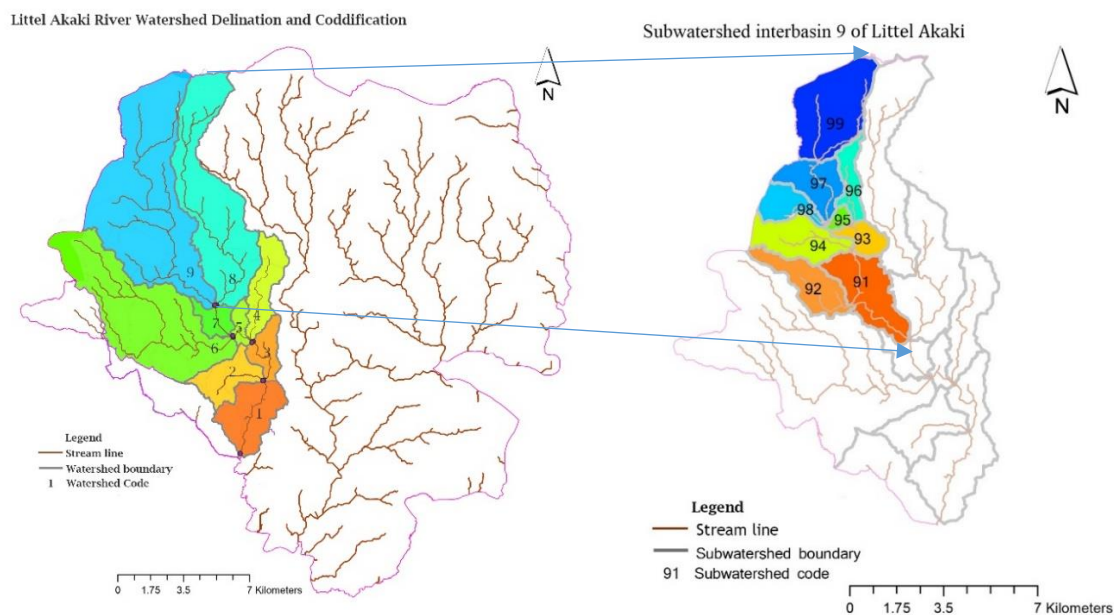


Fig-3.6a Little Akaki Watershed Delineation and Codification

Table-3.1 Built-up Area comparison of Watersheds of Major Tributaries of Little Akaki in the Upstream of interbasin 9

	Catchment area 97&99	Catchment area 94	Catchment area 98	Catchment area 92
Total Catchment (m ²)	13,972,770	6,230,490	3,340,768	5,760,000
Building foot print (m ²)	2,107,688	741,827	118,979	1,334,248.86
% of built up	15.1	12	3.5	23.2

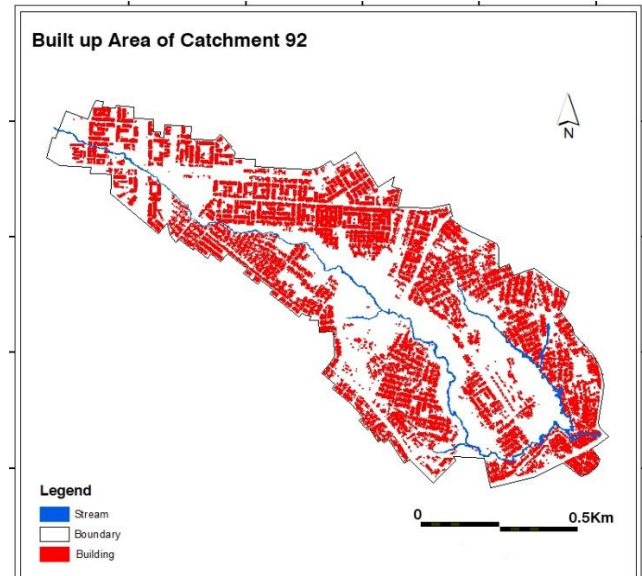
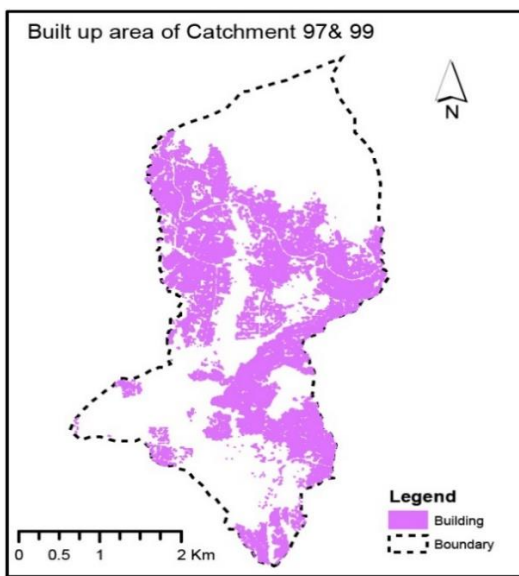
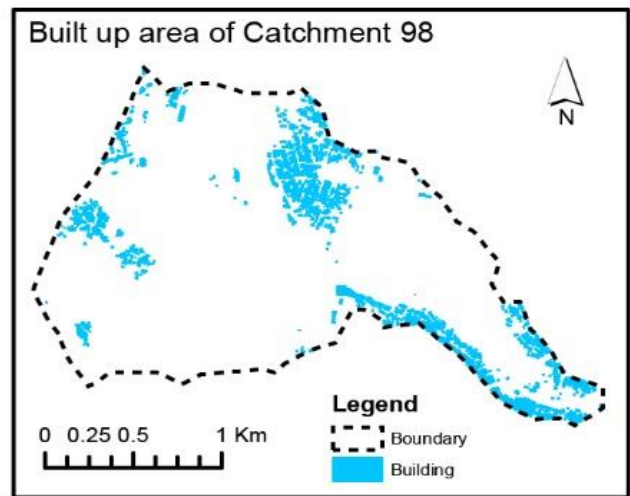
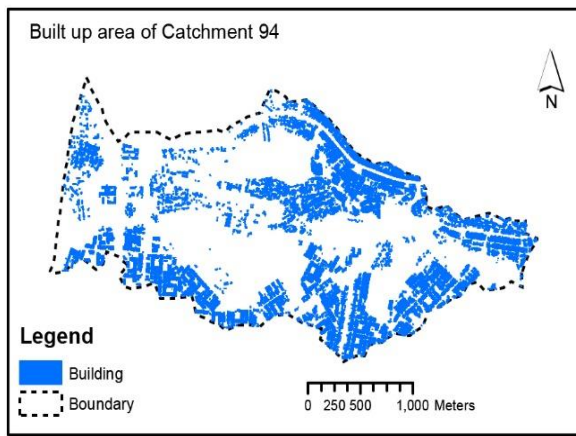


Fig-3.6b Watersheds of major tributaries of Little Akaki in the Upercatchment

For this study, the case area of around 576ha is selected in the ‘Kolfe-keranio’ Sub-city which is one of the peripheral sub-city of Addis Ababa. the study area is densely populated relative to other upstream catchments based on the comparison (Table 3.1). Informal settlements, woodlands, and vacant lands are observed in the riparian area.

3.4.2 Estimation Techniques

Delineation of imperviousness requires a credible method. The existing tools for estimating impervious areas are identical to the traditional land cover mapping (Miltner 1997). The study includes the following: Aerial photogrammetry; Existing maps or digital data; or

satellite remote sensing. The methods and their applications for measuring imperviousness are described below.

Aerial Interpretation is applied for mapping city-level areas to acquire land cover data from aerial photography, it is the most precise technique (Stocker, J. 1998, Hammer 1972). This method can remove most of the camera lens distortion, radial optics, and terrain of the ground (Stocker, J. 1998). Buildings, streets, and sidewalks are defined in CAD format based on map scale and finally impervious data can be estimated. Maps define natural features of streets and pavement in addition to footprints of buildings. To calculate and summarize area, closed polygons features are needed in GIS tools.

Existing digital information is applied to create data set and few data are detailed for impervious data in a CAD format that could be able to identify land cover and impervious surface.

Satellite interpretation of satellite imagery for the study area is also applied. There are some limitations to these data sets. The capture size on the selected satellite limits spatial results. Recent Landsat thematic Mapper imagery is limited to a pixel size of 30 meters which is too large for detailing houses or local roads (Miltner 1997 and Yoder et al. 1999). Satellite imagery is converted to different classes of land cover maps using computer analysis (Stocker, J. 1998). Impervious value in most studies is estimated using residential and urban structures. Summary of the proportion of impervious areas in the local watershed provided by this method. The results are very general.

Rational method for runoff volume estimation

The rational method is used for storm peak runoff estimation of less than 50 hectares (0.5 square kilometers) (Steven et al. 2009, ERA Drainage Design Manual – 2002). This method is applied in this study for block-level runoff volume estimation.

The rational formula is defined as:

$$Q = 0.00278 CIA \dots\dots\dots(1)$$

Where: Q = maximum rate of runoff, m³/s

C = runoff coefficient representing a ratio of runoff to rainfall (Annex 7)

I = Average rainfall intensity for a duration equal to the time of concentration, for a Selected return period, mm/hr,

A= Catchment area tributary to the design location,

SCS unit hydrograph method for runoff volume estimation

This method is established by the U. S. Natural Resources Conservation Service (NRCS) previously recognized as Soil Conservation Service (SCS) for calculating rates of runoff that require the same basic data as the Rational method: catchment area, a runoff factor, time of concentration, and rainfall (Steven et al. 2009, ERA Drainage Design Manual – 2002). Also the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that reduce the passage of a storm (Steven et al. 2009, ERA Drainage Design Manual – 2002). This method is used for storm peak runoff estimation of greater than 50 hectares (0.5 square kilometers) for the watershed scale of the study area. Direct runoff from 24-hour or 1-day storm rainfall can be calculated using the SCS equation.

$$Q = (P - I_a)^2 / (P + I_a) + S \dots \dots \dots (2)$$

Where: Q = accumulated direct runoff, mm.

P = accumulated rainfall (potential maximum runoff), mm.

I_a = Initial abstraction including surface storage, interception, and infiltration prior to runoff, mm.

S = Potential maximum retention, mm.

$$I_a = 0.2S \dots \dots \dots (3)$$

Substituting 0.2S for I_a in equation (2), the SCS rainfall-runoff equation becomes:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \dots \dots \dots (4)$$

S is related to the soil and cover conditions of the catchment area through the CN.

$$S = 1000 / CN - 10 \dots \dots \dots (5)$$

Where CN is a runoff curve number, which theoretically varies from 0 to 100 and is somewhat analogous to the runoff coefficient C in the Rational formula. Annex 1-4 and Annex 7 lists runoff CNs for different urban and natural land uses.

3.4.3 Data analysis method and interpretation for each specific objective

From the above estimation technique, satellite Interpretation is applied for the specific objective 1 to identify city level total imperviousness (Table 3.7). Satellite Interpretation, aerial Interpretation, and existing digital Information are credible techniques for delineating and comparing the built-up area of local watersheds of major streams and rivers that are affected by a high level of imperviousness (section 3.4.1).

Aerial Interpretation and existing digital Information such as land-use data using GIS tools, AutoCAD, Archicad, and Revit Architecture are the appropriate tools and techniques to develop nature-based design measures as green infrastructure for affected watersheds of Addis Ababa in the case of 'Kaba' watershed.

Both quantitative and qualitative techniques were used to analyze the data. Estimating city-level imperviousness and local watersheds requires intensive data and computational efforts using GIS tools, and Excel. Tables and percentages are the main techniques for analyzing.

Table-3.2 Methodology

Purpose	Source of data	Collection methods	Instrument used	Result
To map out and measure the impervious area of Addis Ababa	Land use from digitized data and Satellite imagery	Measure, ground surveying,	GIS tools, GPS, meter, total station, and camera	To identify the % of imperviousness
To Delineate and compare local watersheds of major streams to identify more affected by imperviousness	Land use/land cover, Satellite imagery	GIS-derived land-use intensity maps	GIS tools	To identify the watershed area of major streams and the higher built-up area
To develop nature base retrofitting measures and planning to rivers.	Land use and the ratio of estimated imperviousness	To develop a nature-based design solution	GIS tools, Excel AutoCAD, Archicad, and Revit Architecture	To come up with a sustainable solution for stream health

3.4.4 Research Design

The method to estimate imperviousness, in the watershed can be achieved through Integrating GIS, and Aerial photos. Satellite images have a great contribution to the preparation of impervious areas. Land use and land cover information are of critical importance to classify image object into different classes, as it helps determine impervious area directly connected to the stream (Fig-3.7).

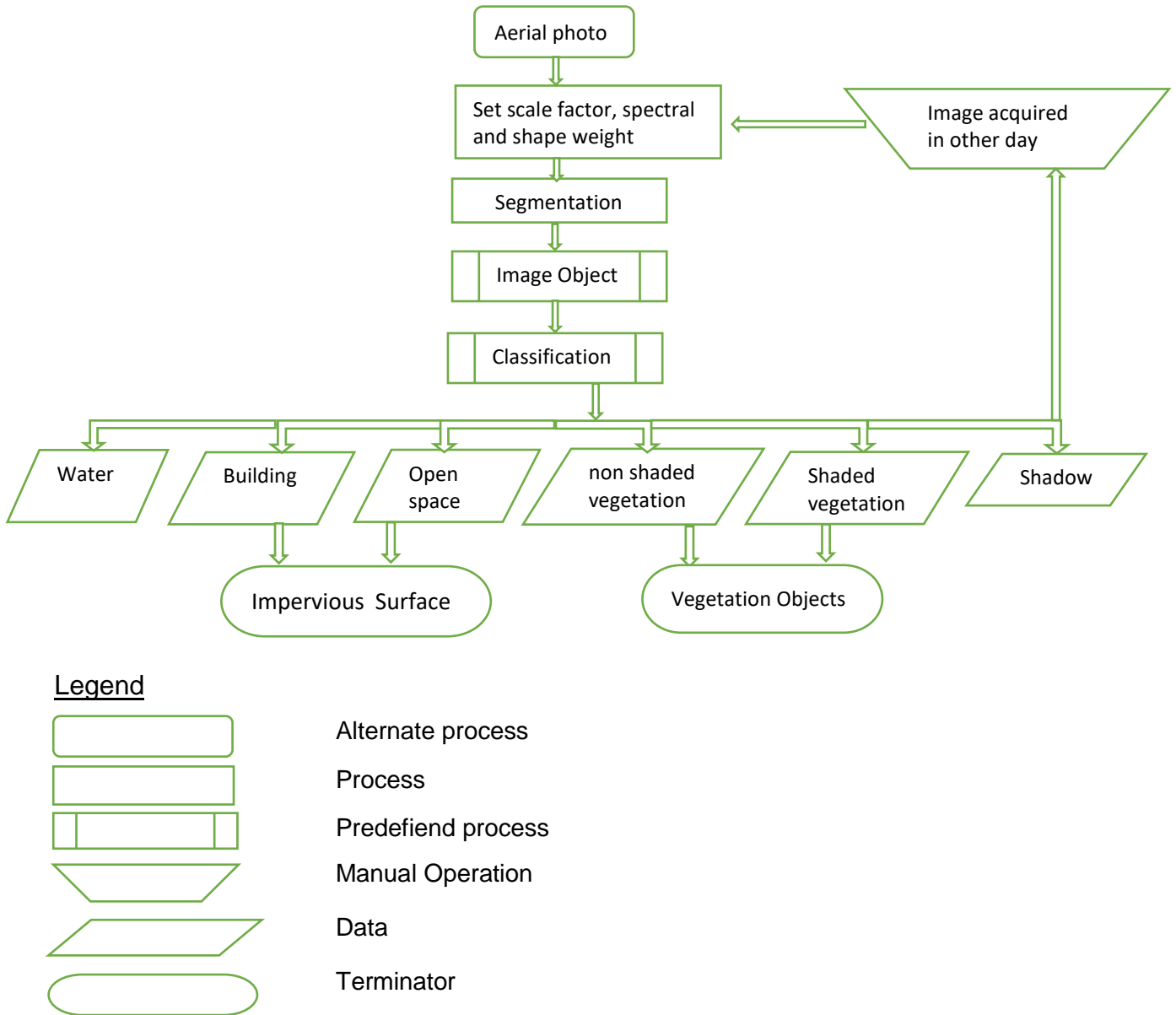


Figure 3.7 Research design and procedure

CHAPTER FOUR

RESULT

Satellite image interpretation and ARC-GIS tools are used to extract impervious areas or built-up (road, car parking, walkways, and rooftops), forest, agriculture, and open land of Addis Ababa city in general. On the other hand, the ARC-GIS tool is also used to delineate the watershed of the study area in the little 'Akaki' catchment for detailed study (road material and road cover, forest cover, grass cover, streams, and building footprints) and helps to obtain physical parameters and spatial information of the little Akaki catchment. Road networks, houses, and buildings, as well as vegetation cover of study area catchment, are digitized and corresponding areas are going to be calculated.

4.1 Total Impervious Area of Addis Ababa

The total impervious surface has a significant contribution to stream health degradation even it has not more contribution as an effective impervious surface. The total impervious area is generally categorized as a built-up area. (Fig-4.1a,b and Table 4.1).

