

Ethiopian Institute of Architecture, Building Construction, and City Development (EiABC)

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A Move from Grey to Green Arba Minch

By

Geremew G/mariam

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Author: Geremew Gebremariam

Date: June 2015

Ato Tibebu Assefa	_____	_____
Advisor	Signature	Date
Dr Fisseha Wegayehu	_____	_____
External Examiner	Signature	Date
Ato Alazar Assefa	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
Chair Person	Signature	Date

Declaration and Confirmation

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: Geremew Gebremariam Kuchufo

Signature:

Confirmation

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

Advisor's Name: Tibebe Assefa Woldeamanuel

Signature:_____

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Acronym

A.M	Arba Minch
BMPs	Best Management Practice
BOCUD	Bureau of Construction and Urban Development
CAD	Computer Aided Design
CIS	Corrugated iron sheet
CSA	Census Statistics Agency
CRGE	Climate-Resilient Green Economy
EGRS	Extensive green roofs
GIS	Geographic Information System
GWE	German Water Engineering
IC	Impervious Cover
mm^3/sec	million-meter Cube per Second
N	Nitrogen
P	Phosphorous
PVC	Poly Vinyl chloride

RHS	Rectangular hollow steel
TSS	Total Suspended Solids
UHI	Urban heat island
WSUD	Water Sensitive Urban Design

Abstract

The importance of green infrastructure in urban area is to maintain climatic condition, increase social and economic benefits of urban dwellers. Nevertheless, urbanization has destroyed urban green and open spaces and this creates problem such as climate change, pollution, and alteration of natural systems on urban dwellers.

The study investigates green infrastructure for Arab Minch city using mixed methodology and surveying methods. The research was conducted to the whole town by taking 68 sample blocks and plots based on systematic random sampling, primary and secondary datas were collected by the use of site survey and observation. Maps and Satellite images were utilized to quantitatively measure and observe the pervious and impervious land cover of the study area. The findings of the paper have been presented in maps, tables, graphs, and figures. Percentages had been used to show the situation in the site.

The findings of the paper revealed that the current green infrastructure cover is 45.14% and Grey infrastructures is 54.86 % which shows that the research area is degraded according to the standard because the grey infrastructure exceded 30% and needs intervension. Therefore the research has proposed design solution to reduce the grey infrastructure to less than 10% to meet the protected standard by redesigning urban grey infrastructures through water sensitive urban design approach.

CHAPTER ONE

1. Introduction

1.1.General Background

Urbanization is a phenomenon that happens in cities due to rapid population growth. In 2005, the human population of the world was more than 6.5 billion, and it is estimated that it will be over 9.1 billion by 2050 (United Nations, 2006). Therefore, infrastructures of urban areas are inadequate and the construction of new roads, streets, and sewage systems becomes inevitable to meet the needs of the population. Impervious surfaces are associated with the construction of new grey infrastructures which alters the natural system of storm water in urban areas, this causes flooding and over flow of rainwater in city that hamper the activities of people during rainfalls. In addition, urbanization causes the replacement of green space and open spaces by built-up areas which leads to urban degradation and climate changes (Rushtone, 2001; Coutts et al., 2008).

At the turn of the 20th century, Sub-Saharan Africa was a region without cities. Its urbanization rate was less than 5%, the same level as in Medieval Europe (Bairoch, 1988). It was 10% in 1950, as low as in Renaissance Europe. It is now around 40%, as high as contemporary Asia, or developed countries after the Industrial Revolution. Urbanization in Europe and Asia is usually seen because of economic development; as a country develops, people move out of the rural based agricultural sector into the urban-based manufacturing and service sectors. Yet Africa's urban growth has not been achieved in a period with only modest economic growth and without widespread industrialization. Africa has high rate of urbanization, which pressurizes the natural areas and is considered to contribute to have been devastated by development that take place in the continent (Shishay Mehari, 2011).

Today over 80 million people live in Ethiopia, and over 80% are living in rural areas. Population growth remains high at 2% and Ethiopia is expected to reach over 120 million people by 2030 (Government of Ethiopia, 2012). In Ethiopia, migration of people from rural to urban area is very high which fueled rapid urbanization in the cost of green areas and this leads to environmental degradation (FDRE PCC., 2008). Environmental challenges in Ethiopia include climate change, soil degradation, deforestation, loss of biodiversity and ecosystem services, and pollution of land, air and water. Ethiopia’s economy is also highly dependent on natural resources. Exploitation of these natural resources may generate large economic benefits in the short

term. However, in the long term unsustainable use of these resources not only increases environmental degradation, but also decreases economic growth and livelihood opportunities.

Arba Minch is one of the naturally gifted towns in Ethiopia. It is the largest town in Gamo Gofa Zone and the second town in SNNPR next to Hawassa. In the town, there are various natural resources like water bodies, vegetation, soil and other land uses. Arba Minch is losing its natural resources due to high rate of urbanization and lack of proper attention in planning, and management of urban landscape that has resulted in climate change, and increase in average temperature. However, still, there are no environmental interventions incorporated in the town. As a result, different problems have been occurred and have become a set of environmental issue that need to be considered in order to reduce the problems. Therefore, the design of GI elements to the existing grey infrastructures and landscape based on storm water management systems are carried to mitigate the problems and to make the town more Greener, livable and sustainable.

1.2. Problem Statement

City is a multi complex ecological system that made up of sub system such as social, economic, hard escape and soft escape. However, urban areas are dominated by hard escapes and this pose problem of climate change, pollution, and alteration of natural systems on urban dwellers.

Arab Minch town was very rich in green natural areas, but due to rapid urbanization, those natural areas had been replaced (wiped out) by new development that takes place in the town. Much of the study area is covered by constructed surfaces such as rooftops, sidewalks, roads, and parking lots covered by impenetrable materials such as asphalt, concrete and stone. Those impermeable materials increase the urban heat island effect acting as huge heat sinks and raising the overall temperature of the area, seal natural ground surfaces, repel water and prevent precipitation and melt water from infiltrating soil, increasing surface runoff, and making the area susceptible to risk of flooding. Hence, the main concern of this research is assessing and analyzing the existing situation of the town and emphasizing on areas of conservation of green space, implementation of GI elements to the existing grey infrastructures to mitigate the environmental problems and making the study area more greener through landscape based storm water management systems.

1.3.Objective

General

To make Arab Minch greener by reducing existing urban grey infrastructures through water sensitive urban design approaches.

Specific

To analyze pervious and impervious area of Arab Minch town

To sort-out spaces and structures for GI development / suitability

To introduce some water sensitive urban design elements such as green roof, green wall, and green streets of Arba Minch city.

1.4.Research questions

How could the gray Arba Minch town be greened?

1.5.Significance of the study

GI is a new idea that deals with greening of urban grey areas. This new concept can support students for further study. Scientific researchers can also use as a base to innovate new idea. In addition, Arab Minch city municipality can use it for implementing and controlling of urban development through GI and policy makers can use as an input in urban environmental policy.

1.6.Scope of the study

The research focuses on the administrative boundary of Arba Minch town, which has an area of 2177.14 hectares and Greening grey infrastructures with GI elements particularly green roof, green wall, and Green Street design.

1.7.Limitation

The research encountered limitations of data. There was a scarcity of well-organized base map; soil and geologic information; ground water table and others relevant for catchment characterization.

1.8.Research Methodology

Mixed methodology was used to collect GI data from the field and other data sources through surveying and observational methods. Extensive literature about GI was used to understand GI techniques of analysis for the research area.

1.8.1. Research Design

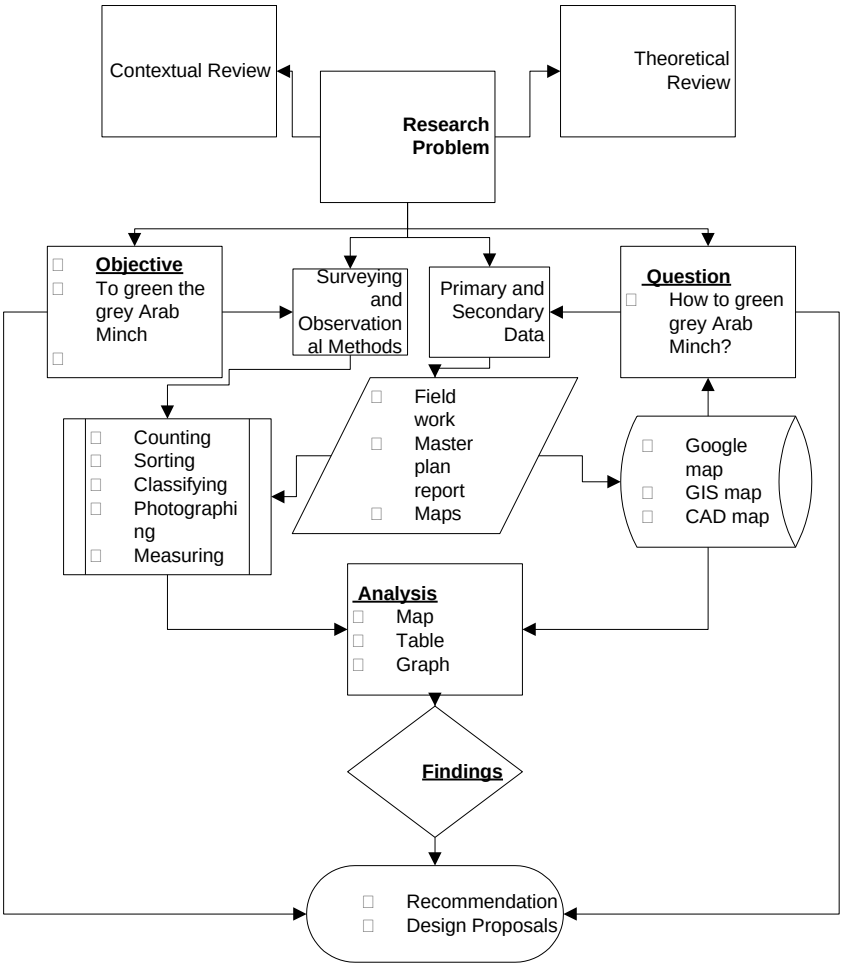


Figure 1 Research Design

1.8.2. **Data collection methods**

GI relays on primary data hence, a surveying and observation method was employed to collect data from fields. The data was collected through counting, classifying, sorting, GIS digitizing, photographing and sketching of buildings, plots, green and open spaces, blocks, streets and fences.

Table 1 collection method and techniques.

Data type	Source type	method	Techniques
primary	Maps (CAD)	GIS analysis	Shape file
	Google map	GIS analysis	Shape file
	Base map	GIS analysis	Shape file
	Field work	Surveying	Counting
			Classifying
			Measuring
			Sorting
		Observation	Photographing
			Sketching
Secondary	Books	Scanning and skimming	citing
	Journals		
	Reports		
	Articles		
	Magazines		

1.8.3. Data sampling

Purposive sampling methods have been employed to choose the sample blocks and plots from commercial, residential, mixed use services, administration, and transport land use. Thus, from the total study area 68 blocks and plots have been taken as a representative samples.

1.8.4. Data analysis

For accomplishing the objectives of the study and to answering the research questions, the researcher edited, coded, classified, and tabulated the collected raw data in order to make it ready for analysis. Information from primary and secondary sources was analyzed by using qualitative and quantitative methods. Data that have quantitative nature such as average, percentage and the like have been computed with Microsoft Excel software. Furthermore, spatial analyses were conducted using GIS (Geographic Information System), Arch CAD and Auto CAD software as analytical tools. Finally, the analyzed data's were presented with maps, tables, graphs, and pictures in the following table.

Table 2 Data Analysis

Data type	Software type	Means to present
Roof area	GIS	Table Map Graph
Street area	GIS Ms Excel	Map Table Graph
Green area	GIS	Map Table
Built-up area	GIS	Map Table

CHAPTER TWO

2. Literature Review

2.1.Green infrastructure

The term ‘green’ can be used to reflect the environment, environmentalism, nature or recycling (Benedict & McMahon (2002). The semantic nature of the term ‘green’ can be viewed as a long as Grey-Green continuum where the functions of green infrastructure cannot rigidly defined because of its interactions with different landscapes. The continuum represents a view that both grey and green are not necessarily steadfast infrastructure descriptions. Consequently, elements of the built landscape can be both grey in form (e.g. a cycle lane) and green in function (e.g. sustainable transport network). Furthermore, the use of the term green is subjective to each user and can constitute a number of diverse meanings.

Urban green space includes everything in cities that has vegetation. Collectively, it is sometimes referred to as “Green infrastructure” encompassing the entire working landscape in cities that serve roles such as improving air quality, flood protection, and pollution control (Girling and Kellett 2005).



Figure 2 the Grey-Green continuum
(Source: Sarah E. Francis Grey to Green 2008)

Grey space as the built environment incorporating buildings, pavements, and roads. High degrees of sealed surfaces such as concrete or asphalt provide no potential for plants or wildlife to live. In addition, it creates rapid runoff of rainfall into the drainage system and can lead to flooding. At its broadest, GI refers to an interconnected network of green space that conserves natural systems and provides assorted benefits to human populations (Benedict & McMahon, 2006). GI is an approach to managing storm water by infiltrating it in the ground where it is

generated using vegetation or porous surfaces or by capturing it for later reuse. GI refers to the techniques used to implement low impact development with regard to storm water.

The concept GI is thought as to have been originated in the United States in the 1990s emphasizing the 'life support' functions provided by the natural environment. Green Infrastructure can provide a range of tangible environmental services including storm water management, air quality improvement, carbon sequestration, and mitigation of urban heat island effects. However, the GI concept also includes the more anthropocentric functions of the natural environment including those related to human social, recreational, and cultural values. For example, Green Infrastructure has been described as an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations (Benedict and McMahon, 2002). Kosei concluded concept of green infrastructure that provides an environmentally friendly space where people can interact with environment in a similar manner as human interact with each other GI ideally provide educational and recreational opportunities through wild life reserves, hiking areas, golf courses, sports facilities, public gardens, bike trails, and other opportunities. In the urban area, it is critical to maintain the GI for the following reasons. If the place has lots of green environment can lead to positive benefit not only for the citizen but also for the ecosystem as well as improve the environmental quality (Kosei Takahashi, 2008). A typology of urban GI is suggested based on a classification of categories with in definition of the different types of urban green space. In London and New York According to Helen Wolley, the typology divides all GI in to four main categories such as amenity GI, functional GI, semi-rural habitats and liner GI (Helen Wolley, 2002).

2.2.GI Theories

GI is not new in the design field. It is dated back to prehistory ancient Ziggurat of Mesopotamia are the first described of man-made gardens were constructed above grade (Osmandson, 1999). Many of the flat landings of these stepped pyramids of stone had been planted with trees and shrubs. These vegetated terraces offered resting places and relief from the heat during the climb to the top of the structure. The Hanging Gardens of Babylon provide another legendary example of GI. The terraced structures have been supported by a series of vaults to hold the soil and plant material. Generally, GI had been seen in many ancient

civilizations of Egypt, India, Greek… the idea of integrating GI was to solve climatic condition (comfort) and to use local material and construction techniques (vernacular).

The depth of thinking to elaborate GI has been increased in the course of time, to mention some of the theories: Garden city, the theory of Howard in 1902; is to solve pollution and social problems by providing gardens and green belt (Corocic, 2009),communal garden space. While Broad acre theory by Wright, was advocating individual conquering of nature (Duany et al., 2003) and disperse densified city to enable individuals‟ enjoyment of open space and gardens. And also there were city beatification movements, to heal cities problem by parks and geometric orders (Levy, 2009). The most recent theory is linking theory, as its name implies that it links city with nature and advocates nature in city (Pickett et al., 2013). Bio-urbanism is also another theory emerged as recently as 2010. It is an inter disciplinary science which focuses on urban organisms and their complex interaction with urban systems (Caperna and Tracada, 2013).

2.3.GI Benefits

The GI benefits accentuated in urban and suburban areas where green space is limited and environmental damage is more extensive. The main benefits of vegetation or green space in hot climates are reduced solar radiation and lower air temperature due to shading and evapo-transpiration. Lower air temperatures are essential both to improve thermal comfort conditions of pedestrians and to limit energy use for cooling (Akbari, Pomerantz, Taha, 2001). Peak energy demand in the USA raises 2–4% for every 1°C increase in maximum air temperature. Among other factors, the effect of vegetation on the microclimate depends on the size of the vegetated area. While the cooling effect on the air temperature is limited for a single tree or a small group of street trees, larger areas such as parks can have a significant cooling effect (Oke, 1989). The evapo-transpiration of vegetated areas is highly dependent on soil humidity; for dry soils, which are common in urban areas due to sealing of the ground evapo-transpiration cooling, will be limited. There are also negative effects of vegetation in warm climates. One drawback with trees is that they block the wind a deciduous tree may reduce wind speeds by 30-40% (Ali-Toudert, & Mayer, 2008). Trees with large canopies will also reduce nocturnal cooling as they block some of the net outgoing long wave radiation. Several recent studies have shown that vegetation is beneficial in lowering air temperatures, in

providing shade and in improving thermal comfort. Field measurements showed that some tree-aligned streets and boulevards in the Tel-Aviv area, Israel, had 1–2.5°C lower air temperatures than non-vegetated streets at the hottest part of the day (15:00 h) (Shashua-Bar & Hoffman, 2004). The cooling effect was found to increase with rising number of trees. In the hot dry climate, shading trees could improve the thermal comfort in streets considerably. In another simulation, study of different greening scenarios found that an increased amount of urban green (tree cover of 30% of the ground and 100% green roofs) could nearly re-create the comfortable conditions of a natural forest (Spangenberg, 2004).

Permeable surfaces allow water to percolate through pavement or vegetation and reach a substrate layer that facilitates deep infiltration (Albanese and Matlack, 1999). A layer of gravel on top of soil has long been used as a permeable surface. This type of surface facilitates infiltration of water into the soil if the soil is not too compacted but this approach is not frequently used in urban areas (Gilbert and Clausen, 2006).

Impermeable surfaces do not provide water filtration and absorption functions such as asphalt and most building materials that caused changes in the types of ground cover due to intensification in urbanization (Rushtone, 2001; Coutts et al., 2008). Impervious surfaces associated with urbanization alter the natural storm water route resulting decrease in the volume of water that percolates into the ground and increase in volume and decrease in quality of surface water (Ellicott City, 2003).

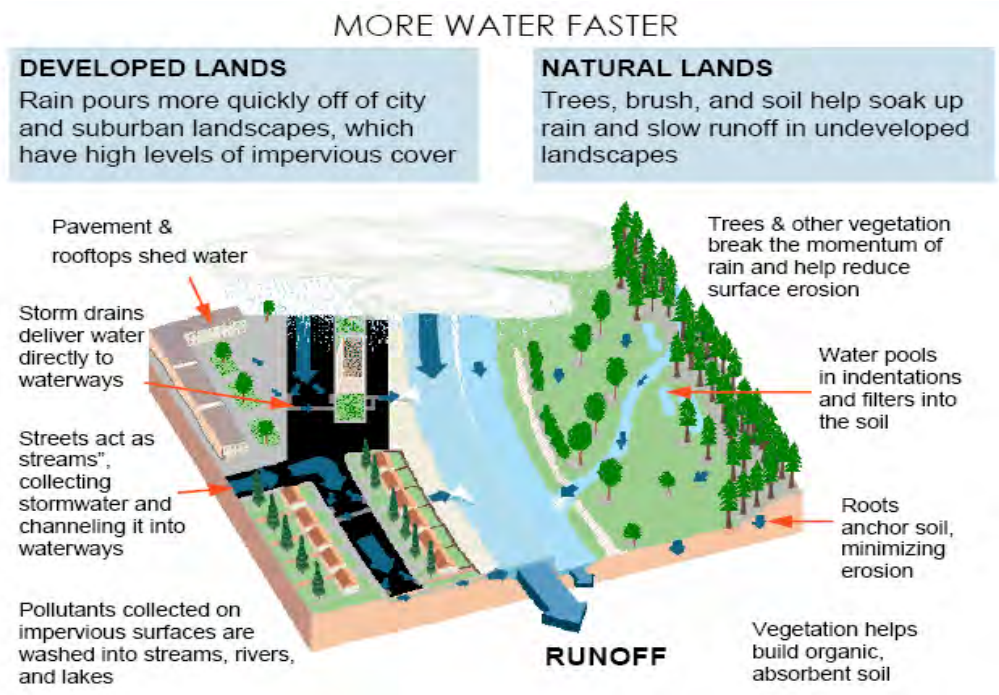


Figure 3 Impervious surfaces associated with urbanization alter the natural Path of storm water and cause flooding.
(Source: Keith A. Greer. 2005 How Urbanization Affects the Water Cycle)

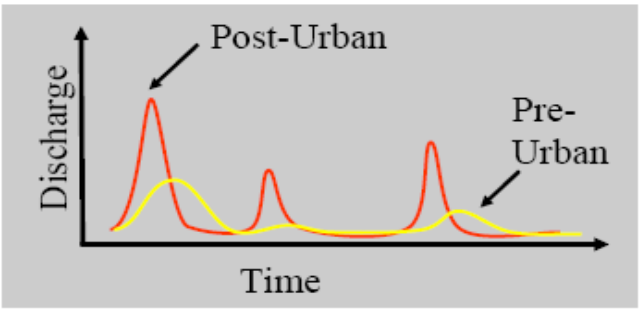


Figure 4 storm water peak discharges.

(Source: Keith & Greer. 2005 How Urbanization Affects the Water Cycle)

The hydrograph (above) illustrates storm water peak discharges in urban watershed (red line) and a less developed watershed (yellow line). In watersheds with large amounts of impervious cover, there is a larger volume and faster rate of discharge than in less developed watersheds often resulting in more flooding and habitat damage.

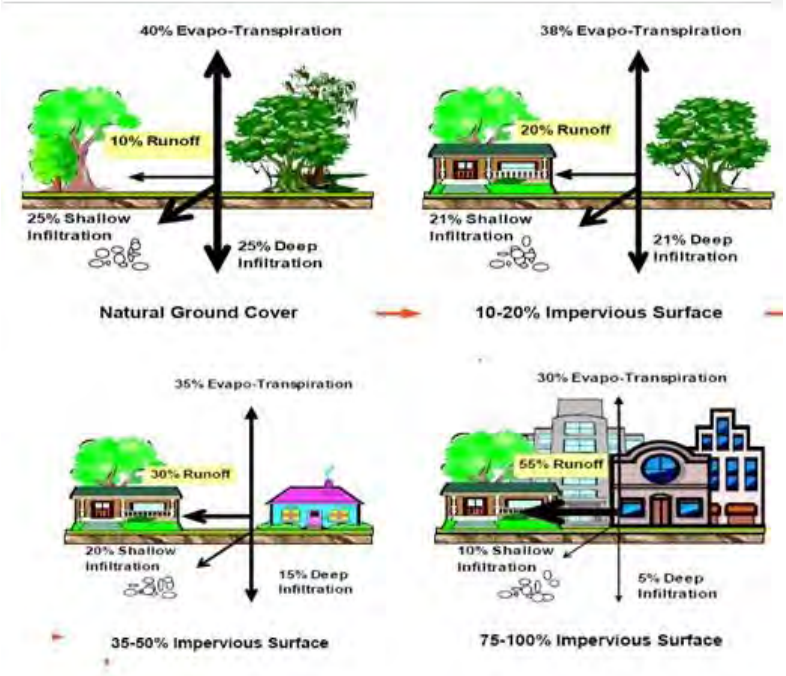


Figure 5 How impervious cover affects the water cycle.
(Source: Chester L. Arnold and C. James Gibbons. Journal of the American Planning Association. Spring, 1996)

According to Fig 5 above, Deep infiltration rate in cities is reduced to 15% due to change in natural ground surface associated with urbanization, and surface runoff is increased to 55% where as in the natural environment 50% infiltrates the soil and 10% runoff towards watercourse (Chester and James, 1996). The increased surface runoff requires more infrastructures to minimize flooding. Natural waterways end up as drainage channels and are mostly lined with rocks or concrete to move water more quickly and prevent erosion. In addition, as deep infiltration decreases the water table drops reducing groundwater for wetlands, riparian vegetation, wells, and other uses.

In most cases when impervious cover (IC) is less than 10% of a watershed streams remain healthy. Above 10%, impervious cover common signs of the following stream degradation are evident (Booth & Derek, 1991).

• Excessive stream channel erosion (bed and bank)
• Reduced groundwater recharge
• Increased size and frequency of 1-2 year floods
• Decreased movement of groundwater to surface water

• Loss of stream bank, tree cover

• Increased contaminants in water

• Increased fine sediment in stream bed

• Overall degradation of the aquatic habitat > 10% IC

2.4. Conceptual relationship between impervious cover (IC) and stream habitat quality

As seen in Fig - 6 Between 10 – 25% imperviousness major alterations in stream morphology occur that significantly reduce habitat quality. At greater than 25%, impervious cover streams suffer from loss of habitat, floodplain connectivity, and bank stability as well as decreased water quality.

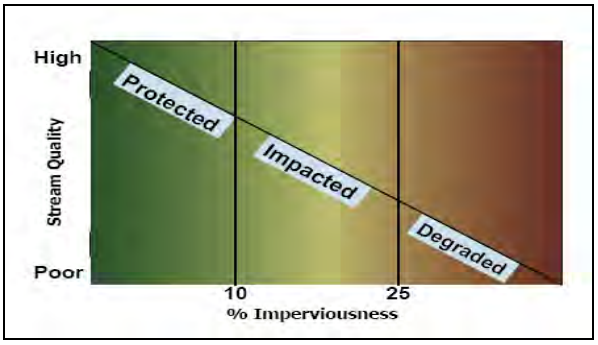


Figure 6 Conceptual relationship between impervious cover.
(source: American Planning Association. Spring, 1996.)

Impervious area calculation methods

Calculation methods of impervious areas have been developed for different urban areas using different conditions. The most common methods are total impervious area and effective impervious area, (EPA, 2011) the former uses for calculation of runoff water to design drainage canals in urban areas and it is a given standards (Table 3). While, the second one (effective impervious area) is used to calculate the water quality of watershed area and employs some term of conditions. These are Directly Connected Impervious Area (DCIA) and Indirectly Connected Impervious Areas (IDCIA). Table 3 shows the condition of (DCIA) and (IDCIA). DCIA means when rainwater flow from roof (gutter) into a street and IDCIA means also when rainwater flows from roofs in to some area (infiltrates) before reach to the street.

$IA_{Lui} =$ Total area Lui $*$%IA---------- (1)

Where,

IA_{Lui} = Total impervious area of a single plot land use

Lui = Single plot land use

%IA =Total impervious area percent of a single plot land use given Table 4

$TIA=\sum_{i=0}^{n} AI_{Lui}$---------- (2)

Where,

TIA = the summation of all impervious area of each plot land use within the Urban area.

Table 3 Directly Connected Impervious Area and Indirectly Connected

No	Watershed Selection Criteria	Assumed Land Use	. Equation (where IA(%)>1)
1	Average: Mostly storm sewered with curb & gutter, no dry wells or infiltration, residential rooftops not directly connected	Commercial, Industrial, Institutional/ Urban public, Open land, and Medium density residential	$DCIA = 0.1(IA)^{1.5}$ ------(1) Where, DCIA= Directly Connected Impervious Area IA=Impervious Area
2	Highly connected: Same as above, but residential rooftops are connected	High density residential	$DCIA = 0.4\ (IA)^{1.2}$ ------(2)
3	Totally connected: 100% storm sewered with all IA connected		DCIA = IA ----------(3)
4	Somewhat connected: 50% not storm sewered, but open section roads, grassy swales, residential rooftops not connected, some	Low density residential	$DCIA = 0.04(IA)^{1.7}$ ---(4)

	infiltration		
5	Mostly disconnected: Small percentage of urban area is storm sewered, or 70% or more infiltrate/disconnected	Agricultural; Forested	$DCIA = 0.01(IA)^2$ ---(5)

(Source: Roger C. Sutherland P.E. method of estimating effective impervious area)

Directly connected impervious areas are also considered as Effective Impervious Area (EIA) and it is related to the Total Impervious Areas (TIA) in the watershed urban area (Roger and Sutherland, 1983)

$EIA = 0.1(TIA)^{1.5}$, $TIA \geq 1$---------- (3)

$EIA = 0.4(TIA)^{1.2}$, $TIA \geq 1$---------- (4)

$EIA = TIA$, $TIA \geq 1$---------- (5)

$EIA = 0.04(TIA)^{1.7}$, $TIA \geq 1$---------- (6)

$EIA = 0.01(TIA)^{2.0}$, $TIA \geq 1$---------- (7)

Where

EIA = Effective impervious area

TIA = Total impervious area

Watershed area is an area of land in which water known as runoff drains across and moves down hill (slopes) towards river or other water bodies (Chamber, 2011). It is collection of rainwater that flows to one common converging area (Ministry of Agriculture and Rural Development, 2005). Water flows from higher position to lower position due to gravitational forces.

Calculation methods: different estimation method is used to calculate the amount of runoff volumes; mainly Rational Methods is used for small watershed areas. The calculation uses rainwater intensity, impervious area (runoff coefficient), regional factors, and time of concentration and assumes uniform rainfall intensity throughout the drainage areas.

Rational Method

One of the most commonly used equations for the calculation of peak flow from small areas is the rational formula, given as:

$Q = CIA/ K_u$---------- (8)

Where:

Q = Flow, m3/s

C = dimensionless runoff coefficient

I = rainfall intensity, mm/hr

A = drainage area, hectares, ha

Ku = units conversion factor equal to 360

Assumptions inherent in the rational formula are as follows:

• Peak flow occurs when the entire watershed is contributing to the flow.

• Rainfall intensity is the same over the entire drainage area.

• Rainfall intensity is uniform over time duration equal to the time of concentration, etc. The time of concentration is the time required for water to travel from the hydraulically most remote point of the basin to the point of interest.

• Frequency of the computed peak flow is the same as that of the rainfall intensity, i.e., the 10-year rainfall intensity is assumed to produce the 10-year peak flow.

• Coefficient of runoff is the same for all storms of all recurrence probabilities.

Because of these inherent assumptions the rational formula should only be applied to drainage areas smaller than 80 ha

Runoff Coefficient

The runoff coefficient, C in equation (8), is a function of the ground cover and a host of other hydrologic abstractions. It relates the estimated peak discharge to a theoretical maximum of 100 percent runoff. Typical values for C are given in table 4. If the basin contains varying amounts of different land cover or other abstractions, a composite coefficient can be calculated through areal weighing as follows:

Weighted C = ∑(Cx Ax)/Atotal ----------(9)

Table 4 Runoff Coefficients for Rational Formula

Type of Drainage Area	Runoff Coefficient, C*
Business:	
Downtown areas	0.70 - 0.95
Neighborhood areas	0.50 - 0.70
Residential:	
Single-family areas	0.30 - 0.50
Multi-units, detached	0.40 - 0.60
Multi-units, attached	0.60 - 0.75
Suburban	0.25 - 0.40
Apartment dwelling areas	0.50 - 0.70
Industrial:	
Light areas	0.50 - 0.80
Heavy areas	0.60 - 0.90
Parks, cemeteries	0.10 - 0.25
Playgrounds	0.20 - 0.40
Railroad yard areas	0.20 - 0.40
Unimproved areas	0.10 - 0.30
Lawns:	
Sandy soil, flat, 2%	0.05 - 0.10
Sandy soil, average, 2 - 7%	0.10 - 0.15
Sandy soil, steep, 7%	0.15 - 0.20
Heavy soil, flat, 2%	0.13 - 0.17
Heavy soil, average, 2 - 7%	0.18 - 0.22
Heavy soil, steep, 7%	0.25 - 0.35

Streets:	
Asphaltic	0.70 - 0.95
Concrete	0.80 - 0.95
Brick	0.70 - 0.85
Drives and walks	0.75 - 0.85
Roofs	0.75 - 0.95
Higher values are usually appropriate for steeply sloped areas and longer return periods because infiltration and other losses have a proportionally smaller effect on runoff in these cases.	

(Source: Johnny Morris (2001) urban design manual Second Edition)

2.5.Impervious surfaces and its impact

Impervious surfaces are mainly constructed surfaces--rooftops, sidewalks, roads, and parking lots--covered by impenetrable materials such as asphalt, concrete, and, stone. These materials effectively seal surfaces, repel water, and prevent precipitation and melt water from infiltrating soils. Impervious surfaces are nearly 100 percent hydrological active and high percentages of such surfaces occur within urbanized areas containing commercial, industrial, transportation, and medium to high density residential land uses (Novotny, and Chesters., 1981).

Other impervious hydrological active surfaces include compacted soils, high clay content soils, frozen soils, saturated soils, and soils with high groundwater tables. Paving watershed areas with asphalt and concrete makes these surfaces “desert like” in terms of hydrology and climate. Storm water washes over paved sparsely vegetated urban surfaces in much the same manner as it does over a desert landscape. Intense storms over urban and desert areas can quickly generate large volumes of runoff even flash floods followed by relatively dry conditions a short time later (Christopher son, .2001). Rapid runoff and the paucity of vegetation over these surfaces also reduce the amount of water available for evapo-transpiration. Therefore, much of the incoming solar energy that could have been, utilized to evaporate water is instead transformed

into sensible heat. This effectively raises the temperatures of these surfaces and of the overlying atmosphere. Moreover, impervious urban surfaces behave like rocky desert surfaces in that they tend to have high thermal conductivities and heat storage capacities in comparison to vegetated pervious surfaces (Douglas. 1983).