Table 4.1 Area of land use cover of Addis Ababa

Type	Area(m ²)
Forest/Grass Land	114,939,312
Built Up	268,177,920
Open Land	120,156,296
Agriculture	16,285,829

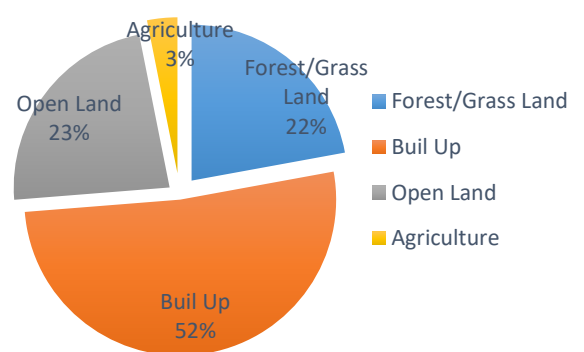


Fig-4.1a Area proportion of land use cover of Addis Ababa

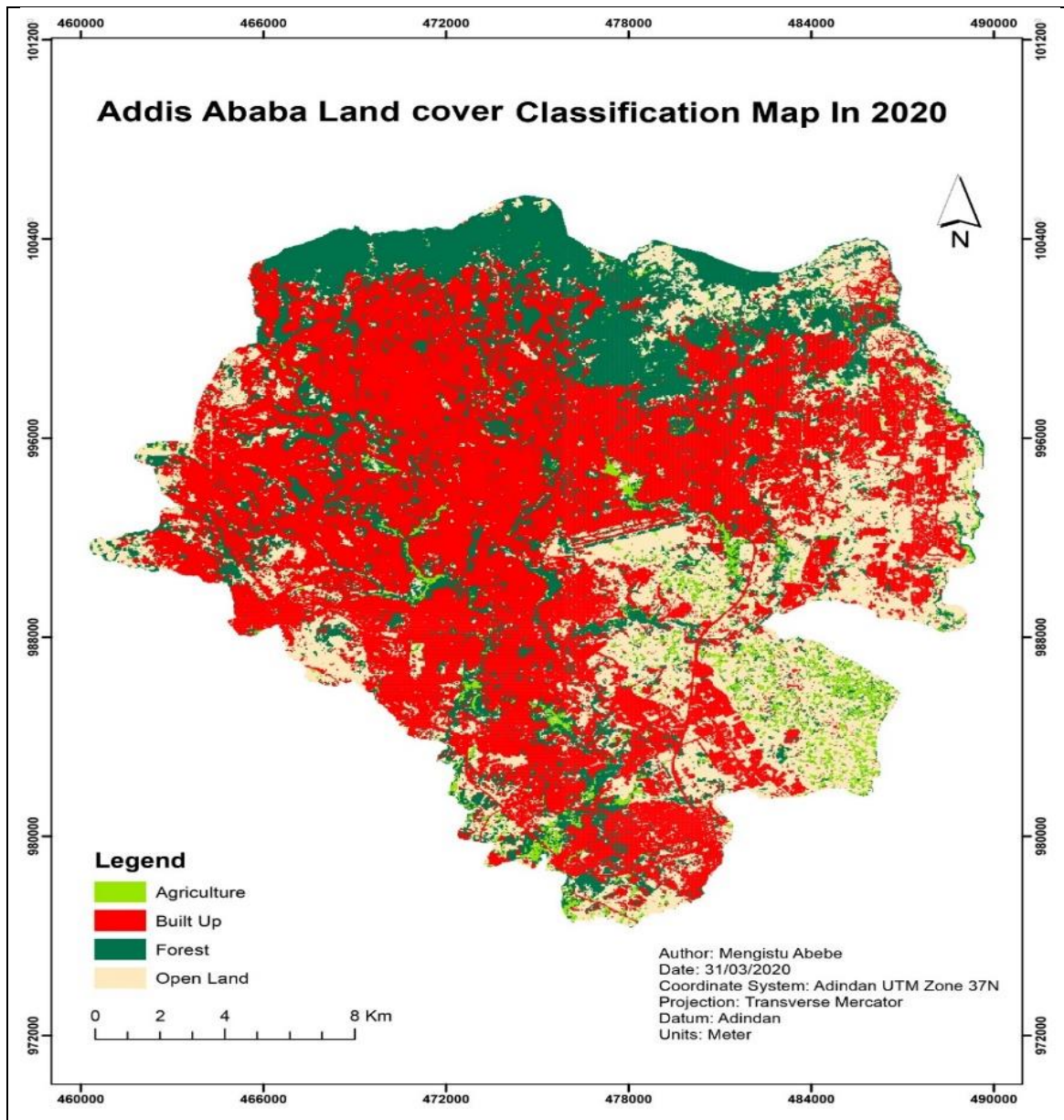


Fig-4.1b Land-cover classification of Addis Ababa in 2020

Based on the above figure and table the total impervious area of Addis Ababa is 268,177,920 sq. meter. That implies more than 50% of the total as described in (Table 4.1). A high level of imperviousness has a direct relation to the highly degraded stream health of the city based on Arnold and Gibbons (1996). The result also shows among the four categories of urban streams related to the level of impervious cover defined by the Center for Watershed Protection (CWP 2003), the stream of the study area is categorized under non-supporting. Total imperviousness or ineffective impervious surface includes all non-infiltrating surfaces that will infiltrate all or a portion of the stormwater, depending on ground cover, slope, and soil characteristics but it does not mean equally degrade the

stream as an effective impervious surface that is directly connected to the stream network and contribute more on stream health degradation (see section 2.1).

4.2 'Kaba' River Watershed

The stream of the case area is locally known as 'Kaba' river which is one of the major tributaries of the little 'Akaki' river. Delineating a local watershed that is affected by a high level of imperviousness is one of the specific objectives. The method of delineating the local watershed is based on the 'Pfafstetter' method, considering the little 'Akaki' river of Addis Ababa from its mouth to its source (Fig 3.6) by distinguishing the main stem and the tributary.

(See chapter 3)

4.3 Existing and Structure Plan Proposal of Road Network of Study Area

All existing and proposed roads of structure plan in the study area are classified according to road width and material (asphalt, coble stone, compacted soil, and greenery) Fig-4.2

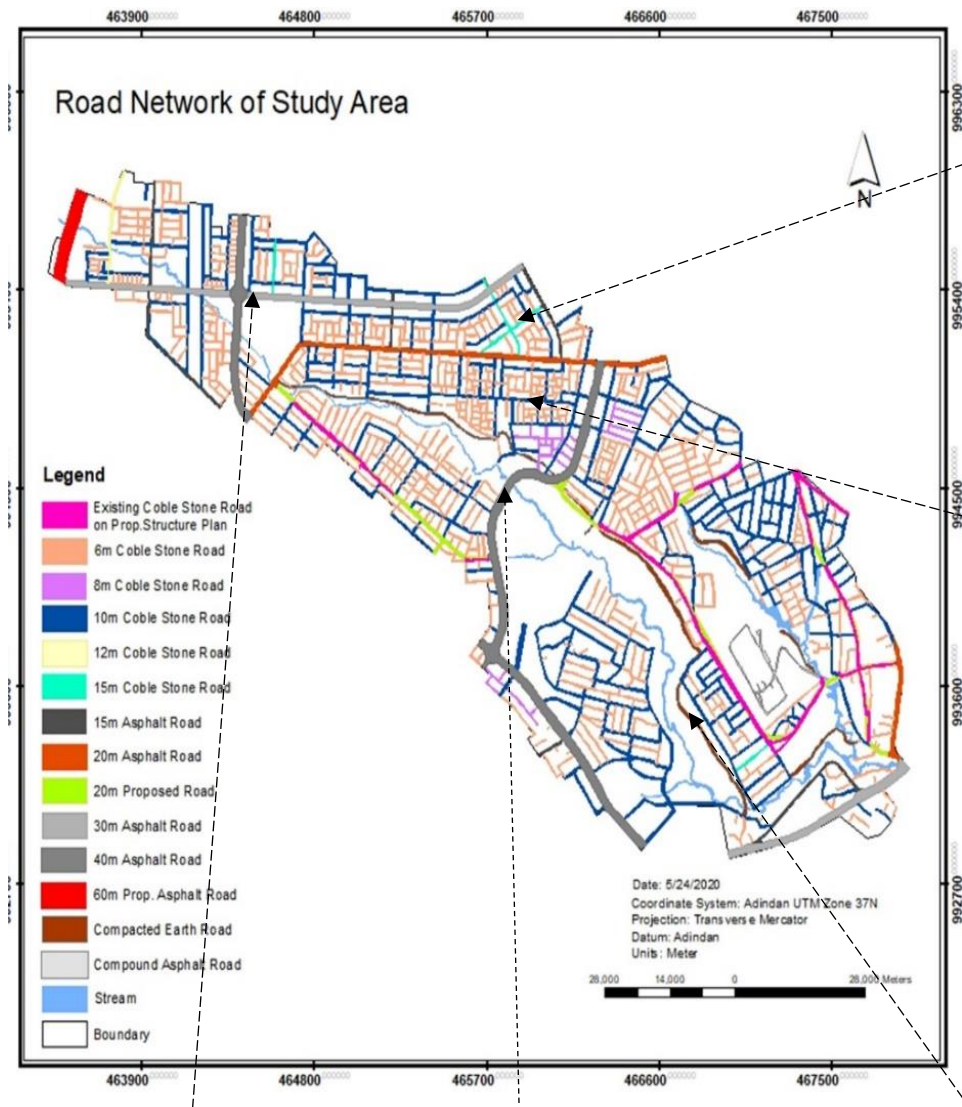


Fig 4.2a 15m asphalt road with side walkway paved with tile



Fig 4.2b Typical 8m Coble stone road with sewerage line



Fig 4.2c Typical 30m asphalt road with side walkway paved with tile and greenery at the median



Fig 4.2d Typical 40m asphalt road with side walkway paved with Coble stone and greenery at the median



Fig 4.2e Typical Compacted soil road

Fig-4.2 Existing and structure plan proposed road network of case area based on the road width.

Table-4.2 Types of road and area coverage on the study area

ROW			Walkway			Median			%	Remark	
Width (m)	Material	Area(m ²)	Width (m)	Material	Area(m ²)	Width (m)	Material	Area(m ²)			
6	Coble Stone	397,002.5	-	-	-	-	-	-	28.3		
8	Coble Stone	19,749.27	-	-	-	-	-	-	1.42	-	
10	Coble Stone	449,884.5	-	-	-	-	-	-	32.6	-	
15	Coble Stone	17173.87	5	Coble Stone	5,667.37	-	-	-	1.24	-	
15	Asphalt	42216.93	5	Coble Stone/ Cement tile	13,931.6	-	-	-	3.04	-	
20	Asphalt	57,854.41	5	Cement tile (20*10)c m	14,463.6	-	-	-	4.16	-	
20	Asphalt	128,488.7	5	Cement tile	32,122.2	-	-	-	-	Proposed on St. Plan	
30	Asphalt	109,267.2	6	Cement tile (30*30)c m	21,853.4	2	Grass/ Tree	7,284.5	7.86	-	
40	Asphalt	162,658.9	10	Coble Stone	40,664.7	10	Grass/ Tree	40,664.7	11.7	-	
60	Asphalt	25,308.93	10	Coble Stone	4,218.15	11	Grass/ Tree	4,639.97	-	Proposed on St. Plan	
vary	Asphalt	10,282.85	-	-	-	-	-	-	0.74	Compound Road	
vary	Compacted Soil	58,897.52	-	-	-	-	-	-	4.24	Around Stream buffer	
vary	Coble Stone	42,147.19	-	-	-	-	-	-	3.03	20m Asphalt Road is Proposed on St. Plan to revise it.	
vary	Asphalt	23,374	-	-	-	-	-	-	1.68		
Existing Total		1,390,509							100		

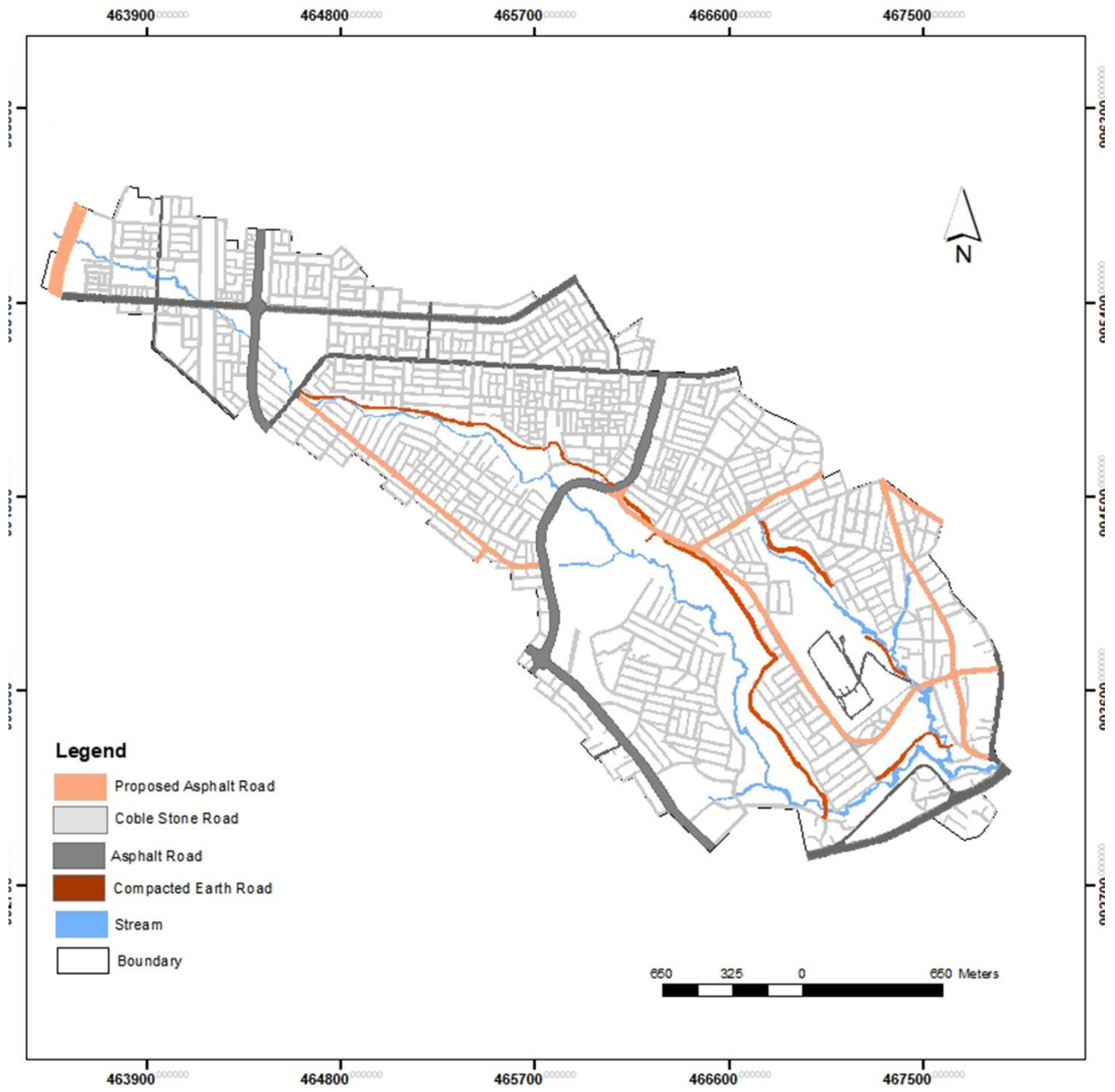


Fig-4.3a Existing and proposed road network of case area based on road material

4.3.1 Road area summery

The existing road is constructed from asphalt, coble stone, gravel, and soil. The main roads (CS, SAS, and PAS) are made of Asphalt. 71%, of the total which is more than 50% of the road is paved with cobblestone. So, this implies that it has its contribution to reducing runoff (Table 4.3, 4.4 and Fig-4.1a, 4.2)

Table-4.3 Total area of existing road materials

Material	Area (m ²)
Asphalt	266,991.77
Compacted soil	58,897.52
Coble Stone	980,553.54
Cement Tile	36,317.04
Greenery	47,949.21
Total	1,390,709.08

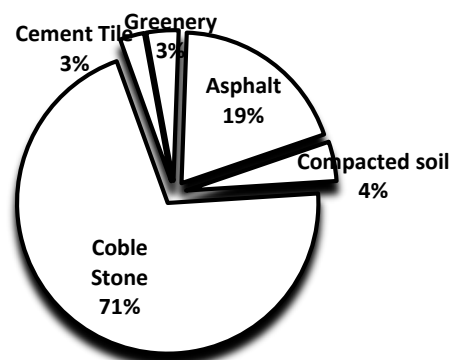


Fig-

4.3b Area proportion of road materials

The area proportion of asphalt road on the proposed structure plan increases by 4%, as a result, the area proportion of coble stone in the proposed road network is less than the existing by 4%, which implies it contributes less in reducing runoff. (Table 4.4. and Fig 4.3c)

Table-4.4 Total area of existing and proposed road materials.

Material	Area (m ²)
Asphalt	337,635.18
Compacted soil	58,897.52
Coble Stone	993,519.86
Cement Tile	36,317.04
Greenery	52,589.18
Total	1,478,958.78

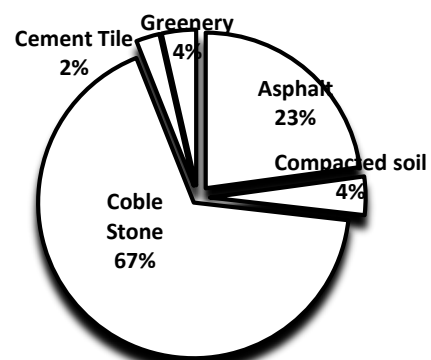


Fig-4.3c Area proportion of existing and proposed road materials

4.3.2 Runoff volume and (EIA) estimation for the study area's existing road based on the (SCS) method.

Peak runoff volume varied among different road materials (Tables 4.5, 4.6). Around 33.26% of the total peak runoff volume is generated from only 19% of the total road area covered by asphalt that contributes higher than its area proportion. On contrary to that greenery which covers 4% of the total road area contributes only 0.4% of the total runoff volume that implies it generates less than its area proportion. Although 59% of total peak runoff is generated from coble stone road, it contributes less than its area proportion (71%). As a result percentage of (EIA) can be reduced.

Table 4.5: Existing total runoff volume and percentage of imperviousness estimated for all road cover of the watershed excluding the proposed asphalt road on the structure plan.

Street and Road	³ CN _B (83%)	⁴ CN _D (17%)	² CN _{wt}	Area(m ²)	24hr Peak Runoff Depth Q(mm)		24hr Peak Runoff Volume q(m ³)			% EIA	
					Q _{25y}	Q _{5y}	Q _{2y}	Q _{25 years}	Q _{5 years}		Q _{2 years}
Asphalt	98	98	98	266,991.8	94	61	45.7	25,097.2	16,286	12,201.53	50.7¹
Coble	85	91	86.02	980,553.5	60	34	22	58,833.2	33,339	21,572.18	
Soil	82	91	83.53	58,897.5	54	29	19	3,180.5	1,708	1,119.05	
Cement tile	98	98	98.00	36,317	94	61	45.7	3,413.8	2,215	1,659.69	
Greenery	61	80	64.23	52,589.2	25	7.6	2.54	1,198.7	400	133.58	
Total				1,390,709				91,723.4	53,948.4	36,686.0	

4.3.3 Runoff volume and (EIA) estimation of existing and proposed road on structure plan based on (SCS) method.

Table 4.6: Existing total runoff volume and percentage of imperviousness estimated for all road cover of the watershed including the proposed asphalt road on the structure plan.