Table 5 Increases in impervious surfaces and its impact

	Resulting impacts				
Increased Imperviousness leads to:	Flooding	Habitat Loss	Erosion	Channel widening	Streambed alteration
Increased volume	X	X	X	X	X
Increased peak flow	X	X	X	X	X
Increased peak flow duration	X	X	X	X	X
Changes in sediment loading	X	X	X	X	X
Decreased base flow		X			
Increased stream temperature		X			
Increased stream acidity		X			
Increased water pollution		X			

(Sources: Grant, 2000; urbanization and streams: studies of hydrologic impacts, 1997)

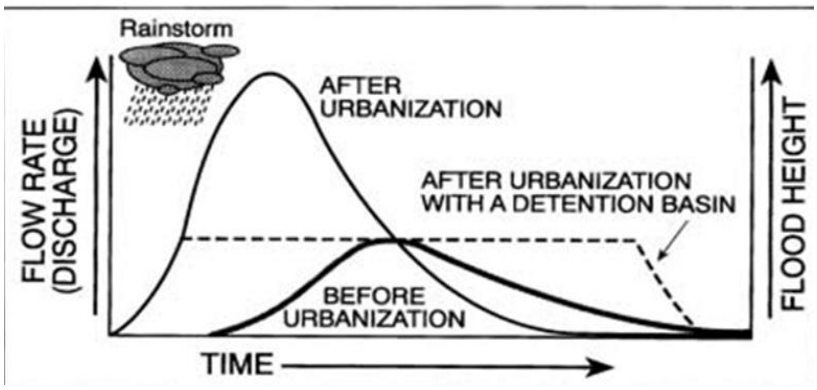


Figure 7 the impact of urbanization on storm water runoff
(Source: Harbor, 1994)

2.5.1. Flooding

Urbanization increases the frequency and severity of flooding due to increased runoff. Because of the decreased availability of pervious, permeable surfaces, and the related decrease in storage capacity, smaller more frequently occurring storms can create flooding problems. Hydrographs in urban streams peak higher and faster than streams in undeveloped areas. Surface runoff from impervious areas may be hundreds of times greater than runoff from some natural areas. Coupled with the effects of soil erosion and sedimentation in rivers and canals resulting from urban construction flooding in the low-lying areas is more frequent (Kasarda and Parnell, 1993).

2.5.2. Urban Heat Island Effect

Another drawback to the continued removal of green space from cities is the increase of the urban heat island effect. This describes the effect of cities - with their many square miles of concrete and asphalt - acting as huge heat sinks and raising the overall temperature of the area. Plants can cool air temperatures through evapotranspiration as "heat energy is drawn from the surrounding air to convert water to water vapor."

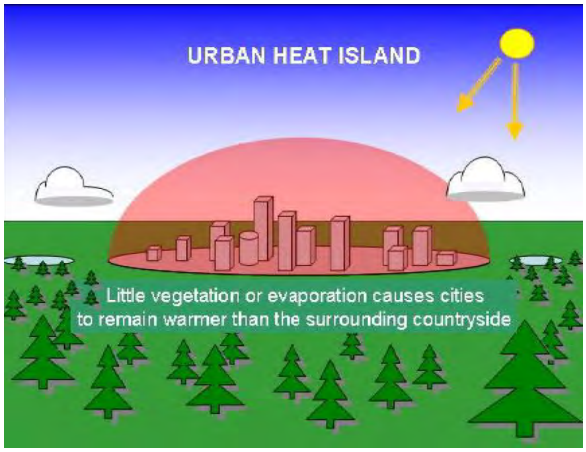


Figure 8 Figure 7 A depiction of the urban heat island effect.
(source: Grimond .S. 2007 Urbanization and Global Environmental Change).

The result is increased heat storage and production on such a scale that it even alters weather and rainfall patterns. The temperature variance between urban cores and rural areas can be as much as 7° Fahrenheit (Martinez, 2007). Adding plants back into the urban mix can begin to return temperatures back to those, which would be, considered normal (i.e. unaltered by human

civilization). The reduction in solar gain would mean less reliance on artificial indoor climate control (air conditioning) and thus less waste heat. If significant steps were taken to vegetate the walls, roofs and streets of urban areas, part of this heat island effect could be mitigated and perhaps someday eliminated altogether.

2.6. Elements of Green Infrastructure

Sustainable drainage systems, swales, wetlands, rivers and canals and their banks, and other water courses, parks, green spaces, urban landscaping and gardens, green roofs and walls Connections like footpaths, cycle ways, and wildlife corridors. Energy efficient infrastructure: wind turbines, solar panels, and sustainable design principles.

In the long term, Green Infrastructure has real benefits in terms of saving money and energy for residents and end users. The image of places can be improved and should be seen as property values including house prices are boosted. The appeal of green spaces with enhanced natural features and the availability green energy can attract new residents, tourists, creative people, entrepreneurs, businesses, and inward investment however; the scope of this paper does not include green energy.

2.6.1. Green Wall

A green wall or vertical garden prefers to all forms of vegetated wall surfaces. Green wall technologies may be divided in to two major categories such as green screens and living wall. (Hopkins and Goodwin 2011)

Green screens

Green screens are a type of green wall system in which climbing plants or cascading groundcovers are trained to cover specially designed supporting structures. Rooted at the base of these structures in the ground in intermediate planters or even on rooftops the plants typically take 3-5 years before achieving full coverage. Green screens can be anchored to existing walls or built as freestanding structures such as fences or columns. (Thompson and Sorving, 2008).





Figure 9: Green Screen Wall

(source: Randy Sharp and Jakob, Introduction to Green Walls Technology, Benefits & Design 2008)

Green screens support structures

Green screens differs greatly from living walls in how their plants are supported. Whereas living walls are concerned with providing a growing medium on the wall and keeping their plants rooted in it. Screens must provide support for the plants as they grow. Green screens do not create instant walls of vegetation; instead, their plants slowly grow up the support structure. (Dunnett, & Kingsbury, . 2008)

Living Walls

Living wall systems are composed of pre-vegetated panel's vertical modules or planted blankets that are fixed vertically to a structural wall or frame. These panels can be made of plastic, expanded polystyrene, synthetic fabric, clay, metal, and concrete, and support a great diversity and density of plant species

Soil cell (living wall plant growing medium)

Soil cells are a modular system composed of hundreds or even thousands of cells used as a media for planting. Each cell is filled individually with soil and whatever amendments are desired, and then planted as though it were a pot. The cells are then attached to a support system which have been connected to the building or wall. Generally, a metal frame on the exterior of the building, which was bolted into place, is sufficient but designs can vary between manufacturers. Key considerations here are being able to hold the combined weight of the cells

keeping them locked in place to prevent injury permeability to water and air and resistance to corrosion.



Figure 10 Soil cells, pre grown modular panel.
(source: Introduction to Green Walls Technology, Benefits & Design, 2008)

Equally important is the design of the cells themselves. Most cell systems use a trickle-down watering system that irrigates the top cells only and relies on gravity to provide water to those below. The cells must be designed as funnel water from one cell into the next to minimize water loss. The advantages of cell systems lie in their modularity and ease of construction. A single panel can be removed for repair or replanting at any time without disturbing the other plants. The panels' rectangular shape can be somewhat limiting aesthetically, however, and living walls using soil cells tend to take on a very geometric and squad appearance. Whatever the method used plants have a few common needs that cannot be compromised: sunlight, water, nutrients and something to support their weight (ELT Living Walls, 2006).



Figure 11 The exposed mounting frame during construction of a living wall.
(Source: The Green roof Project Database, 2006)

Green wall plant Selection

Plant selection is a critical aspect of designing green walls. The plants used differ tremendously between living walls and green screens, and each requires carefully chosen species that can tolerate the specialized environments.

Plants for Green Screens, Vines & Vine Morphology

Screens require any of a variety of climbing plants (vines) that are able to graft themselves onto structures which they use for support. Methods of attachment vary greatly among vines and determine which variety of plant can be, used on a given structure. Climbing plants can be divided up into five distinct groups based on their method of growth and attachment. (Western Garden Book)

These groups are:

- Plants with tendrils
- Plants with twining stems or leaves
- Plants with suction disks or pads
- Holdfasts, plants with aerial roots or stem roots
- Scramblers, which have no direct means of attachment

Vines with tendrils grow skinny wiry growths from their stems or leaves. The tendrils reach out in all directions until they make contact with an appropriate structure at which point they curl and wrap around the object. The combined tension on these coiled tendrils supports the weight of the plant. Peas (Pisum sativum), grapes (Vitis) and passion flower (Passiflora) are all examples of tendril plants. Because of their morphology these types of vines require a fine structure to attach to. Anything thicker than roughly 1/4" is too large for the tendrils to wrap around. Thin wires or string work best, so a trellis system using chain-link would be best suited for these plants (Western Garden Book).



Figure 12 examples of vine attachments.
(Source: Calkins, "A New Twist on Trellis Design." Landscape Architecture., 2000)

Twiners fall into two categories: twining stem and twining leaf vines. Twining stem plants have a stem that coils either clockwise or counter-clockwise – depending on species – around

the support structure. Twining leaf plants use their leaves in a fashion similar to tendrils which wrap around nearby objects. Whatever the plant meets tends to coil around. Species of Clematis have twining leaves, while Honeysuckle (Lonicera), Wistera and Jasmine (Jasminum) all has twining stems. Twiners are less picky about what structure they attach to and will do well even on thick arbor beams (Hart Farrell Hedberg, 2008).

Vines with suckers attach themselves through sticky pads or disks. These pads are less suited to attaching to a trellis system and do well on flatter surfaces, such as the side of a building or trunk of a tree. In this way, they are a less demanding plant for creating green screens though are not without their disadvantages. Their growth right up against buildings, rather than on a trellis system, means that they trap more moisture than other types of vines and can cause degradation in this way. Boston Ivy and Virginia Creeper (Parthenocissus tricuspidata and P. quinquefolia) are commonly used species that do well in most climates. Another disadvantage is the lack of control the owner has over where they grow. While twiners, scramblers, and vines with tendrils require some artificial latticework for them to grow on vines with suckers will grow to cover nearly any surface they meet. Constant pruning and management is required to keep them from totally engulfing a building. Holdfasts are a group of vines, which make attachments with small roots that grow out of their stems and cling to surfaces. Similar to suckering vines, holdfasts benefit little from trellis systems and prefer flat surfaces with some degree of unevenness to them, such as brick or stonework. Their stem roots grow into cracks and crevices and expand until they can provide enough tension to help support the vine. English ivy, Irish Ivy (Hedera helix and H. hibernica) and Hydrangea are examples of holdfasts. This group of vines is notorious for finding its way into weak points in building exteriors and exacerbating structural problems. Over time, their stem roots can expand cracks and split already weakened hardscape materials. Like vines with suckers, holdfasts will also grow wherever they please and must be periodically, pruned. The final group of vines is sometimes referred to as scramblers, or those vines, which have no means of attaching to the structures they climb. Bougainvillea and roses (Rosa sp.) are commonly seen examples. These plants have long flexible stems that can be loosely woven through a supporting structure such as a trellis or arbor. Scramblers are often woody and possess thorns which can help grip and entangle nearby structures. While they may be showy, these plants are not low maintenance due to their relative inability to climb without assistance. Their shrubby form also limits their

height to significantly less than what other climbers can attain, even with their limbs tied or tacked in place. On the other hand, their woody and thorn-covered stems can form a painful deterrent to would-be trespassers.

Plants for Living Walls

Patrick Blanc whose background is that of a botanist turned landscape architect/interior designer (Hohenadal, 2007). His fascination with cliff-dwelling plants led him to experiment with bringing these plants back into urban settings where they otherwise have been relegated to horizontal surfaces. He describes the occurrence of these plants and its influence on his work: "For instance in Malaysia, 2,500 out of the 8,000 known species are growing without any soil. Even in temperate climate zones many plants grow on cliffs, cave entrances or cracked up rocks. On these rather steep places many Berberis, Spiraea, and Cotoneaster species are able to grow. Their naturally curved branches indicate that they originated from natural steep biotopes and not from flat areas like the gardens where they are usually planted. Therefore it is possible for plants to grow on virtually any vertical surface nearly free-of-ground as long as there is no permanent shortage of water. One of the key concerns is the amount of light these plants receive. Indoor living walls suffer from one of the same problems indoor potted plants do: they receive minimal light. The problem can be addressed partly through smart placement of light fixtures and skylights but the biggest gains can be seen by using shade-tolerant plants. Plant geneses adapted to low light tend to have large thin leaves year-round and are often seen living under thick tree canopies (Vowles, 2007). Queen's University in Canada has an indoor living wall used for studying biofiltration that uses much same plants. Some notable additions are rubber plant, snake plant, and ficus all of which are reported to thrive (Queen's University, 2006).



Figure 13 Tropical plants used by living wall systems.
(source: Dunnett, N. & Kingsbury, N. (2004) Planting Green Roofs and Living Walls, Portland, Timber Press)

Cremnophytes

Another important consideration for living walls is the physical plant structure including height and root structure. Whether using soil cells or hydroponics the growing medium available for plants is going to be at most a few inches deeper. Plants with deep growing roots those with taproots should not be considered. It is understood that taller, heavy plants such as large shrubs and trees simply will not have the depth necessary for them to take root and hold themselves onto a vertical surface. Ground covers and very low growing shrubs are better suited to this environment. Plants that have naturally adapted to growing on cliffs are sometimes referred to as cremnophytes. This term applies to any plant, which often found on cliff surfaces. Plants, which are able to grow on cliffs but are found mainly on flat surfaces, are called opportunistic cremnophytes. Species vary widely but share a tolerance for harsh conditions including species of Aloe in southern Africa and columbine (Aquilegia sp.), nodding wild rye (Elymus Canadensis) and species of lichen to name a few in Minnesota (Department of Natural Resources of Minnesota).

2.6.2. **Green roofs**

Civilization in Mesopotamia originated the concept of green roof, (Dunnett.and Kingsbury., 2004) and Greeks, Romans, Persians, and other cultures had some form of roof gardens to green and cool their often brutally hot landscapes. The famed hanging garden of Babylon, for example, was actually planted on rooftops (Edmund. Snodgrass, 2006). Planted roof or green roof is a roof that consists of vegetation and growing medium (Dunnett. & Kingsbury, 2004). It is also defined as roof that supports vegetation. There are two types of green roofs: intensive roofs, which are thicker and can support a wider variety of plants but are heavier and require more maintenance and extensive roofs, which are covered in a light layer of vegetation and are lighter than an intensive green roof. The term green roof may also be used to indicate roofs that use some form of green technology such as a cool roof a roof with solar thermal collectors or photovoltaic panels. Green roof can be divided into two distinguished types, which are considered either as extensive or intensive. According to (Osmundson, 1999), intensive green roof or generally known as roof garden can only be built on the roofs of building that are strong enough to support the load. They are ideally suited to reinforced–concrete structures and steel frame. A green roof or living roof is a roof of a building that is partially or completely covered with vegetation and a growing medium planted over a waterproofing membrane. It

may also include additional layers such as a root barrier and drainage and irrigation systems. Rooftop ponds are another form of green roofs, which are used to treat grey water. Green roofs serve several purposes for a building, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, and helping to lower urban air temperatures and mitigate the heat island effect.

Extensive green roofs (FGFs)

The use of a shallow growing medium or substrate to support rooftop vegetation constitutes an Extensive Green Roof (EGR). In this situation, plantings are predominantly designed to provide functional benefits whilst requiring minimal maintenance.

The functional benefits provided by EGRs address a number of environmental, economic, and social issues arising from increased urbanization. EGRs have an insulation effect that reduces the need for air conditioning to cool buildings in summer. In temperate North America, a cost-benefit analysis of an EGR on a retail store found small but significant reductions in energy consumption (Kosareo and Ries 2007). In warmer climates, much greater reductions in energy usage are likely to result. Wong et al. 2007 found that in Singapore over 60% of heat gain by a building could be stopped by an EGR. In subtropical southern China, less than 2% of the heat gained by an EGR during a 24 h period in summer was retained by the plants and substrate or transferred to the building below. The remainder was lost through evapo-transpiration, re-radiated to the atmosphere, or used in photosynthesis (Feng et al. 2010, Susca et al., 2011). Implementation of EGRs on a large scale has the potential to reduce urban heat island (UHI) effects. Susca et al. 2011 reported an average 2°C temperature difference between areas of New York city that have high and low levels of vegetation. EGRs with their biological activity high thermal resistance and low surface albedo compared with traditional bitumen rooftops were considered a useful way of combating this UHI effect. Other benefits include carbon sequestration (Getter et al. 2009), reductions in air and noise pollution (Yang et al., 2008; Van Renterghem and Botteldooren, 2008); habitat provision for wildlife (Coffman and Davis, 2005), and extended roof membrane longevity (Köhler and Poll, 2010). Socially, a general sense of enhanced well-being is also gained by virtue of the aesthetic value of plants (Maas et al., 2006).

Extensive green roofs Plant selection

Low growing plant species that establish quickly to provide good coverage of the substrate are generally recommended. Snodgrass prescribe an ideal rate of spread of between 15-25 cm in the first year for plants transplanted as plugs and caution against using plants with more aggressive growth rates. Drought tolerance is another highly desirable trait. The shallow substrate of non-irrigated extensive green roofs can regularly dry out and drought tolerant species can better maintain adequate vegetation cover during these periods. In Singapore, it has been estimated that a green roof substrate can be depleted of moisture for 4 days or more in eight out of 12 months of the year despite the region's high rainfall and humidity (Yok and Sia, 2008). Drought tolerance takes various botanical forms, including succulent leaves, thick leaf cuticles, in-rolled leaf margins, or curved leaf surfaces, grey or silver foliage; compact twiggy growth, and small evergreen leaves (Dunnett and Kingsbury, 2008). Plants that rely on deep taproots for drought tolerance are however unsuitable for extensive green roofs (Snodgrass, 2006). In order to provide consistent long-term vegetation cover, the green roof planting should be comprised predominantly of hardy succulents or herbaceous perennials. Grasses can also be useful but regular thatch removal is generally required to reduce fire risk. Plants that have the ability to self-propagate, such as geophytes or self-seeding annuals, can be used for seasonal interest - provided they do not become invasive. A root system that gives good anchorage for the plant and which binds the substrate together is desirable to prevent substrate scouring / erosion from strong winds or heavy rainfall. This is best achieved by using species with a shallow and dense rooting system and with stems that root into the substrate as they grow.

Plant types for green roofs

Plants are usually classified as annuals, biennials or perennials based on yearly and continuing growth cycles. Annuals grow flower, set seed, and die in one growing season such as marigolds, petunia, corn, and squash. Biennials grow vegetation the first growing season, and then they flower, set seed, and die the second growing season. Biennials are not generally used on green roofs as they create gaps in the roofs cape after they finish blooming and die such as radish, cabbage, onions, mustard, and bluebonnets. Perennials grow, flower, and set seed in

one or more growing seasons and they do not die after setting seed such as woody shrubs, trees, and many grasses (Snodgrass, 2006).



Figure 14 intensive and extensive Green roofs.

(Source: Groundwork Sheffield - Green roof developers guide 2011)

Components of green roof

The term green roof actually denotes a system comprises several components or layers that work together to function as a single combined unit. All of the systems component must have been designed for a similar life span so that no single layer fails prematurely and necessitates replacement of entire system. Functional layers of a typical extensive green roof:

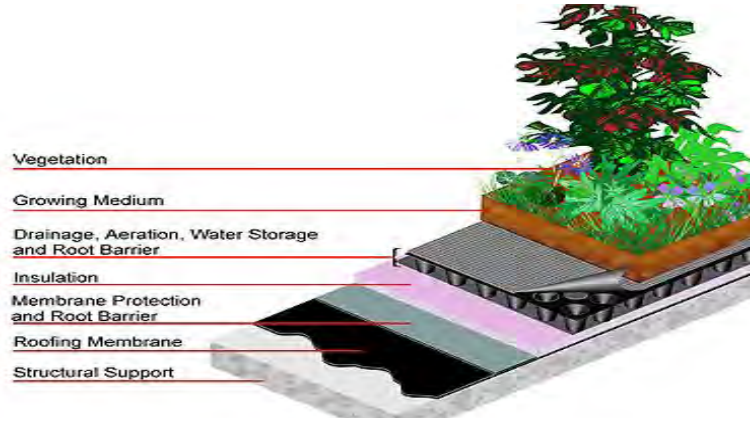


Figure 15 Components of green roof

(source: Snodgrass, A Resource and Planting Guide, Portland, Timber Press 2006)

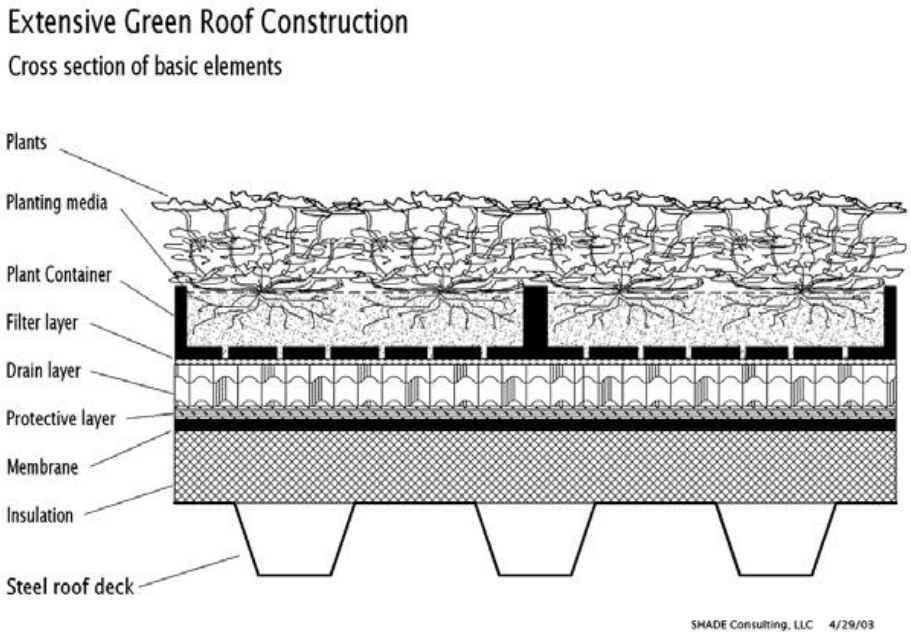


Figure 16 Extensive green roof cross section

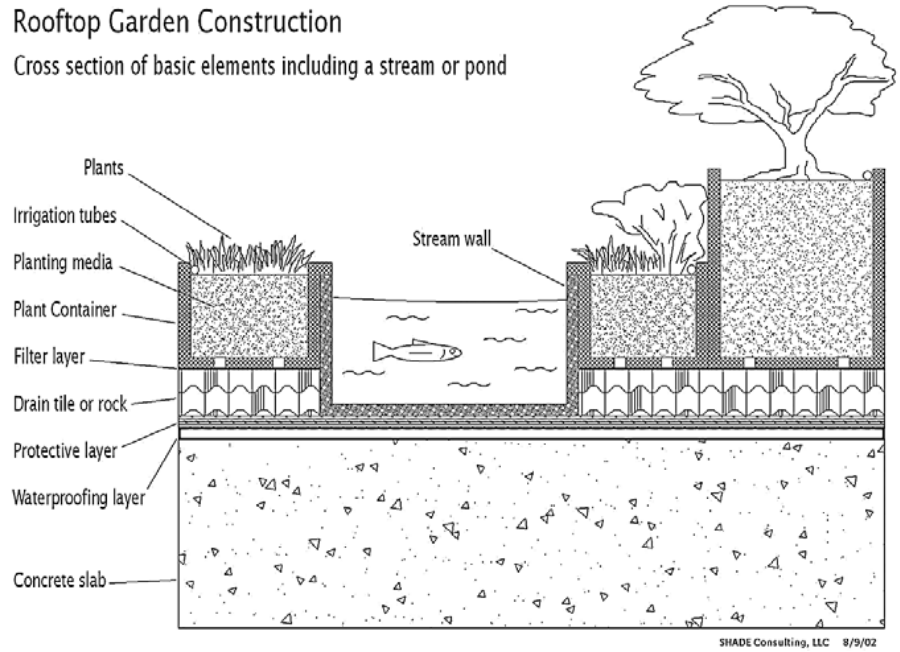


Figure 17 Intensive green roof cross section

Description of Green Roof components

The components used in green roofs are generally the same as those in rooftop gardens differing only in depth and project-specific design application (Figures 1 and 2), and include the following:

Vegetation

Almost any plant can be put on a roof. The only limitations are climate, structural design and maintenance budgets, and the roofs cape designer's imagination. Since green roofs are typically lightweight, they often contain ground cover that can thrive in very shallow soils with little to no maintenance.

Planting medium

Not to be confused with soil, the planting medium is distinguished by its mineral content, which is synthetically produced and expanded clay. The clay is considerably less dense and more absorbent than natural minerals providing the basis for an ultra-lightweight planting medium. Perlite is a common form of expanded clay and is found in garden nursery planting mix (not planting soil). The types of expanded clays used in green roofs are also used in hydroponics.

Filter layer

Somewhere between the planting media and drain layer lies a filter which not only allows water to flow through while retaining the planting medium but also serves as a root barrier. The filter usually comprises one or two layers of non-woven geotextile, where one of the layers may be treated with a root inhibitor (i.e. copper or a mild herbicide). As in many landscaping applications filter fabric can also be used to control erosion at the surface of the planting medium.

Containment

In modular systems, containment refers to actual plant containers. In non-modular systems, the planting medium is supported by the drain layer and contained at the perimeter by a metal plastic barrier or the roof parapet.

Drain layer

Between the planting medium and roof membrane is a layer through which water can flow from anywhere on the green roof to the building's drainage system. Some systems simply use a layer of large-diameter expanded clay, but most green roof companies now use a corrugated

plastic drain mat with a structural pattern resembling an egg carton or landscape paver. The minimum drain layer thickness is usually less than 20 mm (0.8 in), but a thicker mat can provide additional insulation and root restriction.

Protective layer

The roof's membrane needs protection primarily from damage during green roof installation, but also from fertilizers and possible root penetrations. The protective layer can be a slab of lightweight concrete, sheet of rigid insulation, thick plastic sheet, copper foil, or a combination of these, depending on the particular design and green roof application. Some green roof systems do not necessarily require a protective layer.

Insulation

The thermal protection provided by the vegetation planting medium and drain layer sufficiently eliminates the need for additional insulation in warm dry climates. However, building codes usually require a certain level of added insulation, regardless of the overall roof design.

Waterproofing

A green roof can be installed with any kind of waterproofing system, but single-ply membranes have become very popular in recent years and are specified by nearly all green roof companies for their cost effectiveness and simplicity. As such the waterproofing layer is typically assumed a membrane.

Irrigation

Watering systems used in landscaping can be adapted to rooftop applications but several commercial green roof designs combine passive irrigation methods with active components. Passive irrigation describes the process of storing rainwater in the drain layer which eventually wicks back up through the planting medium while excess is allowed to drain off. One type of water storage medium is a polypropylene fiber mat directly below the planting medium, which acts as a sponge. Other types include small reservoirs in the drain mat filled with expanded clay up to the bottom of the planting medium. Irrigation is rarely necessary however when drought-tolerant plants like sedums are used.

2.6.3. Green Street

A Green Street is a street right-of-way that through a variety of design and operational treatments gives priority to pedestrian circulation and open space over other transportation

uses. The treatments may include sidewalk widening, landscaping, traffic calming, and other pedestrian-oriented features.



Figure 18 Green street. (source: Nijmegen, NL)

• Improves air quality at street level by up to 30%
• Creates a comfortable microclimate along streets for pedestrians and bicycles
• Provides structure and orientation in urban environments

Permeable Pavement

Permeable pavement incorporates the use of permeable asphalt or concrete, plastic grid systems, or pavers to form a durable and attractive surface that water can infiltrate. These applications are designed to allow water infiltration and produce almost no runoff. In fact, permeable pavement areas can be receiving areas (sinks) for runoff from other areas of the home; by directing water to these areas, significant amounts of runoff can be captured. These permeable surfaces can be incorporated into existing driveways and walkways or can be installed in new applications. As water flows through the pavement it is then filtered by the sub-base gravel and soil under the pavement, and infiltrates into the ground (Adams, & Michelle. 2003).

Table 6 permeable pavers

Type of Paving System	General Description of Paving System	Adopted TSS Removal Rate
Porous paving	Porous asphalt or concrete paving constructed over runoff storage bed of uniformly graded broken stone	80%
Permeable pavers with storage bed	Impervious concrete pavers with surface voids constructed over runoff storage bed of uniformly graded broken stone	80%
Permeable pavers without storage bed	Impervious concrete pavers with surface voids constructed over structural bed of sand and crushed stone	Volume reduction only

(Source: New Jersey Storm water BMP Manual 2004)

Porous Paving Details

Porous paving systems consist of a porous asphalt or concrete surface course placed over a bed of uniformly graded broken stone. The broken stone bed is placed on an uncompacted earthen sub grade and is used to temporarily store the runoff that moves vertically through the porous asphalt or concrete into the bed. The high rate of infiltration through the porous paving is achieved through the elimination of the finer aggregates that are, typically, used in conventional paving.

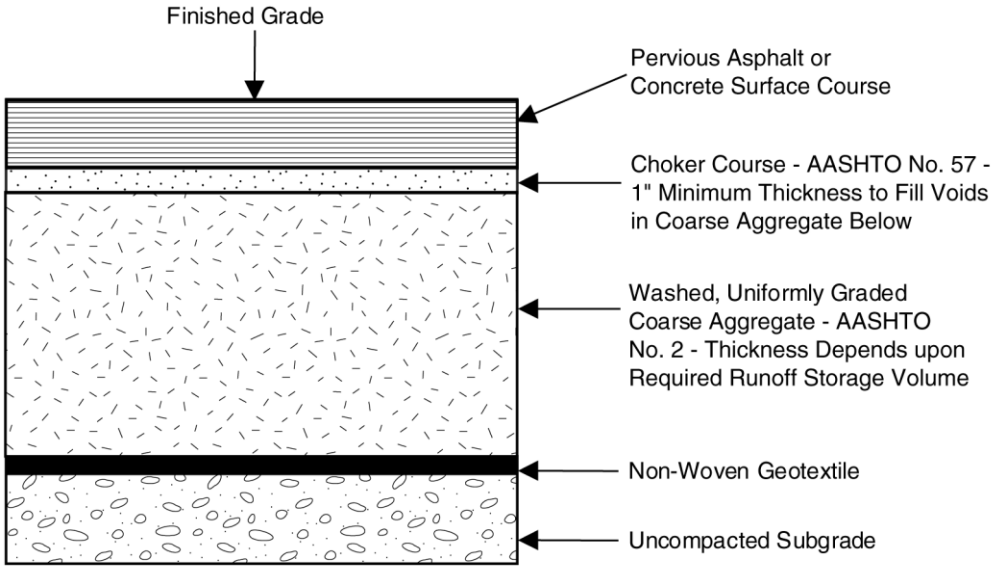


Figure 19 Porous paving Details.

(Source: New Jersey Storm water Best Management Practices Manual 2004)

Permeable Pavers with Storage Base

A permeable paver with storage bed system also has a subsurface storage bed and functions in a similar manner to a porous paving system. However, instead of a continuous porous asphalt or concrete surface course the system's surface consists of impervious concrete blocks known as pavers that either have void spaces cast into their surfaces or interlock in such a way as to create such void spaces that allow storm water to pass to the sub-base and infiltrate into underlying soils.

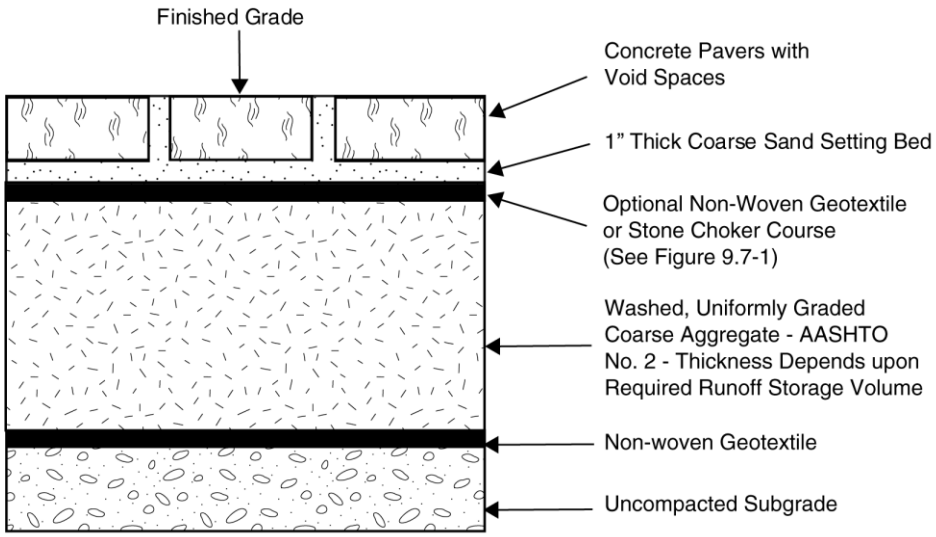


Figure 20 Permeable Pavers with Storage Base.

(Source: New Jersey Storm water Best Management Practices Manual 2004)

Permeable Paver without Storage Base

Permeable paver, without a storage bed, is the third type of pervious paving system. As described by its name, this type of system does not have a broken stone runoff storage bed beneath it. Instead, the permeable pavers are placed on a generally thinner bed of sand and crushed stone that provides only structural support to the paver surface course and has no significant runoff storage volume. This lack of storage volume prevents the system from storing and infiltrating the relatively larger volumes of runoff typically achieved by a porous paving or permeable paver with storage bed system.

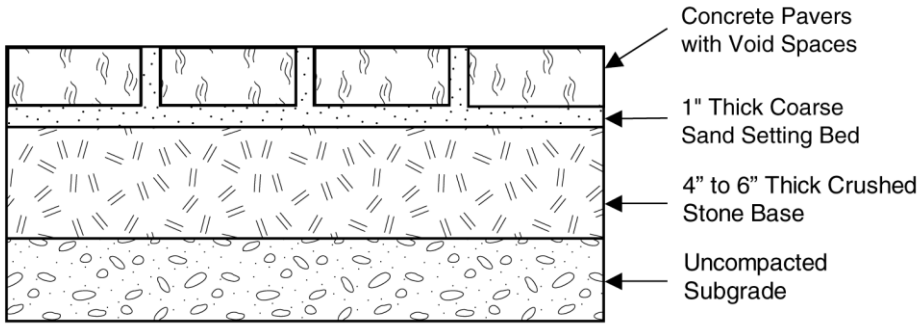


Figure 21 Permeable Paver without, Storage base (Source: New Jersey Storm water Best Management Practices Manual 2004)

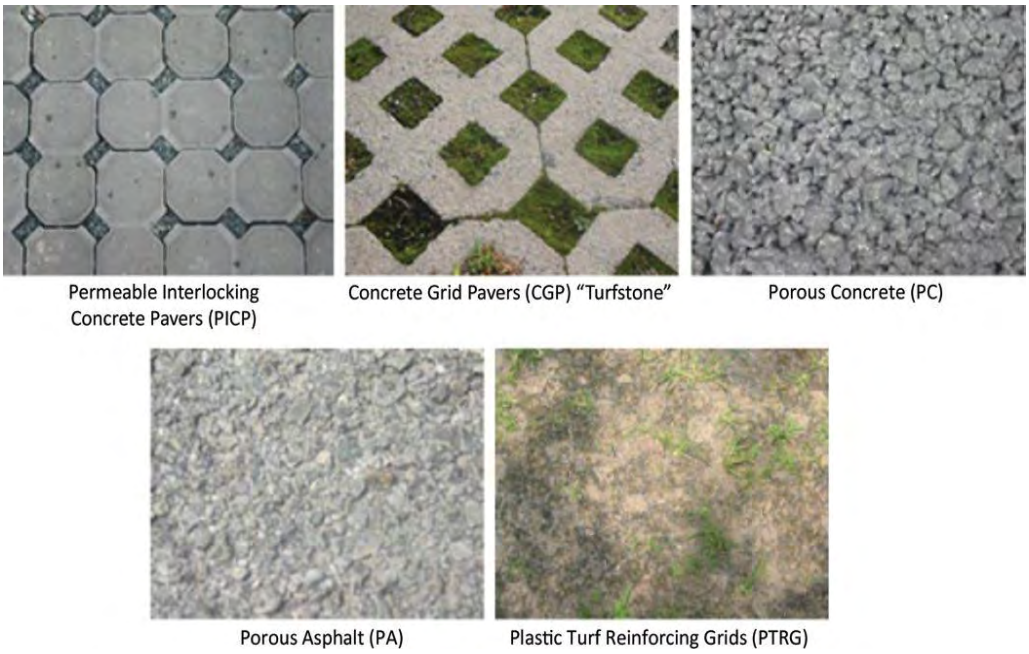


Figure 22 Examples of porous and permeable pavers.
(Source: N.C. State University 2011).

Figure above shows how interlocking concrete and concrete grid pavers and plastic turf reinforcing grid, porous asphalt, and porous concrete are placed over sand setting bed under it.

Rainwater harvesting

Where there is no surface water where groundwater is deep or inaccessible due to hard ground conditions or where it is too salty acidic or otherwise unpleasant or unfit to drink another source must be sought. In areas that have regular rainfall, the most appropriate alternative is the collection of rainwater called 'rainwater harvesting'. Falling rain can provide some of the cleanest naturally occurring water that is available anywhere. This is not surprising as it is a result of a natural distillation process that is at risk only from airborne particles and from man-made pollution caused by the smoke and ash of fires and industrial processes particularly those that burn fossil fuels.

The term 'rainwater harvesting' is usually taken to mean the immediate collection of rainwater running off surfaces upon which it has fallen directly. This definition excludes run-off from land watersheds into streams, rivers, lakes, etc (Malesu, Oduor, Odhiambo., 2008); Rainwater harvesting consists of a wide range of technologies used to collect, store and provide water with the particular aim of meeting demand for water by humans and/or human activities (SIWI., 2001).

Basic Components

Regardless of the complexity of the system, the rainwater harvesting system comprises six basic components:

Catchment surface: the collection surface from which rainfall runs off

Gutters and downspouts: channel water from the roof to the tank

Leaf screens, first-flush diverters, and roof washers: components which remove debris and dust from the captured rainwater before it goes to the tank

One or more storage tanks, also called cisterns

Delivery system: gravity-fed or pumped to the end use

Treatment/purification: for potable systems, filters and other methods to make the water safe to drink

The Catchment Surface: The roof of a building or house is the obvious first choice for catchment. For additional capacity, an open-sided barn – called a rain barn or pole barn – can be built. Water quality from different roof catchments is a function of the type of roof material, climatic conditions, and the surrounding environment (Vasudevan, 2002).

Gutters and Downspouts: Gutters are installed to capture rainwater running off the eaves of a building. Some gutter installers can provide continuous or seamless gutters. For potable water systems, lead cannot be used as gutter solder, as is sometimes the case in older metal gutters. The slightly acidic quality of rain could dissolve lead and thus contaminate the water supply. The most common materials for gutters and downspouts are half-round PVC, vinyl, pipe, seamless aluminum, and galvanized steel.

Leaf Screens: To remove debris that gathers on the catchment surface, and ensure high quality water for either potable use or to work well without clogging irrigation emitters, a series of filters are necessary. Essentially mesh screens remove debris both before and after the storage tank.

Storage Tanks: The storage tank is the most expensive component of the rainwater harvesting system. It is made of different materials such as plastic, metal, concrete, masonry, and wood according their use and capacity of water they can store.

Delivery system: The laws of physics and the topography of most homesteads usually demand a pump and pressure tank between water storage and treatment and the house or end use.

Treatment / purification: For potable water systems, treatment beyond the leaf screen and roof washer is necessary to remove sediment and disease-causing pathogens from stored water. Treatment generally consists of filtration and disinfection processes in series before distribution to ensure health and safety (Asudevan L., 2002).

2.7.Water Sensitive Urban Design (WSUD)

It is a technique developed for environmental benefits and improvements in the area of water consumption, water recycling, waste minimization and environmental protection, employed urban landscape, reducing pollutant export, retarding storm flow and reducing irrigation requirements (Allison, & Francey, 2005). WSUD has some elements of techniques that used in urban watershed areas. These are sediment basin, bio-retention swale, bio-retention basins, sand filters, swale/buffer system, constructed wetlands, ponds, infiltration measures and aquifer storage and recovery. Although Water Sensitive Urban Design considers all parts of the urban water cycle, storm water is a key element both as a resource and for the protection of receiving rivers (Melbourne Water 2005).

Bio-retention Swale: is a storm water treatment and conveyance system and installed in the base of swale to convey minor floods. The swale component provides pretreatment of storm water and remove coarse to medium sediments and other associated contaminant.

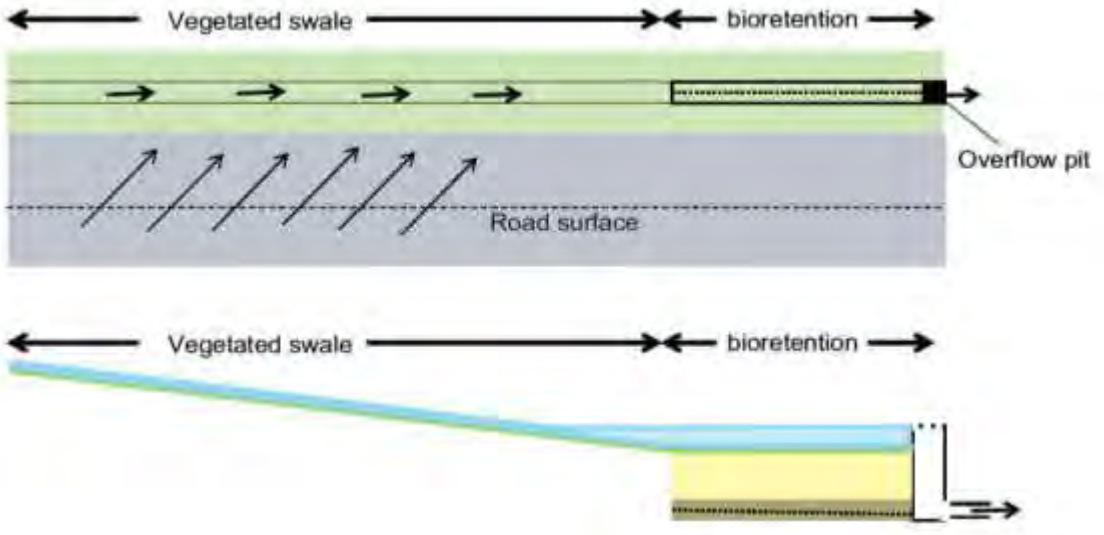


Figure 23 Bio-retention Swale lay Out (Source; Allison & Francey, 2005)

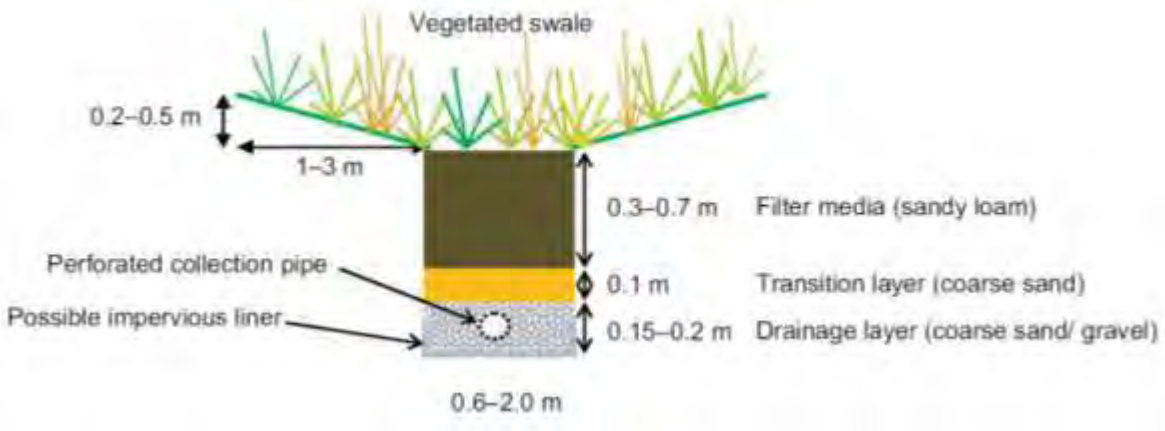


Figure 24 Typical Bio-retention Section Source (Allison & Francey, 2005)

Bio-retention Basin: is used to maximize the volume of runoff treated through filtration media by employing pounding above. The treatment is similar to that of bioretention swale, but they convey above design flow through over flow pits. It is installed in various ways including planter box, and it is effective for treatment sediments and other contaminants.

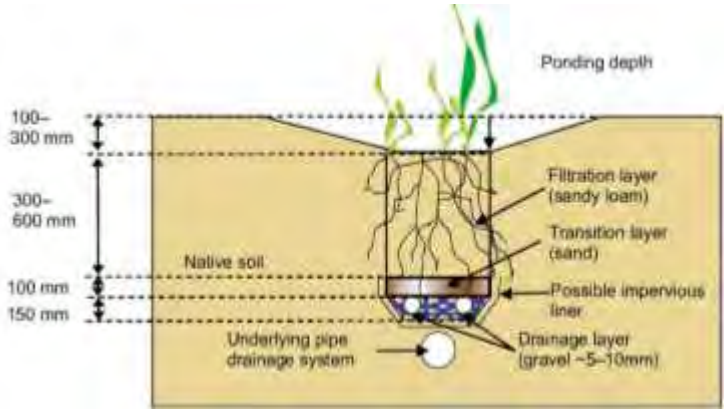


Figure 25 Bio-retention Basin Typical Section (Source;Allison & Francey, 2005)

Constructed wetland is an extensively vegetated shallow water body which is used to improve sedimentation, fine filtration and pollutant trapping process to remove pollutants from storm water. Wetlands consists of inlet zone and high flow by pass channel and designed to remove storm water pollutants related to fine colloidal particles and dissolved contaminants.

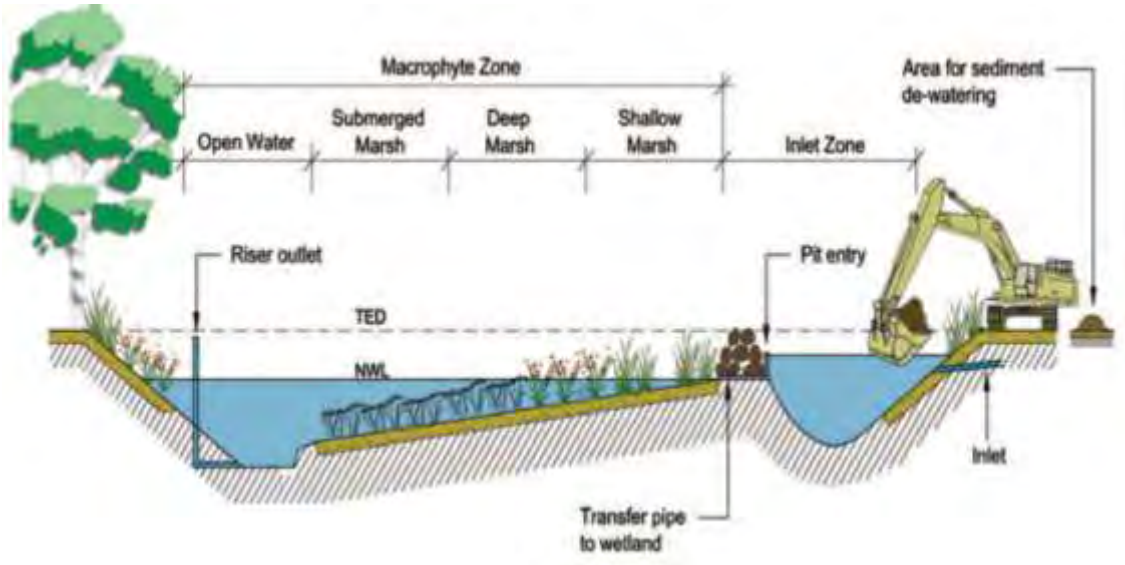


Figure 26 Constructed Wetland System (Source: Allison & Francey, 2005)

Sand Filters

Sand filters provide storm water treatment for first flush runoff. The runoff is filtered through a sand bed before being returned to a stream or channel. Sand filters are generally used in urban areas and are particularly useful for groundwater protection where infiltration into soils is not feasible. Alternative designs of sand filters use a top layer of peat or some form of grass cover through which runoff is passed before being strained through the sand layer. This combination of layers increases pollutant removal.

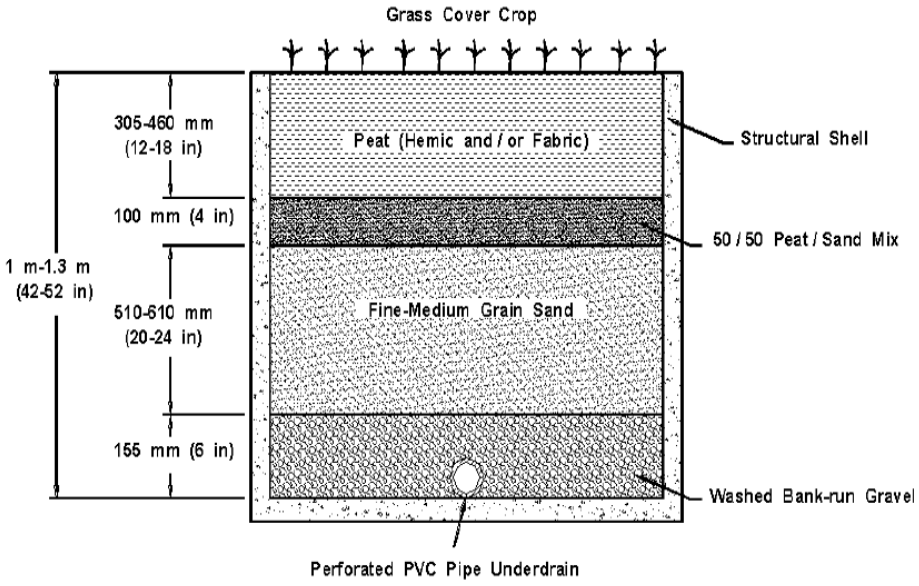


Figure 27 Cross-section schematic of peat-sand filter.

Vegetative Practices

Several types of vegetative BMPs can be applied to convey and filter runoff. They include:

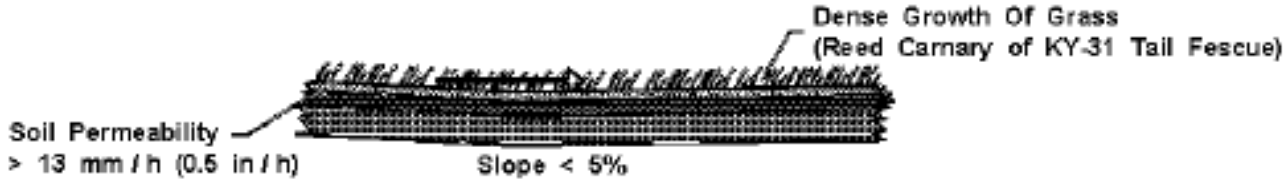
• Grassed swales

• Filter strips

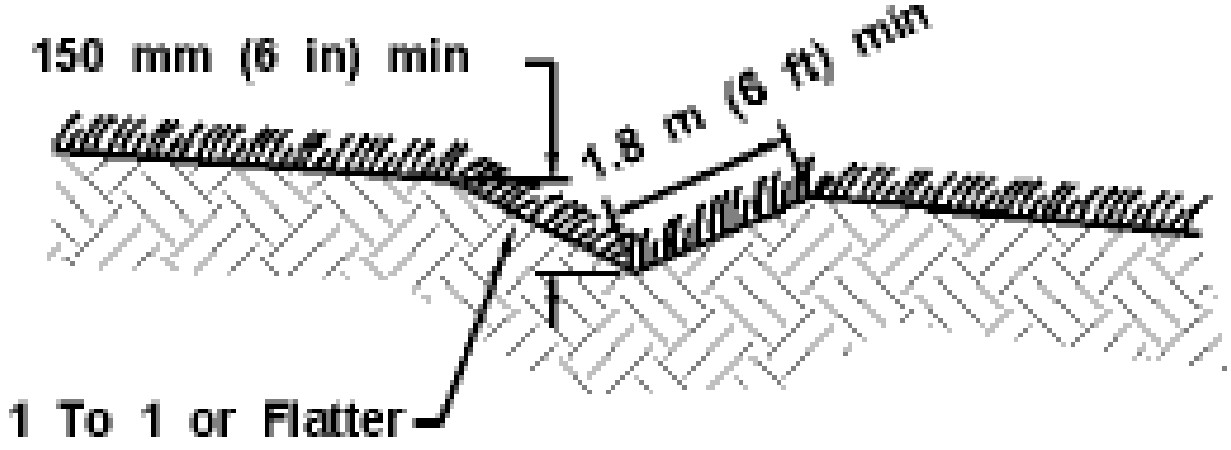
• Wetlands

Vegetative practices are non-structural BMPs and are significantly less costly than structural controls. They are commonly used in conjunction with structural BMPs, particularly as a means of pre-treating runoff before it is transferred to a location for retention, detention, storage or discharge.

Grassy swale- slows runoff; filters sediments; roots bind surface of soil and enhance infiltration; grass and leaves protect soil surface from rainfall impact; and litter layer improves porosity.



Level sprider- Redistributes concentrated flow to sheet flow, increase infiltration.



Check Dam- reduces erosive velocity

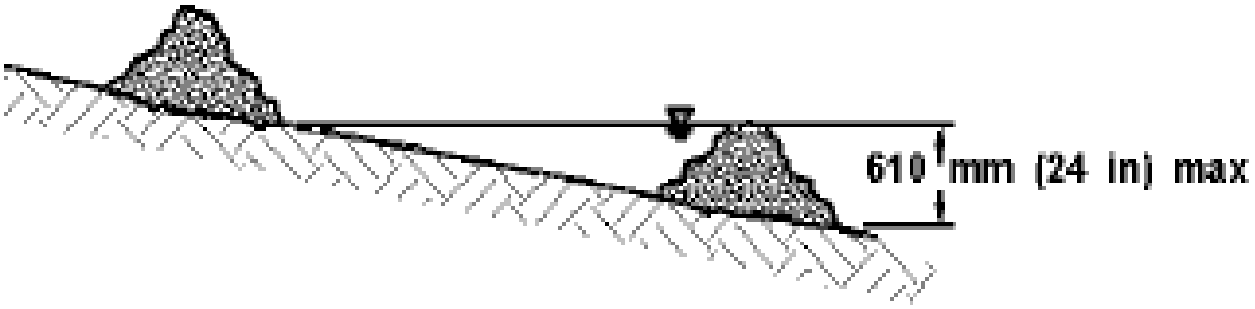


Figure 28 Schematic of grass-swale level spreader and check dam.
Source: S.A.Brown, 2001 Urban drainage design manual

CHAPTER THREE

3. Contextual Review

3.1. Description of the study area

Arba Minch has its name after the local springs from where the city is supplied with naturally clean water. Astronomically, it is located at the geographic co-ordinates of $6^0$15` north latitudes and $37^0$38` east longitudes. It is found in the Gamo Gofa Zone of the Southern Nations Nationalities and Peoples Region about 500 kilometers away to the south of Addis Ababa at an elevation of 1285 meters above sea level at the base of the western side of the great rift valley and has 55.57 km^2 area. It is the largest town in Gamo Gofa Zone and the second town in SNNPR next to Hawassa. It consists of the upper town Shecha, Lower town Sikela and Limat. Since 1999E.C/2006 G.C, the town becomes city administration with 4-sub town and 11 kebeles.These sub towns are Sikela, Shecha, Nechsar and Abaya. Arba Minch is known of its fruit, fish, and crocodile farms. Moreover, it is surrounded by natural resources, which enhanced the attraction of the town such as Lake Abaya, Kulfo River that crosses the city, A.M natural forest, and Bridge of God in the east, and Lake Chemo. The eastern side of Sikela is the gate to Nechisar National Park which covers the isthmus between Lake Abaya to the north and Lake Chamo to the south. Forty springs from where the town is supplied with naturally clean water in the west of the natural forest (Gamo Gofa zone Bureau of Finance and Economic Development, 2013).

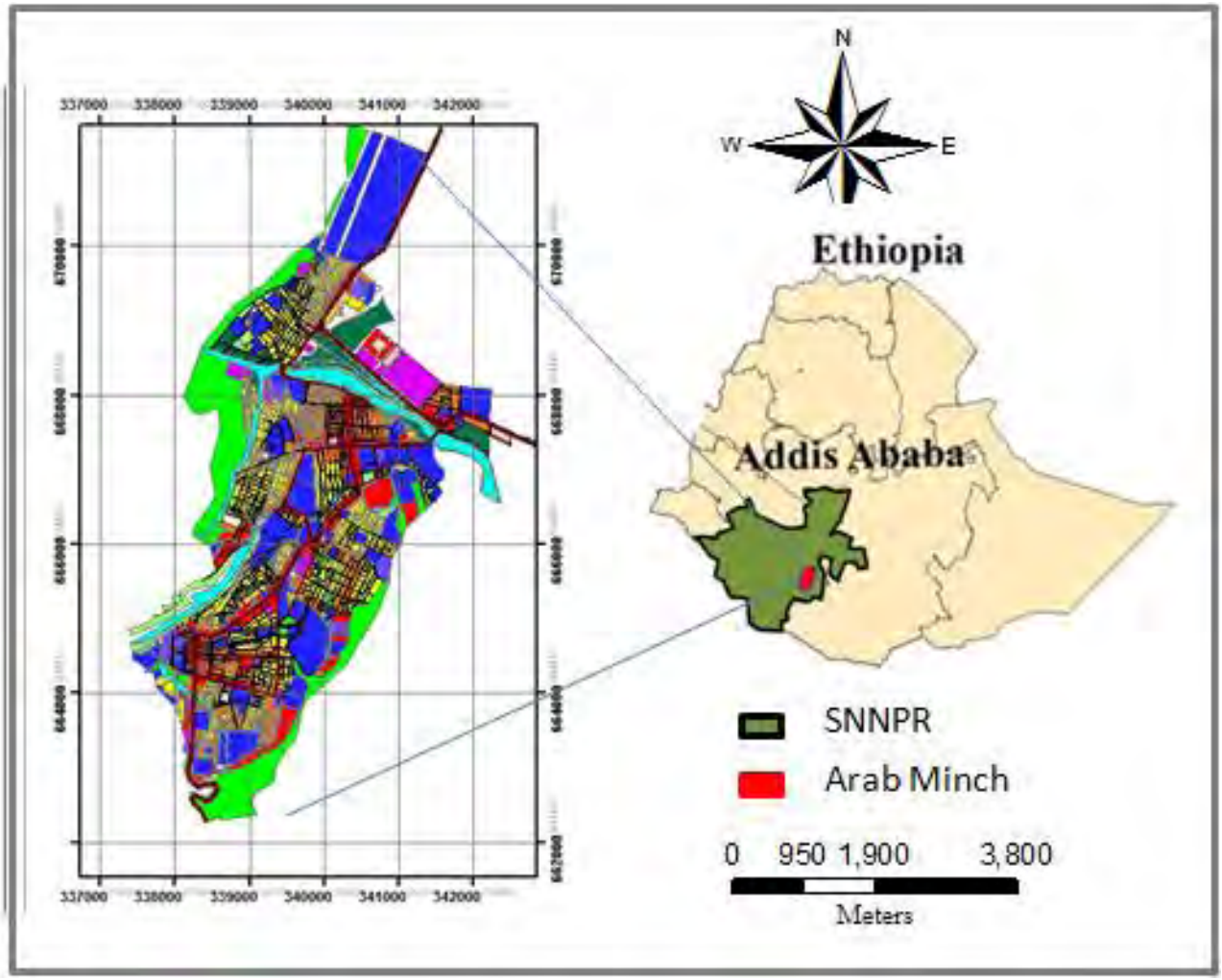


Figure 29 location map of the study area (source own)

Precipitations

The mean annual precipitation depth recorded at Arab Minch station in 13 years period from 2001 to 2013 is about 871.64 mm. There is a significant seasonal variation for rainfall. Almost 35 % of the mean annual rainfall occurs in the two rainy months of April and May with maximum mean values of more than 144.8 mm. November, December, January, and February, on the other hand, are the driest months, which account for 25 percent of the annual total.

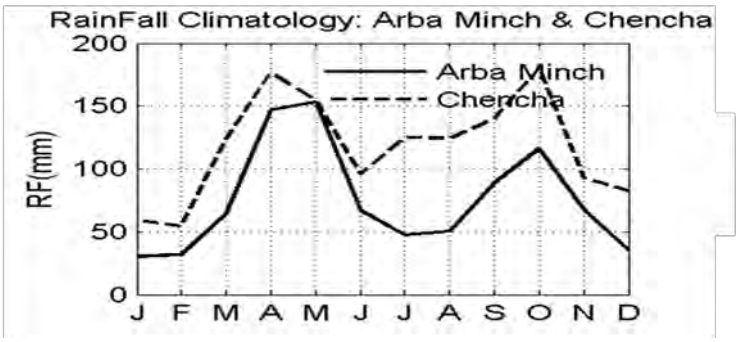


Figure 30 Precipitations

Temperature

The monthly mean Maximum and minimum temperature records of Arab Minch In the year between 2001 to 2013 indicates that the highest mean monthly maximum temperature occurs in the months of February and March 33.5 ^{0}C July 27.8 ^{o}C. While the mean monthly minimum temperature range for the lowest 15.4 ^{0}C in December to the highest 18.4 ^{o}C in the month of March. In Arba Minch, the temperature often exceeds 15 ^{o}C. In general, the temperature is considered as hot Humid for most days with some sort of uncomfortable climatic conditions.

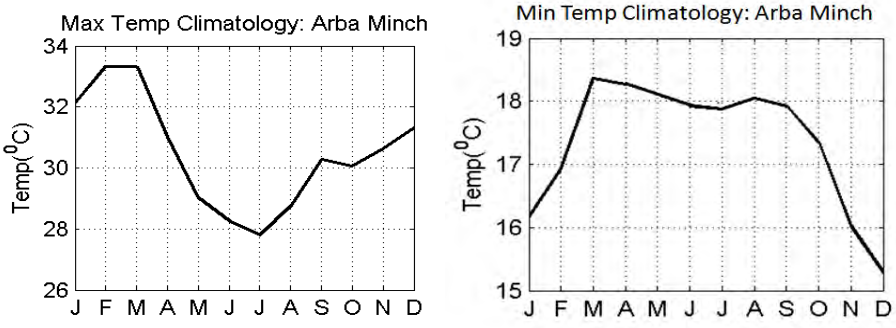


Figure 31 Temperature

Humidity

The monthly mean Maximum and minimum humidity records of Arab Minch In the year between 2001 to 2013 indicates that the highest mean monthly maximum humidity occurs in the month May which is 64.7 %. While the mean monthly minimum humidity occurs in the month of February which is 42.01 % as shown in the graph below.

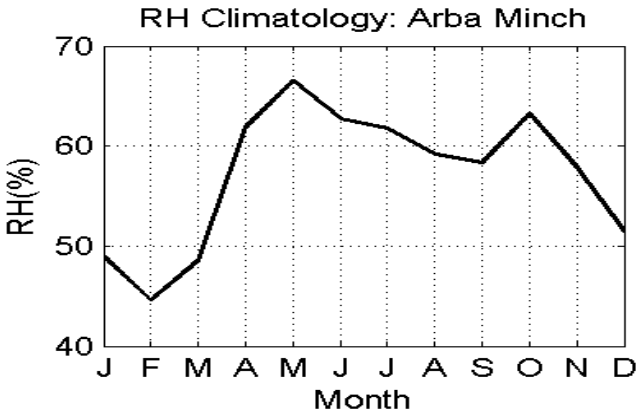


Figure 32 Humidity

Demography

The data used in the article were drowning from CSA /central statistical agency and the data was, collected by CSA as part of 2007 housing and population census, and then the current data were, projected by using the growth rate of the town. Hence, population of the study area is 103,637 out of which 54195 are male and 49441 are female.

Soil type

Soil is the growing media of plants and its fertility depends on its property of soils. Hydrological soils are grouped under four types of soil based on the infiltration capacity. These are A (Sandy, Loam Sandy or Sandy Loam), B (Silt Loam or Loam), C (Sandy Clay Loam) and D (Clay Loam, Silt Clay Loam, Sandy Clay, Silt Clay) (Gebremedhn, 2010).