Street and Road	³ CN _B (83%)	⁴ CN _D (17%)	² CN _{wt}	Area(m ²)	24hr Peak Runoff Depth Q(mm)		24hr Peak Runoff Volume q(m ³)			% EIA	
					Q _{25y}	Q _{5y}	Q _{2y}	Q _{25 years}	Q _{5years}		Q _{2 years}
Asphalt	98	98	98	337,635.2	94	61	45.7	31,737.7	20,595	15,429.9	52.3¹
Coble	85	91	86.02	993,519.9	60	34	22	59,611.2	33,779.7	21,857.4	
Soil	82	91	83.53	58,897.5	54	29	19	3,180.5	1,708	1,119.1	
Cement tile	98	98	98.00	36,317	94	61	45.7	3,413.8	2,215.3	1,659.7	
Greenery	61	80	64.23	52,589.2	25	7.6	2.54	1,314.7	399.7	133.6	
Total				1,478,958.8				99,257.9	58,698.5	40,199.7	

Note:

1. Runoff curve number (CN), 2 years of 24hours peak runoff depth (Q), and 2 years of 24hours peak rainfall (P) for the effective impervious area (EIA) is =100,52mm,52mm respectively.
2. CN_{wt} = Weighted curve number.
3. CN_B= Curve number of hydrologic soil group B
4. CN_D= Curve number of hydrologic soil group D

4.4 Existing Land use

Based on the on-site investigation, existing maps or digital data, and GIS tools, existing building footprint, and existing land use maps are developed to identify the total built-up area of all land uses of the study area. In figure 4.4 and Figure 4.5a, the area proportion is also described in table 4.7 and Fig-4.3c.

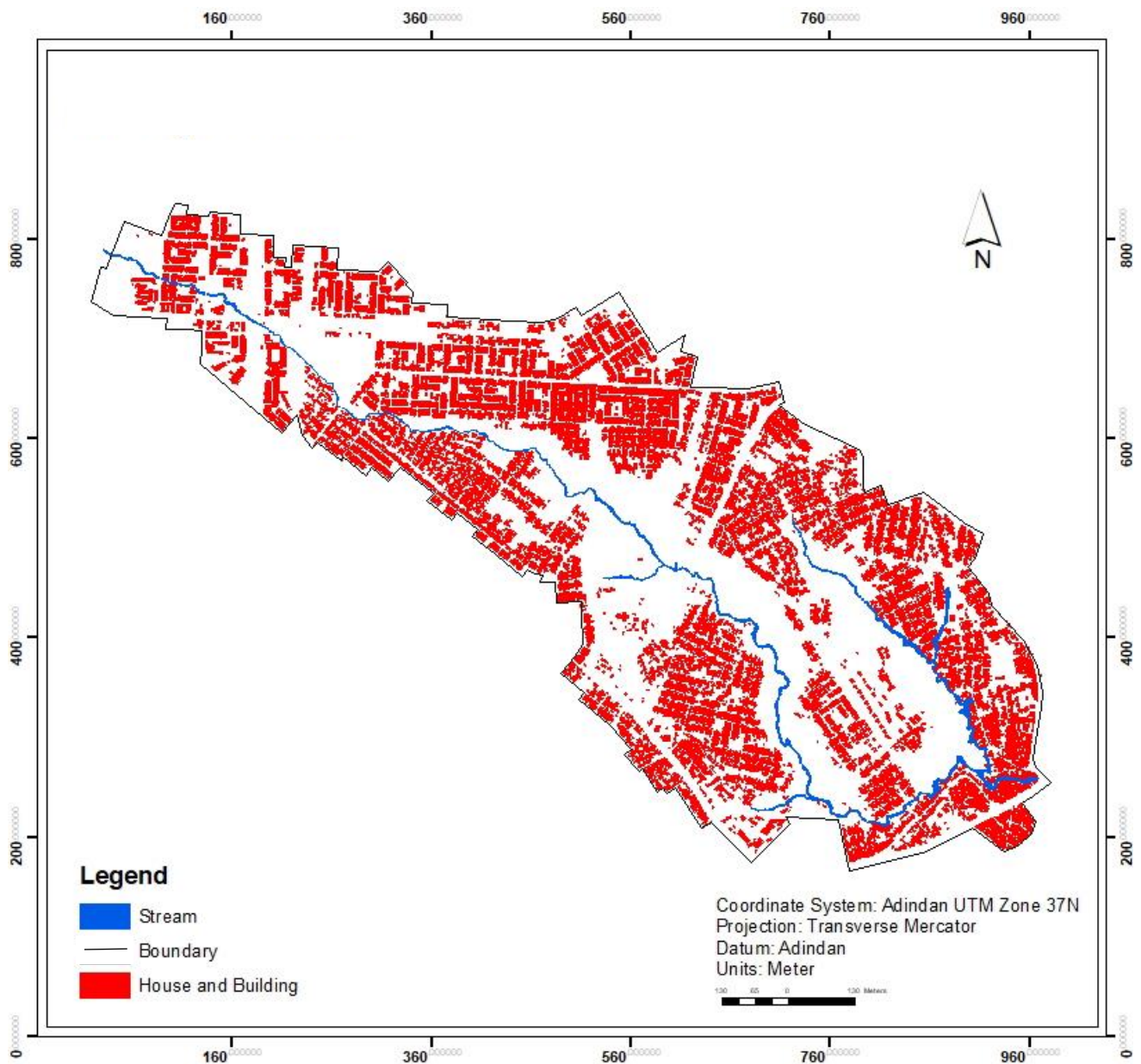


Fig-4.4 Existing impervious surface (buildings) of case area

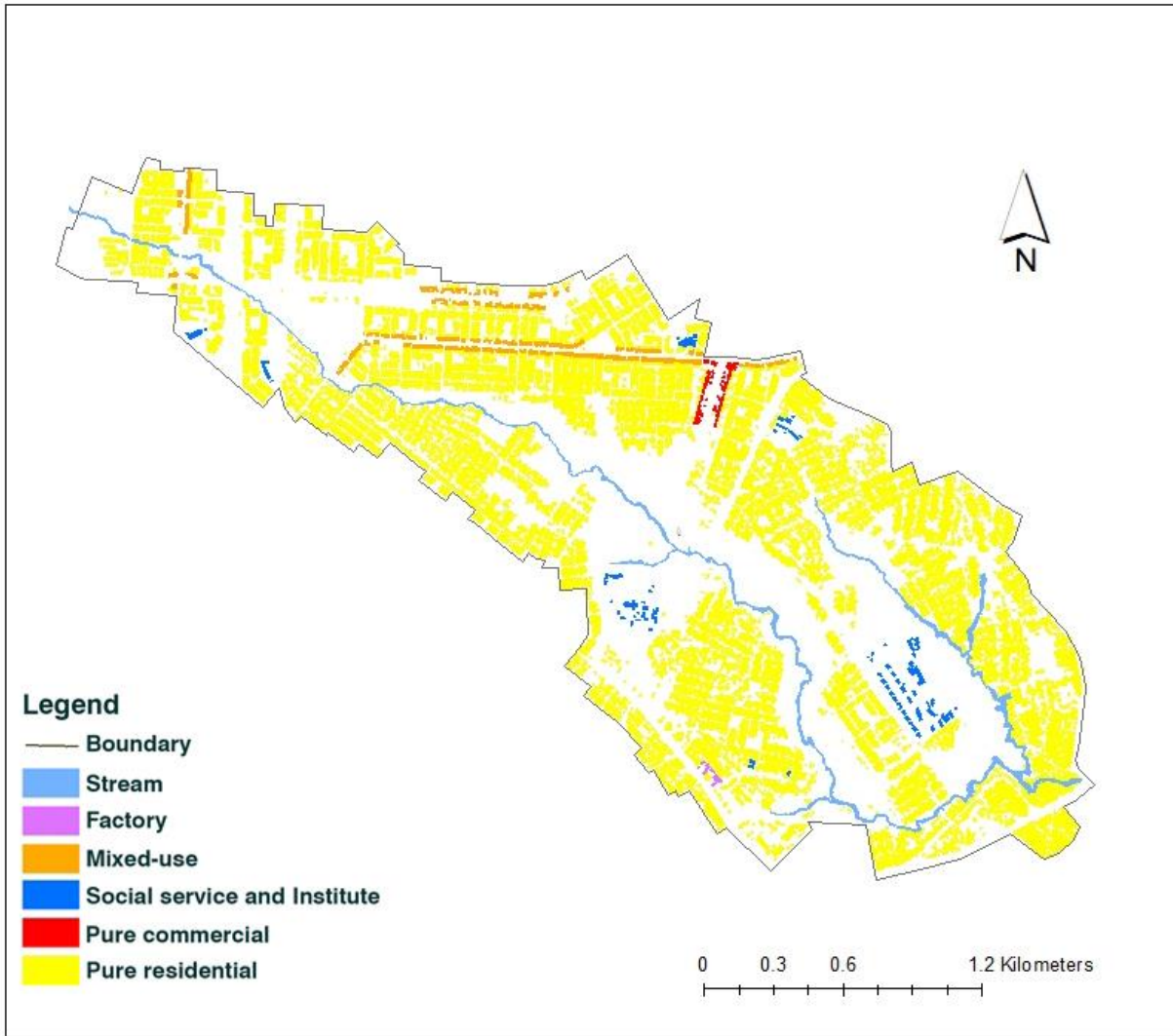


Fig-4.5a Existing land use of case area

Table-4.7 Total area of built-up land use classification

Function	Area(m ²)	Unit
Social service	18,372.38	155
Residence	1,272,943.22	30,736
Commerce	5,877.42	68
Mixeduse	35,584.02	741
Factory	1,471.82	18
Total	1,334,248.86	

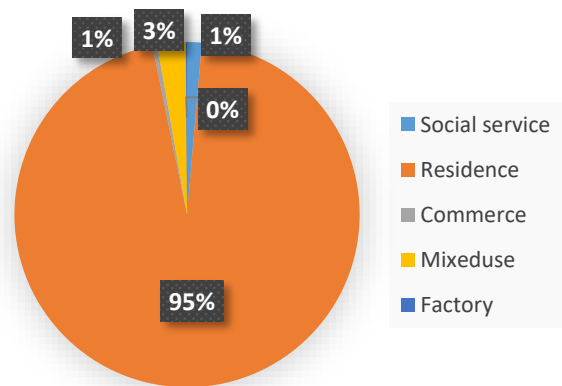


Fig-4.5b Proportion of land use

4.4.1 Existing land use runoff volume and (EIA) estimation for the study areas based on (SCS) method.

The percentage of imperviousness and runoff volume varied among different land uses (Tables 4.8). Unlike industry districts, social service and institute are the richest of the pervious cover (woodland and green cover) in proportion to its total area. Industry district has the highest level of imperviousness (47.95%) and contributes the highest runoff volume proportion (0.025m³/m²), whereas social service and institute have the lowest level of imperviousness (16.9%) and contributes lowest runoff volume proportion (0.01m³/m²).

Table-4.8: Existing total runoff volume and percentage of imperviousness estimated for all land-use of the watershed.

Land use	CN _B (83%)	CN _D (17%)	CN _{wt}	Per Ave.plot Area(m ²)	Total area(m ²)	24hr.Peak Runoff Depth Q(mm)in a plot		24hr. Peak Runoff Volume(m ³)			%EIA	
						Q _{25y}	Q _{5y}	Q _{2y}	q _{25y} total	q _{5y} total		q _{2y} total
Residential District												
Wood	60	79	63.23	35.6	387,601.7	24	7.11	2.03	9,302.44	2,755.8	786.8	
Greenery	61	80	64.23	45.8	499,248.4	25	7.6	2.54	2,481.2	3,794.3	1,268.1	
Con.tile	98	98	98.00	52	566,519.9	94	61	45.7	53,252.9	34,557.7	25,890.0	
Built-up	85	92	86.19	116.8	1,272,925.3	60	34	22	76,375.5	43,279.5	28,004.4	
Total				250	2,726,295.2				151,412	84,387.3	55,949.2	39.46
Industry District												
Greenery	61	80	64.23	411.3	822.7	25	7.6	2.54	20.6	6.3	2.1	
Asphalt	98	98	98.00	779.6	1,559.2	94	61	45.7	146.6	95.1	71.3	
Wood	60	79	63.23	318.9	637.8	24	7.11	2.03	15.3	4.5	1.3	
Built-up	88	93	88.85	735.9	1,471.8	68	38.1	25.4	100.08	56.1	37.4	
Total				2245.8	4,491.50				282.5	162.0	112.0	47.95
Commercial District												
Con.tile	98	98	98.00	150.3	5,410.8	94	61	45.7	508.6	330.1	247.3	
Greenery	61	80	64.23	57.2	2,059.2	25	7.6	2.54	51.5	15.6	5.2	
Wood	60	79	63.23	133.6	4,808.5	24	7.11	2.03	115.4	34.2	9.8	
Built-up	92	95	92.51	163.2	5,877.4	72	45.7	31.8	423.2	268.7	186.6	
Bare land			86.93	88.96	3,202.56	60	35.6	21.1	192.15	113.9	67.5	
Total				593.29	21,358.46				1,290.8	762.5	516.4	46.49
Mixed-use												
Con.tile	98	98	98.00	13.5	4,249.4	94	61	45.7	399.4	259.2	194.2	
Greenery	61	80	64.23	28	8,832.6	25	7.6	2.54	220.8	67.1	22.4	
Wood	60	79	63.23	53.8	16,940.7	24	7.11	2.03	406.6	120.4	34.4	
Built-up	92	95	92.56	113	35,585.6	72	45.7	31.8	2,562.2	1,627	1,129.8	
Total				208.28	65,608.2				3,589	2,073.8	1,380.9	40.47

Social Service and Inst.

Con.tile	98	98	98.00	1480.5	11,844.0	94	61	45.7	1,113.3	722.5	541.3	
Greenery	61	80	64.23	9,942.7	79,541.6	25	7.6	2.54	1,988.5	604.5	202.0	
Wood	60	79	63.23	12,791	102,325.4	24	7.11	2.03	2,455.8	727.5	207.7	
Bare land			86.93	4,421.5	35,372.0	60	35.6	21.1	2,122.3	1,257.8	745.6	
Asphalt	98	98	98.00	1,285.4	10,282.9	94	61	45.7	966.6	627.3	469.9	
Built-up	65	82	67.89	2,296.6	18,372.4	23	10.2	5.1	1,727	186.7	93.3	
Total				32,217.3	257,738.3				10,373.6	4,126.3	2,259.93	16.86

Others

Greenery	61	80	64.23	209.6	2,515.2	25	7.6	2.54	62.9	19.1	6.4	
Bare land			86.93	2176.4	26,116.2	60	35.6	21.1	1,567	928.7	550.5	
Wood	60	79	63.23	269.7	3,236.6	24	7.11	2.03	77.7	23.0	6.6	
Total				2655.7	31,868				1,707.5	970.82	563.49	34

Note: $CN_{EIA}=100$, $P_{25}=95\text{mm}$, $P_5=67$ and $P_2=52\text{mm}$ and the corresponding $q_{25,5\&2}=95,67\&52\text{mm}$ Respectively

4.5 Existing vegetation cover

Vegetation cover map developed and vegetation-covered area of the site estimated based on-site investigation, existing maps or digital data, aerial photogrammetry, and GIS tools. Watershed level, Plot level, and riparian area vegetation cover could be extracted in the study area. According to the map, vegetation cover dominates around the stream buffer. (Figure 4.6a) and (Figure 4.5a), the area proportion is also described in (table 4.9) and (Fig-4.5b). Existing total runoff intensity, runoff volume, and proportion of effective impervious area in the riparian zone are elaborated on (table 4.10-12)

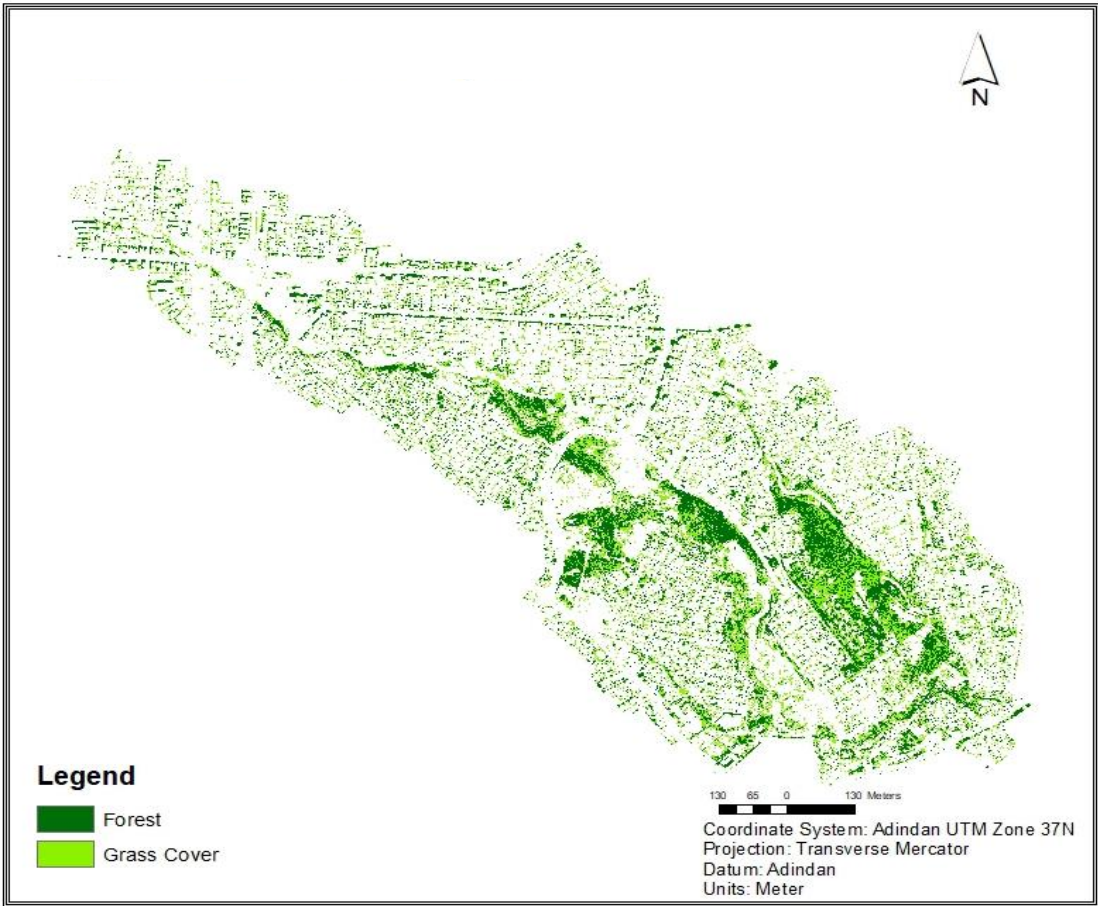
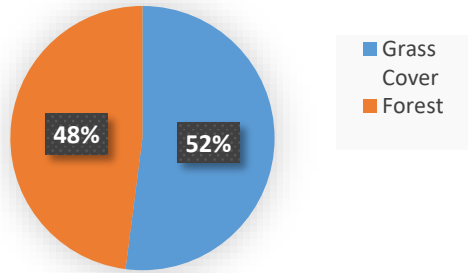


Fig-4.6a Existing vegetation cover of the case area.

Table-4.9 Total area of vegetation cover including land uses

Veg.	Area(m2)
Grass Cover	792,903.21
Forest	730,545.31
Total	1,523,448.52

Fig-4.6b Total area proportion of vegetation cover



4.5.1 Existing riparian zone runoff volume and EIA estimation for the study area's based on the SCS method.

Runoff intensity, percentage of imperviousness, and runoff volume varied among different land covers in the riparian zone (Table 4.10-4.12). The riparian area is the richest of the pervious cover (forest, grass cover, and shrubs) relative to others. It has the relatively lowest level of imperviousness (27.02%) and contributes to the lowest runoff volume proportion (0.014m³/m²).

Table 4.10: Existing total area of forest, stream, grass, and shrubs, bare land, and agriculture of riparian

Location	Total Area (m ²) in the watershed			
	Forest	Grass and Shrubs	Bare land and Agriculture	Stream
Riparian area	214,994.56	199,883.56	695,112.63	69,118.53

Table 4.11: Existing Total Runoff Intensity based on average annual rainfall for Riparian zone

Location	Total Runoff intensity (m ³ /average year) in the Riparian			
	Forest	Grass and Shrubs	Bare land and Agriculture	Total
Riparian area	25,754.20	43,534.64	249,802.63	319,091.46

Table 4.12: Existing total runoff volume and percentage of imperviousness estimated for all riparian of the watershed.

Riparian	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr. Peak Runoff Depth Q(mm)		24hr. Peak Runoff Volume Q(m ³)			%EIA	
					Q _{25y}	Q _{5y}	Q _{2y}	q _{25y} total	q _{5y} total		q _{2y} total
Greenery	61	80	64.23	199,883.56	25	7.6	2.54	4,997.09	1,519.12	507.7	
Bare land			86.93	695,112.63	60	35.6	21.08	41,706.76	24,718.21	14,652.97	
Wood	60	79	63.23	214,994.56	24	7.11	2.03	5,159.87	1,528.61	436.44	
Total				1,109,990.75				51,863.72	27,765.9	15,597.1	27.02

Note: CN_{IA}=100, P₂₅=95mm, P₅=67 and P₂=52mm and the corresponding q_{25,50&100}=95,67&52mm respectively

4.6 Existing land cover classification of case area

Overlay of all land use (buildings) and land cover (road cover, green cover, woodland, and bare land) the map is shown below can be generated using ArcGIS tools (Figure-4.7a).

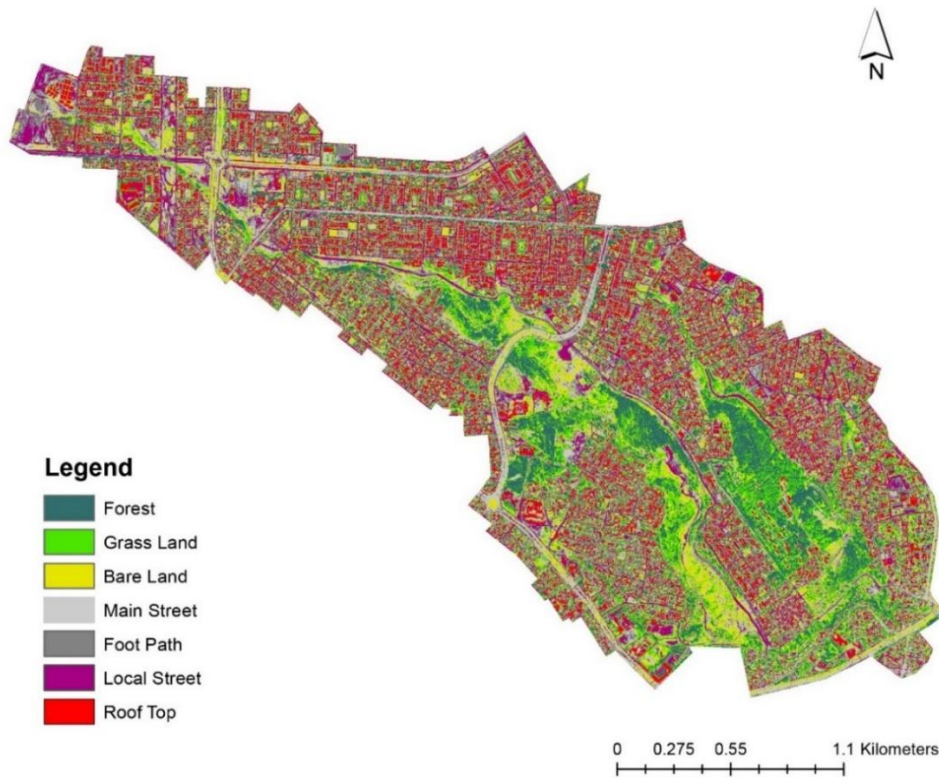


Fig-4.7a Existing land cover classification of case area

Table-4.13 Land cover area

Type	Area(m ²)
Urban land use	3,107,392.94
Road cover	1,478,958.78
Grassland	199,883.56
Forest	214,994.56
Stream	69,118.53
Bare land and Agriculture	695,112.63
Total	5,765,461.00

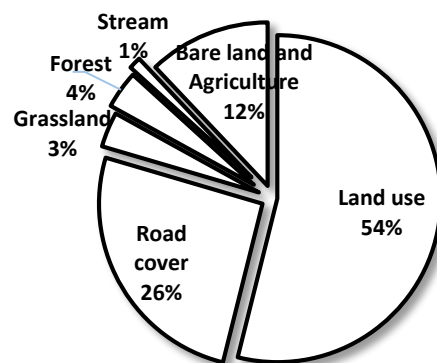


Fig-4.7b Area proportion of land cover

4.6.1 Summary of land cover runoff depth, volume, and percentage of imperviousness for case area

The land cover and land use that contribute to the highest, moderate, and lowest runoff volumes in the watershed are identified in (table 4.14 and 4.15). Residential districts, streets, and roads, riparian zone, social services and institutes, mixed-use, others, commercial districts, and industrial districts contribute watershed level runoff volume from highest to lowest respectively. As is shown on the table the watershed has the highest level of imperviousness (27.8%) using 2 years of the return period of rainfall. In other words, every square meter of the entire watershed contributes 0.014 cubic meters of runoff volume.

Table 4.14: Summary of existing total cumulative runoff volume and percentage of imperviousness estimated for all land cover of the watershed excluding proposed asphalt road on the structure plan.

Land Cover	CN _{wt}	Area(m ²)	24hr.Peak Runoff Depth Q(mm)			24hr.PeakRunoff Volume (m ³)			%EIA
			Q _{25y}	Q _{5y}	Q _{2y}	q _{25y} total	q _{5y} total	q _{2y} total	
Street and Road	79.6	1,390,709.08	45.72	24.13	14.48	63,583.2	33,669.8	20,204.7	27.8
Residential District	79.6	2,726,295.2	45.72	24.13	14.48	124,646	65,811.8	39,492.5	
Commercial District	79.6	18,155.9	45.72	24.13	14.48	830	515.4	309.3	
Mixed-use	79.6	65,608.2	45.72	24.13	14.48	2,999.6	1,583.1	950.0	
Social Service and Inst.	79.6	257,738.3	45.72	24.13	14.48	11,783.8	6,219.2	3,732.1	
Industry District	79.6	4,491.50	45.72	24.13	14.48	205.4	108.4	65.0	
Riparian	79.6	1,198,240.45	45.72	24.13	14.48	50,748.8	26,784.1	16,072.7	
Others	79.6	31,868	45.72	24.13	14.48	1,457	769.0	461.4	
Stream	-	72,354.38	-	-	-	-	-	-	
Total		5,765,461.00				256,254.1	135,460.7	81,287.7	

Note: CN_{wt} for watershed level is **79.6**, Q_{25,5&2}=45.75,24.13 & 14.48mm Respectively

Table 4.15: Summary of total cumulative runoff volume and percentage of imperviousness estimated for all land cover of the watershed including the proposed asphalt road.

Land Cover	CN _{wt}	Area(m ²)	24hr. Peak Runoff Depth Q(mm)			24hr. Peak Runoff Volume (m ³)			%EIA
			Q _{25y}	Q _{5y}	Q _{2y}	q _{25y} total	q _{5y} total	q _{2y} total	
				25.40					
Street and Road	81	1,478,958.8	45.72		15.24	67,618	37,565.6	22,539.3	
Residential District	81	2,726,295.2	45.72	25.40	15.24	124,646	69,275.6	41,565.4	
Commercial District	81	18,155.9	45.72	25.40	15.24	830	542.5	325.5	
Mixed use	81	65,608.2	45.72	25.40	15.24	2,999.6	1,666.4	999.9	
Social Service and Inst.	81	257,738.3	45.72	25.40	15.24	11,783.8	6,546.6	3,927.9	
Industry District	81	4,491.50	45.72	25.40	15.24	205.4	114.1	68.4	
Riparian	81	1,109,990.75	45.72	25.40	15.24	50,748.8	28,193.8	16,916.3	
Others	81	31,868	45.72	25.40	15.24	1,457	809.4	485.7	
Stream	-	72,354.38	-	-	-	-	-	-	
Total		5,765,461.00				260,288.8	144,713.9	86,828.4	29.3

Note: CN_{wt} for watershed level is 81, q_{25,5&2}=45.75, 25.40 & 15.24mm Respectively

4.7 Analysis of existing impervious cover (Effective Impervious Area)

Based on the result the level of effective impervious cover of the study area is 27.8% excluding structure plan proposal and 29.3% including structure plan proposal. The result shows Among the four categories of urban streams related to the level of impervious cover defined by the Center for Watershed Protection (CWP 2003), the stream of the study area is categorized under non-supporting, based on (CWP 2003), and ICM (Fig.2.1). It indicates the stream will not support its designated uses in terms of hydrology, channel stability, habitat, water quality, or biological diversity. In other words, it surpasses by 2.8% even from the maximum threshold of the fair range of stream health that is **25%**, and it also surpasses by 17.8% from the maximum threshold of the retaining hydrologic function that supports well to excellent aquatic diversity which is **10%**. (Fig.2.1). **Therefore, a nature-based design solution will be applied to restore it and chapter six describe it in detail.**

CHAPTER FIVE

DISCUSSION

According to the result, the total impervious area of Addis Ababa in 2020 is 268,177,920 sq. Meter. That implies nearly half of the total area as described in (Fig-4.1b, and Fig-4.1a.). This value of total imperviousness has a detrimental effect on the highly degraded stream health of the city based on ICM (Fig 2.1) of the center for watershed protection (CWP 2003), even if not equally degrading as an effective impervious cover as recent studies stated.

Among several systems, based on topological characteristics, the natural and common, Pfafstetter system is used to delineate local watersheds of major streams and rivers. So that the system makes it easy to identify the watershed that is seriously affected by a high level of imperviousness (Verdin, K. and Verdin, J. (1999)). The result also identifies that 'Kaba' river watershed is seriously affected local watershed concerning a high level of imperviousness than other upper catchment local watersheds that flow into major streams of the little 'Akaki' river. The impervious area accounts for 23% (only rooftop) and, it becomes nearly half of the total area (47%) including the road network. This upstream basin has a significant contribution to the major stream health of the little Akaki river. Similarly, in all studies about impervious surface state high level of imperviousness is correlated to stream health.

Reducing impervious surfaces is the best practice using tools of nature-based design to stream rehabilitation according to (Ladson et.al. 2006), and the result of the study shows the existing percentage of imperviousness at a watershed, land use, block, and plot level. Based on the result watershed level, land-use level, block-level, and plot-level interventions have introduced using nature-based design to restore stream health of the study area that has correlated with the percentage of imperviousness.

Lists of the level of interventions (see design recommendations) are:

- Road level EIA of 50.7%, 52.3% could be reduced to 4.79%.
- Riparian zone level EIA of 27.02% could be reduced to 4.4%.
- Land use level EIA of 37.6% could be reduced to 5.34%.

- The average block-level EIA of 58% could be reduced to 54% (Using very limited tools).
- The average plot level EIA of 58% could be reduced to 43.8% (Using very limited tools).

The overall watershed-level effective imperviousness (EIA) of **27.8%** could be reduced to **4.66%** in the study area without altering most of the total impervious area(TIA) of **47.3%**. That will be in the threshold of sensitive streams. Based on the overall predictions of the ICM, streams with less than 10% sub-watershed IC normally capable to maintain their hydrologic function and support good to excellent aquatic diversity Schueler et al. (2009).

In general, the type of impervious surface determines the level of degradation and recent studies have revealed that stream health is strongly influenced by the amount of directly connected impervious surface in a catchment to waterways. The study achieves to reduce the impervious surface that directly delivers water with pollutants to the stream and it has major damage to stream health.

CHAPTER SIX

CONCLUSION, AND RECOMMENDATION

6.1 Conclusion

Nature-based design is an important issue in stream rehabilitation. This study shows that the total percentage of imperviousness for Addis Ababa in 2020 is 52 percent, a high level of imperviousness has a direct relation to the highly degraded stream health of the city. The study also found the level of imperviousness of the subwatershed of the 'Kaba' river which is delineated using the Pfafstetter system. The current proportion of imperviousness of sub-watershed, At road level, riparian zone level, land uses level, average block level, average plot level of each land-use and the overall sub-watershed scale are 50.7% (or 52.3%),27.02%,37.6%,58%,58%, and 27.8% respectively.

The nature-based design of 'Kaba' river subwatershed to reduce impervious levels, will improve stream health significantly. The reduced percentage of imperviousness in design at road level, riparian zone level, land uses level, average block level, average plot level, and the overall watershed scale are 4.79%, 4.4%,5.34%,54%,43.8%, and 4.66% respectively (Section 6.2.1)

Using this principle, Mt Evelyn in Australia has been the first site for investigation, in the little Stringybark creek catchment (recent percentage of imperviousness EIA = 5.5%) which drains the Dandenong range in Melbourne's east (Ladson et.al. 2006). There are also streams adjoining that can be used as experimental controls, and there are data for both control streams and little Stringybark creek (Ladson et.al. 2006). Nature-based design options analogous to those shown in (Figures 4-8a through Figure 4.22 and Table 4.0 through Table 6.20) were considered to reduce the percentage of effective impervious area (EIA).

Finally, we can conclude that proportion of effective impervious surface (EIA) was probable to be a good predictor of the ecological condition of the stream in the study area.

6.2 Recommendations

The quantitative relationship between land use planning and its impact on hydrology or the environment in Addis Ababa has to be described. Land-use policies have a contribution to maintain stream health by providing a reasonable percentage of imperviousness. As far as the proportion of effective impervious areas can be managed using nature-based design solutions, the total imperviousness proportion at the city core area and intermediate area could be up to 60%, and 30% respectively. But at the periphery area, it would be better not to be greater than 10 percent to minimize stream health degradation, particularly at the watershed level.

Based on findings lists of recommendations are suggested:

- Swales, conversion of impervious surface to pervious and rainwater harvest are highly recommended in the study area.
- Bare lands are encouraged to be covered by greeneries.
- Early planning, identification, and prioritizing of the several valuable uses are very important in ensuring a sustainable urban runoff water management, stream rehabilitation, and urban design scheme.
- 4% of the Catchment area for a rain garden is recommended for all land uses in the watershed and the depth of the rain garden should not be greater than the recommended depth.
- Artificially created wetlands are encouraged to address the treatment of stormwater and stream rehabilitation.
- Artificially created wetland has to comprise of at least two compartments– an open Water inlet and vegetation (macrophyte) zone with related high-flow by-pass Structure for the macrophyte zone.

Policy and goals of nature-based design

The nature-based design objective and goals should be established before the planning phase. These goals should be considered legally binding by all parties of Urban Designers, Planners, Architects, Landscape Architects, and other responsible parties at the planning meeting. Policies and goals may include:

- Reducing runoff and flood at an individual site, block, neighborhood, and watershed scale.
- Reducing impervious surface that is directly connected to storm waterways, streams and other water bodies.
- Maintaining stormwater treatment goals (Councils, S. E. (2007),
- Water conservation has to be addressed.
- Local environment and landscape has to be improved.
- Including community benefits (such as high-quality recreation areas, fishing, irrigation).
- Cultural benefits (such as 'Irrecha').

6.2.1 Decreasing runoff volume to restore stream health using nature-based design of urban catchments.

The aim of the study to decrease the runoff volume on urban areas closer to natural conditions to restore urban streams is by developing a new type of urban drainage system. This means a portion **of the rain that would have produced runoff from an impervious surface must be intercepted** and then infiltrated, evaporated, transpired, or stored for domestic use. The intensity of rainfall for our study area is 1089mm per average year.

6.2.1.1 Options for reducing runoff volume on impervious surfaces

Nature-based design measures need to be implemented to retain rainfall and reduce runoff volume for impervious surfaces. The purpose is to intercept; infiltrate, reuse, evaporate, or transpire, the rainfall. It will be most feasible to think of design treatment near the source of runoff or upstream, and for large downstream, nature-based design measures, such as wetlands, are feasible to reduce the runoff frequency.

Based on the site condition, and space requirements, potential options to achieve reductions in runoff volume have their constraints and opportunities. To achieve decreasing in runoff volume, in a connected impervious area, a suitable tool or combination of tools is selected. (Swales, Detention and Retention pond, converting impervious surface to pervious and rainwater harvest are the tools. for further detail and type refer to Steven et al. (2009).)

6.2.1.1.1 Road level nature-based landscape design

Bioretention and rain garden (nature-based landscape design) systems are probable to be an important tool to decrease the effective imperviousness of urban developments on the streetscape scale.