In Arab Minch the type of soils are Red (lateritic) clay soil around Bekele Mola hotel, Chemo campus, and condominium building site areas in Secha. Gravel (sandy soil) is found along the sides of Kulfo River. Sediment silt soil covers the whole Limat, flat area of Sikela and Konso sefer. Black cotton soil covers the whole Yetnebersh, Medhanialm church, Full Gosple church and around Mekaneyesus Technical college. Bed rock covers the areas around Kalehiwt church (Robot school), Arab Minch detention center and around High land area. Abel Yohannes, (2015)

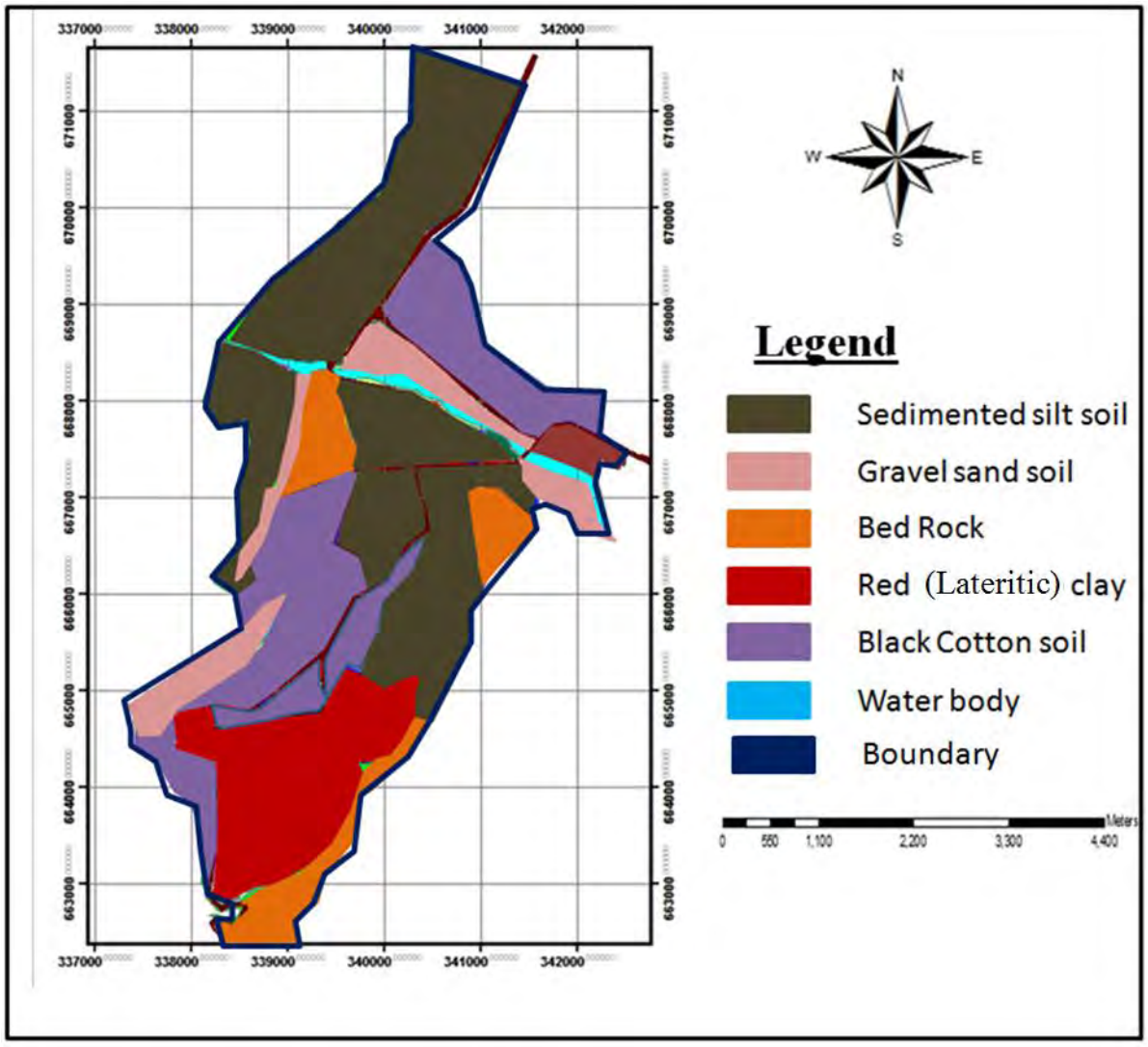


Figure 33 shows soil map of the research area

3.2. Topography of the study area

The town has a sloped land topography situated on the north western of the natural forest and forty springs.

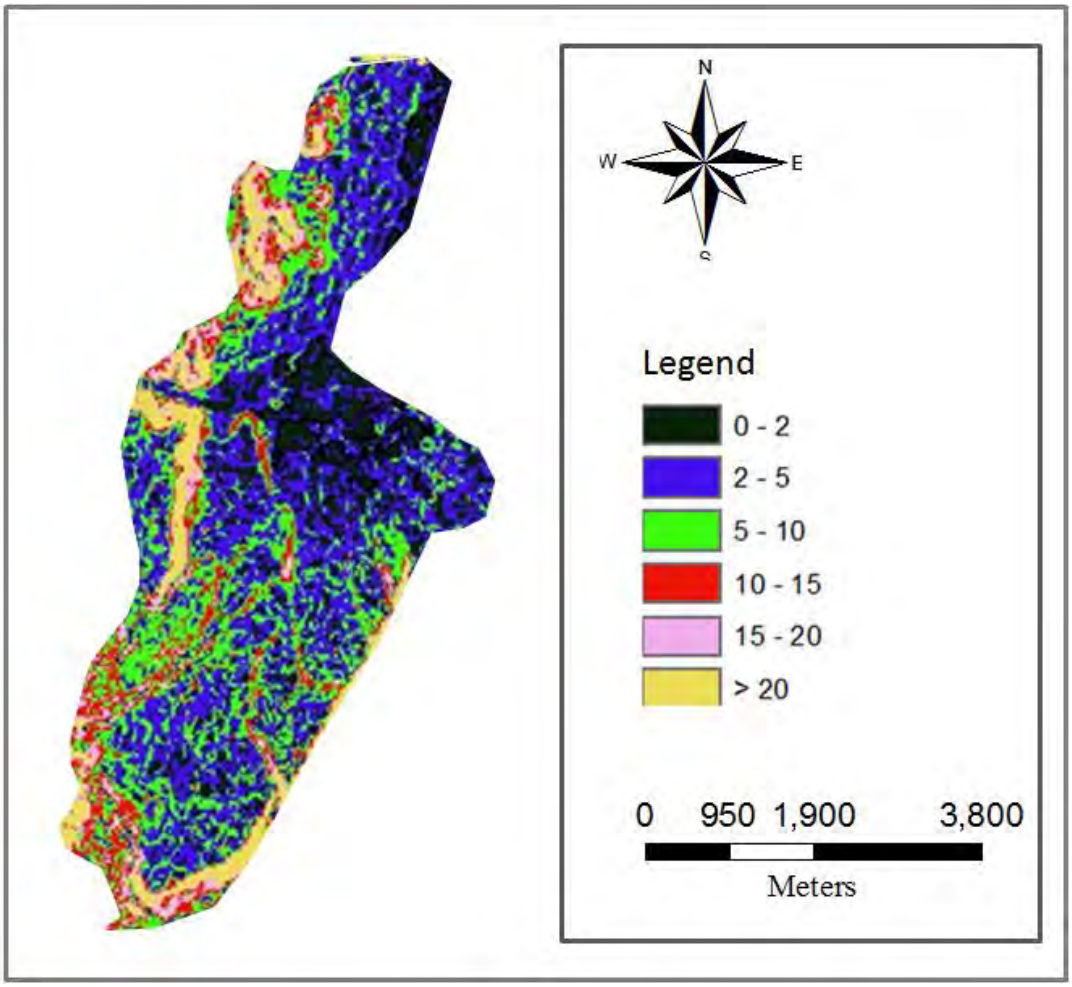


Figure 34 slope classification map of the study area (source own)

The slope varies from apparently zero to slightly over 20 % in specific area. The general slope orientation of the town is slightly towards Lake Abaya and the natural forest, which are located to the east of the town. The drainage direction is most dominantly towards Kulfo River, which crosses the town except for some areas, which drain in Lake Abaya. According to the slope analysis, the most dominant slope cover of the study area is 2 – 5 %, which is 856.1 hectares (39.3 %), and the minimum slope category of 15 – 20 % covers 187.89 hectares (8.63 %) of the total study area.

Table 7 slope classification and percentage share calculated from slope map

S/N	Slope category	Area in hectares	Percent
1	0-2	328.75	15.10 %
2	2-5	856.10	39.32 %
3	5- 10	309.37	14.21 %
4	10-15	226.42	10.40 %
5	15-20	187.89	8.63 %
6	>20	268.65	12.34 %
Total		2177.14	100 %

(Source own)

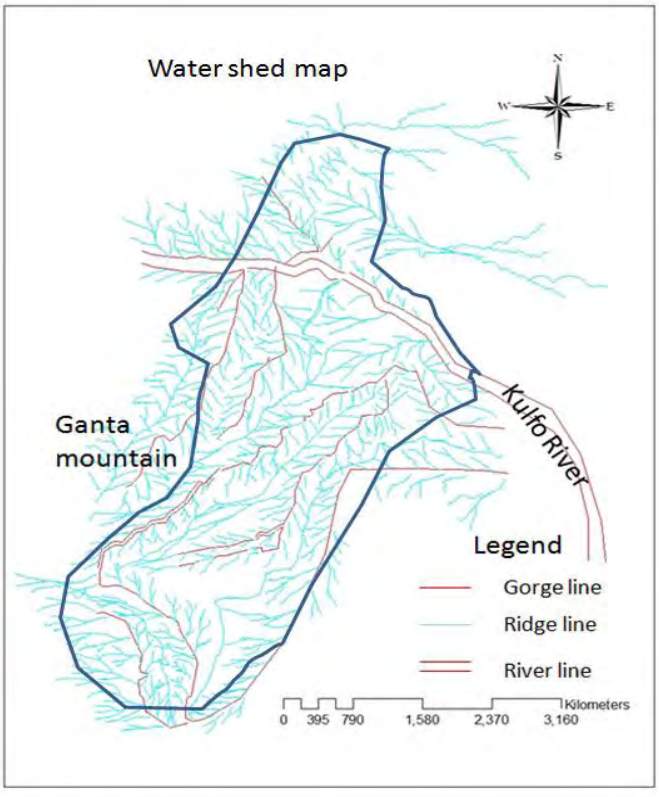


Figure 35 watershed and drain direction

(Source own)

Elevation variation in the area ranges, from 1188 m above sea level at the central part of the town Sikela and the higher is 1446 m above sea level at Secha area around the higher-level court.

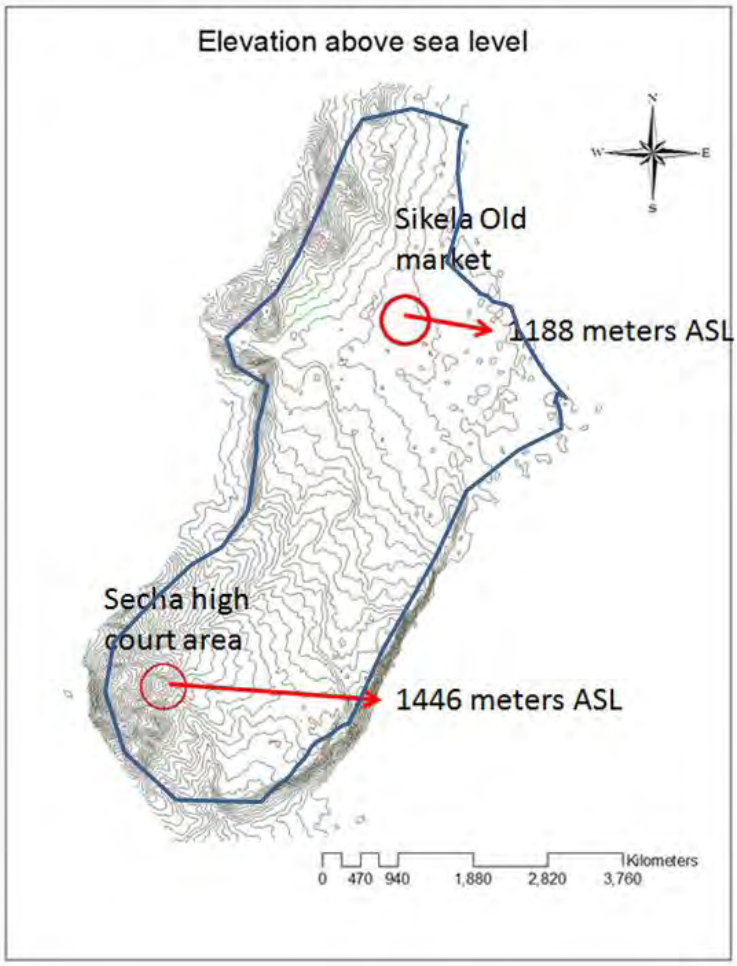


Figure 36 Max & Min elevation (source own)

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3.3. Existing land use

According to the existing situational analysis, there are thirteen land use types. Broadly categorized in to **build up and none built up** areas. Built up areas include residential, service, transport, administration, manufacturing and business areas. None built up areas include water bodies, green spaces and other open spaces. This gives 2177.14 ha.

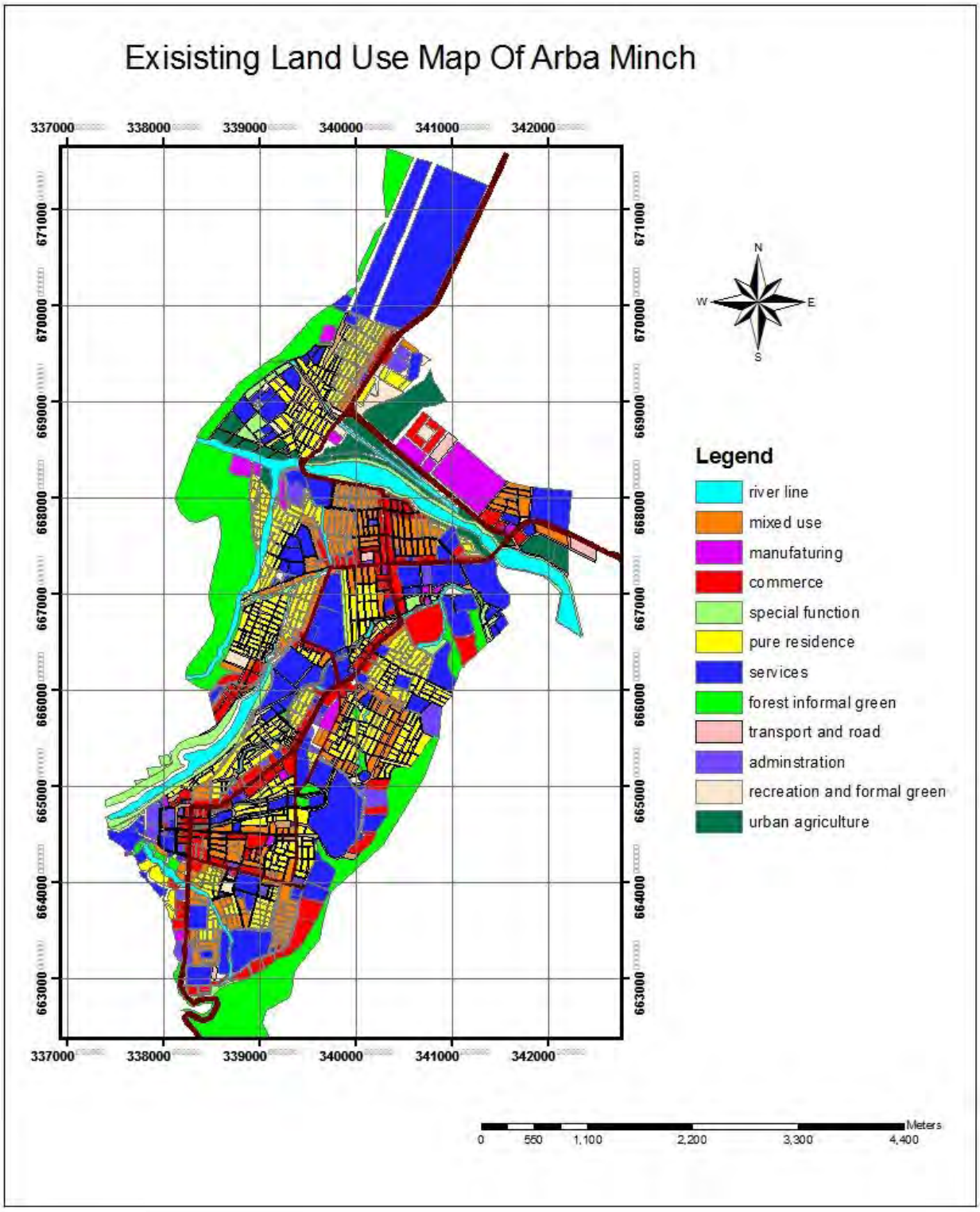


Figure 37 existing land use of the study area

In the Figure above, about 13-land use types are shown in different colors and road, which is one of the land uses, is classified in to asphalt, cobble, and gravel and earth road according to their surfacing materials.

Table 8 Existing Land Use Area in Hectares

Land use type	Area (ha)
Gravel Road	64.67
Cobble Road	36.67
Asphalt Road	92.02
Earth Road	103.56
Open space without vegetation	207.49
Mixed use	149.71
Pure Residence	281.02
Commerce	143.87
Administration	39.63
Service	440.82
transportation	8.68
Manufacturing	57.17
Urban Agriculture	73.23
River Line	121.16
Recreation	23.11
Forest Informal Green	254.82
Special Function	79.51
Total area	2177.14

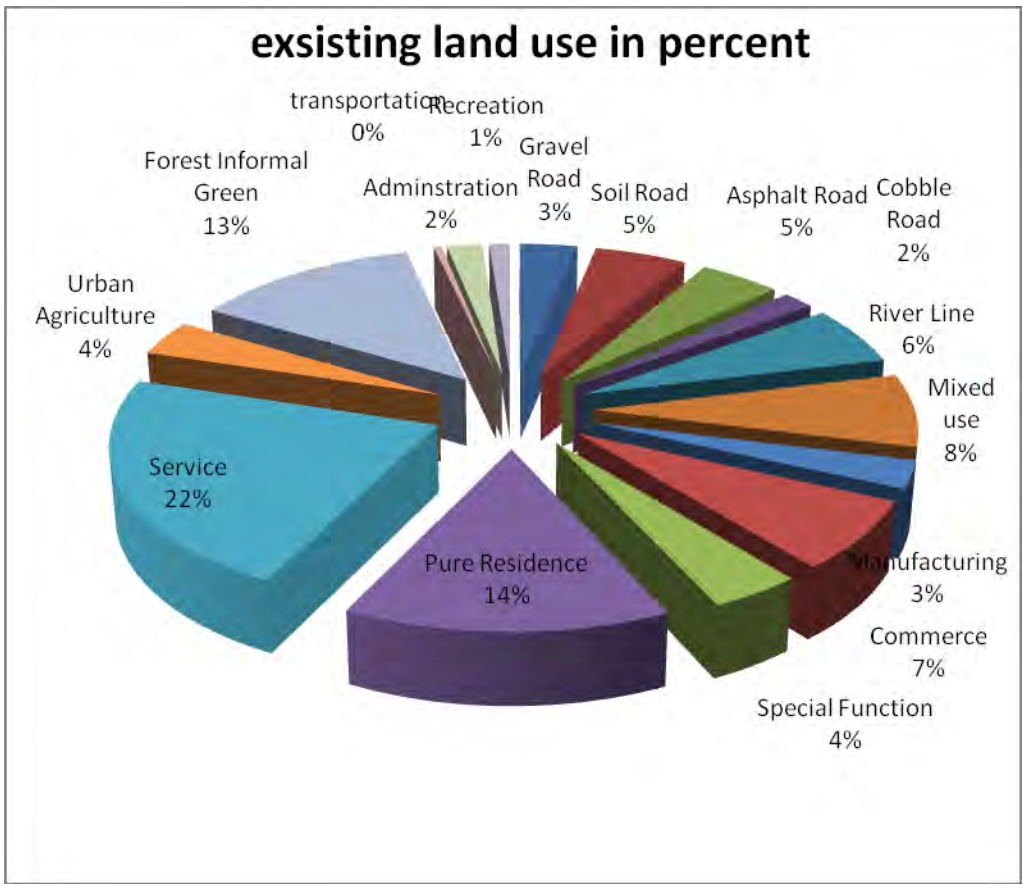


Figure 38 Existing land use area in percent

Table 6 and Fig 34 show the cover area in hectares and in percent. The maximum and minimum land use covers in the study area are service and transportation that covers an area of 440.82 hectares and 8.68 hectares respectively which shows that service occupies 22 % of the total area where as transportation covers 0.1 %. Based on land use category in to Built up and Non-Built up, the cover area are 1417.82 and 759.32 hectares, 65.12 %, and 34.88 % respectively. Therefore, according to the area and percentage cover it shows that built up land use is dominating.

3.4.Existing Building height

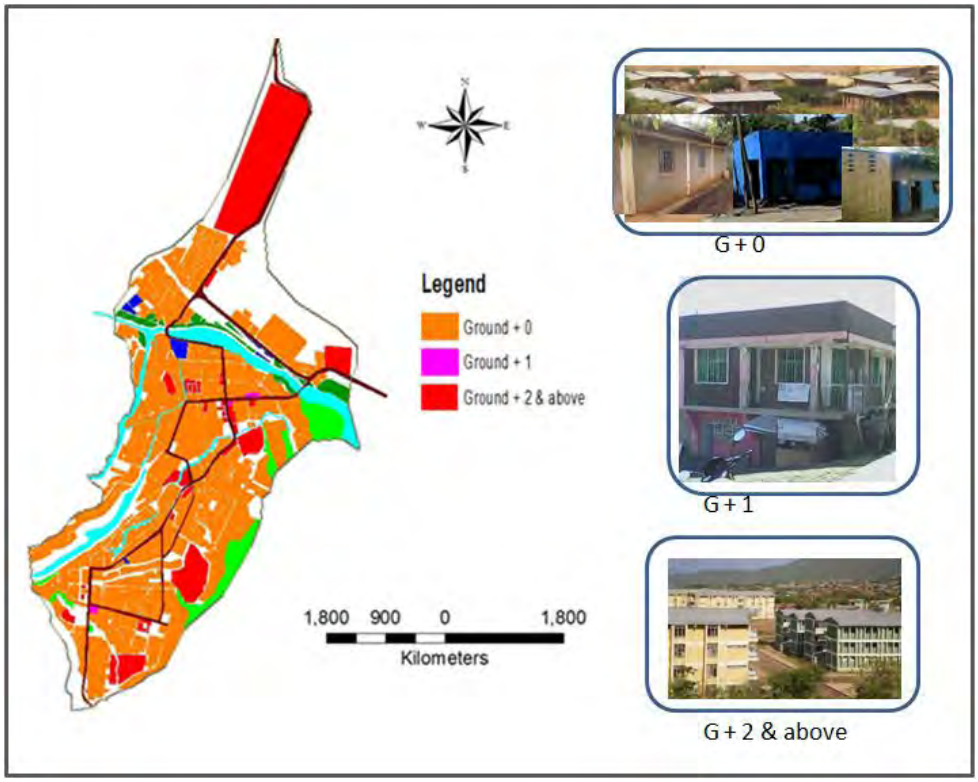


Figure 39 Building height (source own)

According to the survey made about building hight and construction materials of their wall and roof from 68 sample blocks, 68 plots were selected as sample and buildings in those plots were analyzed. Hence most G + 0 buildings in Arab Minch are constructed from wooden wall of eucalyptous plasterd with soil mud (chika). The external wall is renderd with wier mesh reinforced cement mortar for prevention of wall damage from rain fall and some times coverd by bambu webing or left as it is. The use of hollow concrete block (HCB), as a wall construction material, is not common specially in G + 0 residencial and institutional buildings. In the case of G + 1 and above are constructed from reinforced concret structure and HCB as external curtain wall and internal partition. Gable and shade roofs are used with slope of 15 – 25 % and coverd with corrugated Iron sheet (CIS) of different type and size.

G + 0 occupies = 808.39 hectares

G + 1 occupies = 2.86 hectares

G + 2 and above =245.1 hectares

Total plot area = 1056.35 hectares

Area occupied by building

G+0 = 192.02ha

G+1 & above =60.96ha

Total area occupied by building = 252.98 ha

Which is 75.9% G+0 and 24.1% G+1 & above.

G+0 building wall area to be greened is estimated two times the foof cover 192.02 x 2 = 384.04 ha or 23.24%, and G+1 & above building wall area is estimated three times the roof cover 60.96 x 3 = 182.88ha or 2.8%. Hence 26.04 % Green wall will be add to enhance green cover. Total area left as green and open space without vegetation within the plots is = 803.37 hectares.

Table 9 spaces with in Residential blocks and their Area

Urban structural typology	Area	Percentage
Building	1467.0 m^2	33.89 %
Green	479.59 m^2	11.08 %
Open space without vegetation	2381.73 m^2	55.02 %
Total	4327.91m^2	100%

(Source own)

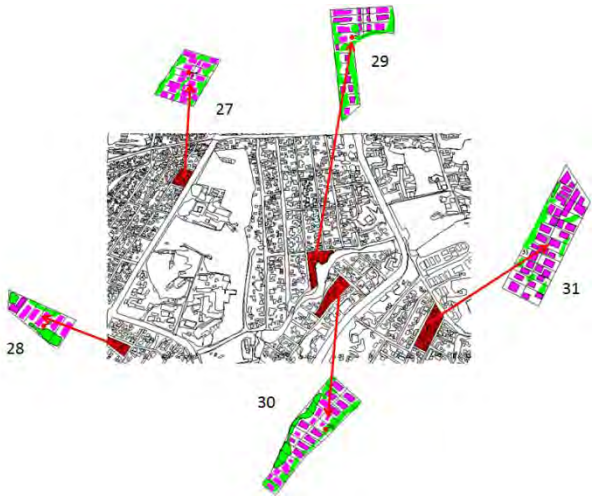


Figure 40 Nechsar sub city AM hospital area sample blocks mapping

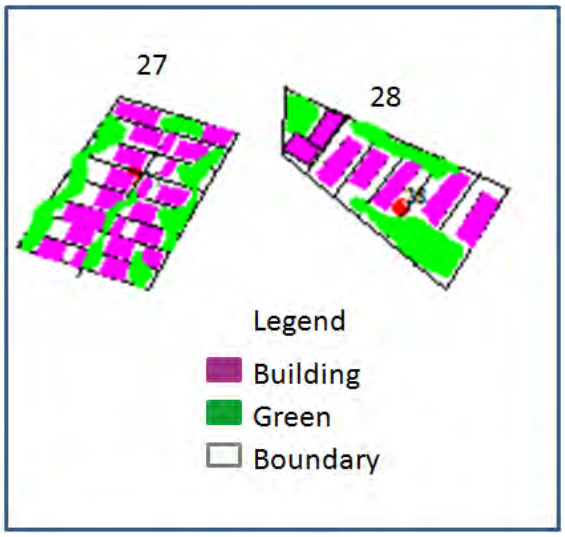


Figure 41 Private residence sample blocks (source own)

Table 10 sample spaces within mixed use block and their Area

Urban structural typology	Area	Percentage
Building	3558.27 m^2	12.33 %
Green	1300.04 m^2	33.75 %
Open space without vegetation	5683.27 m^2	53.90 %
Total	10541.58 m^2	100%

(Source own)



Figure 42 Sikela sub city kebele 02 area sample blocks mapping

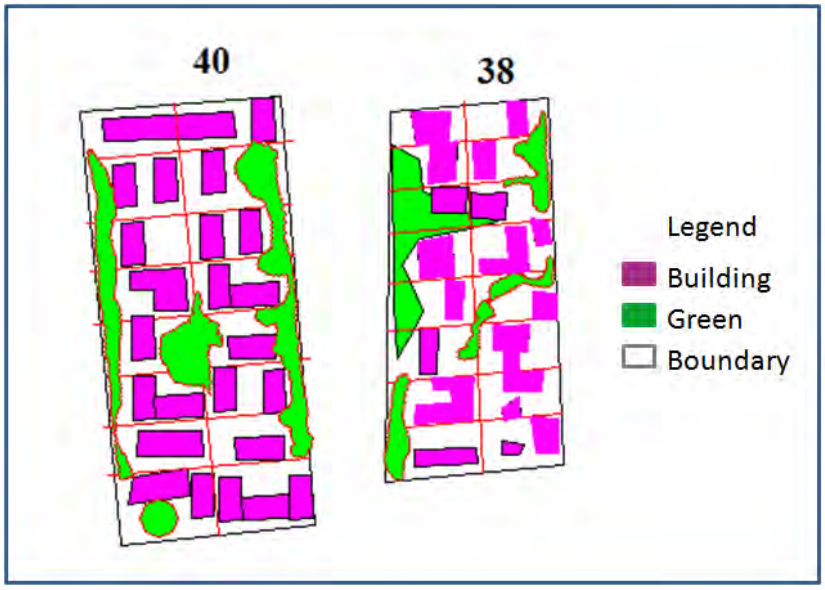


Figure 43 Sample Mixed use blocks (source own)

The above Fig 38 and Fig 39 show the sample blocks taken from Abaya sub city kulfo kebele which is mixed use and from Nechsar sub city Edget Ber Kebele and residential use are seleced as some of those 68 samples and presented here as an example.

According to data collected from 68 sample blocks 15.76 % previous and 84.19 % impervious cover is available in the built up land use category. When the sample result is applied to the whole built up area of 1056.35 hectares, the pervious and impervious surfaces occupy 166.48 hectares and 889.34 hectares respectively. Therefore, adding the none built up land use of 759.32 hectares to the calculated pervious surface of built up land use category and the street cover area 305.03 hectares to the impervious surface the total pervious and impervious surface is found to be 982.77 hectares and 1194.37 hectares respectively. The total pervious and impervious surface cover in the study area is 45.14 % and 54.86 % respectively. Hence, 54.86% impervious cover shows the river /stream quality is deteriorated as shown in the figure below of Kulfo river.



River flow during rainy season



River flow during hot dry season

3.5. Plot level Pervious and Impervious cover

According to the percentage area cover of at plot level green 15.1 %, building 28 % and an Open spaces b/n building 57.5 % which shows that open spaces between buildings is dominating and needs to be intervened to make it vegetated to enhance the green cover. According to the observation made to the entire sample plots most of them have no paved surfaces and defined circulation except in few governmental and private institutions. Hence, the open space is used as a play space for children, parking space for those who have car, and as storage for construction materials. This situation is observed specially in wider plot greater than 300 m^2 where no one gives attention for greening.

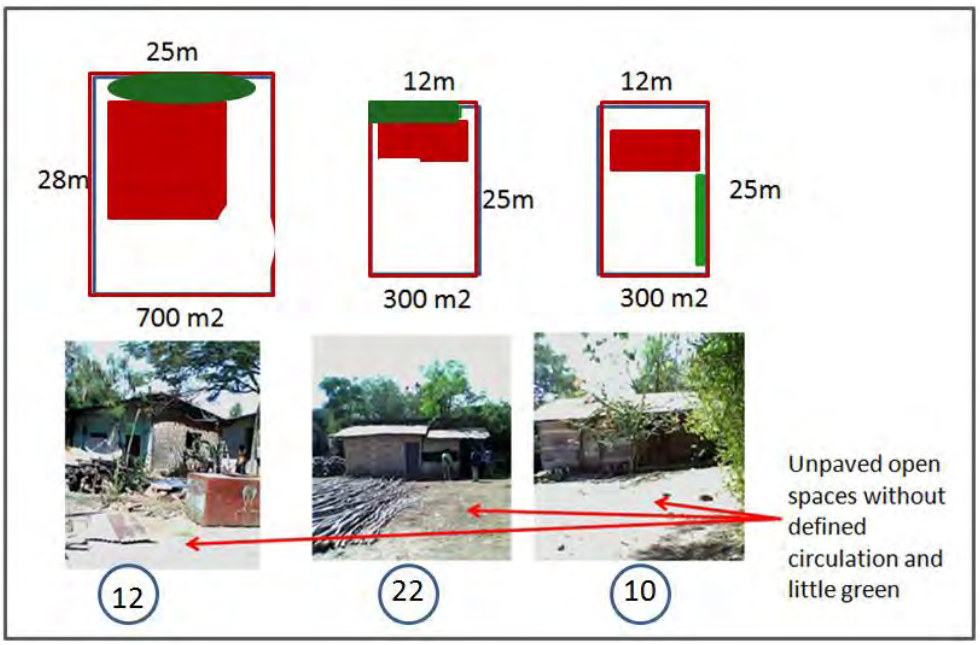


Figure 44 plan & pictures of plots of an area greater than 250 m^2

In plots with an area less than or equal to 250 m^2 more than half of the space is occupied by building and have shortage of spaces for greening, circulation and open spaces for parking and children play.



Figure 45 plots of an area less than or equals to 250 m^2

Plot fences

A plot fence are structures bounding the boundary of a plot and serves as a property line and as a security to prevent entrance and provides privacy to the plot owners. Therefore, according to the observation made to different sample plots, it is found that there are six types of fences based on the type of material of which three are of impervious material such as:

corrugated iron sheet (CIS)

HCB wall fences

Masonry Fences




Figure 46 Corrugated iron sheet

CIS fencing is currently using as the most parts of the town because of its cheap material and construction covers 52%




Figure 47 HCB wall fences

HCB wall fences used for residential plots front fencing and covers 30%



Figure 48 Stone masonry fence

Stone masonry fence is expensive and rarely used for fencing at both private and government level and covers 28%.

3.6.Existing roads and their size

Asphalt road is new and major arterial road of size ranging from 20m up to 45m having paved pedestrian road, medians, and side ditches of concrete. Cobble stone, Gravel and Earth roads are minor arterial, collector and local roads of size from 10m up to16m.