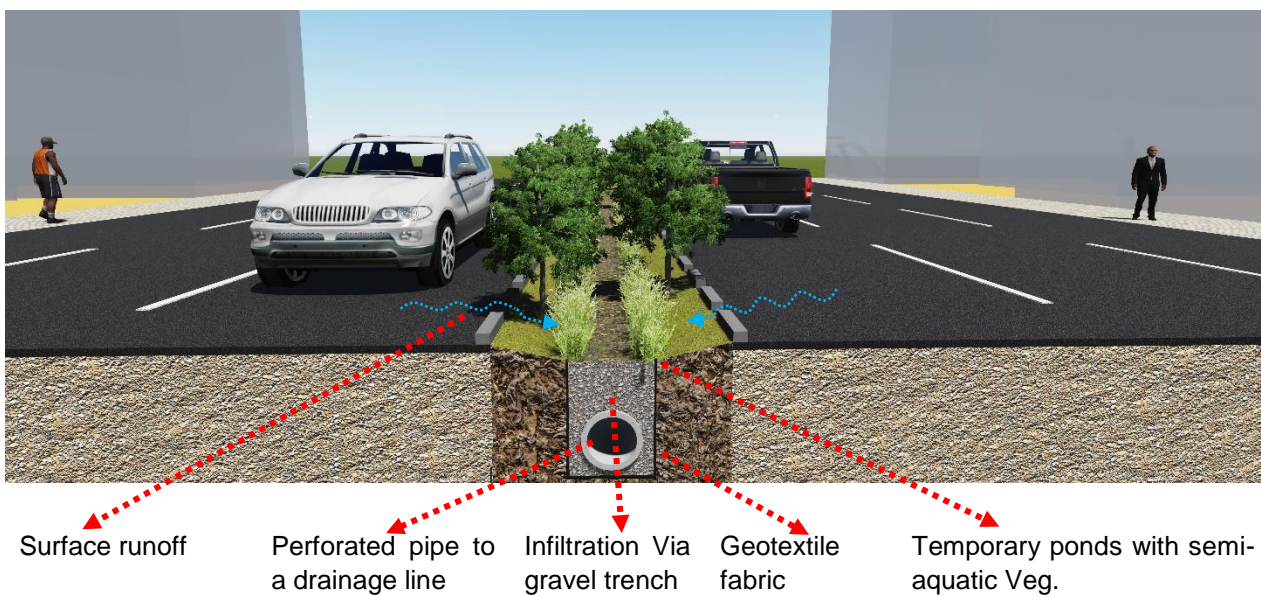


Fig-6.1 Cross-section of landscaped swale for typical 2meter median of 30m asphalt road



Fig-6.2 Road network with highlighted on section line of the above detail and 40m width road



Fig-6.3: Aerial view of a landscaped swale

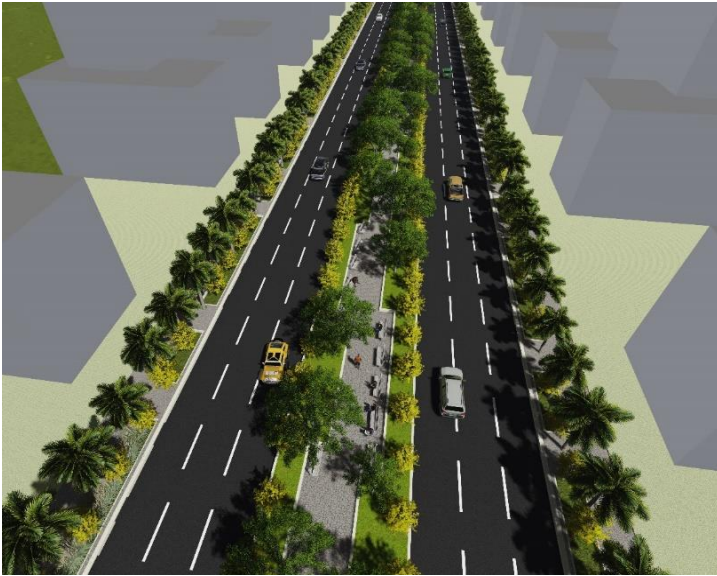


Fig-6.4: 40m width road Aerial view with proposed seating area at the median and rain garden along the walkway.

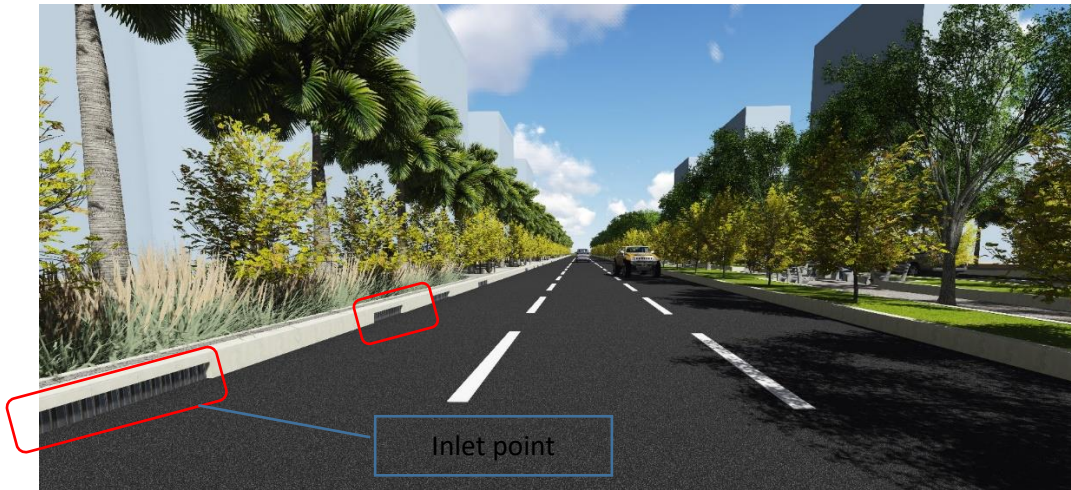


Fig-6.5: Proposed Inlet points of a rain garden for 40m width road



Fig-6.6 Proposed permeable surface and seating area at the median for 40m width road

Table 6.1: Reduced total runoff volume and percentage of imperviousness estimated after new proposed design of street and road in the watershed including the proposed asphalt road on the structure plan.

Street and Road	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr Peak Runoff Depth Q(mm)	24hr. Peak Runoff Volume (m ³)	With rain garden % EIA	W/o rain garden % EIA
					Q _{2years}	Q _{2 years}		
Asphalt	98	98	98	337,635.2	45.7	15,429.93		
Coble	85	91	86.02	993,519.9	22	21,857.44	4.79	49.3
Rain Garden	-	-	-	59,158.35	-	-34,255.93		
PS	81.12	81.12	81.12	36,317	14.5	526.6		
Greenery	61	80	64.23	52,328.35	2.54	132.91		
Total				1,478,958.74		3,690.95		

PS=open-gridded modular pavement infilled with sod. (For impervious surface P₂=52mm)

Reduction of effective impervious area (EIA) from 52.3% to 49.3% using a different type of interception and using a further treatment such as rain garden at the streetscape level that can be reduced from 52.3% to 0%.

6.2.1.1.2 Block-level, Plot-level, and Watershed-level nature-based design in the Watershed.

Based on the built-up area ratio (BAR), plot size, and common open space, three blocks of the high, medium, and low-density blocks are selected based on better-planned areas and stormwater drainage systems. (Fig-4.10). A combination of tools for reducing runoff volume on impervious areas is proposed (Swale along the road and rain garden at the common open space) (Fig-4.11, 4.12, and 4.13). Reducing impervious surfaces will result in a lower proportion of effective impervious areas from 61% to 59%, 58% to 56%, and 55% to 47% respectively from high to low-density blocks using very limited tools. (Table 6. 2) describe a comparison between existing and proposed.

6.2.1.1.2.1 Block-level nature-based design.

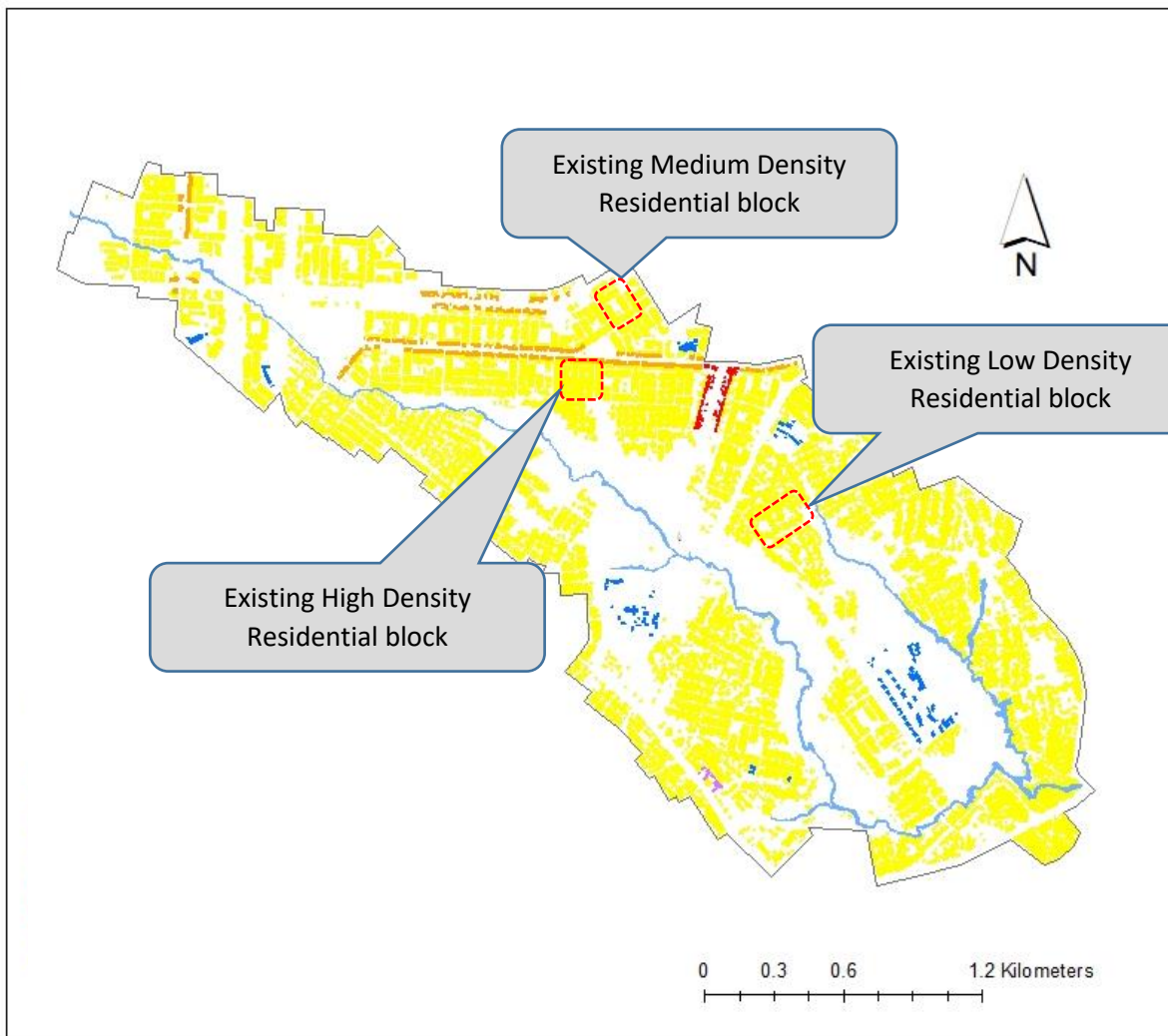


Fig-6.7 Location of the high, medium, and low-density residential block

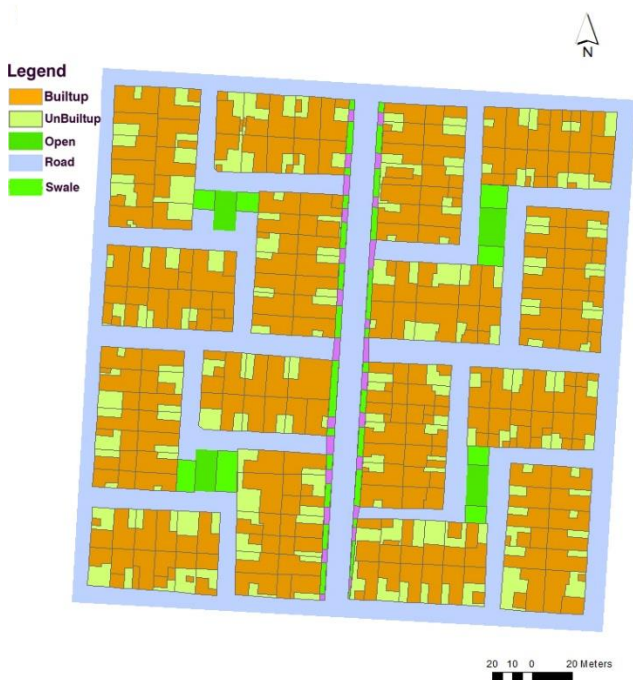


Fig-6.8 High-density residential block: Existing and revised with nature-based landscape



Fig4.11a (1) Untreated open space (2) Frontage garden (3) Inactive road (4) Open Concrete ditch.

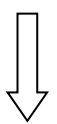


Fig-6.9 Medium density residential block: Existing and revised with nature-based landscape



Fig 4.12a (1) Well Treated Open Space, (2),(3) Impervious tile at the Gate,(4)Frontage garden.

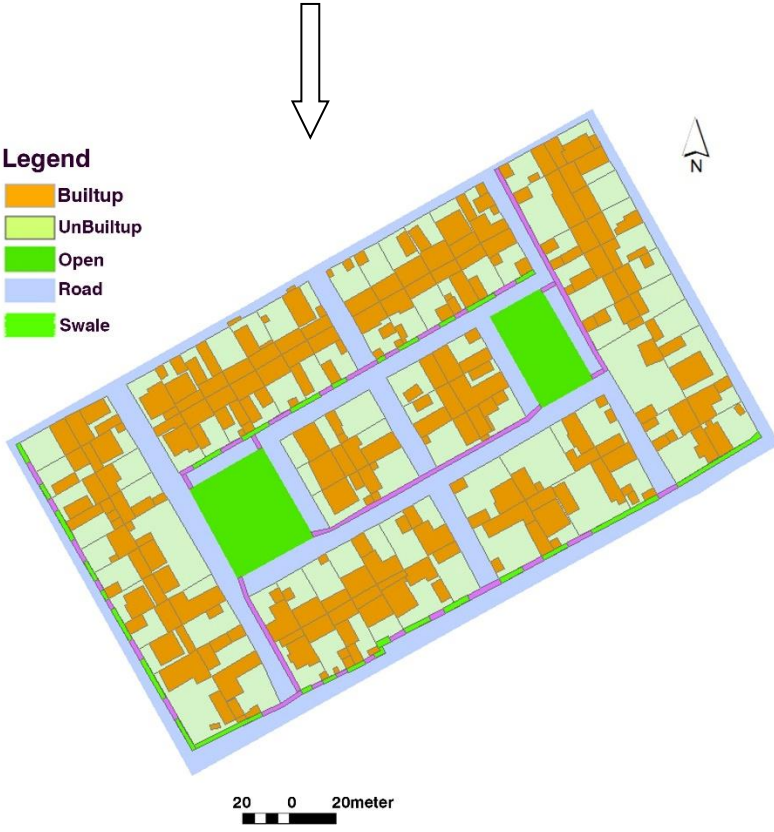
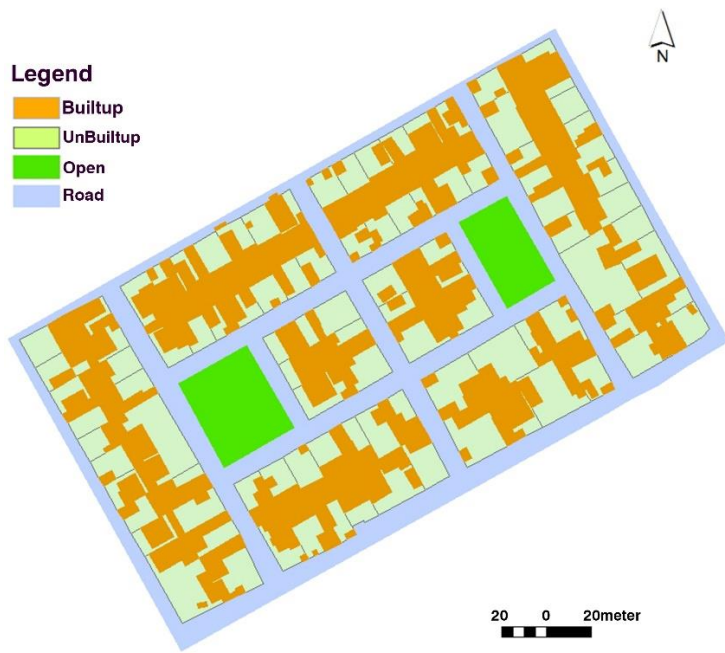


Fig-6.10 Low-density residential block: Existing and revised with nature-based landscape

Fig 6.10a Improperly treated open space,(2),(3) Covered sewerage line,(4)Frontage garden.

Table 6. 2: Comparison of existing and proposed impervious level for low, medium, and high density blocks.

	Low-density		Medium-density		High-density	
	Existing	Proposed	Existing	Proposed	Existing	Proposed
Built up Area(m ²)	9,847.20	9,847.20	6,677.50	6,677.50	10,027.30	10,027.30
Unbuilt up Area tile(m ²)	3,360	3,360	3,193.80	3,193.80	2,857	2,857
Unbuilt up Area bare land(m ²)	7,048	-	-	-	-	-
Unbuilt up Area green(m ²)	-	7,048	-	-	-	-
Road Area(m ²)	8,186.20	7,724.34	5,557.83	5,232.50	7,452.50	6,898.80
Existing Green Area(m ²)	1,723.90	1,723.90	1,221.80	1,221.80	259.2	259.2
Total Block Area	30,165.30	30,165.30	16,650.90	16,650.90	20,596	20,596
BAR	48.60%	48.60%	67.60%	67.60%	77.80%	77.80%
Proposed green area(m ²)	-	461.86	-	325.3	-	553.2
Q(m ³ /Average year)	17,988.65	15,543.45	10,469.48	10,097.08	13,624.90	13,266.96
EIA(m ²)	16,518.50	14,273.14	9,613.84	9,271.88	12,511.39	12,182.70
EI	55%	47%	58%	56%	61%	59%

6.2.1.1.2.2 Plot-level nature-based design from the selected blocks based on density.

The plot size and built-up area for plot-level nature-based design will be estimated based on the average plot size and average built-up area from the previous high, medium, and low-density residential blocks. A combination of tools to reducing runoff frequency on impervious areas is proposed (converting impervious surface to pervious or semi-pervious, incorporating rain garden in the compound and rainwater harvest for domestic use) (Fig- 4.14, 4.15, and 4.16). There is a significant change in the proportion of effective impervious areas from 68% to 55%, 67% to 53%, and 39.8% to 23.44%, respectively from high to low-density plots. (Table 6. 3) describes a comparison between existing and proposed.