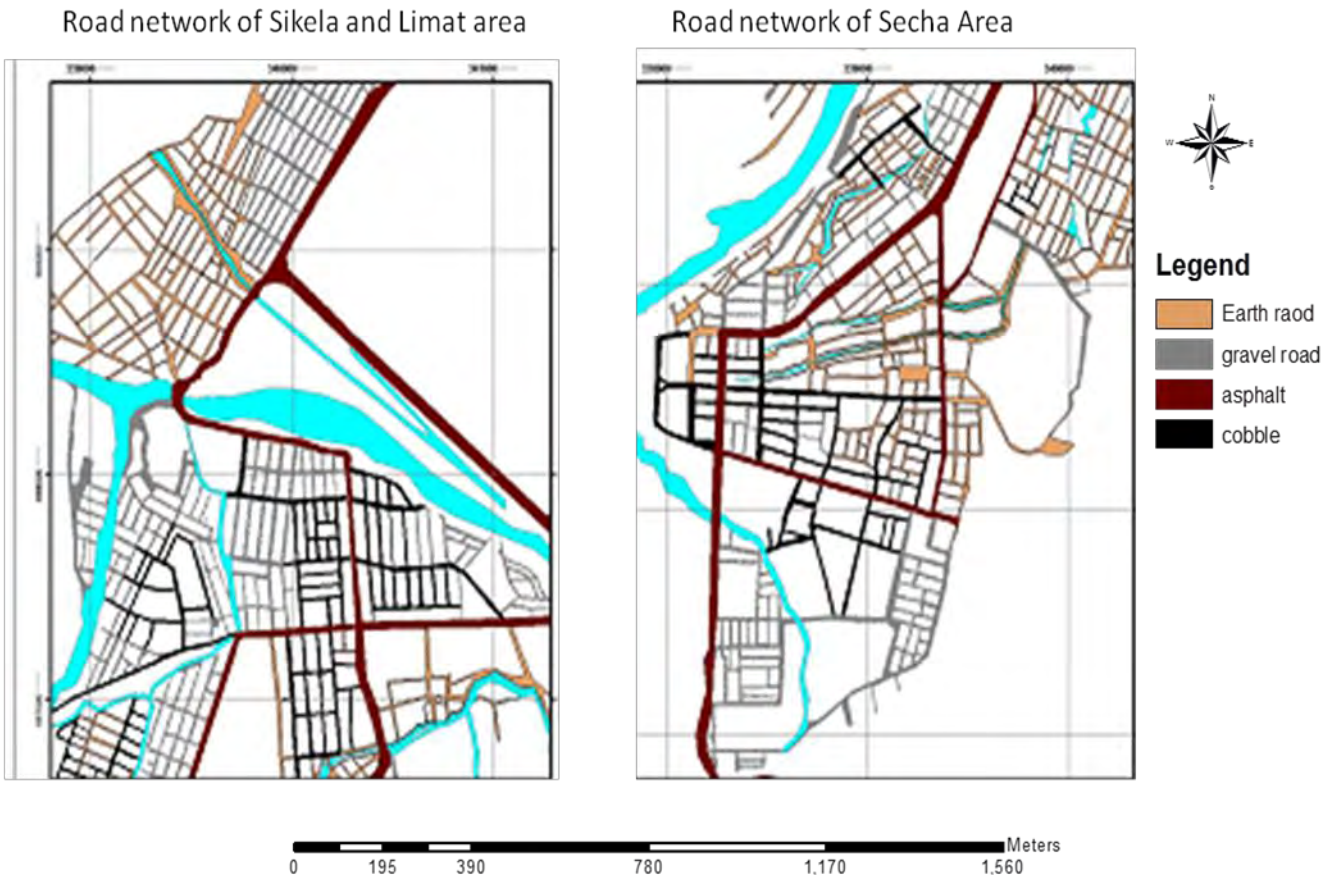


Figure 49 existing road network

Existing Asphalt road type and size

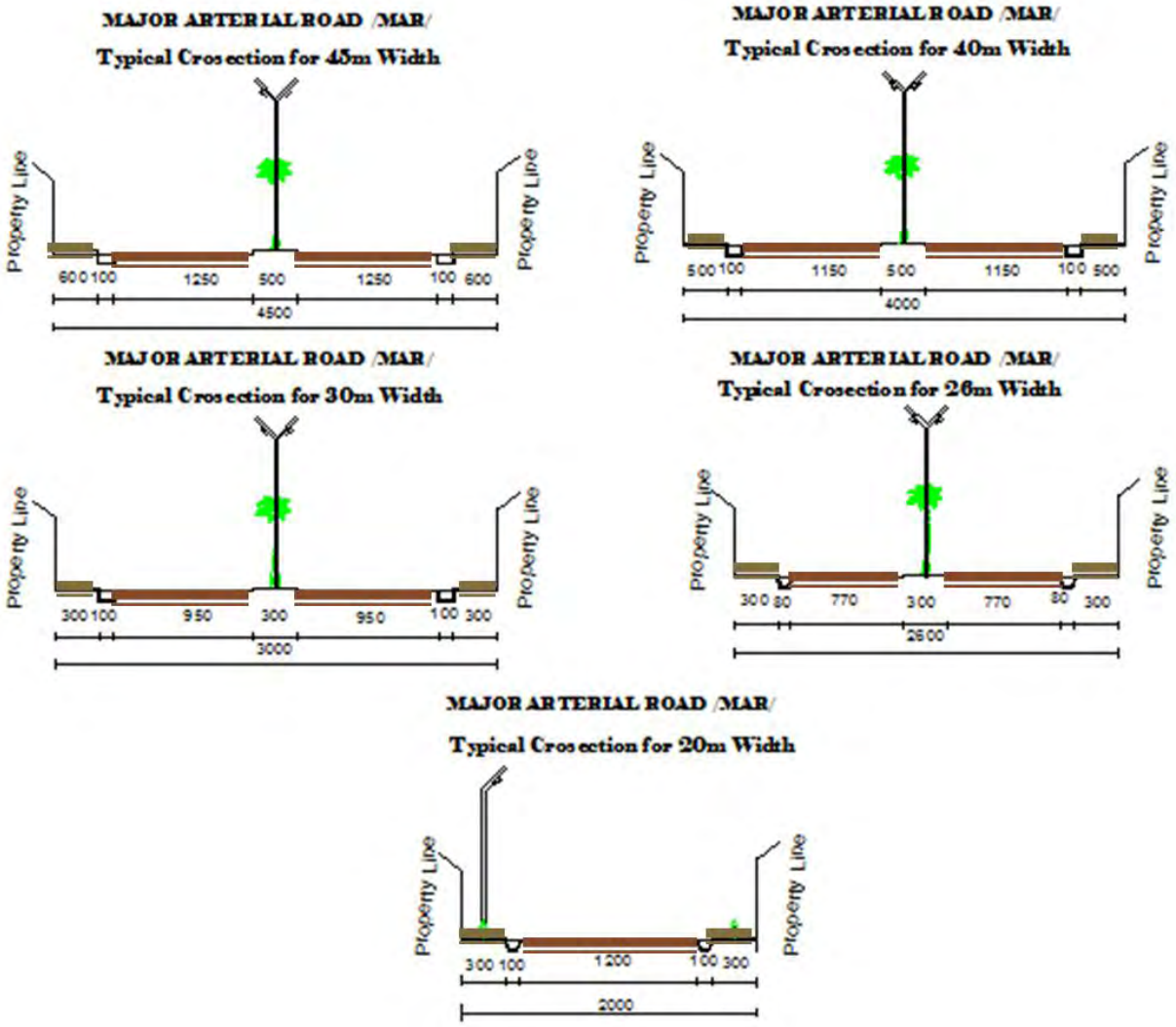


Figure 50 existing asphalt roads

The existing Asphalt roads have a rightof way width of 45, 40, 30, and 26 metres which incorportes medians, pedestrian walkway and from 3 up 6 meters green in both sides. The pedestrian road along the both sides of the asphalt road is constructed and paved with standard paving material; however, it is not in use due to the relatively hot humid weather condition and low wind speed, which results some sort of discomfort in most days of the year. Therefore, the pedestrian walkway needs an intervention to make it attractive and usable during any weather

condition and time. The current situation does not encourage residents for friendly walking rather people are forced to take taxi or Bajaj to arrive at their destination.



Figure 51 Image showing pedestrian walkway

Existing Cobblestone, Gravel, and Earth road type lacking green vegetation

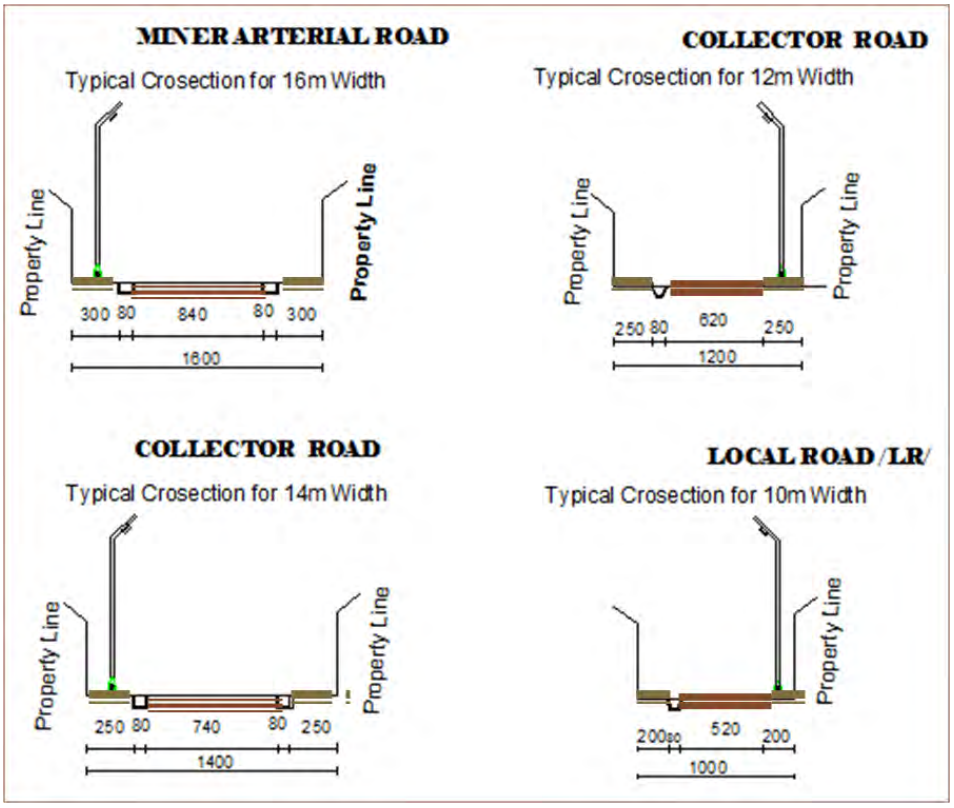


Figure 52 detail road size of cobble, gravel, and soil

Fig 48 shows Cobble, gravel and Soil roads their rihgt of way width and detail dimension of pedestrian walk way, ditch and vhicular access. According to the detail dimension from 250 – 300 cm, pedestrian walk way space for utility and an open space is provided separet and without shade which makes the pedestrian walkway not usable due to adverse weather condition during most days of the year.



Figure 53 Cobble, Gravel & Soil Roads

Figure above shows roads without side shading for pedestrians. There are Gravel and Earth roads with concrete open ditch as drainage line, which needs intervention to allow infiltration, change concentrated flow into sheet flow, reduce flow velocity, and erosion hence Green Street without flooding at the end.

3.7.Exsisting impervious surfaces cover

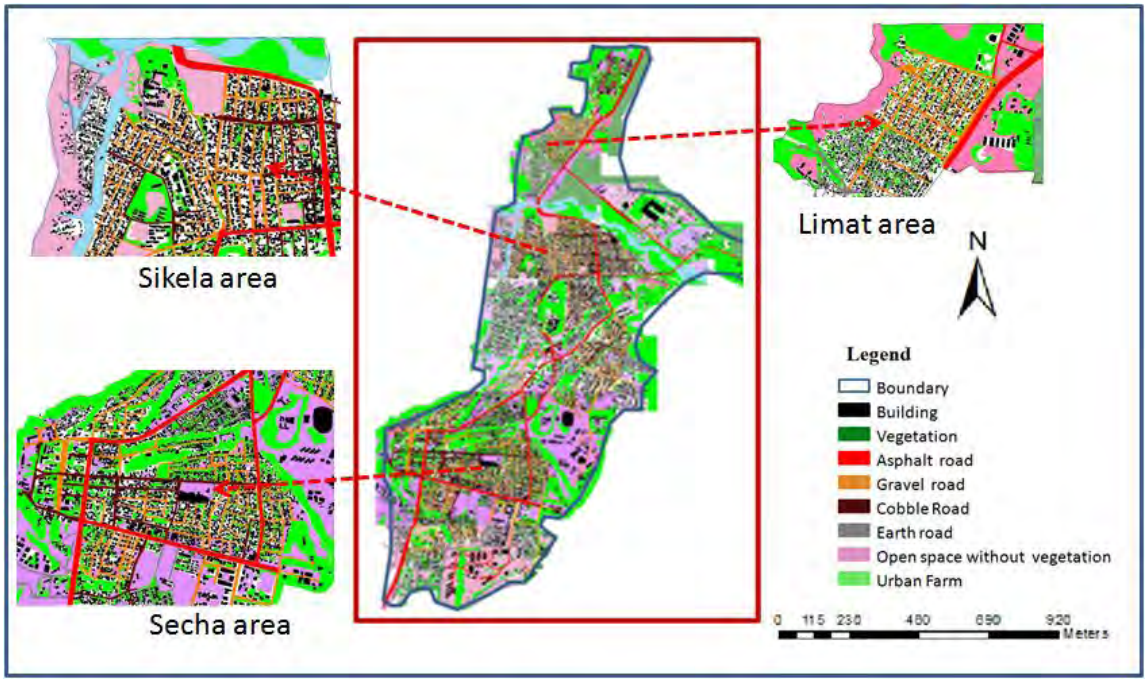


Figure 54 Existing impervious surfaces cover

The above map (Fig 50) shows the types of impervious surface cover available in the town such as Asphalt Road, Cobble Road, Gravel Road, Soil Road, and Roof cover.

Table 11 Impervious surfaces

Surface type	Area in Hectare
Asphalt road	92.02
Cobble road	36.67
Gravel road	72.78
`Earth road	103.56
Roof area	252.98
Total impervious area	558.01

According to table 11, the total area coverd by impervious surface is 558.01 hectares which accounts 25.26 % of the total area.

Watershed

In urban area, rainwater drains from individual plots and streets into lower area through drainage canals. In the study area rainwater drains from individual plots and streets into the nearby river basin through ground surface and manmade drainages of concrete or earth ditch. No practice of WSUD, in the city was found.

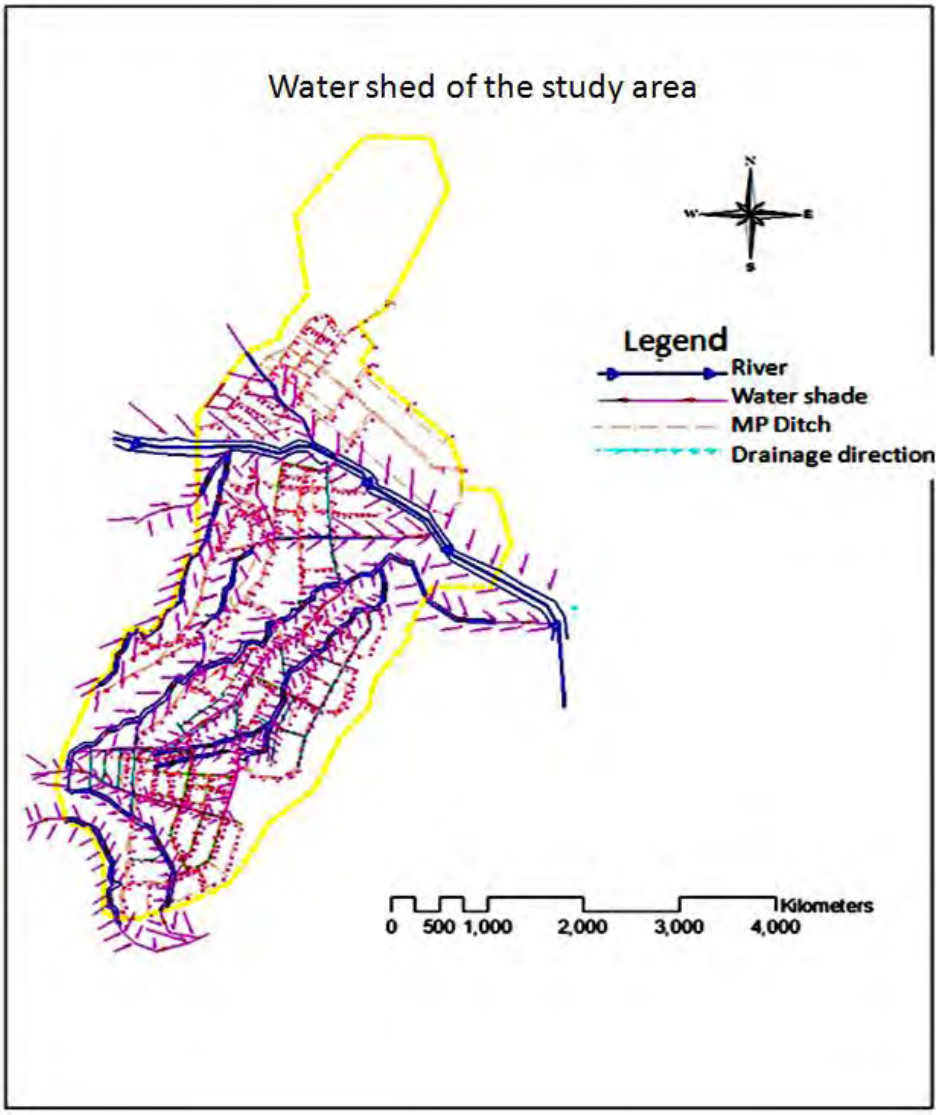


Figure 55 Water shed area of Arab Minch town (source own)

The drainage ditch and inlet type identified on the research area asphalt road is only one typical U shaped where rain water enter through side hole (inlet) of the drainage from the street as shown in figure 55



Figure 56 Asphalt road drainage ditch & rainwater inlet type

The drainage ditch identified for Cobble stone road is also one typical which is U shaped made of concrete without cover as shown in the figure below.



Figure 57 Cobble stone road drainage type

The drainage ditch identified in the study area for Gravel road is of two type's U shaped concrete ditch without cover and U shaped sloped earth ditch without cover as shown in figure 57.

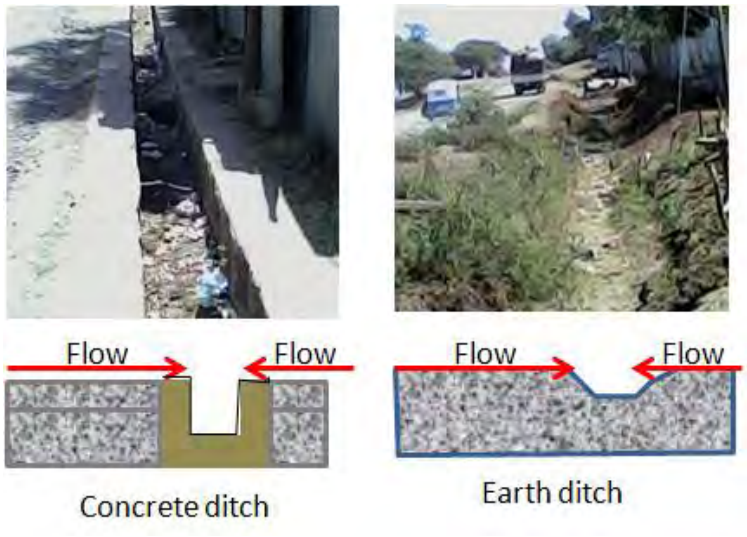


Figure 58 Gravel road drainage Ditch type

Trees, shrubs, and grasses

In the study area, it has been observed that scattered trees and some shrubs are found along Kulfo River, church compounds, different institutions, and vacant spaces. Hence below are some of the indigenous and adapted exotic green plants available in the study area.

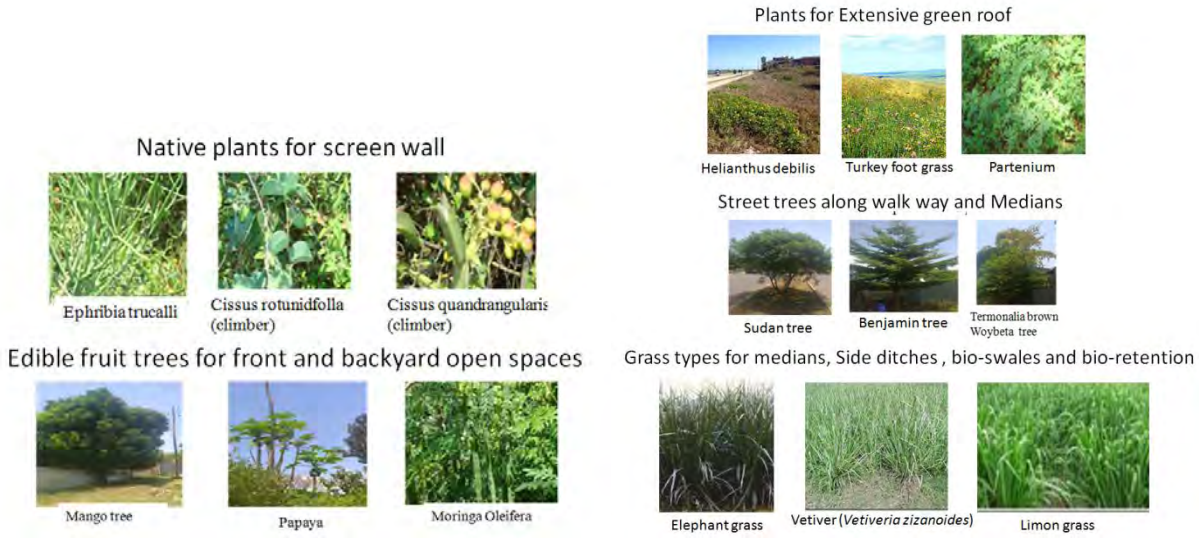


Figure 59 Trees, shrubs and grasses

CHAPTER FOUR

4. Conclusion and recommendation

4.1. Conculussion

Green Infrastructure of a city is vested on Green Street, green space, impervious area, green roofs, green walls, green fences, and WSUD. The study area land use is categorized broadly in to built up and none built up. Accordingly, the surface covers of the built up and none built up was analyzed and found to be 1417.82 ha (65.12 %), and 759.32 ha (34.78 %) respectively. Showing that built up land use is dominating. Further categorizing built up spaces in to grey and green infrastructures have been summarized as follows. Green infrastructures such as vegetation within plots (11.26 %), and non built up space of 34.88% makes a total of 45.14% of the total study area. Grey infrastructures are built impervious surfaces that include CIS roof (10.53%), Cobble stone road (2%), Asphalt road (5%), and Gravel road (3%), Earth road (5%) and degraded bear land (29.33) gives 54.86 %.

According to American Planning Association standard of 1996, the study area impervious exceeds 25 %, considered as degraded, and needs intervention. Inclined CIS roof is the only impervious roof cover used in the area, which is 252.98 ha (11.62%). The annual amount of storm water to be harvested from the entire roof of 252.98 is of the study area is calculated and found to be 1,977,696 m3. The amount of green added from green roof and Green Street covers 558.01ha or 25.63%, hence, enhances the pervious cover from 45.14 % to 70.77 %. Application of green wall and green fence of 26.04% and 4% respectively will further increase the green cover of the area up to 100%. WSUD such as Drainage includes storm water flow velocity control, erosion mitigation, enhancing infiltration and pollution protection by GI techniques of check dam, level spreader, terrace of gabion, infiltration trench, bio-swale, bio-retention and other mechanisms are proposed to protect the environment and to green the grey spaces of the study area.

Generally, the research has proved that streets, walls, roofs, impervious areas, and WSUD of the city are the potential to green grey spaces of the town.

4.2.4.2. Recommendation

The research has investigated the problems and potentials of the research area. The identified problems from the findings analysis are flooding which becomes sources of siltation and pollution of the city due to topography. Therefore, the following key measures are recommended to curb the problems caused due increased impervious surface, lack of awareness about GI and its benefits, poor green space management, and respond to the increasing demand for greenery in the study area.

Green roof, green street, green wall, and WSUD are recommended to solve the shortage of green areas of the town and to improve environmental condition of the study area.

During discussions made with the city administration and environmental protection office experts the main barriers that hinder the development and implementation GI program in the study area is lack of awareness about GI elements and its benefits. Therefore, the concerned body should make meaningful awareness creation program to AM city administration, Private sectors, and the community at large.

The existing indigenous vegetation in the study area and the natural forests near the study area were deforested as construction material and firewood and due to quarrying activity. Therefore, the remaining natural woodland site should be protected and conserved by using those options such as: HCB, mud blocks, hydro form blocks for wall, shrub and climber plants for fence, RHS roof truss, and rafter for roof structure, biogas, electricity, etc for cooking.

The existing pedestrian walkways and recreational spaces are not in use in most hot days of the year due to lack of trees that could provide shade against adverse sun temperature and encourages friendly walking, making the area green, usable and attractive. Therefore, to protect and develop green spaces in the town involvement of different organizations such as, city administration, environment protection office, beautification and park development departments, NGOs, private sectors, and individuals is very crucial.

Rules and regulations should be set regarding the percentage of pervious surface to be left within a plot to enhance the amount of green cover in the town. Therefore, concerned bodies should take part such as city administration, municipality departments such as housing and infrastructure development and land administration.

Residents of the study area should be encouraged to plant trees that have dual benefits such as edible fruit and leaf in addition to shading. Therefore, AM city administration should give

attention to supply the community with appropriate seedlings of the aforementioned tree types, and conduct supervision.

GI element such as green roof, green wall, and green street installation to the existing buildings and streets needs to train the community. Hence, the involvement of concerned groups such as AM city administration, A.M environment protection office, beautification and park development departments, NGOs, private sectors, and individuals is very essential.

CHAPTER FIVE

5. Design Proposal

5.1. Green roof proposal

Implementation of EGRs on a large scale has the potential to reduce urban heat island (UHI) effects. According to Susca et al. reported an average 2°C temperature difference between areas of New York City that have high and low levels of vegetation. EGRs with their biological activity, high thermal resistance, and low surface albedo compared with traditional bitumen rooftops were considered a useful way of combating this UHI effect. Therefore, According to the structure and bearing capacity of existing G + 0 residential and institutional buildings which are dominantly available in the study area existing roofs have slope of 15% - 25% made of eucalyptus trusses of diameter 10-12 cm. Hence, extensive green roof of 6cm up to 12cm sub strata can be best applied depending on the type of material and method of construction.

Proposed extensive green roof plants

Combinations of evergreens and flowering plants with a long blooming season provide a visual impact when grown together. However, summer droughts can turn flowering perennial plants into a mass of brownedout, dead-looking plants that could be a fire hazard. Similarly, grasses are difficult to keep green throughout the summer. To grow most annuals, perennial flowering herbaceous plants, and grasses, either irrigation must be present or substrate depths must be deeper than normally found on extensive roofs which the curent circumstances on existing buildings do not allow to do so. Therfore, succulent species such as Sedum, Sempervivum, Costal Strawbery and Delosperma are considered good choices because of their ability to withstand extended drought conditions and other adverse environmental conditions often present on a rooftop.

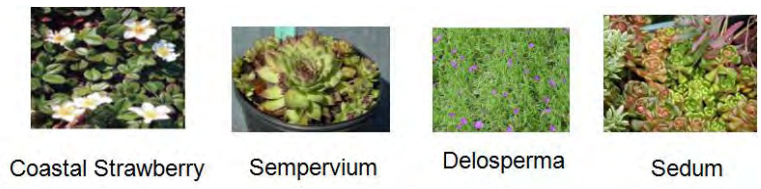


Figure 60 Extensive green roof plants (Source: Brian Taylor, P.E. 2010)

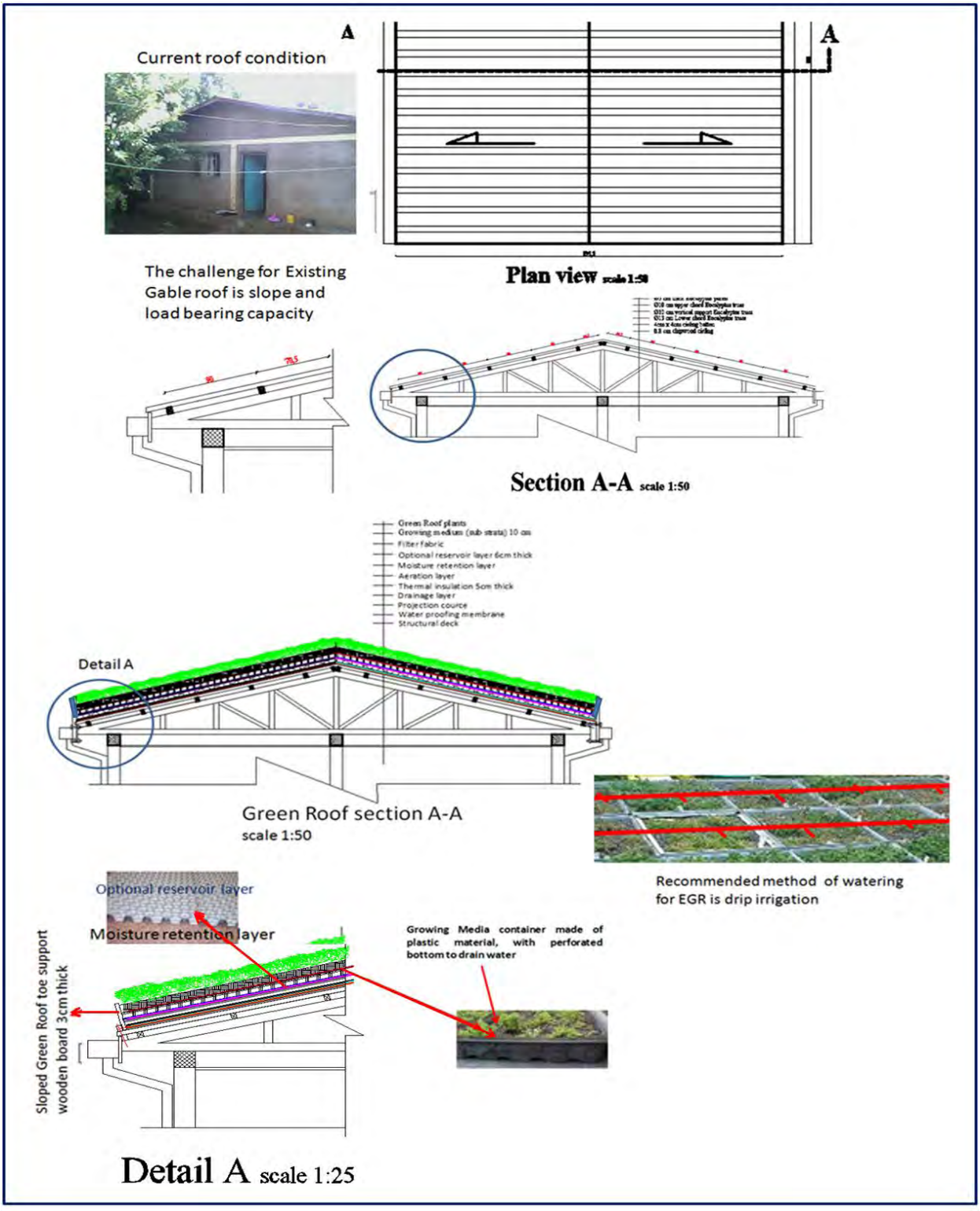


Figure 61 Green roof construction details for Gable roof with slope of 15 to 25 %

Extensive green roof can be applied to the existing roof with only slight maintenance or reinforcement to the roof structure. The planting medium thickness varies according to the roof structure and plant type, therefore, detail inspection was made before deciding thickness of planting medium and plant type. According to the observation made to the study area, the existing roofs have slope of 15% - 25% made of eucalyptus trusses of diameter 10-12 cm. Therefore, it can carry 6cm up to 12cm thick sub strata based on the size and type of material and method of construction.

Extensive green roof planting container can be made of plastic material, with perforated bottom to drain water, which is portable and easy to transport to the rooftops and maintenance.

5.2. Proposed Green Walls

Green screens walls of freestanding structures, such as fences or columns are proposed because of their screening, ventilation and cooling capacity that best fits to give solution and stabilize the weather condition of the study area. It can be applied to residential, commercial, and institutional building terrace, windows and any type of openings of a building. Climbers such as vines, cissus rotunidfolla, and cissus quandrangularis are proposed due to their ability to twining steam or leaves.

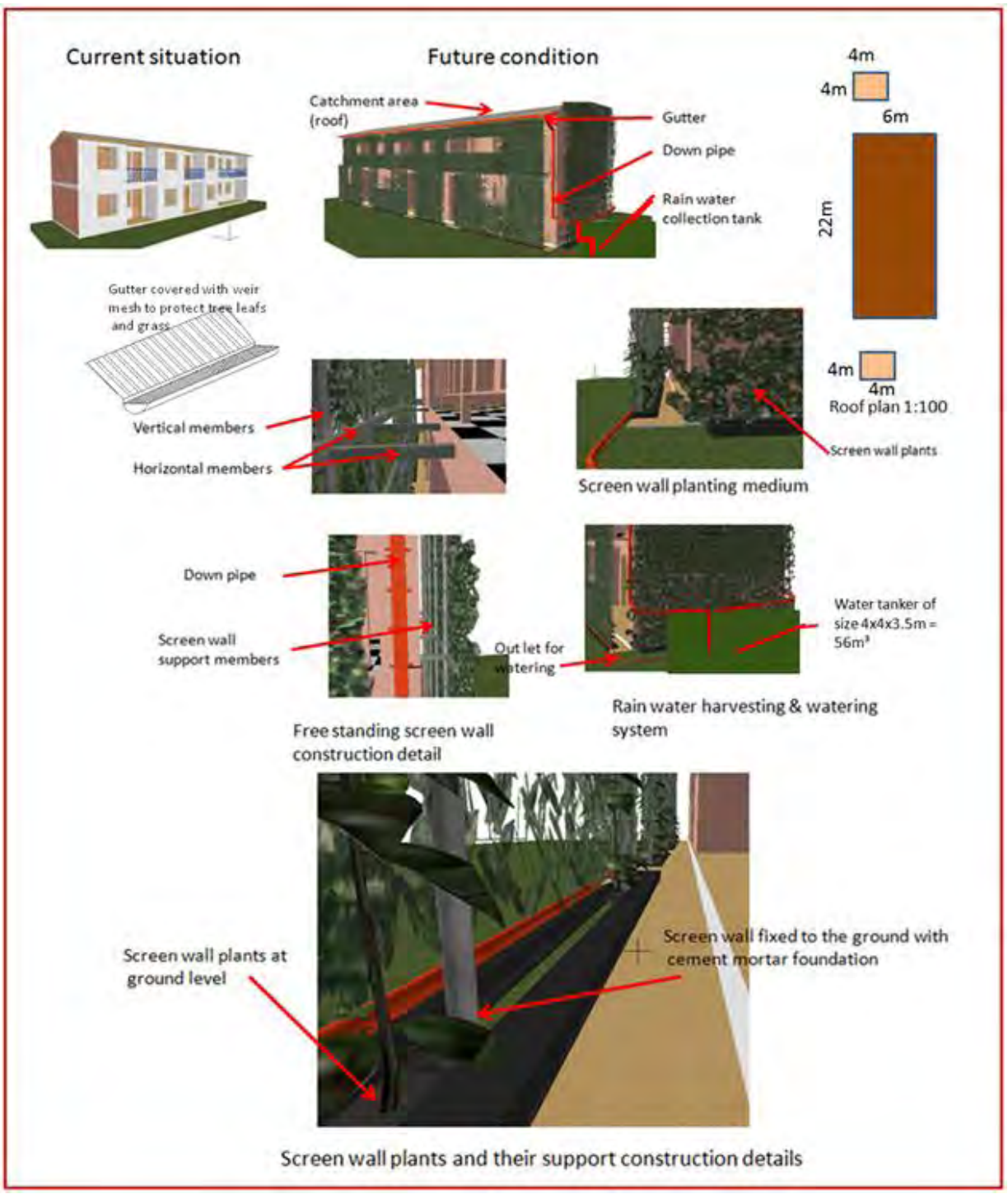


Figure 62 Proposed green screen wall design

As shown in the figure above, green screen wall is constructed separate on freestanding structure made of steel pipe Ø 5 cm welded and erected according to the intended design. The

climbing plants is directed in such a way not to be a barrier to view to outside and serve as screen providing privacy in addition to environmental and ecological benefits. Rainwater from roof should be harvested and stored for irrigation during the hot dry seasons.