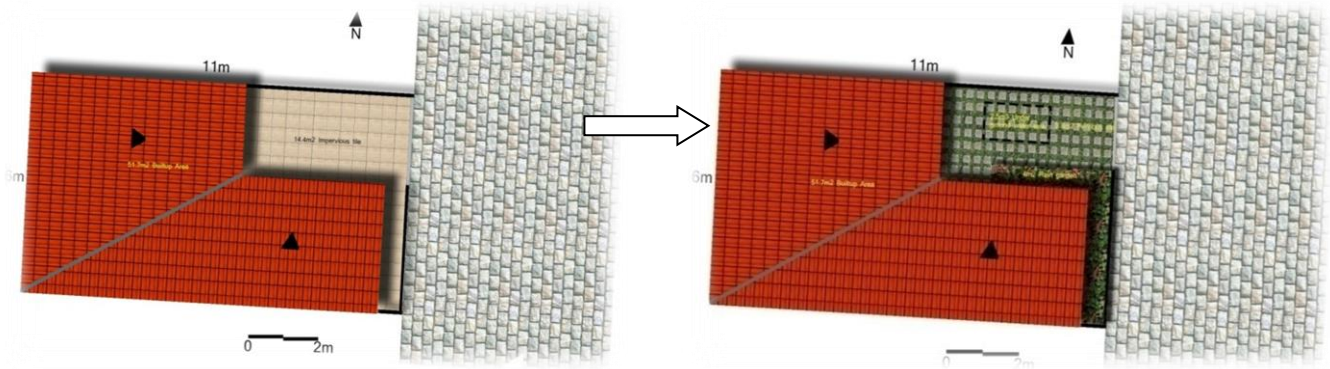
Plot-level nature-based design for high-density residential.

The average plot size is estimated by dividing the total plot area by the total number of the plot.

$$\text{Average Plot area} = 12,884.30\text{m}^2 / 194 = \underline{66.4\text{m}^2}$$

The average built-up area is also estimated by dividing the total built-up area by the total number of the plot.

$$\text{Average built up Area} = 10,027.30\text{m}^2 / 194 = \underline{51.7\text{m}^2}$$



a) Existing

b) Proposed

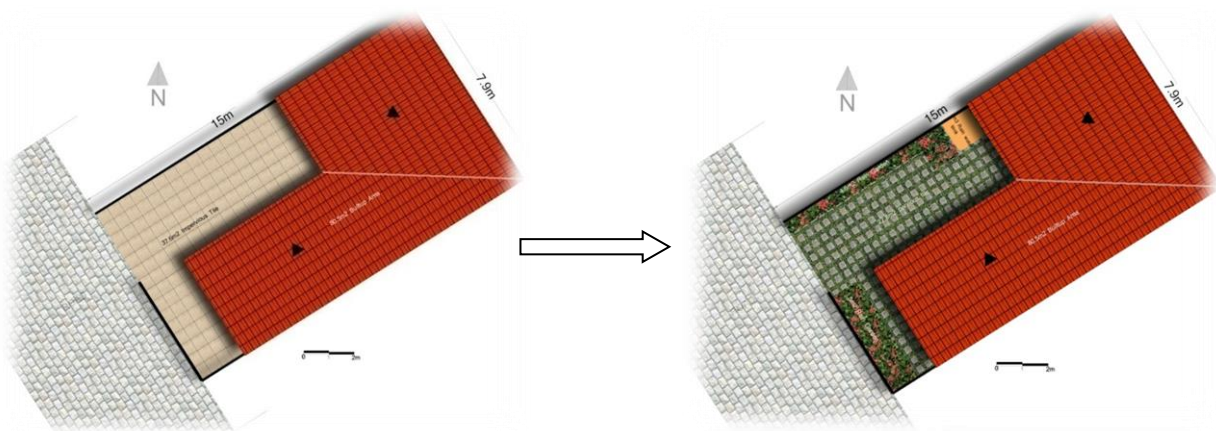
Fig-6.11 Existing and proposed high-density residential plot

Plot-level nature-based design for the medium-density residential block.

The average Plot size and average built-up area are estimated using the above method.

$$\text{Average plot area} = 9873.3\text{m}^2 / 83 = \underline{119\text{m}^2}$$

$$\text{Average built-up Area} = 6,677.5\text{m}^2 / 83 = \underline{80.5\text{m}^2}$$



a) Existing

b) Proposed

Fig-6.12 Existing and proposed medium density residential plot

Plot-level nature-based design for the low-density residential block.

The average plot size and average built-up area for the low-density residential block are estimated using the above method.

$$\text{Average plot area} = 20,255.2\text{m}^2 / 97 = \underline{208.8\text{m}^2}$$

$$\text{Average built up area} = 9,847.2\text{m}^2 / 97 = \underline{101.5\text{m}^2}$$

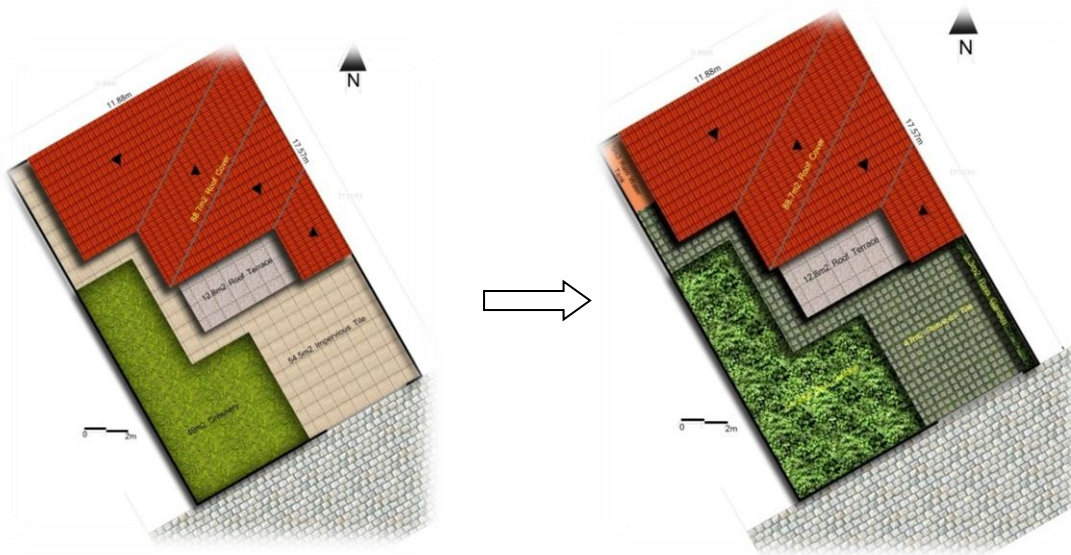


Fig-6.13 Existing and proposed low-density residential plot

Table 6. 3: Comparison of existing and proposed impervious level for low, medium, and high density plots.

	Low-density		Medium-density		High-density	
	Existing	Proposed	Existing	Proposed	Existing	Proposed
Built up area(m ²)	101.50	101.50	80.50	80.50	51.70	51.70
Unbuilt up area existing tile (m ²)	54.50	0	38.50	0	14.40	0
Unbuilt up area proposed paver (m ²)	0	47	0	28.9	0	9.8
Unbuilt up area existing green (m ²)	49	0	0	0	0	0
Proposed green area (m ²)	0	56.90	0	0	0	0
Proposed rain garden (m ²)	0	3.30	0	9.60	0	4.6
Proposed rain water tank (m ³)	0	5.00	0	3.00	0	2.5
Total plot area	208.80	208.80	119.00	119.00	66.40	66.40
BAR	48.60%	48.60%	67.60%	67.60%	77.80%	77.80%
Q (m ³ /average year)	90.50	53.29	86.5	69.23	49	39.67
EIA (m ²)	83.10	48.93	79.43	63.57	45.00	36.43
EI	39.8%	23.44%	67%	53%	68%	55%

6.2.1.1.2.3 Watershed level nature-based design for all land uses

Site data

From a topographic map and site survey, the following data were measured: From the soil map of Addis Ababa, and the site survey (Fig-3.2), it appears that the soils are Eutric, Pelvic, and Chromic (Ne, Vp, and Lc). From Table 6. 4, Ne and Lc are silt loam of hydrologic soil Group B, and Vp is a clay loam, of hydrologic soil group D. from (table 5-3)79% (455 ha) is Ne,17% (98ha) is Vp and 4% (23ha) is Lc.

Table 6.4 Proportion of soil group in the study area

Soil type	Percentage	Hectare	Soil Group
Eutric Nitisols	79%	455	B
Pelvic Vertisols	17%	98	D
Chromic Luvisols	4%	23	B
Total	100.0%	576	

Table 6.5 Basic infiltration rates for various soil types

Soil type	Basic infiltration rate (mm/hour)
Sand (Soil group A)	Less than 30
Sandy loam (Soil group A)	20 - 30
Loam (Soil group B)	10 - 20
Clay loam (Soil group D)	5 - 10
Clay (Soil group D)	1 - 5

From Brouwer, et al. (1988).

The cover types are impervious areas, urban districts and residential districts, grassland, woodland, farmland, and bare land of soil groups B and D.

Rain garden depth estimation of a residential block.

Infiltration rate of Loam (soil group B) is 10 – 20mm/hr.(aver.15mm/hr) and 1-5mm/hr. (aver.3mm/hr) for clay loam (soil group D) and the average infiltration rate is $0.83 \times 15 \text{mm/hr.} + 0.17 \times 3 \text{mm/hr.}$ is 12.9mm/hr.

- Infiltration rate= $1.29 \text{cm/hr.} (1.29 \times 10^{-2} \text{m/hr}) = 3.58 \times 10^{-6} \text{m/s}$
- Duration (t)=2hr.
- Area (A)=Area catchment (A) + Area infiltration Surface (A)
- $250 \text{m}^2 = 240 \text{m}^2 + 10 \text{m}^2$
- Vol.inflow(V_i)(8.15m^3 peak runoff volume for 2 years of 2 hr.of individual parcel (IDF))
- Vol. outflow(V_o) = Area infiltration Surface (A) x infiltration capacity (k) x Duration (t_r)
 $= 10 \text{m}^2 \times 3.58 \times 10^{-6} \text{m/s} \times 7,200 \text{s}$
 $= 0.26 \text{m}^3$
- Magazine(V_r) = Vol. inflow(V_i)-Vol. outflow(V_o)
 $= 8.15 \text{m}^3 - 0.26 \text{m}^3 = 7.89 \text{m}^3$
- Depth (D) = $7.89 \text{m}^3 / 10 \text{m}^2 = \underline{0.79 \text{m}}$

Table 6.6: Recommended rain garden (4% of catchment area) for all land uses in the watershed according to (City of Los Angeles and Geosyntec consultants report(2015)).

land cover	Area(m ²)	Inflow (m ³)	Outflow (m ³)	Inflow-outflow (m ³)
Road	55,628.40	45,337	1,446.34	43,890.8
Residential	10	8.15	0.26	7.89
Commercial	23.5	19.34	0.61	18.73
Mixed use	8.3	6.79	0.22	6.6
Social Service	1,288.70	1050	33.5	1016.8
Factory	90	73.21	2.34	70.87
Others	106.2	86.57	2.76	83.81

Land cover and land use area per plot

Area of **land cover** (road, tree, grass, built-up, bare land, and stream) and **land uses** (residential, mixed-use, commercial, social service and institute, factory, and others) in the watershed has to be classified to incorporate nature-based design tools to reduce runoff volume. Table 6.7, 4.23, and 4.24 describe a land-use area, the number of plots, built-up area, and land cover area per plot in every land uses.

Table 6.7: Total forest, grass, and shrubs area of existing land use in the watershed.

Land use	Total Forest Area(m ²)	Total Grass & Shrubs(m ²)
Residential	387,601.65	499,248.37
Mixed use	16,940.70	8,832.60
Social service and Institute	102,325.44	79,541.60
Commercial	4,808.52	2,059.20
Factory	637.80	822.68
Others	3,236.64	2,515.20
Total	515,550.75	593,019.65

Table 6.8: Average parcel area and built-up area estimation within a plot for all land uses (Estimated from the whole watershed)

Land use	Total Area (m ²)	Parcel Number of Parcel	Aver. Parcel Area (m ²)	Aver. Built-up area (m ²)
Residential	2,726,327.80	10,903	250.053	116.75
Mixed use	65,608.76	315	208.28	112.97
Social service and Institute	257,738.35	8	32,217.29	2,296.55
Commercial	21,358.49	36	593.29	163.26
Factory	4,491.54	2	2,245.77	735.91
Others	31,868.00	12	2,655.67	-
Total	3,107,392.94	11,276	-	-

Table 6.9: Average forest, grass cover, paved surface, and bare land area estimation within a plot for all existing land uses. (Estimated from the entire watershed)

Land use	Aver. Area (m ²)in a Single Plot					total
	Covered by Trees	Covered by grass and Shrubs	Paved with Tile	Paved with Asphalt	Bare land	
Residential	35.55	45.79	51.96	-	-	133.29
Mixed use	53.78	28.04	13.49	-	-	95.31
Social service and institute.	12,790.68	9,942.70	1,480.5	1,285.36	4,421.5	29,920.75
Commercial	133.57	57.20	150.3	-	88.96	430.03
Factory	318.9	411.34	-	779.6	-	1,509.84
Others	269.72	209.60	-	-	2176.35	2,655.67

Table 6.10: New proposed design of open space in a single plot for every land use including rain garden.

Land use	Aver. Area (m ²)in a Single Plot					Total
	Covered by Trees	Covered by grass and Shrubs	Paved with Tile	Paved with Asphalt	Rain G.	
Residential	37.5	37.8	48	-	10	133.29
Mixed use	54.04	20.40	12.57	-	8.3	95.31
Social service and Institute.	11,501.98	14,364.20	1,480.5	1,285.36	1,288.7	29,920.75
Commercial	230	79.55	97	-	23.5	430.03
Factory	324.9	402.34	-	692.6	90	1,509.84
Others	1304.8	1244.6	-	-	106.2	2,655.67

Watershed level nature based-design for a residential block.

Using nature-based design techniques to reduce effective impervious area at the residential house block level of the ordinary drainage system of estimated (EIA=39.5%); house block with some nature-based drainage techniques of estimated (EIA=28.2%), and where the drainage system has been designed using nature-based to achieve the maximum reduction in the effective impervious area of (EIA=5.4%)(See figure 6.14, table 4.8, and 4.26 for details).

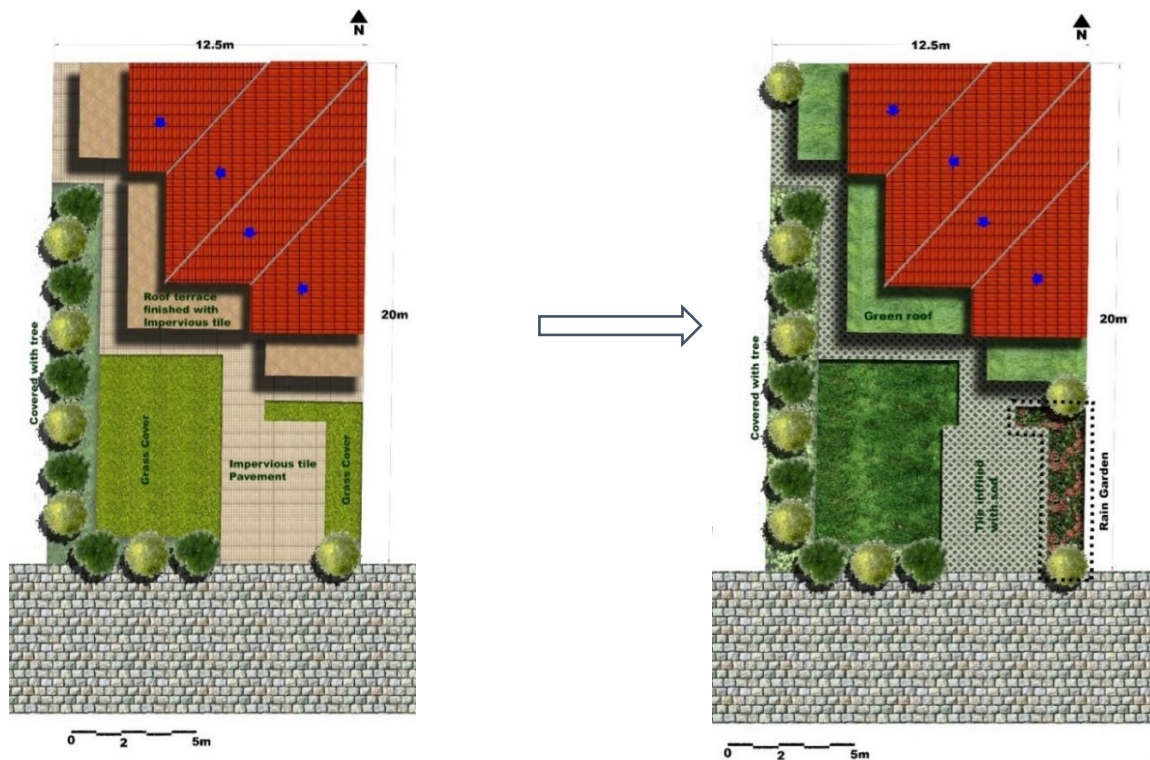


Fig-6.14: Watershed level reduced total runoff volume in the residential plot by reducing or changing impervious surface to pervious.

Table 6.11: Watershed level reduced total runoff volume in the residential plot by reducing or changing impervious surface to pervious.

Residential District	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr Peak	24hr. Peak	With rain garden % EIA	W/o rain garden % EIA
					Runoff Depth Q(mm)	Runoff Volume Q(m ³)		
					Q _{2years}	q _{2 years}		
Builtup	85	92	86.19	1,125,353.25	20.3	25,840.38	5.43	28.2
Wood	60	79	63.23	361,462.50	2.03	829.99		
Rain Garden	-	-	-	96,390.00	-	-28,501.78		
PS	81.12	81.12	81.12	462,672.00	45.72	7,588.49		
Greenery	61	80	64.23	364,354.20	25	1,046.82		
Total				2,410,231.95		6,803.9		

PS=Open-gridded modular pavement infilled with sod. For impervious surface P₂=52mm.

Watershed level nature-based design for the mixed-use block.

Using nature-based design techniques to reduce effective impervious area at the mixed-use block level of the ordinary drainage system of estimated (EIA = 40.47%), house block with some nature-based drainage techniques of estimated (EIA = 36.34%), and where the drainage system has been designed using nature-based to achieve the maximum reduction in the effective impervious area of (EIA = 4.8%) (See figure 6.15: and Table 6.12 for details).

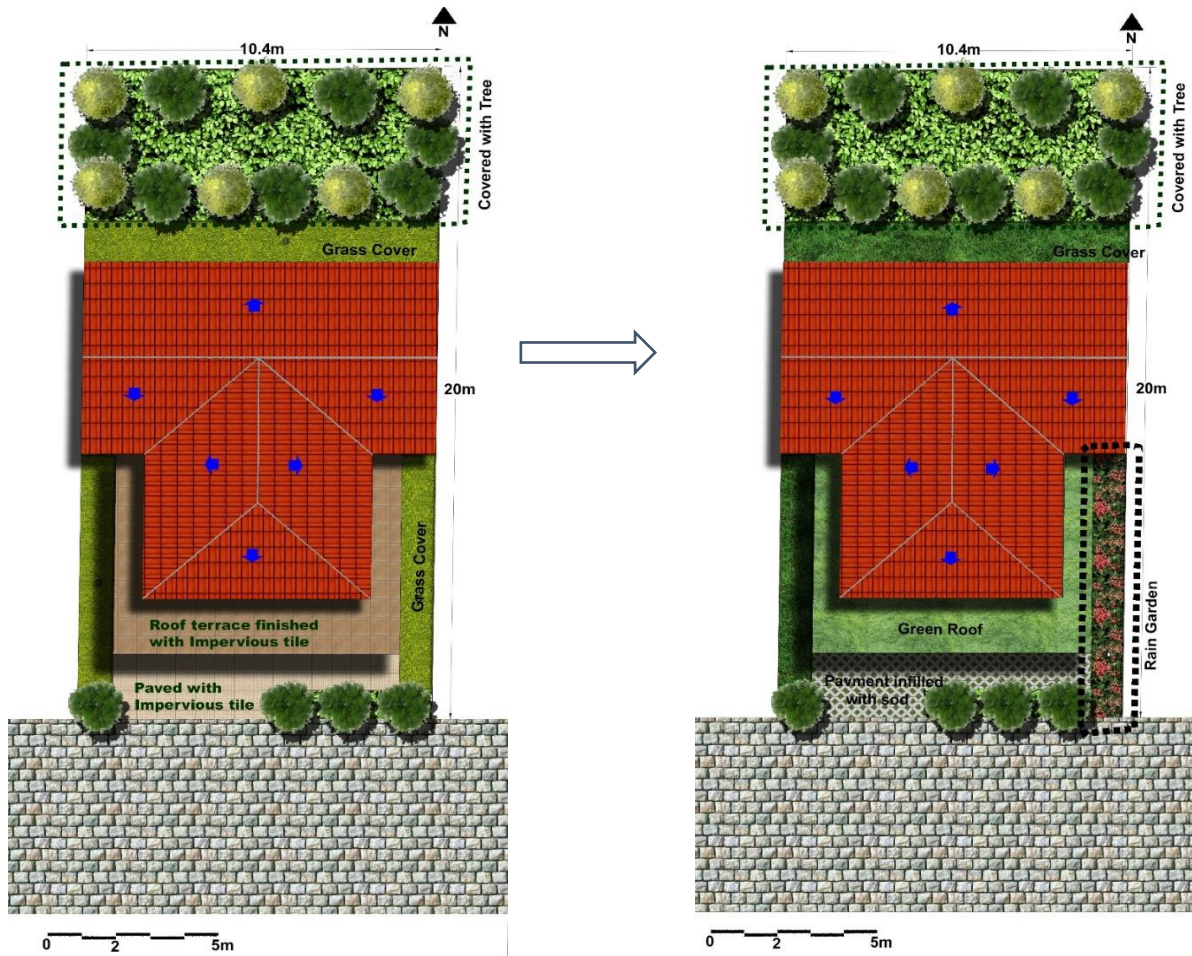


Fig-6.15: Watershed level Reduced Total Runoff Volume in the Mixed-use plot by Reducing or Changing impervious surface to pervious

Table 6.12: Watershed level reduced total runoff volume in mixed-use plots by reducing or changing impervious surface to pervious.

Mixed-use	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr Peak Runoff Depth Q(mm) Q _{2years}	24hr. Peak Runoff Volume Q(m ³) Q _{2 years}	With rain garden % EIA	W/o rain garden % EIA
Builtup	85	92	86.19	35,585.55	31.8	1,131.62		
Wood	60	79	63.23	17,022.60	2.03	34.56		
Rain Garden	-	-	-	2,614.50	-	-1,076.18	4.8	36.34
PS	81.12	81.12	81.12	3,959.55	14.5	57.41		
Greenery	61	80	64.23	6,426.00	2.54	16.32		
Total				65,608.20		163.73		

Watershed-level nature-based design for the commercial and business block.

Using nature-based design techniques to reduce effective impervious area at the commercial and business block level of the ordinary drainage system of estimated (EIA = 46.49%), house block with some nature-based drainage techniques of estimated (EIA = 24%), and where the drainage system has been designed using nature-based to achieve the maximum reduction in the effective impervious area of (EIA = 4.1%) (See figure 4.19: and Table 6.13 for details).

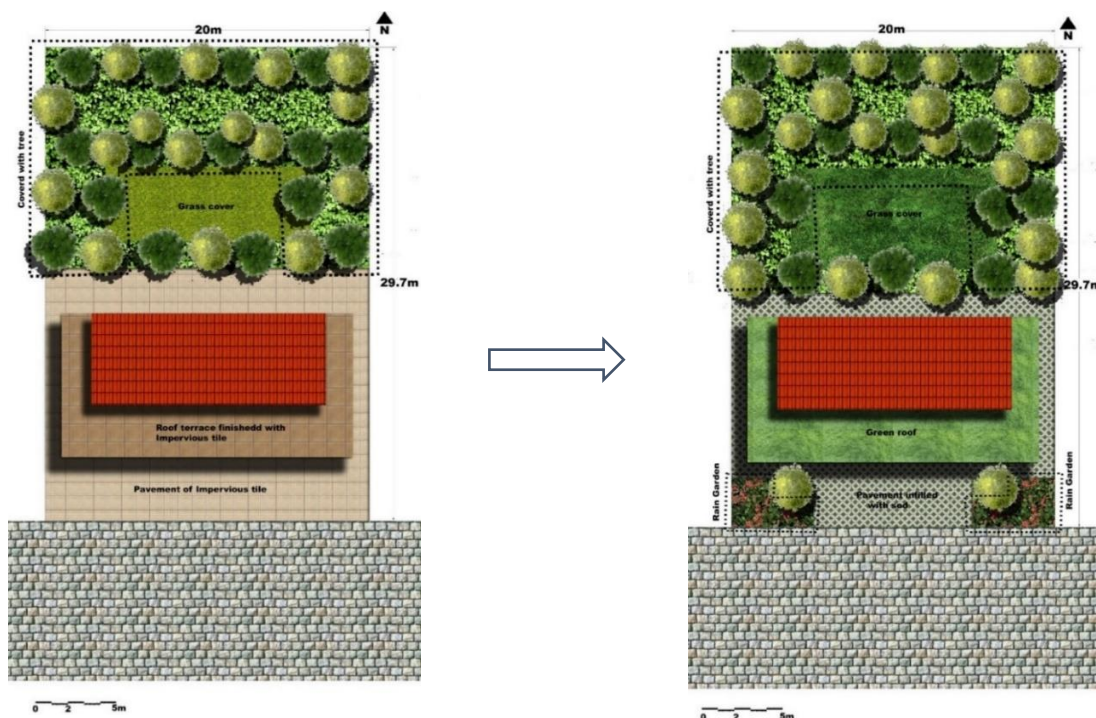


Fig-6.16: Watershed level reduced total runoff volume in the commercial and business plot by reducing or changing the impervious surface to pervious.

Table 6.13: Watershed level reduced total runoff volume in commercial and business plots by reducing or changing the impervious surface to pervious.

Commercial and business	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr Peak	24hr. Peak	With rain garden % EIA	W/o rain garden % EIA
					Runoff Depth Q(mm) Q _{2years}	Runoff Volume Q(m ³) Q _{2 years}		
Builtup	85	92	86.19	5,877.36	31.8	186.9		
Wood	60	79	63.23	8,280.00	2.03	21.03		
Rain Garden	-	-	-	846.00	-	-220.53	4.1	24
PS	81.12	81.12	81.12	3,492.00	14.5	50.63		
Greenery	61	80	64.23	2,863.80	2.54	7.27		
Total				21,359.16		45.31		

Watershed level nature-based design for social service and institute block.

Using nature-based design techniques to reduce effective impervious area at the social service and institute block level of the ordinary drainage system of estimated (EIA=16.86%), house block with some retrofit drainage techniques of estimated (EIA =11.1%), and where the drainage system has been designed using nature-based to achieve the maximum reduction in the effective impervious area of (EIA =4.8%) (See figure 6.17: and Table 6.14 for details).

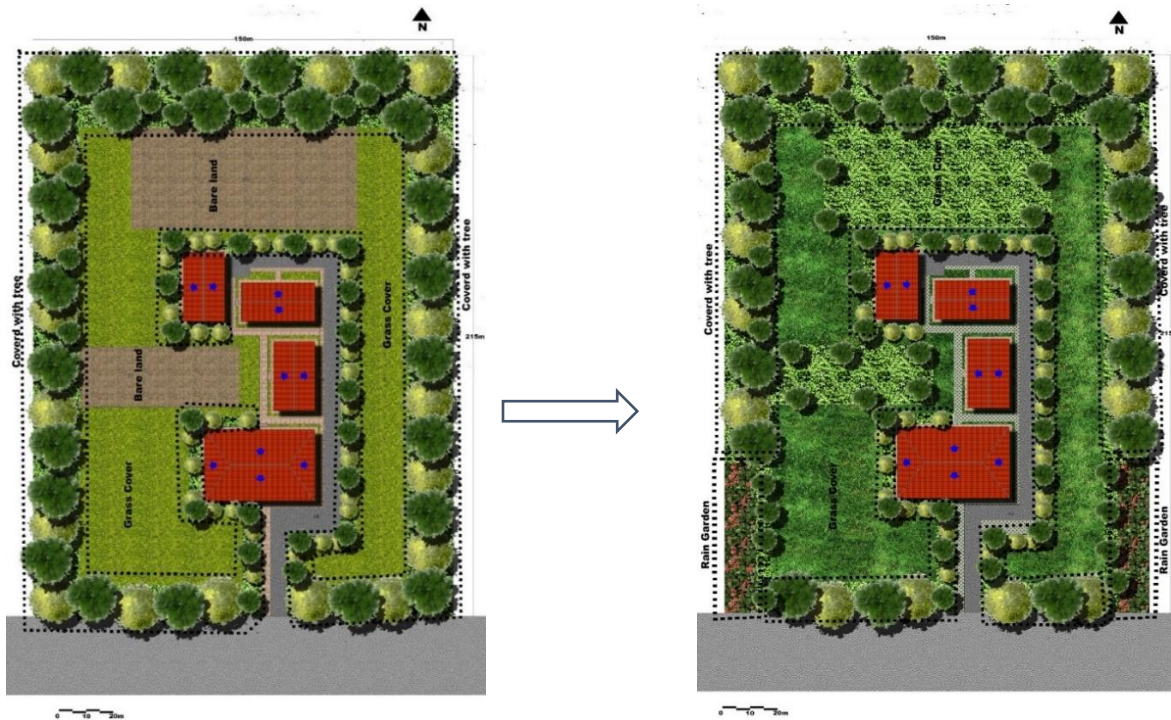


Fig-6.17: Watershed level reduced total runoff volume in the social service and institute plot by reducing or changing impervious surface to pervious

Table 6.14: Watershed level reduced total runoff volume in social service and institute and business plots by reducing or changing impervious surface to pervious.

Social Service and Institute	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr Peak Runoff Depth	24hr. Peak Runoff Volume	With rain garden % EIA	W/o rain garden % EIA
					Q _{2years} (mm)	q _{2 years} (m ³)		
Builtup	85	92	86.19	18,372.40	45.7	839.62		
Wood	60	79	63.23	92,015.84	2.03	186.79		
Rain Garden	-	-	-	10,309.60	-	-846.81	4.8	11.12
PS	81.12	81.12	81.12	11,844.00	14.5	171.74		
Greenery	61	80	64.23	114,913.60	2.54	291.88		
Asphalt	98	98	98	10,282.88	-	-		
Bare Land			63.23	-	-	-		
Total				257,738.32		643.22		

Watershed-level nature-based design for industry block.

Using nature-based design techniques to reduce effective impervious area at the industry block level of the ordinary drainage system of estimated (EIA =47.95%), house block with some nature-based drainage techniques of estimated (EIA =46.2%), and where the drainage system has been designed using nature-based to achieve the maximum reduction in the effective impervious area of (EIA=4.8%) (See figure 6.18: and Table 6.15 for details).

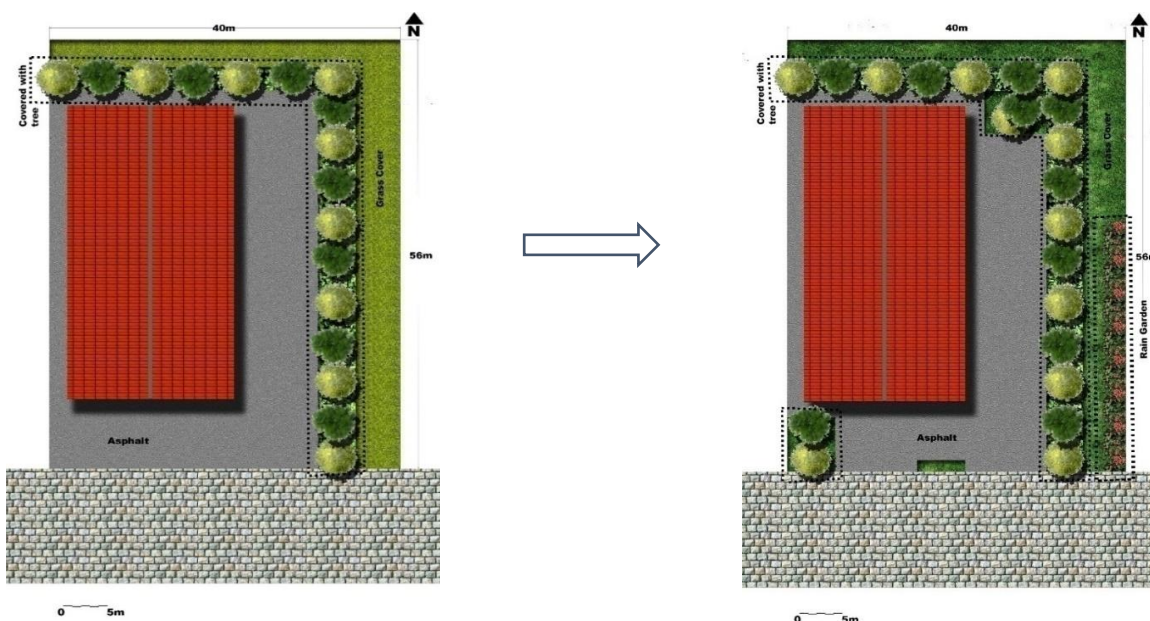


Fig-6.18: Watershed level reduced total runoff volume in the industry plot by reducing or changing impervious surface to pervious

Table 6.15: Watershed level reduced total runoff volume in Industry plots by reducing or converting impervious surface to pervious.

Industry	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr Peak Runoff Depth Q(mm) Q _{2years}	24hr. Peak Runoff Volume q(m ³) q _{2 years}	With rain garden % EIA	W/o rain garden % EIA
Builtup	85	92	86.19	1,471.82	28	41.21		
Wood	60	79	63.23	649.80	2.03	1.32		
Rain Garden	-	-	-	180.00	-	-96.67	4.8	46.2
Asphalt	98	98	98	1,385.20	45.7	63.30		
Greenery	61	80	64.23	804.68	2.54	2.04		
Total				4,491.50		11.21		

For EIA Q_{2y}=52mm

Watershed level nature-based design for 'other' block.

Using nature-based design techniques to reduce effective impervious area at the 'other' block-level of ordinary drainage system of estimated (EIA =34%), house block with some nature-based drainage techniques of estimated (EIA =4.3%), and where the drainage system has been designed using nature-based to achieve the maximum reduction in the effective impervious area of (EIA =4.3%) (See table 4.8 and Table 6.16 for details).

Table 6.16: Watershed level reduced total runoff volume in other plots by reducing or changing impervious surface to pervious.

Others	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr Peak Runoff Depth Q(mm)	24hr. Peak Runoff Volume q(m ³)	With rain garden % EIA	W/o rain garden % EIA
					Q _{2years}	Q _{2 years}		
Wood	60	79	63.23	15,657.60	2.03	31.78		
Rain Garden	-	-	-	1,274.40	-	-		
Greenery	61	80	64.23	14,935.20	2.54	37.94	4.27	4.27
Total				31,867.20		69.53		

For EIA Q_{2y}=52mm

Watershed-level nature-based design for the riparian area.

Using nature-based design techniques to reduce effective impervious area at the riparian zone level of the ordinary drainage system of estimated (EIA =27.02%), house block with some nature-based drainage techniques of estimated (EIA =3.39%), and where the drainage system has been designed using nature-based to achieve the maximum reduction in the effective impervious area of (EIA =3.38%) (See Table 6.17: and Table 6.18 for details).

Table 6.17: New proposed design of landcover in the riparian area including a rain garden

Land cover	Covered Area (m ²)					Total
	Covered by Trees	Covered by grass and Shrubs	Paved with Tile	Paved with Asphalt	RainG.	
Road		52,328.35	36,317	337,635.2	59,158.35	1,478,958.8
Riparian area	259,394.2	850,596.59	-	-	-	1,109,990.75

Table 6.18: Watershed level reduced total runoff volume in the riparian area by reducing or changing impervious surface to pervious.