The amount of storm water harvested for watering the planted green wall plants in the above figure can be calculated by using uniform runoff coefficient table 4 and uniform rainfall intensity used by Tsige Bereha in his thesis Green infrastructure for Mekele city (EiABC) as follows:

S = R*A*Rc

Where, S = Supply of water

R = Mean annual rainfall

A = Catchment area

Rc = Run off coefficient

R = 0. 872m

A = 6 x 22 = 132m^2

Rc = 0.9

Supply of water from roof = 0.872*132*0.9 = **104 m3**

Therefore, two an underground storm water tanks of size 4m x 4m x 3.5m = 56m^3 each are provided to accommodate the amount and placed 3m away from the building to avoid structural damage of the building. The storm water harvested is enough for the green wall plants if used twice a week and 1m^3 at a time and 108m^3 per year. If storm water from every roof of the study area is harvested the supply of water from roof S = R*A*Rc = 0.872*2520000*0.9 = **1,977,696 m3**

The amount of water-harvested per-capita is 19m^3 per year.

Proposed green living walls

Living wall systems are composed of pre-vegetated panels, vertical modules that are fixed vertically to a structural wall or frame. These panels can be made of plastic, expanded polystyrene, synthetic fabric, clay, metal, and concrete, and support a great diversity and density of plant species e.g. a lush mixture of groundcovers, ferns, low shrubs, perennial flowers, and edible plants. Due to the diversity and density of plant life, living walls typically require maintenance that is more intensive. Therefore, panels of plastic, expanded polystyrene, clay, and concrete are proposed due to their availability and easy construction.

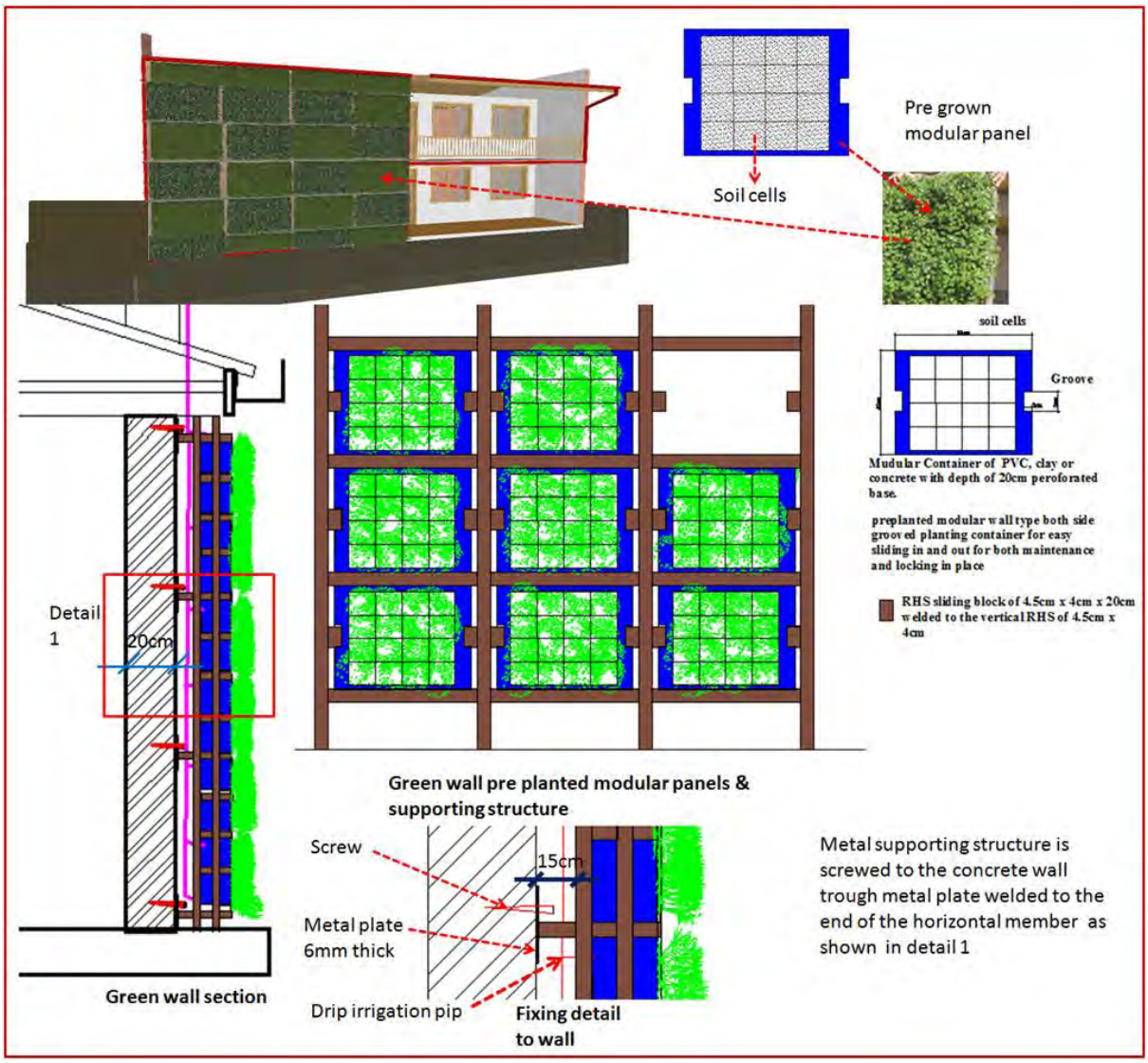


Figure 63 Living Green wall construction steps and necessary materials (source own)

5.3. Green fence

According to the observation made to different sample plots, it is found that there are three types of fences based on the type of material such as CIS, HCB, and masonry wall.

CIS fences

CIS fences are one of the impervious materials that cause heat island effect and need intervention by applying vegetative management practices.

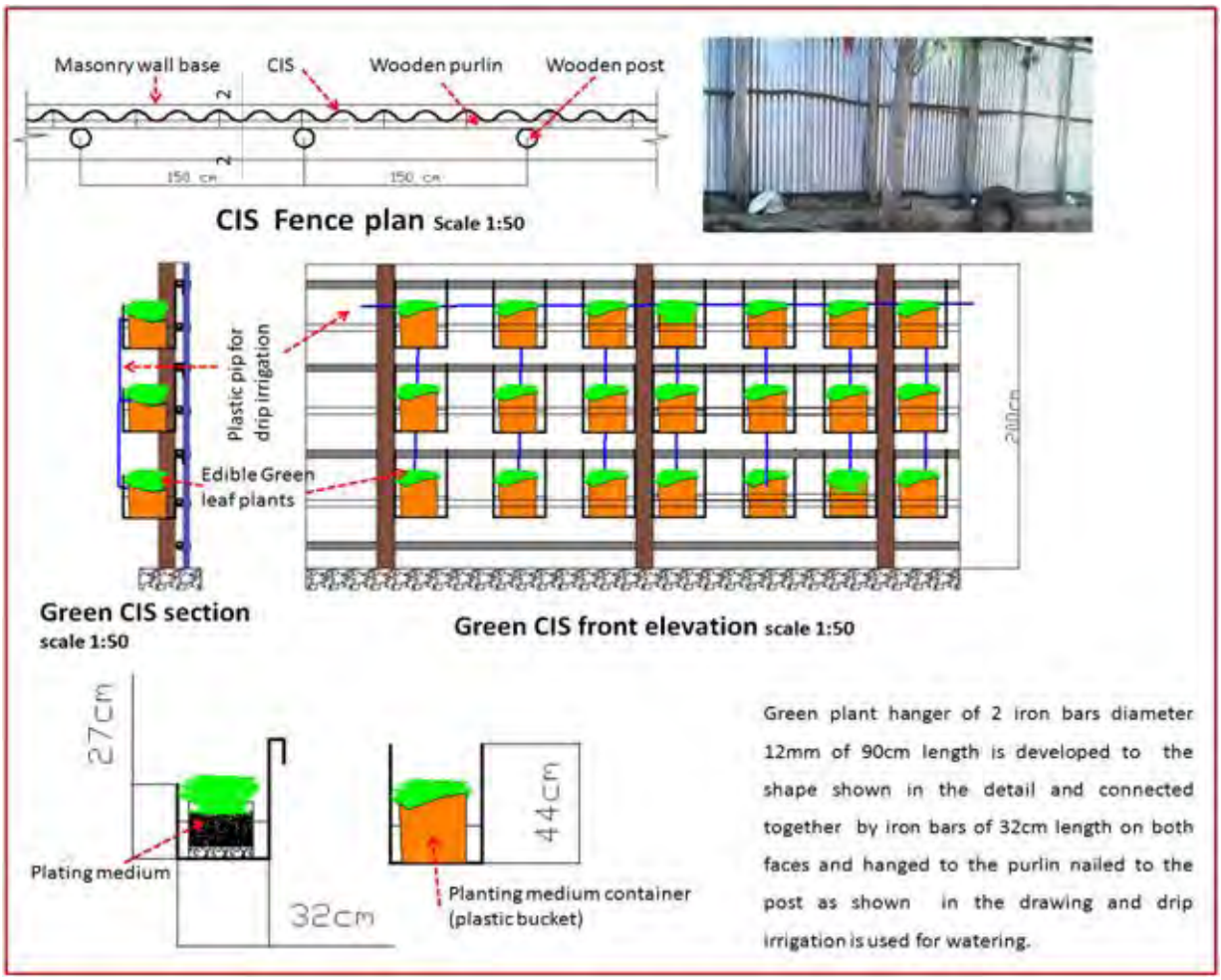


Figure 64 proposed Green CIS fence

HCB and Masonry fences

HCB and Masonry fences are also impervious surfaces, which need an intervention.

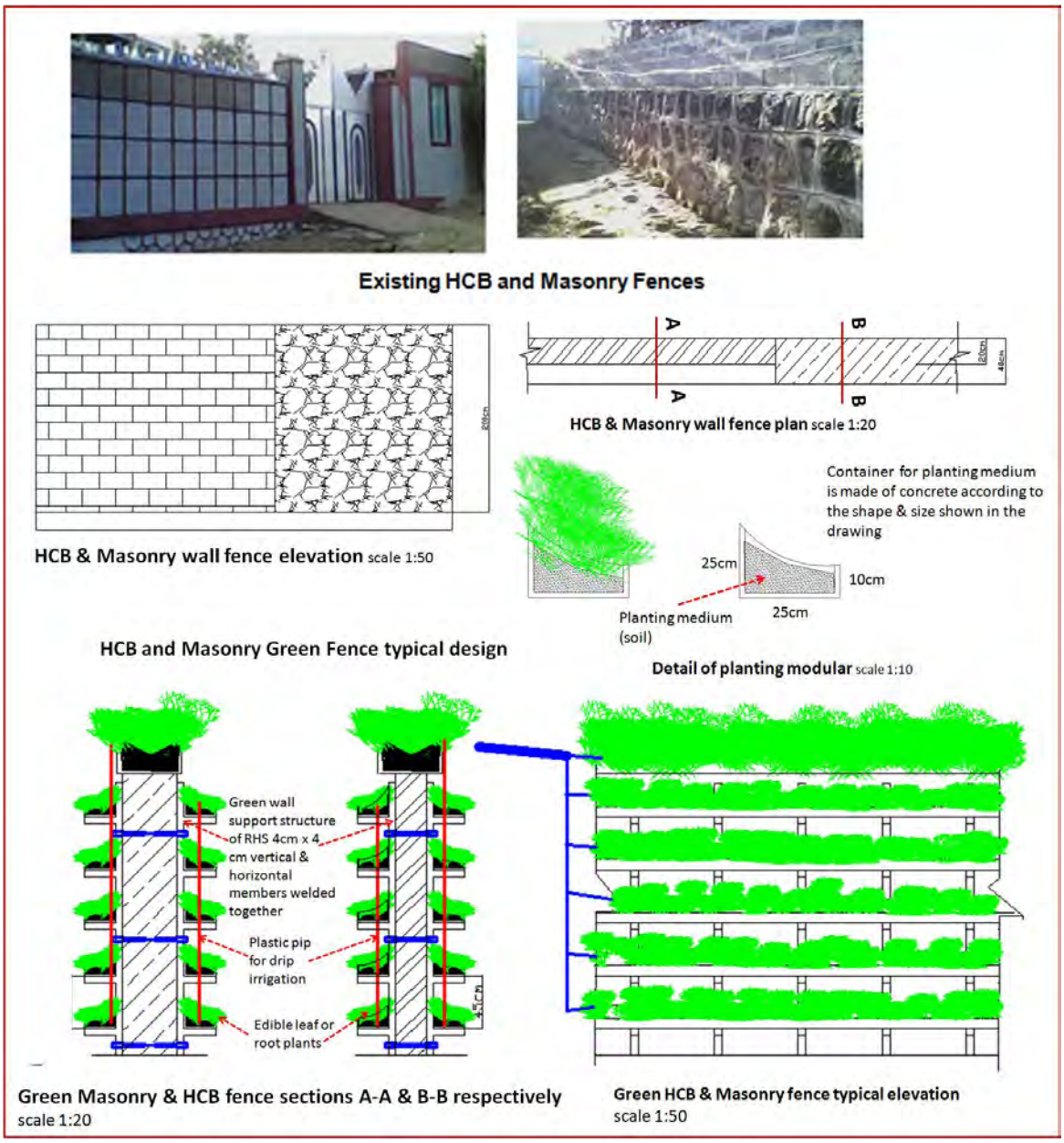


Figure 65 Proposed HCB & Masonry Green fence (source own)

5.4. Proposed green street design

Most streets in the study area have no separet pedestrian walkway, vegitation and drainage ditch. Hence below are the proposed street designs along with appropriate street tree selection

proposal. Termonilla spp and Gravilia Roubusta are, proposed as green street trees due to their evergreen and drought resistance character.

Gravel road

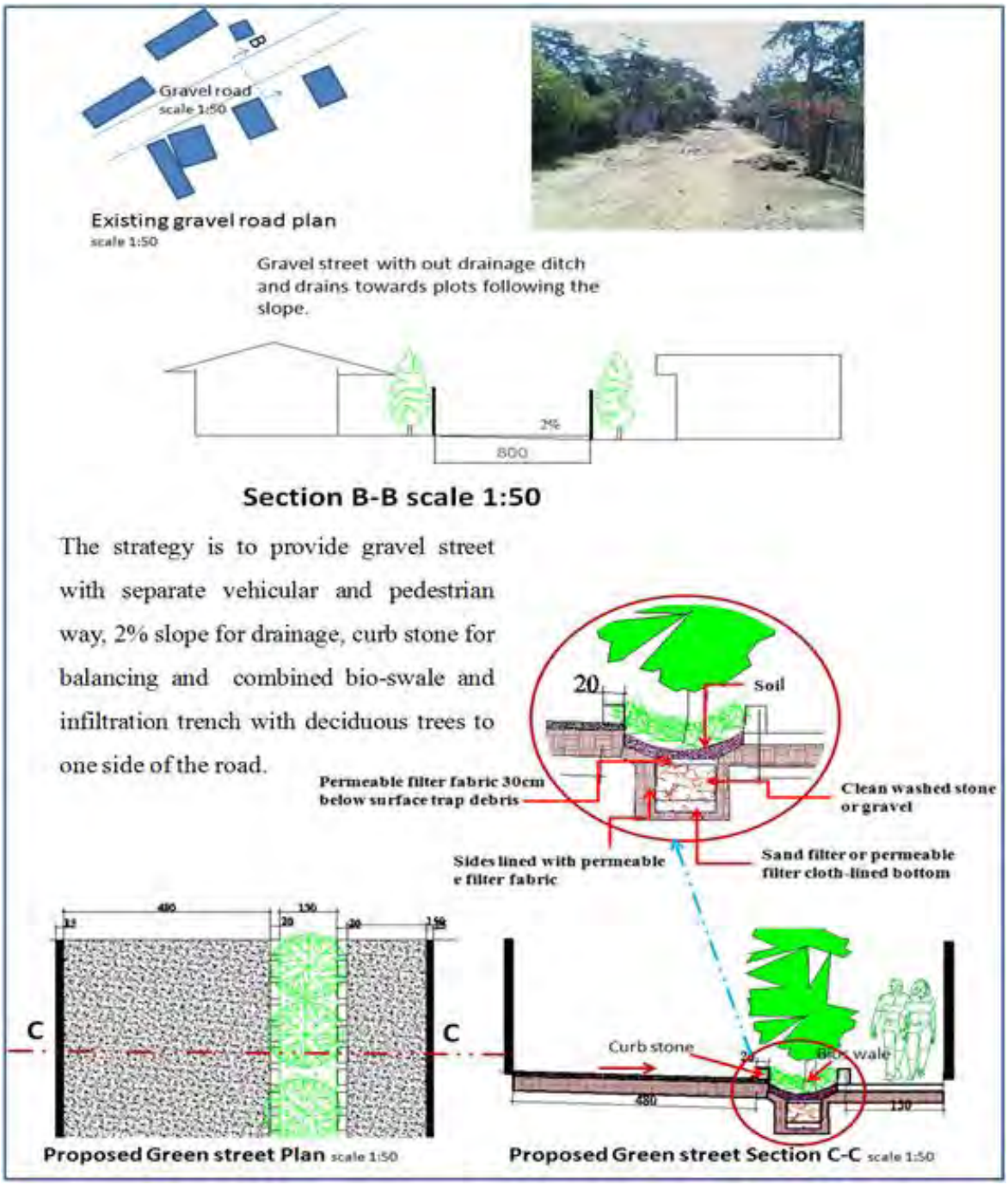
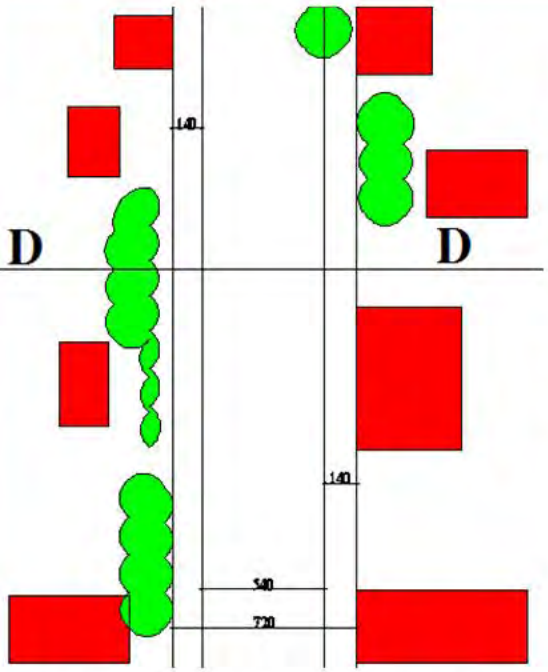


Figure 66 Proposed Green gravel road (source own)

Earth road



Existing Earth road plan scale 1:50



Has no defined Storm water drain line hence running in the middle eroding parts of the road and has no separate pedestrian walk way and vegetation



Existing Earth road section D-D scale 1:50

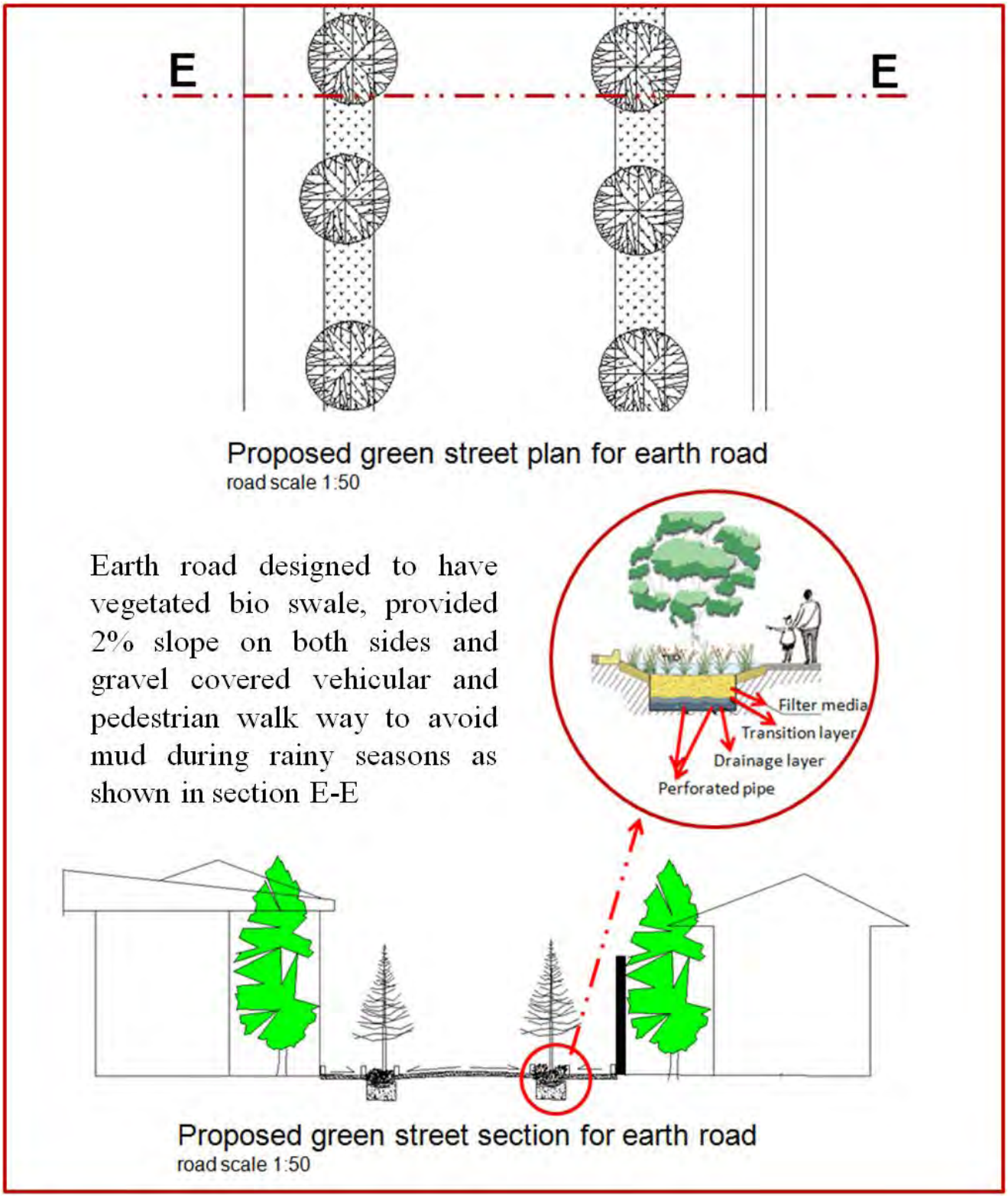
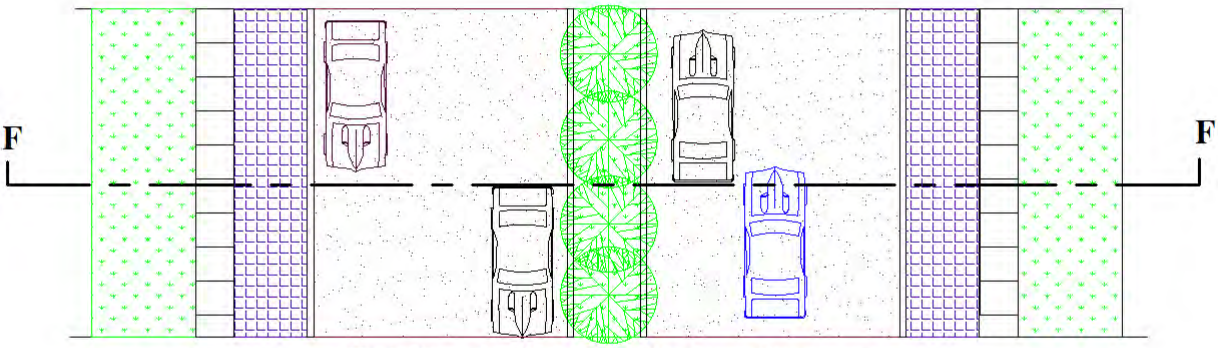


Figure 67 Proposed Green street design to Earth Road (source own)

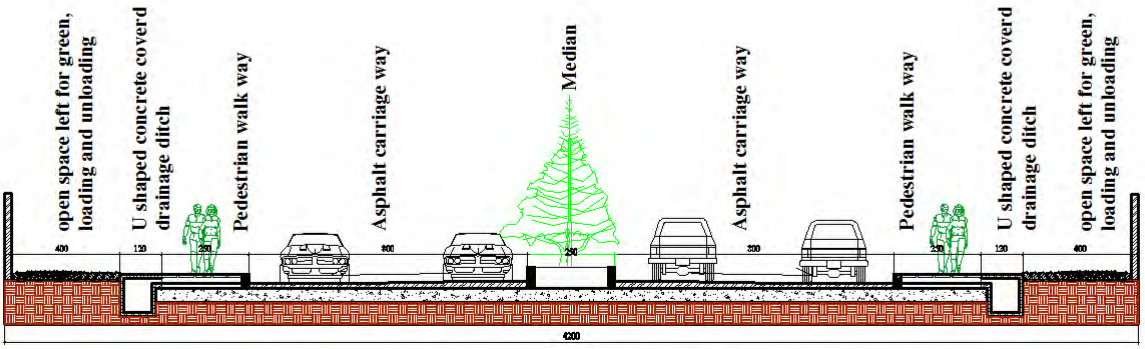
Asphalt Road

The problems of the existing Asphalt road is the design of median which is curbed and above the level of asphalt and does not allow storm run off from asphalt to median. The other problem is the absence of storm water management practices such as infiltration trench, grass buffer, depression, rather the existing ditches are of concrete which does not allow infiltration and lead the whole run off to the near by water shade and has contribution for flooding.





Existing Asphalt Road plan view scale 1: 50



Existing Asphalt Road section F-F scale 1: 50

Figure 68 Proposed Green street design for Asphalt road (source own)

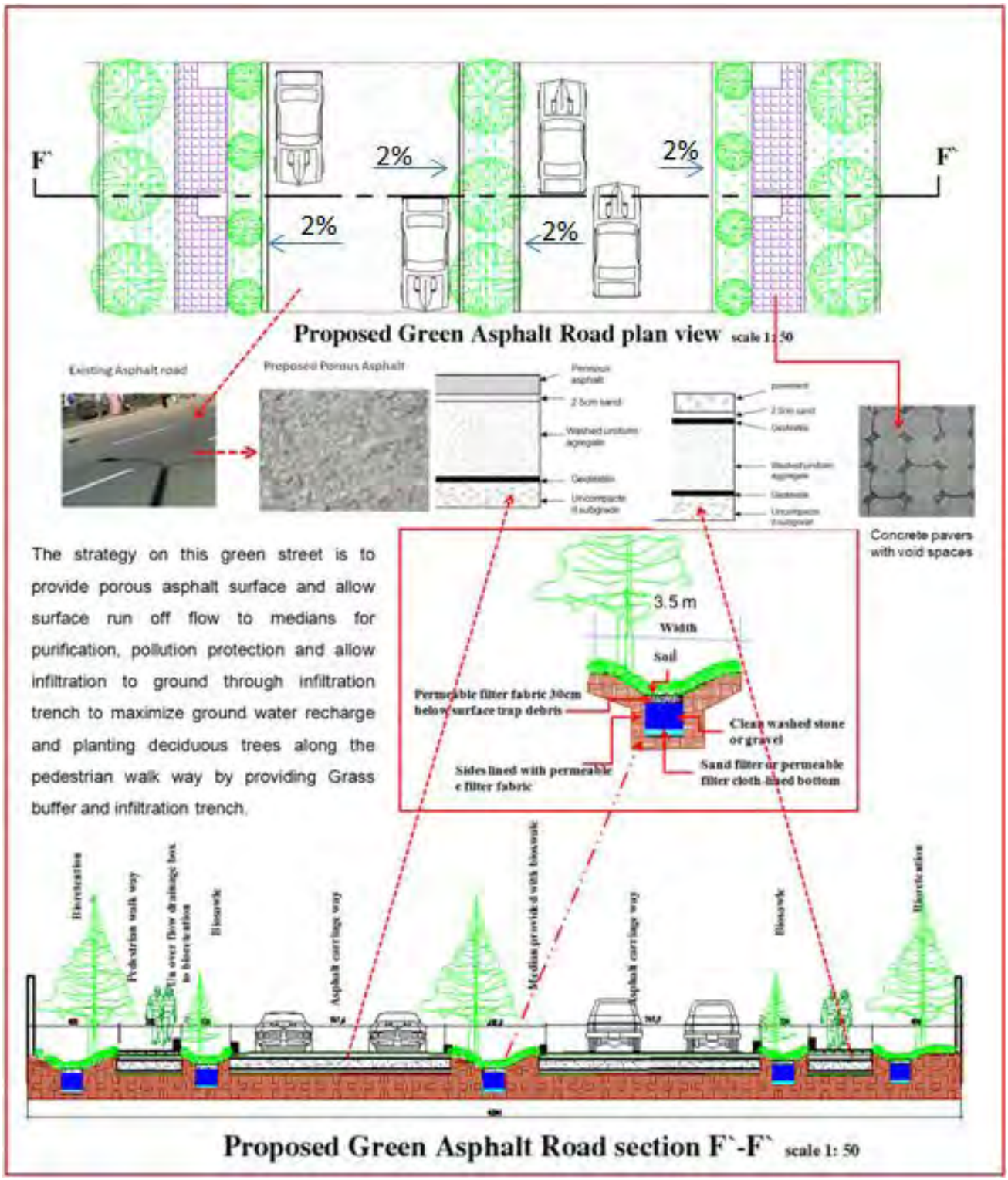


Figure69 Proposed Asphalt Green Street Design



Figure 70 3D of the above green asphalt road design (source own)

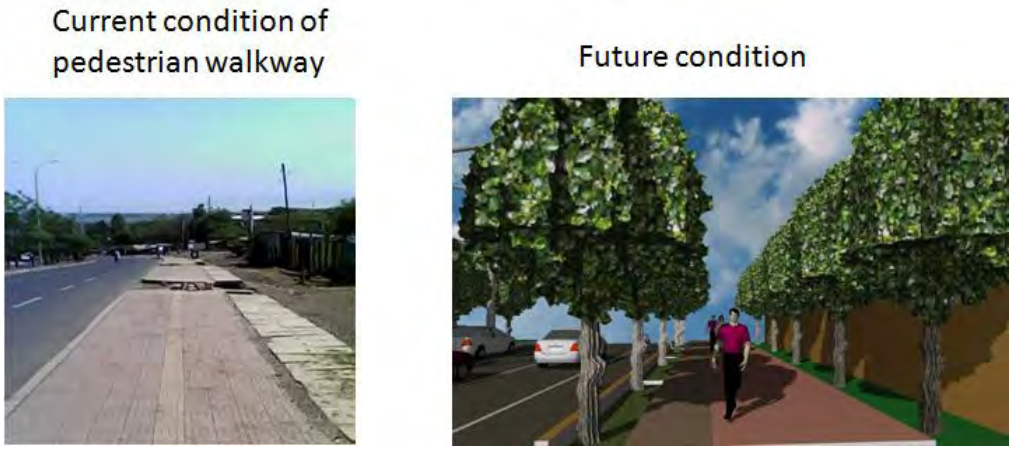
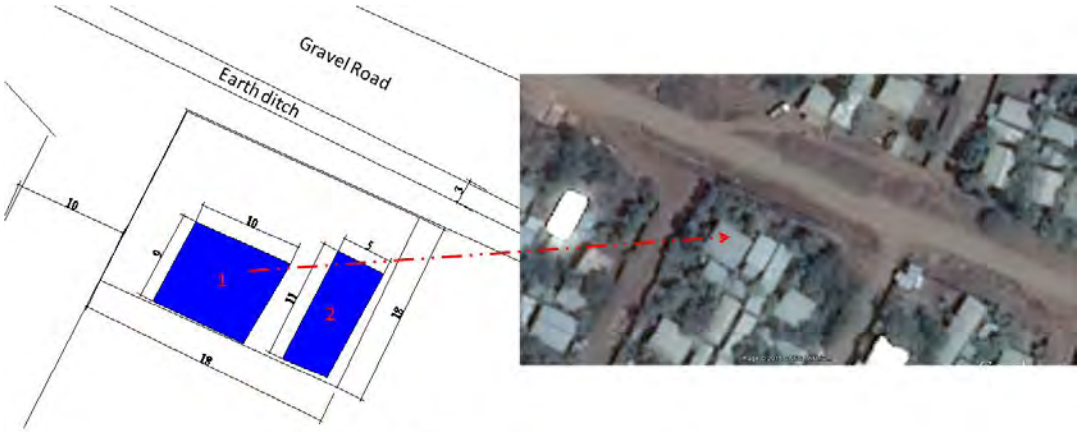


Figure 71 Existing and proposed green cover of pedestrian walkway (source own)

As it is, seen in, the figure above the current condition of the pedestrian, walkway is not attractive to walk during hot sunny days. Hence, it is proposed to have green shading trees along both sides of the pedestrian walkways to provide shading that can encourage pedestrians. Termonilla spp and Gravilia Roubusta are, proposed as green street trees due to their evergreen and drought resistance character.

The existing median in the middle of asphalt road is about 50 cm higher than the asphalt surface and curbed all-around which does not allow surface run off to flow in and utilized to provide maximum infiltration and used by plants. Whereas in the proposal it is, designed to let in storm runoff to the median to provide both storm water treatment and conveyance functions.

Green plot



Plot plan scale 1:50

Plots are the source of storm water (flooding)that every drop of rainfall flow down from gutter and open area of plot to street this causes flooding and siltation on the street. The data's needed for green plot is mean annual rainfall of Arab Minch which is 873mm, catchment area of plot (open area=179m2 and roof area=145m2) and run-off coefficient (roof=0.9, pervious area with slope 2-6% and group-B soil 0.12). The amount of water supplied from rain in this plot is calculated as follows;

S = R*A*Rc

Where, S = Supply of water

R = Mean annual rainfall

A = Catchment area

Rc = Run off coefficient

Supply of water on the plot = 0.873*145+179(0.9+0.12) =288.5 **m3**

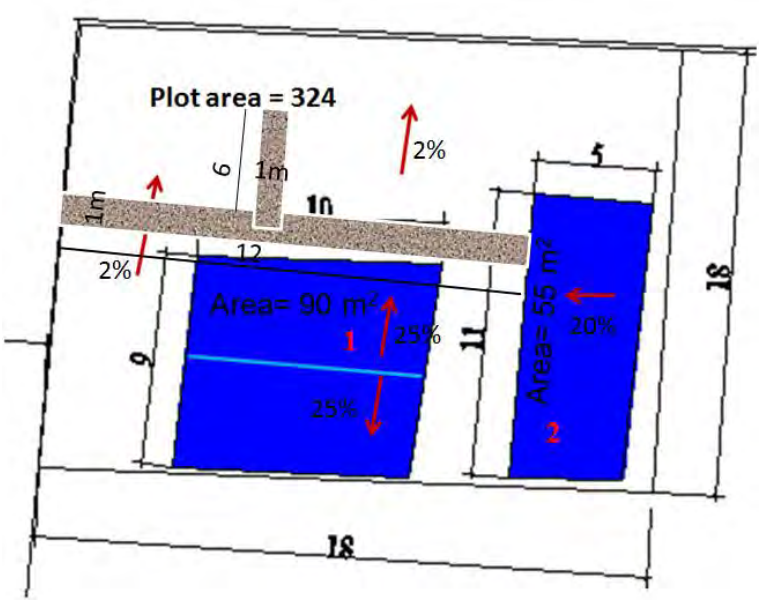
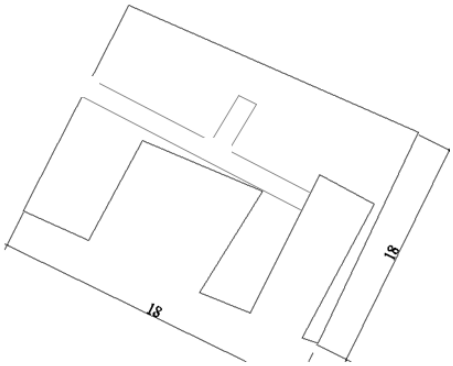
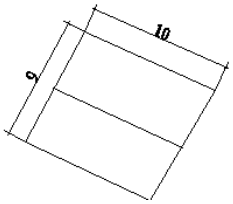


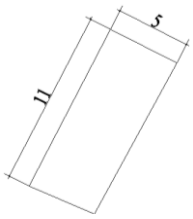
Figure 72 Pervious and impervious surfaces area of a plot (source own)



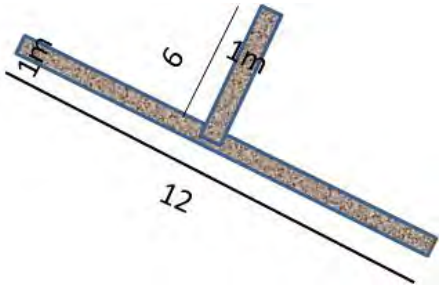
Plot pervious surface of an area 172m^2 ,runoff coefficient 0.12, and mean annual rainfall 872mm therefore the supplied water Sc is: Sc 161m^2 *0.12*0.873m = **16.8m3**



Building "1" of an area 90m^2 , runoff coefficient 0.9 and mean annual rainfall of 873mm the supplied water Sc is: Sc = 90m^2 * 0.9* 0.873m = **70.7m^3** .



Building "2" of an area 55m^2 , runoff coefficient 0.9 and mean annual rainfall of 873mm the supplied water Sc is: Sc = 55m^2 *0.9 *0.873m = **43.2m^3**.



Red ash Walk way of an area 18m^2 , runoff coefficient 0.85 and mean annual rainfall of 873mm the supplied water Sc is: Sc = 18m^2 *0.85 *0.873m = **13.4m^3**.

The aim is to reduce rainwater flooding at plot level by means of harvesting rainwater for garden and domestic uses and by providing infiltration pit in the plot and letting the over flow to the nearby bio-retention swales or ditch.

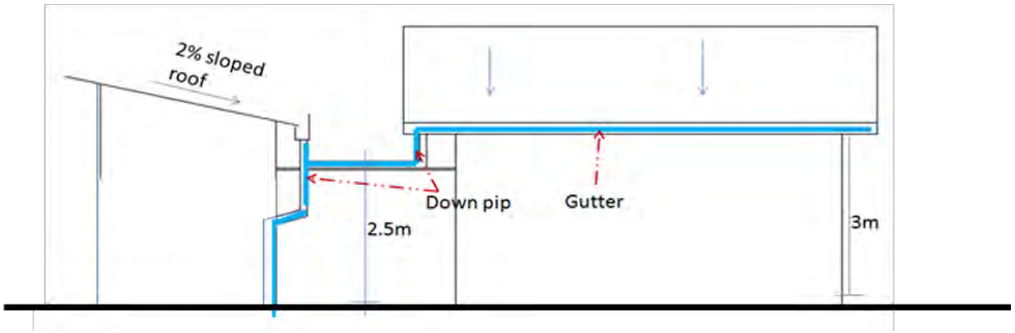


Figure 73 Rainwater harvesting and storage (source own)

The storage required for building "1" and "2" is 114 m3. Therefore, 5m x 5m x 4.6m reinforced concrete tanker is proposed underground and pumped by manual or electric pump connected to the system for use.

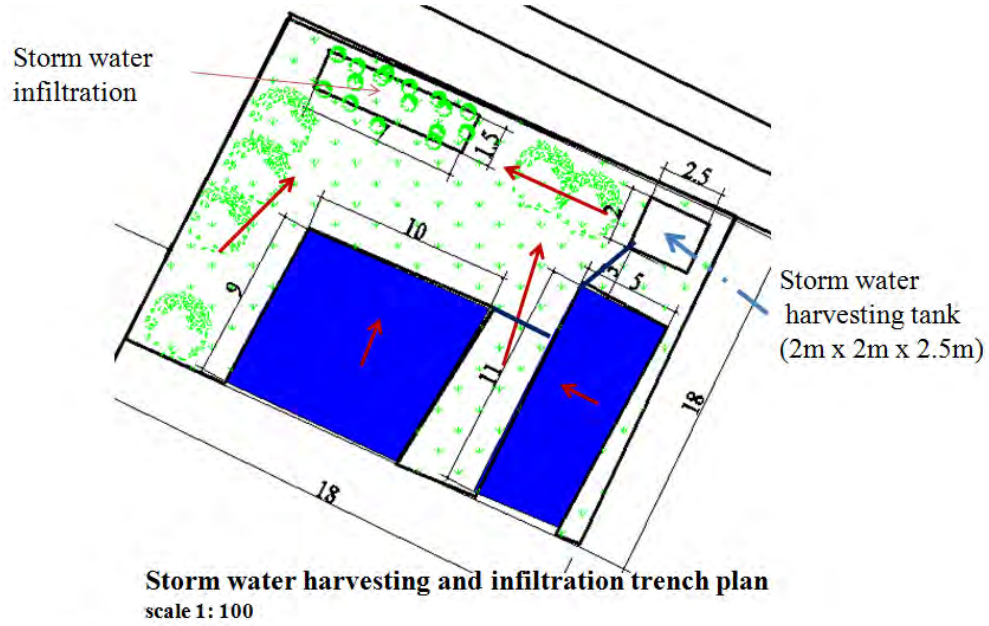


Figure 74 Storm water flood controlling mechanisms at plot level (source own)

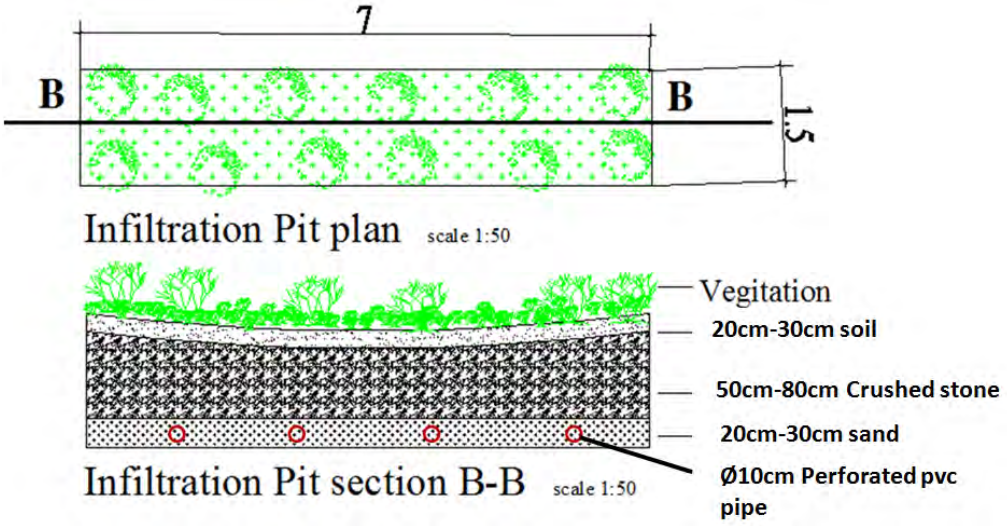
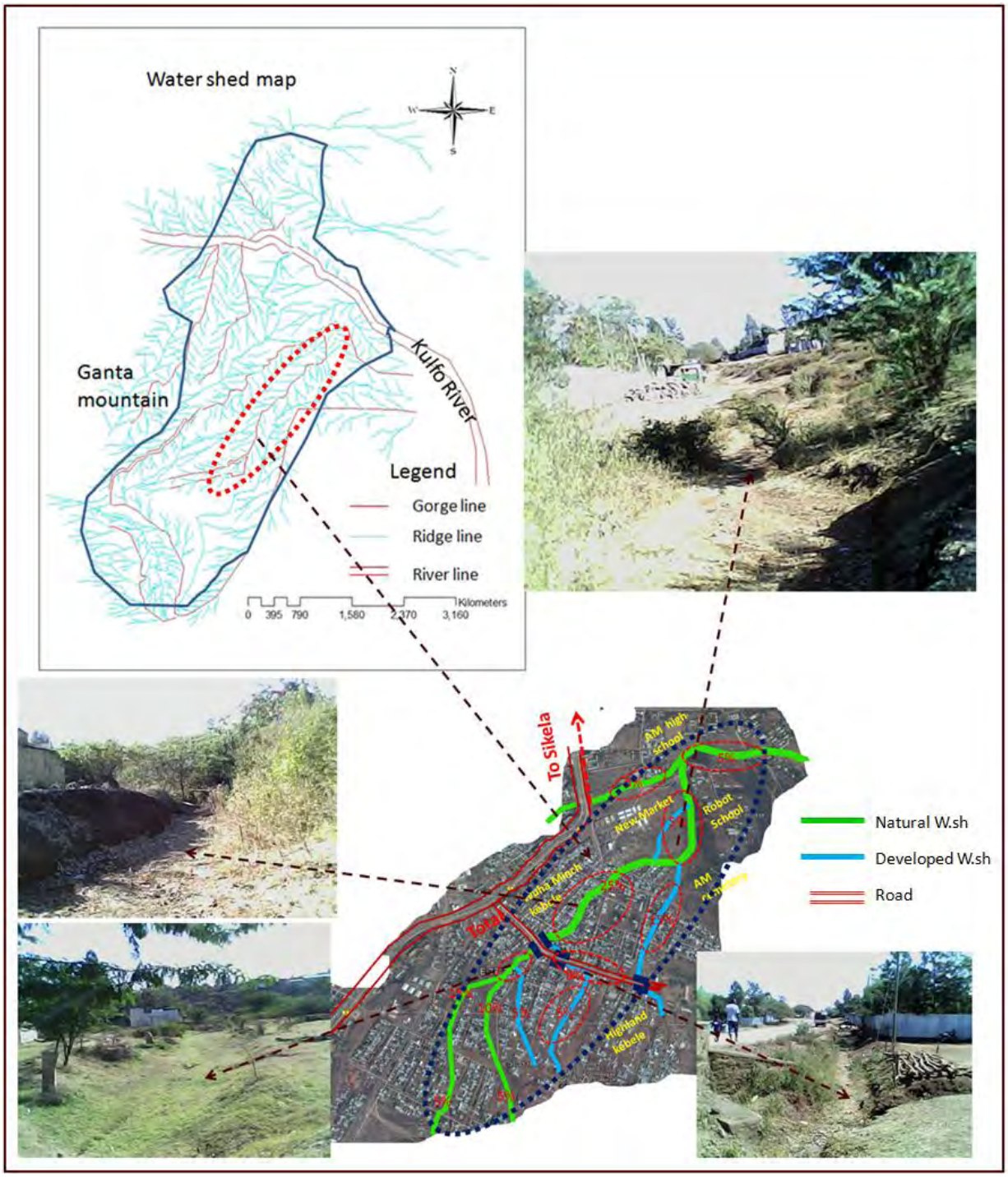


Figure 75 Infiltration pit plan & section
(Source own)

Infiltration trench filled with a layer of materials sand, crashed stone and vegetated soil.

Landscape based structural measure for storm water management.



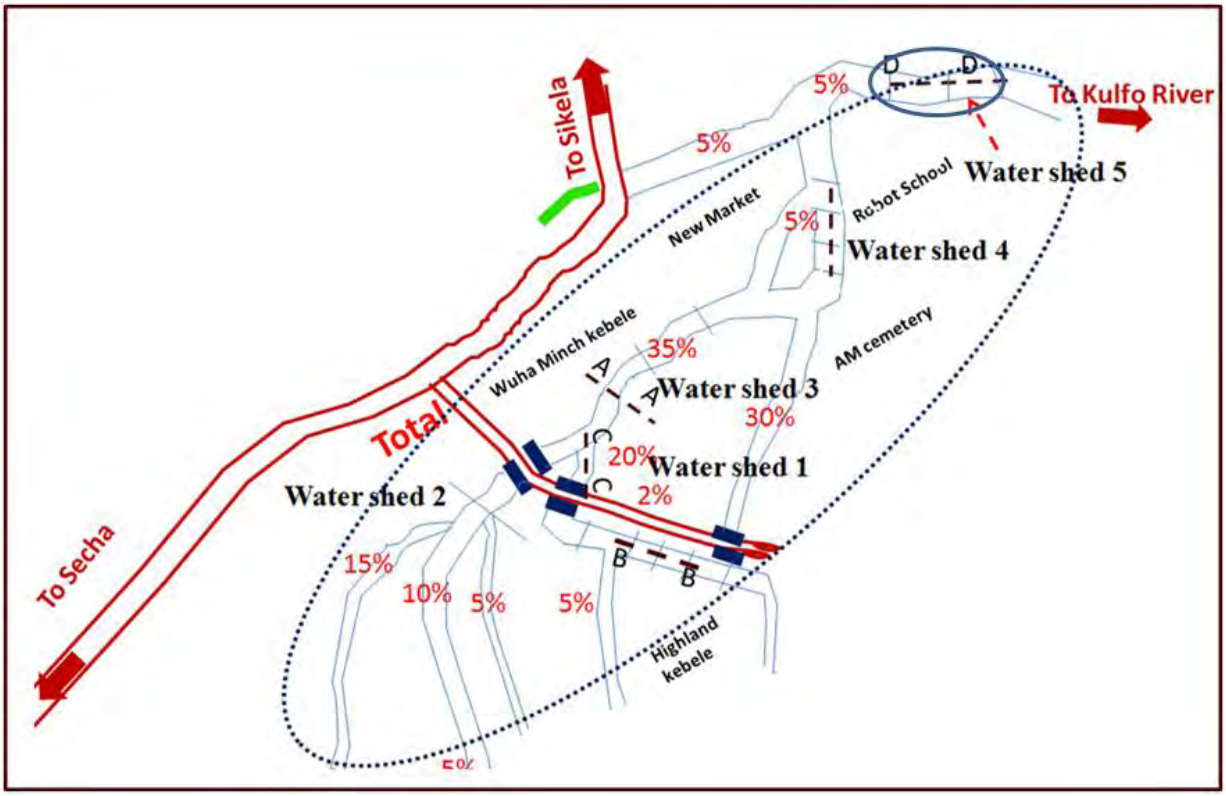


Figure 76 Water shed line of Yetnebrsh & Total sefer (source own)

Storm water from catchment area (plots & earth roads) of 12 ha reaches the earth ditch of 3.6 m wide, 1.2m deep and 2% slope hence, and storm water flow per second had been calculated as:

Q = CIA

Where:

Q = Flow, m3/hr

C = dimensionless runoff coefficient

I = rainfall intensity, mm/hr

A = drainage area, hectares, ha

A = 120000m^2 (12 ha)

C = 0.3 for single family residential (table 4)

I = 25mm/hr

Q = 0.5 x 120000m^2 x 0.025m/hr

Q = 900m3 /hr

Therefore, to redistributes concentrated flow in to sheet flow and increases infiltration Level spreader at every 10m interval is proposed as shown below

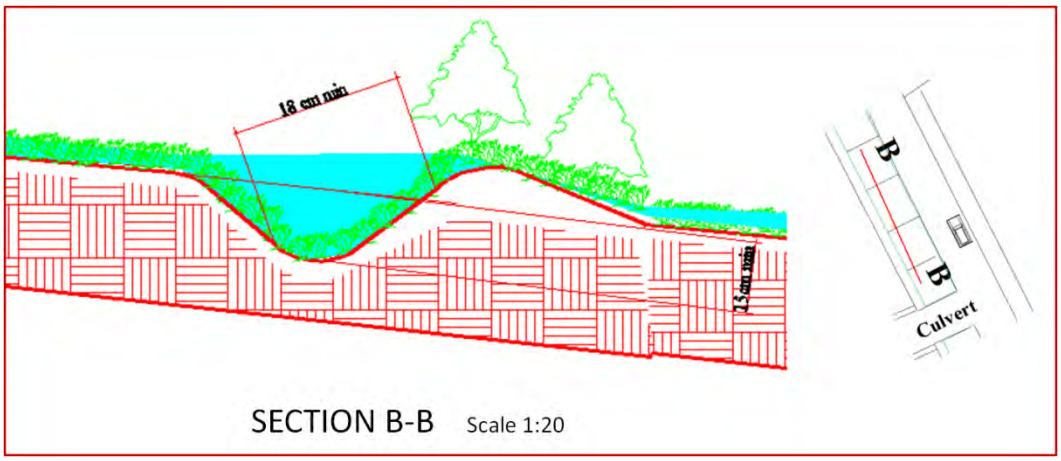


Figure 77 Level spreader provided to Earth ditch (source own)

The amount of runoff, which flows through the aforementioned earth ditch passes through a culvert of diameter 1m to the water shed 1, which has a slope more than 15% therefore to reduce the erosive velocity and detain storm water runoff check dam at every 10m, is proposed as shown below.

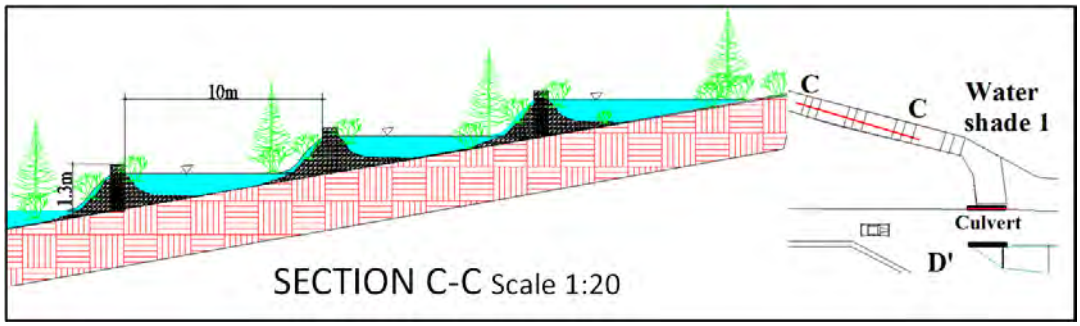


Figure 78 Check Dam provided to water shade 1 (source own)

Water shed 2 has a wider catchment of more than 40 ha (40,000m^2) the storm water flow per second is calculated as Q = CIA

C = 0.3 single family residence area

I = 25mm/hr

A = 40,0000m^2

Q = 3000m^3 /hr

The aim is to change the concentrated flow to sheet flow and reduce erosive velocity of the storm water flow of 3000m^3 /hr through the watershed 2.Ttherefore it is proposed to provide Level spreader at areas of 2% slope and check dam at areas with slope more than 15% alternatively.

Where the two water sheds 1 and 2 meet (watershed 3) the water shed line has a slope more than 18%, storm water flow from the catchment area of 8ha (80,000m2) the storm water flow per second is calculated as Q = CIA.

C = 0.4 detached multiple family residence

I = 25mm/hr

A = 80,000m^2

Q = 800m^3 /hr

Terrace of gabion is proposed to mitigate erosion, sediment filtration, enhances infiltration, and reduce the source of siltation to the cemetery and new market area.

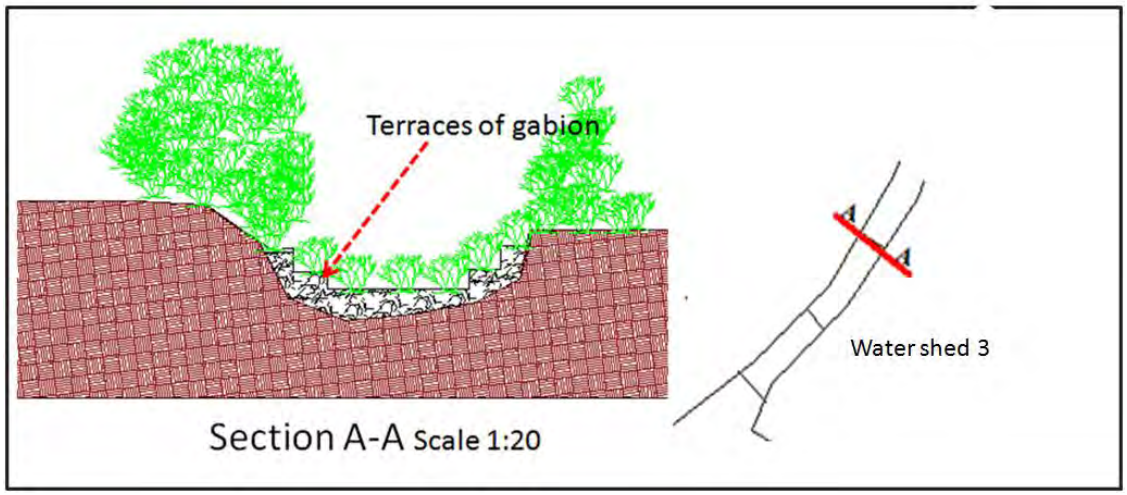


Figure 79 Terraces of Gabions provided to water shade 3 (source own)

Watershed 4 has catchment of more than 10 ha (300,000$m^{2)}$ the storm water flow per second is calculated as Q = CIA.

C = 0.1 for park and cemetery areas

I = 25mm/hr

A = 100,000m^2

Q = 250m^3 /hr

Therefore, to reduce the flow velocity and change the concentrated flow to sheet flow the research has proposed check dam and spread level alternatively.

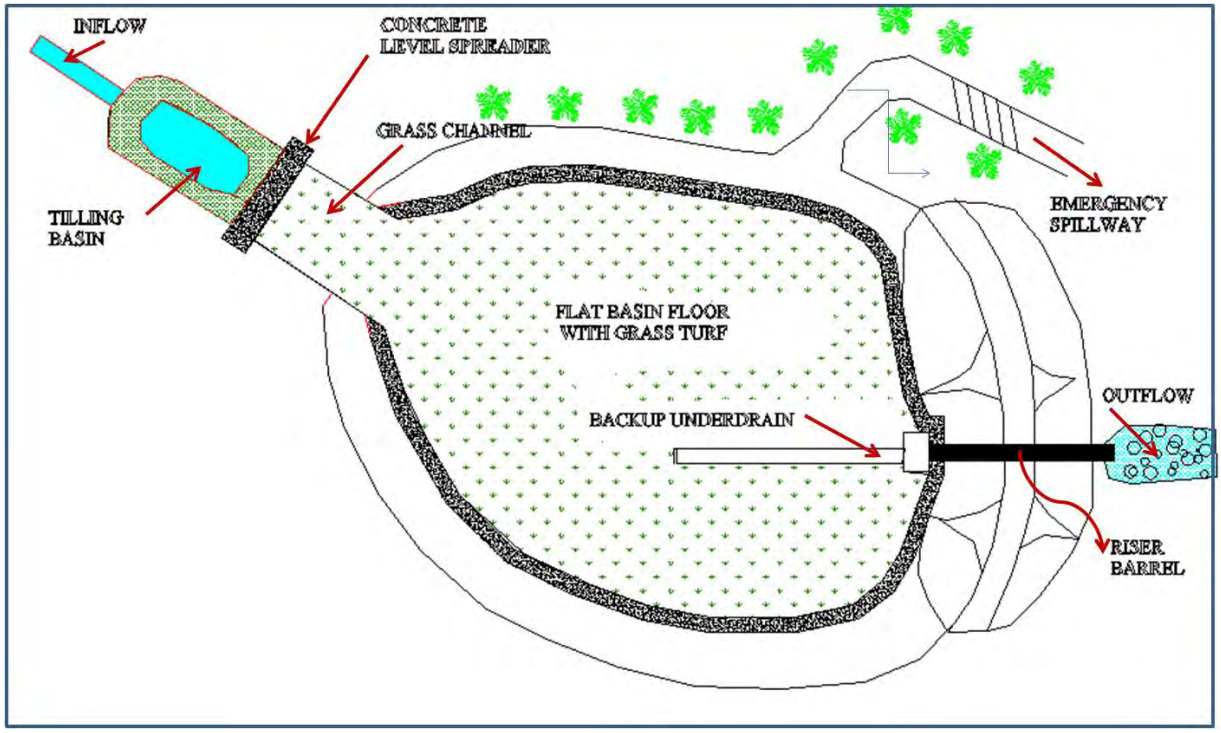


Figure 80 Dry pond design

Dry detention basins, also called dry ponds, are storm water basins designed to intercept a volume of storm water runoff and temporarily impound the water for gradual release to the receiving stream or storm water system. Dry detention basins are designed to completely empty out between runoff events, typically within 48 hours, and therefore provide mainly runoff control as opposed to water quality control. They can provide limited settling of particulate matter, but a large portion of this material can be suspended by subsequent runoff events. Detention basins can limit downstream scour and loss of aquatic habitat by reducing the peak flow rate and energy of storm water discharges. In many areas, the detention basins, when dry, can be used for other recreational purposes. In the water shed 5 dry pond of size 80m x 50m x 1.2m is proposed due to its great advantages in reducing peak flow rate and energy of storm water discharges, limiting downstream erosion and scouring, good potential for removal of sediments, its service as recreation and green space when dry.