Riparian	CN _B (83%)	CN _D (17%)	CN _{wt}	Area(m ²)	24hr Peak Runoff Depth Q(mm)	24hr. Peak Runoff Volume q(m ³)	With rain garden (Pond)	W/o rain garden
					Q _{2years}	q _{2 years}	% EIA	%EIA
Wood	60	79	63.23	249,394.2	2.03	546.09		
Rain Garden	-	-	-	10,000	-	-		
Stream	-	-	-	69,118.53	-	-	4.38	4.39
Greenery	61	80	64.23	781,360.16	2.54	1,984.65		
Total				1,109,872.89		2,530.74		

For EIA Q_{2y}=52mm

Watershed level reduced total runoff volume using a retention storage facility and water budget for Riparian area

The use of a storage facility of retention that has a permanent pool is encouraged to address water quality problems. Proper maintenance and provisions for weed control and aeration to avoid anaerobic conditions are basic issues that have to be considered for permanent pool Steven et al. (2009).

Artificial wet pond (Wetland)

Artificially created wetlands are marsh systems, which regularly fill and drain. The System is designed for the treatment of stormwater which has an open water **inlet zone**, a **macrophyte zone** (which consists of the majority of the system), and an open water **outlet zone**.

The following key design features that artificial wetlands should consist of:

1. An open water sedimentation pond is an inlet zone for the overall Artificial wetland system. It protects the macrophytes zone by reducing the velocity of inflows and traps coarse sediments. For maintenance purposes, sedimentation ponds should be separated from the macrophytes zone. (Melbourne Constructed Wetlands Guidelines(2010))
2. A densely vegetated zone is a macrophyte zone that is predominantly emergent aquatic plants that support a complex of algal and bacterial microscopic organisms. Macrophyte zone traps finer sediments and soluble pollutants. (Melbourne Constructed Wetlands Guidelines(2010))
3. The sedimentation pond and the macrophyte zone can be connected by a pipe or porous rock weir. Where pipe connections are used it is important to have an initial

open water Zone in the macrophyte zone to help disperse flows. (Melbourne Constructed Wetlands Guidelines(2010))

Water budget calculations for the case area are required for all permanent pool (wet ponds) facilities and should consider performance for average annual conditions. The water budget should consider all significant inflows and outflows including, but not limited to, rainfall, runoff, Infiltration, exfiltration, evaporation, and outflow of the area. The basic required data for water budget calculations are as follows

- The mean annual evaporation is less than 1,000mm (700-1000) (Average Actual Evaporation Per Year)

- Infiltration rate of the pond with clay soil of 2.5mm/hr (Table 6.5)

$$\text{Infiltration rate} = 2.5\text{mm/h} * 24\text{h/day} * 365\text{day/year} = 22.8\text{m/year}$$

- The average annual runoff is estimated as for riparian area

$$\text{Runoff} = 319,091.46\text{m}^3 / \text{year} \text{ (table 4.11)}$$

- The assumed wet pond (Retention Pond) area is 1000m² and at least 10 ponds are required, the total area will be 10,000m².

- The average annual evaporation is estimated as:

$$\text{Evaporation} = (1\text{m}) (10,000\text{m}^2) = 10,000\text{m}^3$$

- The average annual infiltration is estimated as: by assuming the bottom area of the

pond is 660m²

$$\text{Infiltration} = (22.8\text{m}) (6,600) = 150,480\text{m}^3$$

- Neglecting pond outflow and assuming no change in storage, the runoff (or Inflow) less evaporation and infiltration losses are:

Net budget = 319,091.46 – 10,000 – 150,480 = **158,611.46m³** (**19,881m²** of surface area and **13,121.5m²** bottom area are the maximum pond size at which the average runoff of riparian zone and infiltration and evaporation losses will be the same) by assuming pond depth is 1.5m and average area 8,300m² (10,000+6,600/2) this can accommodate **12,450m³** of water per year and the rest will be considered as outflow.

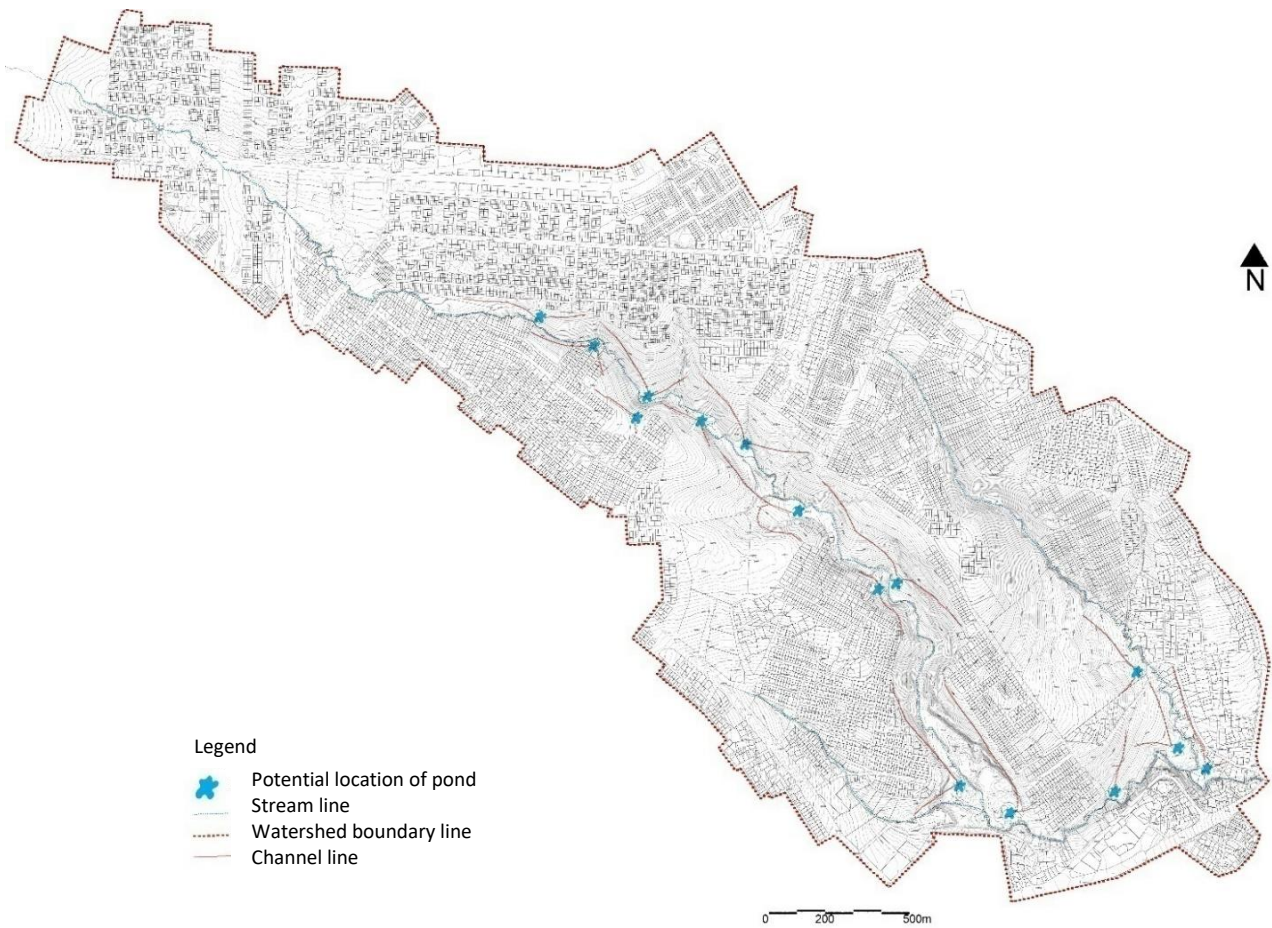


Fig-6.19: Watershed level reduced total runoff volume in the riparian area by introducing wet pond (retention pond) to restore stream health.

Table 6.19: Summary of proposed total cumulative runoff volume and percentage of imperviousness estimated for all land cover of the watershed including proposed asphalt road.

Land Cover	CN _{wt}	Area(m ²)	24hr. Peak Runoff Depth Q _{2y} (mm)	24hr. Peak Runoff Volume Q(m ³)		With rain g. %EIA	W/o rain garden % EIA
				q _{2y} tot.W/o rain g.	q _{2y} tot With rain g.		
Street and Road	72.6	1,478,958.8	7.62	11,269	3,690.95		
Residential District	72.6	2,726,295.2	7.62	19,943.6	6,803.85		
Commercial District	72.6	18,155.9	7.62	32.85	45.31		
Mixed-use Social Service and Inst.	72.6	65,608.2	7.62	156.3	163.73	4.66	14
Industry District	72.6	4,491.50	7.62	1,885.4	11.21		
Riparian	72.6	1,109,990.75	7.62	242.82	2,530.74		
Others	72.6	31,868	7.62	8118.9	79.53		
Stream	-	72,354.38	-	-	-		
Total		55,765,461.00			13,968.55		

*CN_{wt} for watershed level is **72.6**, q₂=7.62mm

Comparison of existing and proposed watershed level land use and land cover runoff volume and level of imperviousness

Using nature-based design techniques to reduce effective impervious area at the watershed level of the ordinary drainage system of estimated (EIA =27.8%), with some nature-based drainage techniques of estimated (EIA =14%), and where the drainage system has been designed using nature-based to achieve the maximum reduction in the effective impervious area of (EIA =4.66%) (see table-4.35 for details).

Table 6.20: Comparison of proposed and existing total cumulative runoff volume and percentage of imperviousness estimated for all land cover and land use of the watershed

Land Cover	Area(m ²)	24hr. Peak Runoff Volume Q(m ³)		%EIA	
		q _{2y} total (Existing)	q _{2y} total (Proposed)	Existing	Proposed
Street and Road	1,478,958.8	20,204.7	3,690.95		
Residential District	2,726,295.2	39,492.5	6,803.85		
Commercial District	18,155.9	309.3	45.31		
Mixed use	65,608.2	950.0	163.73		
Social Service and Inst.	257,738.3	3,732.1	643.22	27.8	4.66
Industry District	4,491.50	65.0	11.21		
Riparian	1,109,990.75	16,072.7	2,530.74		
Others	31,868	461.4	79.53		
Stream	72,354.38	-	-		
Total	5,765,461.00	81,287.7	13,968.55		

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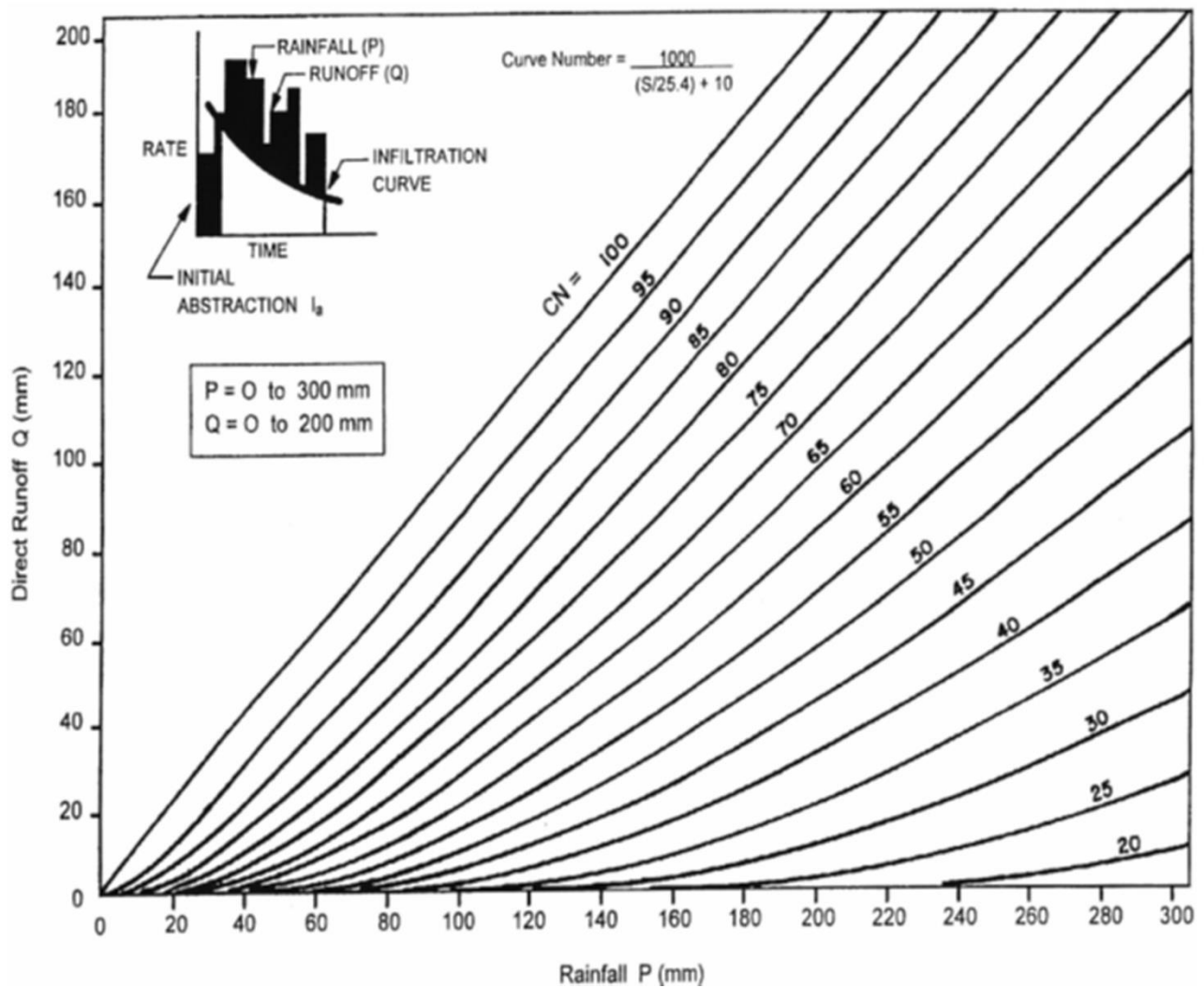
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Appendix 1: SCS Relation between direct runoff, curve number and precipitation

(ERA Drainage Design Manual (2002), From Steven et al (2009))



Appendix 2: Runoff curve numbers urban area (Steven et al. 2009).

Cover description	Curve numbers for hydrologic soil groups				
	Average % impervious area ²	A	B	C	D
Open space (lawns, parks, cemeteries, etc.) ³					
Poor condition (grass cover <50%)		68	79	86	89
Fair condition (grass cover 50 % to 75%)		49	69	79	84
Good condition (grass cover >75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm drains (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Desert urban areas:					
Natural desert cover		63	77	85	88
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average plot size:					
0.05 hectare or less	65	77	85	90	92
0.1 hectare	38	61	75	83	87
0.135 hectare	30	57	72	81	86
0.2 hectare	25	54	70	80	85
0.4 hectare	20	51	68	79	84
0.8 hectare	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

Appendix 3: Runoff curve numbers agricultural lands (Steven et al. 2009).

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing ²	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing	--	35	59	72	79
Brush-weed-grass mixture with brush the major element ³	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 ⁴	48	65	73
Woods-grass combination ⁵	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods ⁶	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 ⁴	55	70	77
Farms—buildings, lanes, driveways, and surrounding lots	--	59	74	82	86

¹Average runoff condition, and $I_a = 0.2S$

²Poor: < 50% ground cover or heavily grazed with no mulch

Fair: 50 to 75% ground cover and not heavily grazed

Good: > 75% ground cover and lightly or only occasionally grazed

³Poor: < 50% ground cover

Fair: 50 to 75% ground cover

Good: > 75% ground cover

⁴Actual curve number is less than 30; use $CN = 30$ for runoff computations.

⁵CNs shown were computed for areas with 50% grass (pasture) cover. Other combinations of conditions may be computed from CNs for woods and pasture.

⁶Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.

Fair : Woods grazed but not burned, and some forest litter covers the soil.

Good : Woods protected from grazing, litter and brush adequately cover soil.

Appendix 4: Runoff curve numbers arid and semiarid rangeland (adapted from Steven et al. 2009).

Cover type	Hydrologic condition ²	A ³	B	C	D
Mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Mountain brush mixture of small trees and brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Small trees with grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Brush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub brush	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

¹Average runoff condition, and $I_a = 0.2S$

²Poor :< 30 % ground cover (litter, grass, and brush overstory)

Fair : 30 to 70 % ground cover Good: > 70 % ground cover

³Curve numbers for Group A have been developed only for desert shrub

Appendix 5: Intensity, Duration and Frequency (IDF) (ERA Drainage Design Manual – 2002, Ethiopia Metreology Agency)

duration	IDF-Region A2& A3, mm/hr					
	frequency					
	2	5	10	25	50	100
5	94,1	122,4	143,8	172,1	193,5	214,9
10	79,3	103,2	121,3	145,1	163,2	181,3
20	55,8	72,6	85,3	102,1	114,8	127,5
30	43,5	56,6	66,5	79,6	89,5	99,4
60	27,1	35,3	41,5	49,6	55,8	62,0
90	20,2	26,3	30,9	36,9	41,5	46,1
120	16,3	21,2	24,9	29,7	33,4	37,1

Appendix 6: Years; Frequency Interval of Addis Ababa (ERA Drainage Design Manual – 2002, Ethiopia Metreology Agency)

Frequency (years)	2	5	10	25	50	100
24hours Depth (mm)	52	67	79	95	107	118

Appendix 7: Recommended runoff coefficients (C)

Urban Areas'

Downtown Business	0.70-0.95
Neighborhood Business	0.50-0.70
Single-Family Residential	0.30-0.50
Detached Multiunit Residential	0.40-0.60
Att ached Multiunit Residential	0.60-0.75
Suburban Residential	0.25-0.40
Apartment	0.50-0 .70
light Industry	0.50- 0.80
Heavy Industry	0.60-0 .90
Parks. Cemeteries	0.10-0.25
Playgrounds	0.20-0.35
Railroad Yards	0.20-0.35
Unimproved	0.10-0.30

Urban Surfaces

Roofs	0.80-0.95
Asphalt and Concrete Pavements	0.75- 0.95
Gravel	0.35-0.70

Soil Texture

Rural and Suburban Areas			
Woodland	Sandy Loam	Clay and Silt Loam	Clay
Flat (0-5% slope)	0.10	0.30	0.40
Rolling (5-10% slope)	0.25	0.3 5	0.50
Hilly (10-30% slope)	0.30	0.50	0.60
Pasture and Lawns			

Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated or No Plant Cover			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82

From Steven et al (2009), From American Iron and Steel Institute (1980), From Schwab et al (1971).