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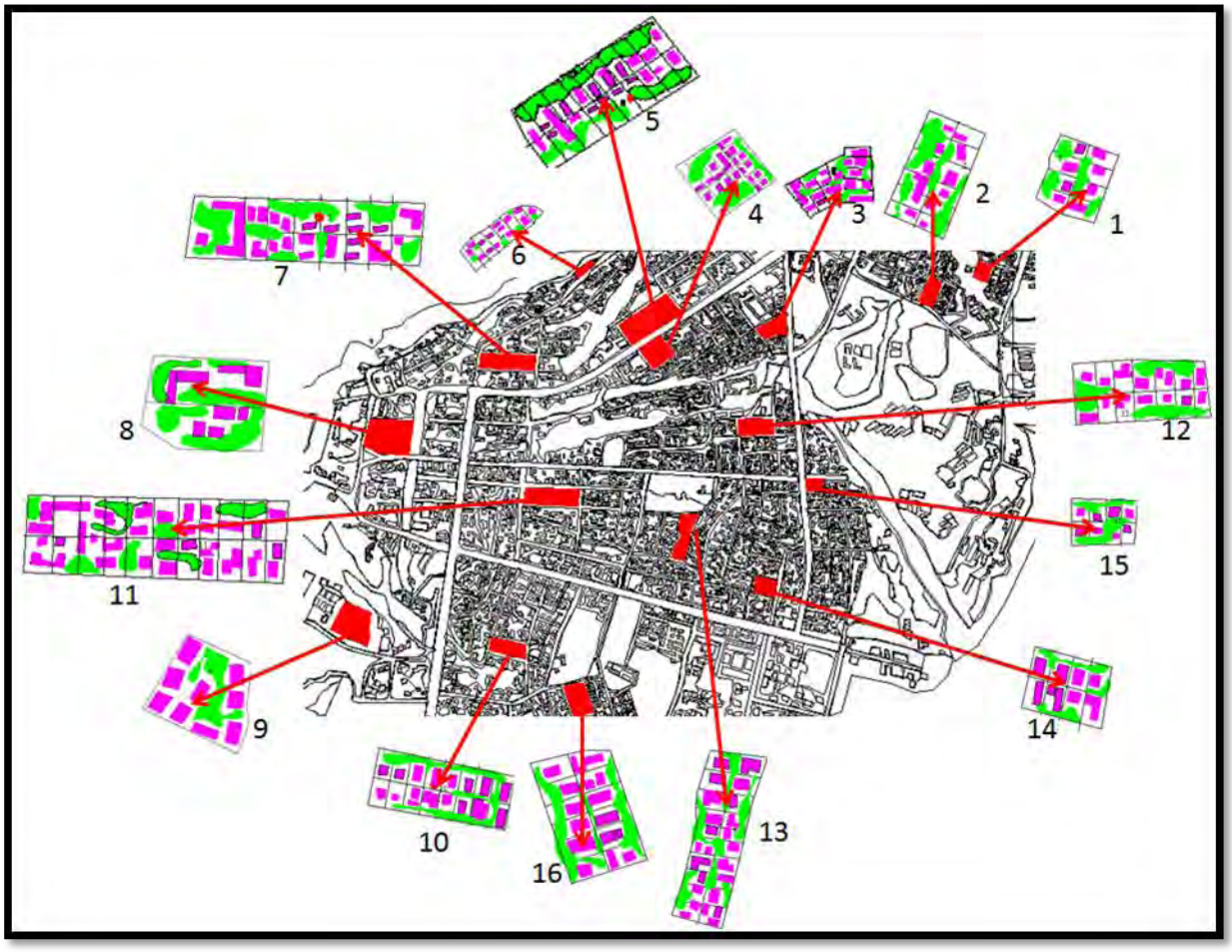
7. Appendices

7.1. Appendix-I Sample Block mapping

Secha center and the surrounding area



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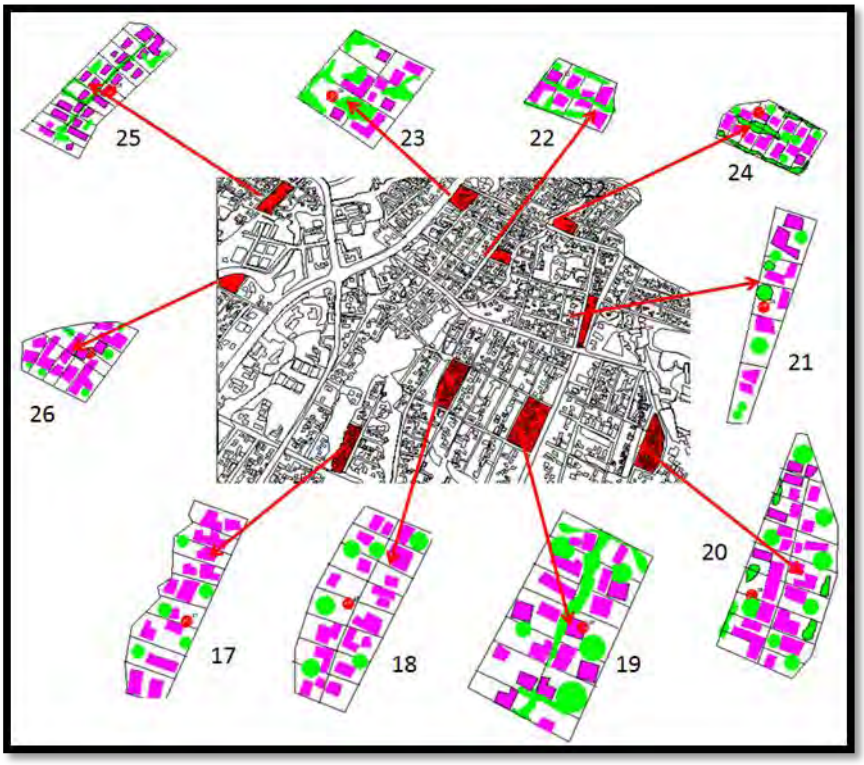


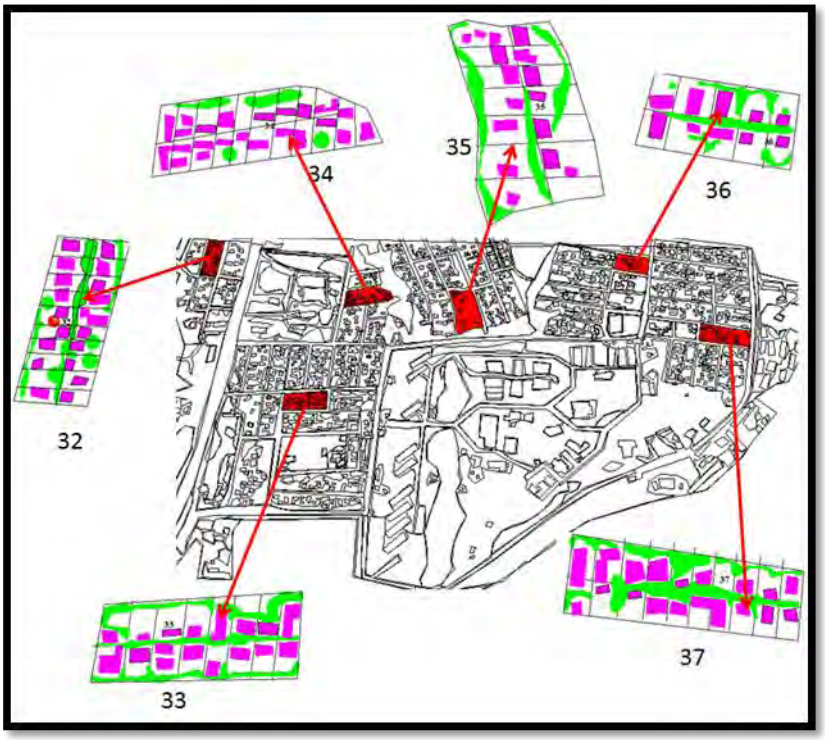
Fisash

Around AM Hospital and Nursing



School

Chamo campus

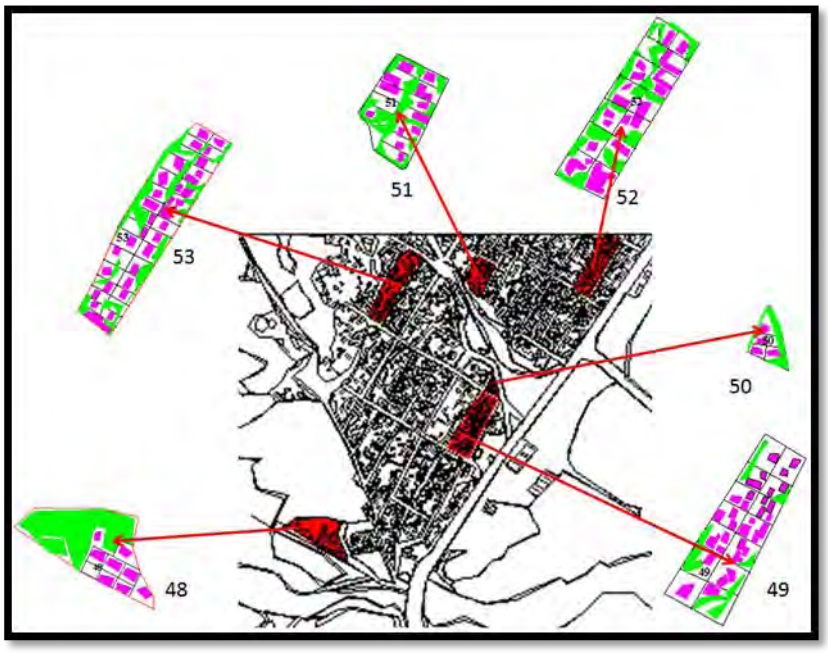


Sikela around Technical school

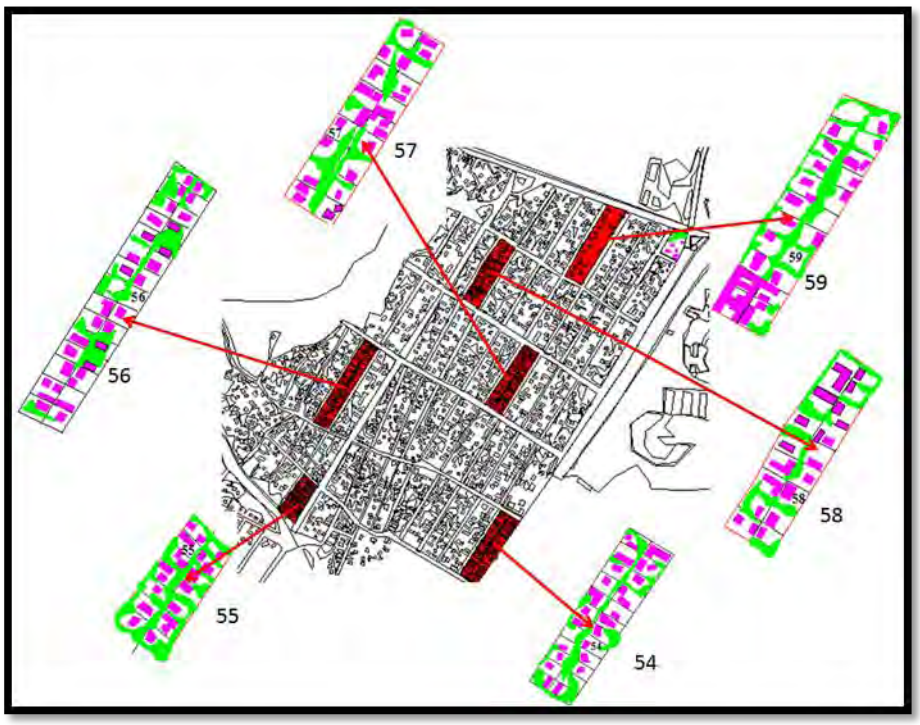


Limat 1

7.1.1.



Limat 2



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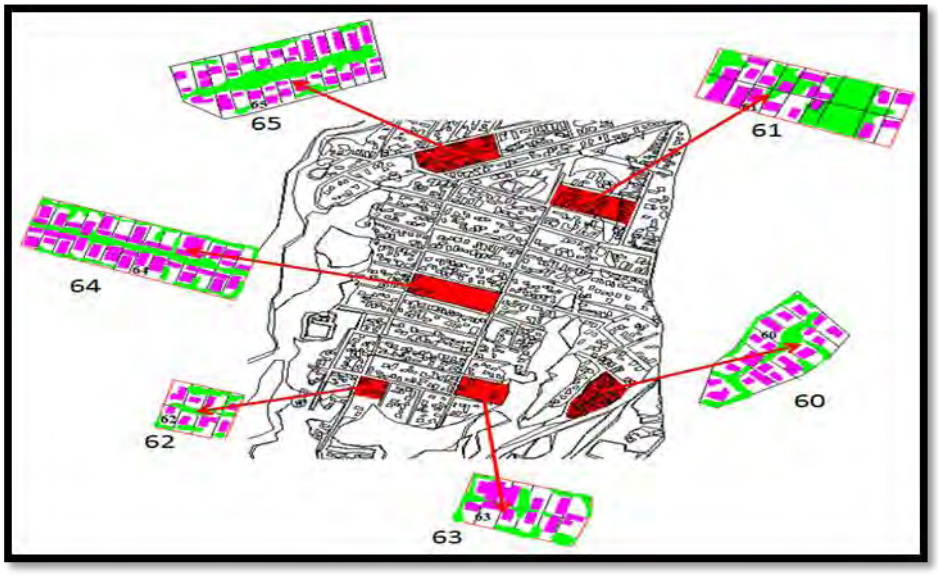
7.1.2.



Old Market area



7.2. Appendix-II Sample blocks pervious & Impervious cover

Table 12 Data from 68 sample blocks pervious & impervious cover

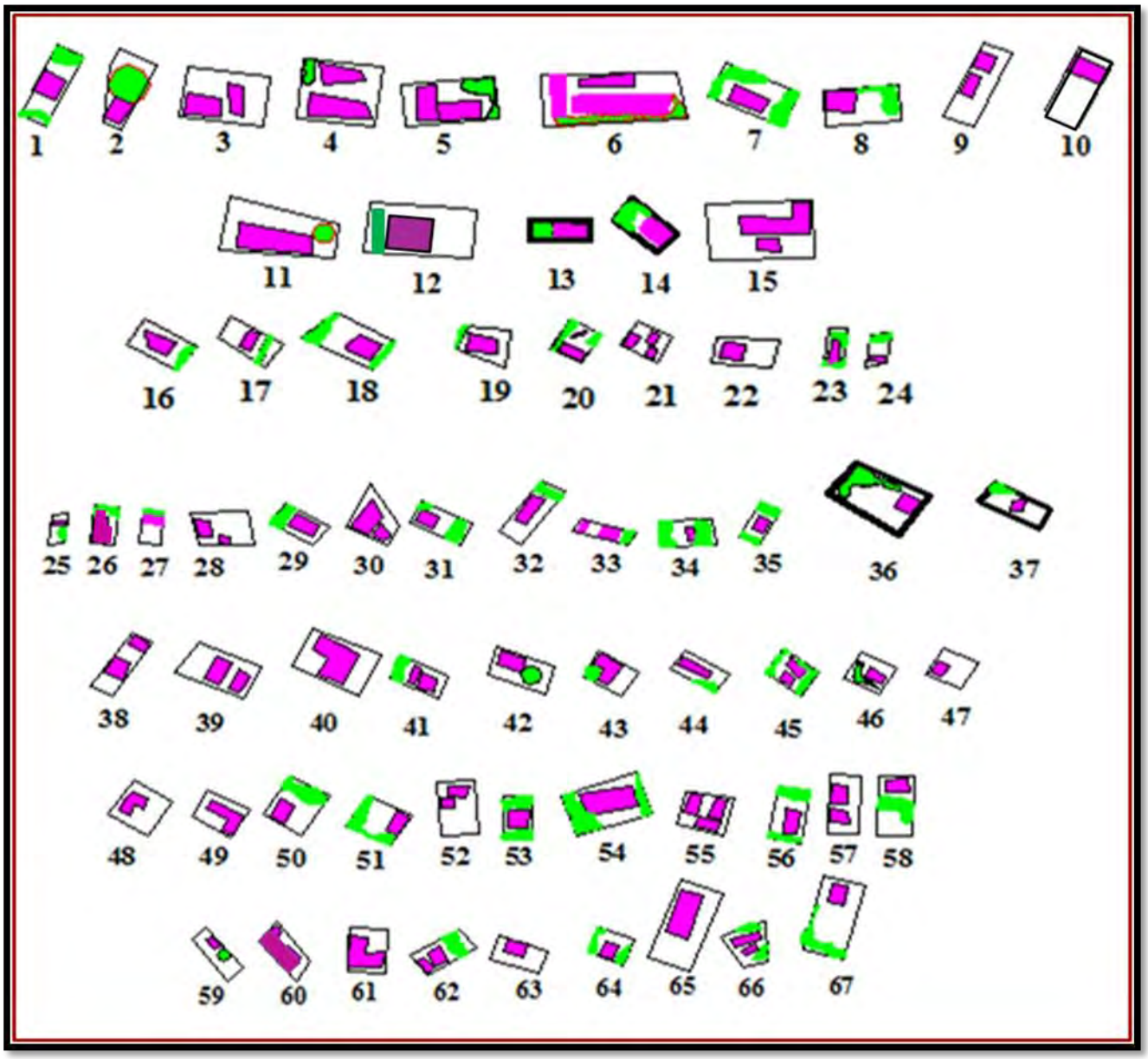
Block No	Block size in m^2	Roof area In m^2	Pervious surface (green) in m^2	Impervious open surface in m^2
1	5340.88	1802.55	658.53	2878.73
2	5200.70	1755.24	641.25	2803.18
3	2177.89	735.04	268.53	1173.88
4	2150.21	728.71	265.12	1183.05
5	4486.23	1514.10	497.07	2468.32
6	2361.85	797.12	291.22	1273.04
7	7413.22	2283.27	1126.81	3410.10
8	3392.92	1156.98	441.10	1794.85
9	25041.50	8509.10	2774.60	13777.83

10	5225.30	1609.40	794.25	2403.64
11	21705.71	7325.68	2676.31	11699.4
12	17633.25	5431.04	2680.25	8111.29
13	11467.20	3910.32	1490.74	6066.15
14	6643.80	2251.58	736.13	3655.42
15	8443.62	2600.63	1283.43	4466.67
16	5702.08	1944.4	741.27	3016.40
17	9814.61	3022.99	1491.82	4514.72
18	23640.27	8061.33	3073.24	12505.70
19	8043.10	2725.80	891.17	4425.31
20	6057.23	1865.62	920.70	2786.33
21	2408.42	821.27	313.10	1274.05
22	4859.35	1943.74	485.94	2915.61
23	5537.50	1705.55	841.70	2574.25
24	6398.80	2047.62	895.83	3455.35
25	3794.56	1138.37	569.18	2087.01
26	5772.10	1956.16	639.55	3175.81
27	5580.45	1883.40	688.10	3007.86
28	6877.65	3094.94	550.21	3232.50
29	4323.32	1729.33	432.33	2593.99
30	1331.8	454.14	173.13	704.52
31	6388.54	2156.13	787.71	3443.42
32	5621.2	1731.33	854.42	2585.75
33	8084.00	3233.60	808.40	4850.40
34	7810.2	3124.08	781.02	4686.12
35	7184.65	3233.09	574.77	3376.78
36	6040.25	3020.13	724.83	2295.29
37	3036.54	1670.09	303.65	1062.79
38	5246.32	2360.84	419.70	2465.77
39	8665.40	2599.62	3466.16	2599.62

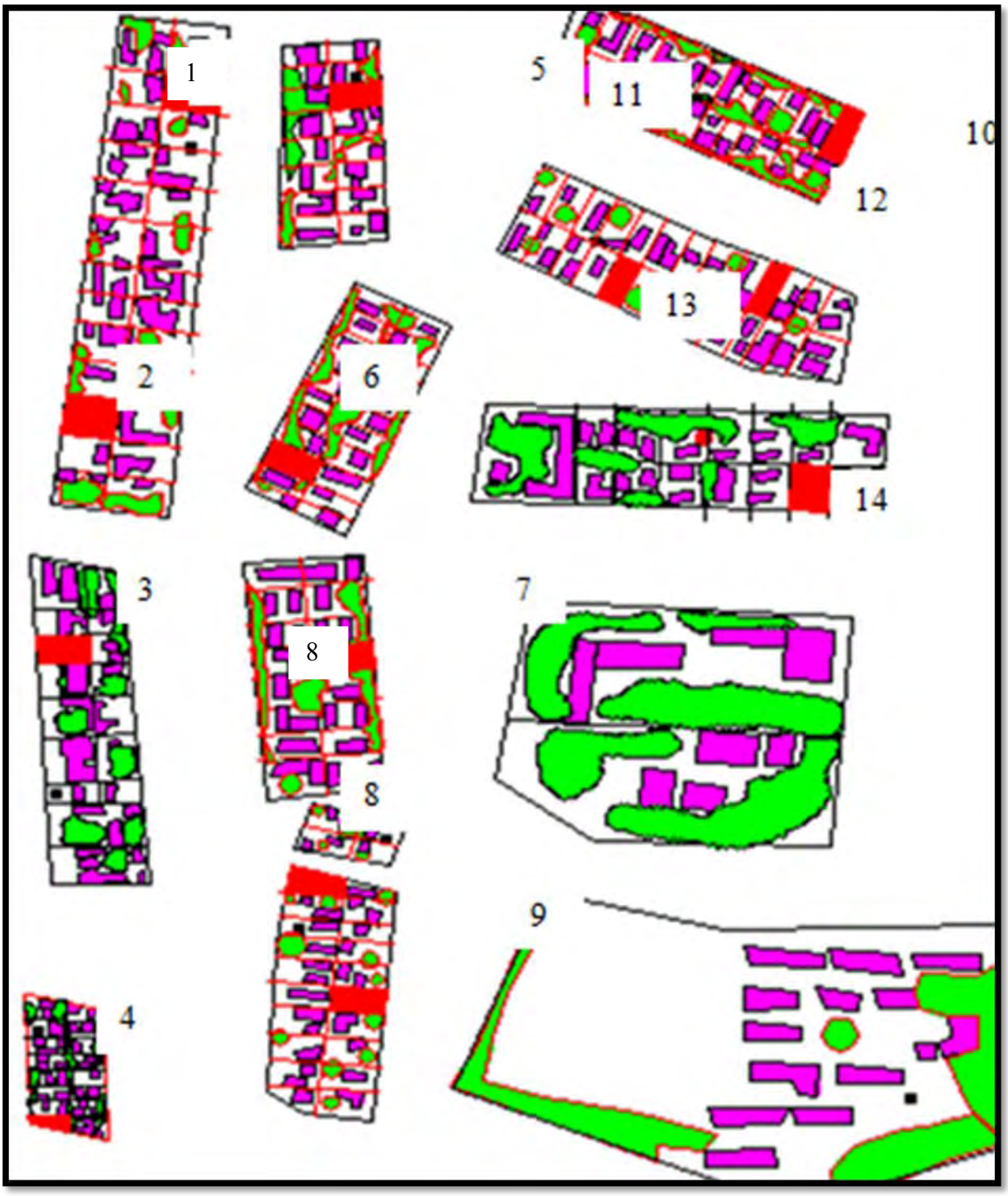
40	7115.24	2864.10	1423.05	4269.14
41	7311.50	2193.45	2924.60	2193.45
42	5689.54	1752.37	864.81	2617.19
43	5589.93	1906.17	726.69	2957.07
44	5169.50	1744.70	637.40	2786.36
45	5144.83	1646.36	720.28	2778.21
46	7810.21	2343.06	3124.08	2343.06
47	6011.83	1803.55	2404.73	1803.55
48	4100.20	1312.06	574.03	2214.11
49	8356.34	4345.30	2506.90	2339.78
50	1947.66	599.87	296.04	895.92
51	6313.78	1894.13	2525.51	1894.13
52	3070.30	1036.23	378.57	1654.89
53	2407.50	741.51	365.94	1107.45
54	2980.20	917.90	452.99	1370.89
55	2407.46	820.94	312.97	1273.55
56	15509.25	6203.70	3101.85	6203.70
57	638.9	351.40	63.89	223.62
58	5012.21	1692.62	618.01	2701.58
59	3013.54	1027.62	391.76	1594.16
60	772.20	261.70	85.60	424.86
61	5088.24	1628.23	712.35	2747.65
62	4920.40	1515.48	747.90	2263.38
63	1189.60	380.67	166.54	642.38
64	3864.25	1309.59	428.16	2126.11
65	5014.01	1544.32	762.13	2306.44
66	2513.33	774.10	382.02	1156.13
67	1719.56	582.76	190.53	946.10
68	4010.68	1367.64	521.39	2121.65
Total area	421594.81	146495.86	66463.99	208634.96

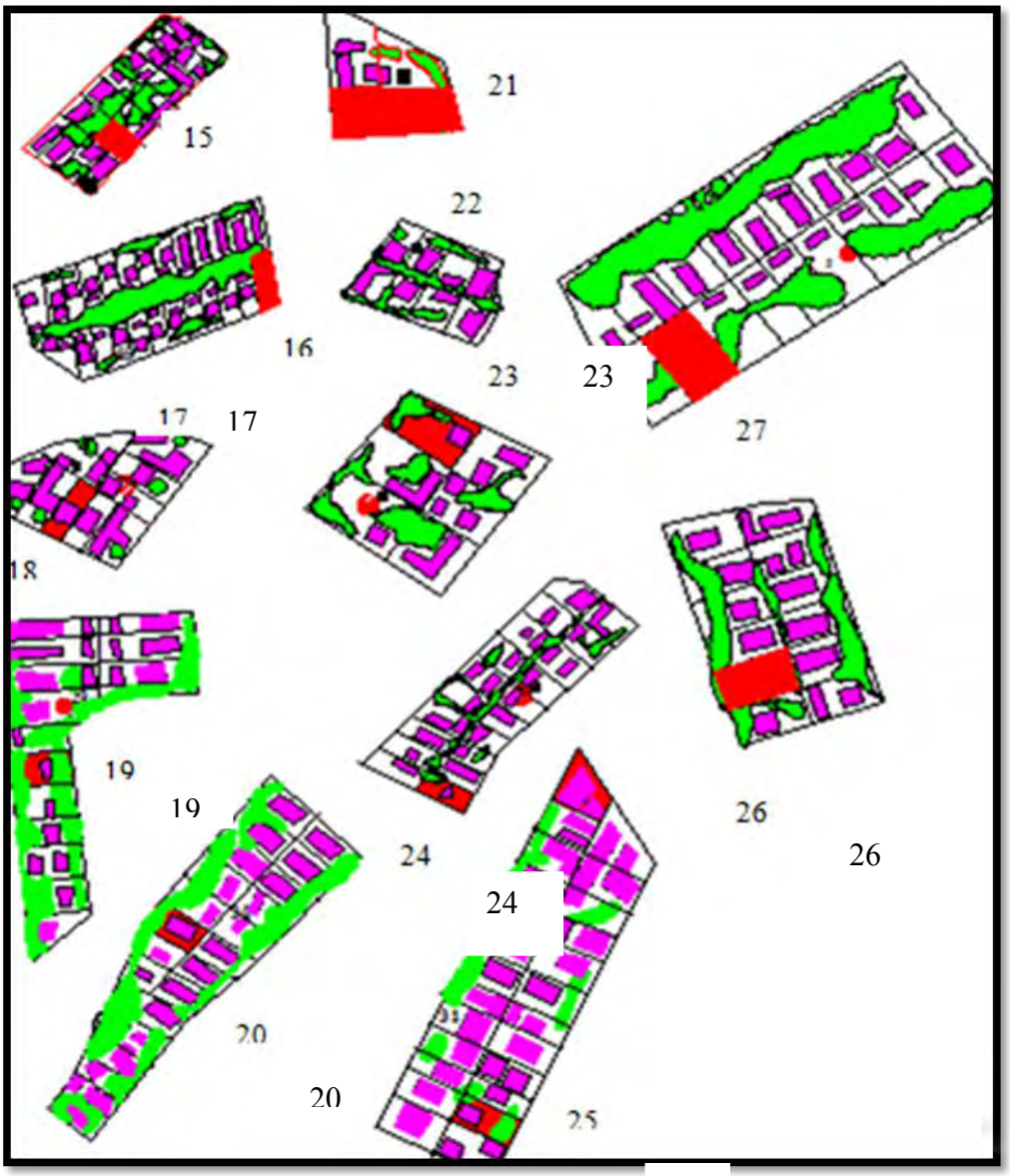
in m^2				
Total area in hectares	42.16	14.65	6.65	20.86
percentage	100%	34.75 %	15.76 %	49.49 %

7.3.Appendix-III Sample plots



7.4.Appendix-IV Plot Mapping

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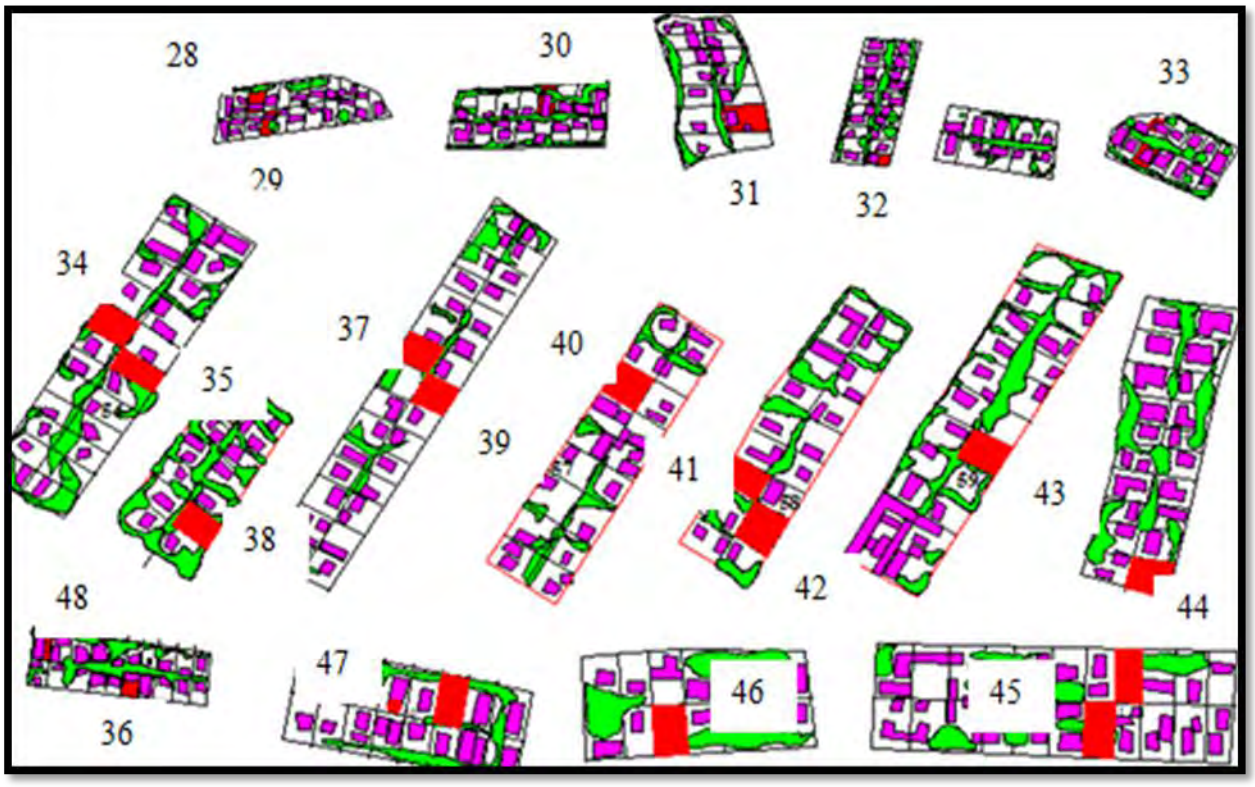
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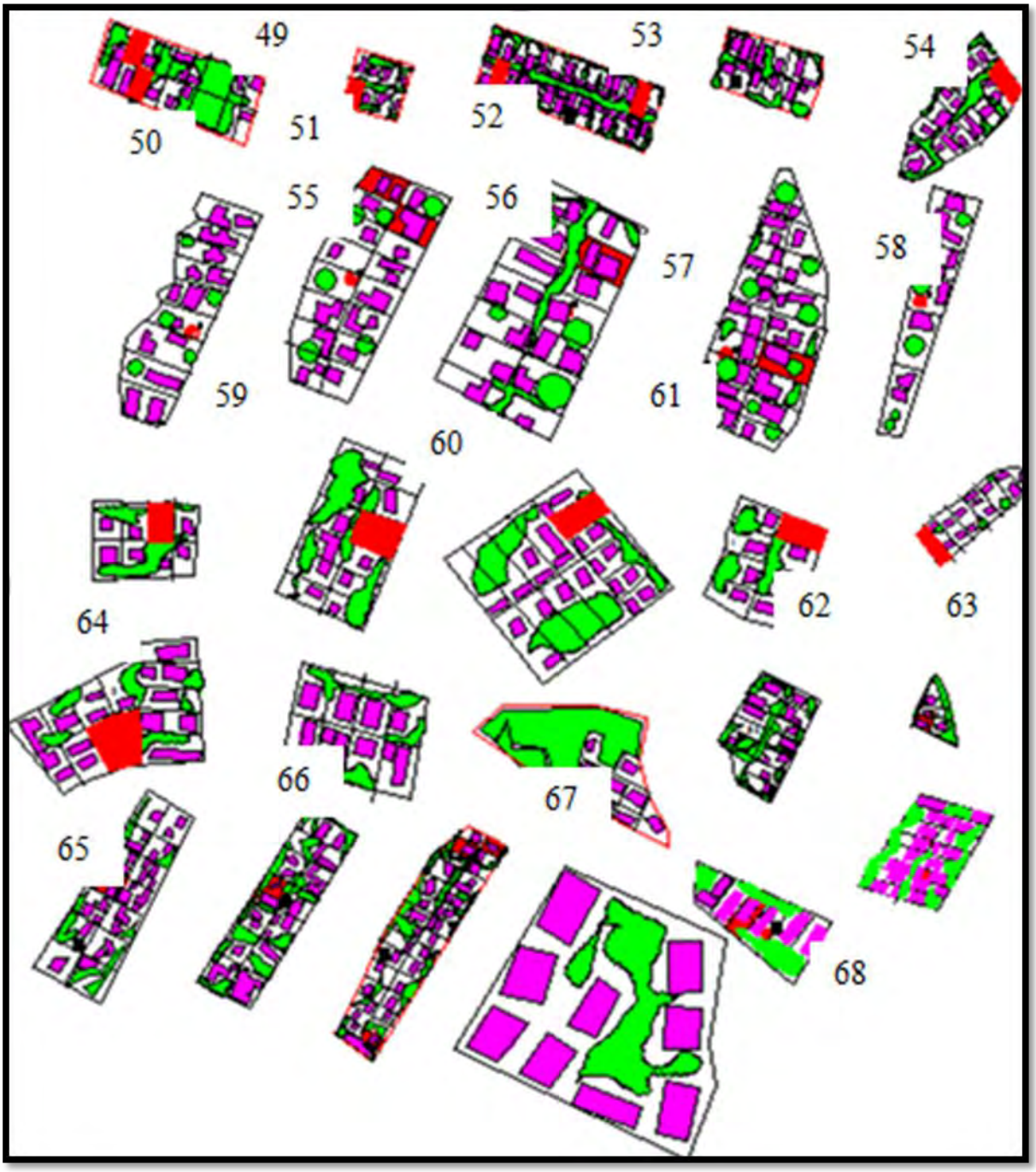
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7.5.Appendix-V Plot level Pervious and Impervious cover

Table 13 Plot area coverage by Green, Building and open spaces and total percentage cover.

Item No	Plot size in m^2	green area in m^2	Built-up area in m^2	Open space b/n buildings
1	330	80	80	170
2	350	110	70	170
3	600	0	170	430
4	700	37	250	413
5	500	93	220	287
6	1000	136	450	414
7	450	175	85	190
8	370	72	100	198
9	350	0	90	260
10	350	0	160	290
11	400	25	130	245
12	400	0	125	275
13	170	43	50	307
14	170	75	27	68
15	400	0	150	250
16	250	25	54	169
17	200	21	33	146
18	300	85	66	149
19	200	10	65	125
20	300	75	80	145
21	200	0	56	144
22	300	0	100	200
23	300	77	61	162
24	250	43	53	154

25	400	59	168	173
26	300	50	85	165
27	400	0	82	318
28	250	62	84	104
29	350	0	170	180
30	300	82	60	158
31	400	54	98	148
32	350	50	148	152
33	300	155	60	85
34	200	67	45	88
35	300	42	36	222
36	750	164	64	522
37	300	71	37	192
38	500	0	200	300
39	200	43	64	93
40	150	56	70	24
41	250	27	89	134
42	200	26	59	115
43	200	61	55	84
44	200	35	31	134
45	200	0	23	177
46	350	0	66	284
47	250	0	95	155
48	300	103	56	141
49	350	0	75	275
50	500	120	180	200
51	300	0	120	180
52	300	88	60	152
53	300	0	111	189
54	350	99	57	144

55	250	30	24	196
56	300	0	79	221
57	350	0	150	200
58	300	72	85	143
59	300	0	65	135
60	200	57	51	92
61	500	150	134	216
62	300	56	80	164
63	200	30	20	150
64	200	32	43	125
65	200	0	74	126
66	170	30	66	74
67	170	33	23	114
68	300	155	54	91
Total area in m2	22080	3341	6221	12696
Percentage area cover	100%	15.10%	28.17%	57.50%

(Source own)