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Enhancing Green Infrastructure of Mekelle City: Through Green
Technology, Elements and Green Corridor Development

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DECLARATION

I hereby declare that the thesis (entitled Enhancing Green Infrastructure of Mekelle City: Through Green Technology, Elements and Green Corridor Development) has been carried out by me under the supervision and continuous advise of Tibebu Assefa , within Ethiopian Institute of Architecture, Building Construction and City Development, Addis Ababa University, during the year of 2014/15 as a part of Master of Science program in Urban Design and Development. I further declare that this work is my original work and has not been presented and submitted to any other University or Institution for the award of any degree or diploma.

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CONFIRMATION

This thesis has been submitted for examination with my approval as a university advisor.

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Acknowledgement

First and foremost I thank my God for He save me out of my temptation. I would like to extend my deepest thankful to my advisor excellences Tibebu Assefa Weldeamanuel for his invaluable and tirelessly advice to bear fruit my thesis and to the insight I gain from. My thanks goes to AAU, EiABC and Mekelle University for they gave me this chance.

I am thankful to municipality of Mekelle city, planning and land development department, particularly Ato Habtu Mebrahtu, for their kind and collaborative effort in providing the needed document to my thesis. My thanks also goes to meteorology office of Mekelle for their collaboration in delivering the metrological data. I would like to show my gratitude to the following people who have a great role in my thesis input Tesfay Girmay, Azeb Tesfay, Tarekegn Kidanu, G/kidan Alemayo, Essayas Jebo and Solomon W/gebrel.

Last but not least, my thanks goes to my families my brother and my sisters for their help. I also appreciate the help of my uncle and friends.

Abstract

Green infrastructures are the lungs and eco-friendly structures of urban areas which save guard the living in the non-living built-up urban areas. However, it is being challenged by the process of urbanization which has been changed and replaced it, by built up areas in city. The study investigates green infrastructure for Mekelle city using mixed methodology and surveying methods. Full sample of the research area was taken based on block division of the research area, primary and secondary data was sources of data and analyzed by GIS software and digitizing maps methods. The analysis was shown in tables, maps and graphs form and the research finds that GI in the research area was problematic and the research recommends remedial green infrastructure for the city.

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Acronyms

DCIA	Directly Connected Impervious Area
EIA	Effective Impervious Area
FAO	Food and Agriculture Organization (of the UN)
GI	Green Infrastructure
GIS	Geographical Information System
GS	Green Space
IA	Impervious Area
IDCIA	Indirectly Connected Impervious Area
TIA	Total Impervious Area
UN	United Nations
WHO	World Health Organization
WSUD	Water Sensitive Urban Design

CHAPTER ONE

1. Introduction

1.1. Background

Urbanization is a phenomenon that takes place in cities and puts pressure on the urban environment. This is being fueled by population explosion throughout the world (Lindfield and Steinberg,2012). Climate change is challenging urban areas due to loss of Green Infrastructure by the development that takes place in cities (UN-Habitat, 2011). The conversion of green spaces into buildings and roads are the sign of environmental distress, which impedes ecological function and biodiversity (Jessica M., 2004). Generally, the loss of Green Infrastructure is inversely related to urban development, i.e. in the increasing of urbanization, green infrastructure decreases and urban problem increases, which poses challenge on the urban dwellers.

In Africa the phenomena is characterized by rapid and uncontrolled urban growth (Shishay, 2011). It causes the destruction of natural environment and sensitive areas of urban area. The level of urbanization in Africa was about 58% at 2008 in the globe (UN-Habitat, 2009). Sub-Saharan country has high urbanization trends in Africa, In 2008 the level of urbanization was 68% (ibid). As part of sub-Saharan country Ethiopia has experienced rapid urbanization and increase urban population in the last few years due to more rural-urban migration (FDRE PCC, 2008).

One of the city that observed green space in Ethiopia is Mekelle. In the city rapid urbanization has brought many changes. A significant change has been observed in land cover type between 1985 and 2010. The magnitude of land cover change reflected in the city was basically due to an increase in the human population density coupled with an increase in residential, industrial and institutional building at the expense of bare lands and agriculture lands (Mary et al, 2013). Generally the rapid urbanization in Mekelle is in the expense of Green Infrastructure.

1.2. Problem statement

Urban area has different state of nature compared to that of rural areas (Gill et al, 2005). It is an area where the natural state is totally or partially replaced by artificial elements. It is expressed as “society begins nature ends” (Heynen et al., 2006) . Following the changes in urban area, many problems are emerging and challenging the society.

Mekelle City had been developing both vertically and horizontally starting from the time of Yohans IV. Since its foundation the number of buildings, road construction and other infrastructure has been increasing. On the contrary, green areas, open spaces and vegetation coverage are decreasing. This situation creates problem on the dwellers of the city. Such as flooding (storm water runoff), increasing ambient temperature, green fragmentation, bio-diversity loss, depleting aquifer water, loss of vegetation, drying of stream, river and wet lands, and pollution.

The Municipality of Mekelle city has made efforts to improve greenness of the city through beatification movement of drainage line construction, watering and maintaining street trees and cobble stone road construction. However, this focuses on discharging of storm water rather than harvesting as the city has shortage of water and rain water harvesting can alleviate the problems. The maintaining of existing street tree is not enough to increase the city’s greenness and coverage rather it should be expand to the private to increase green areas in the city. Therefore the specific problems are high impervious surfaces, no refinement mechanism of storm water on drainage lines (inlets) and less vegetation coverage and not accessible to the public. Hence, the level of greenness of mekelle city is highly challenged that investigates this research. Population number and built-up area increase and correspondingly the green in decreasing.

1.3. Objective

- General Objective

To investigate the existing situation of green and blue structure and to develop Green Infrastructure network for Mekelle City.

- Specific Objective

- To identify the level of green fragmentation of the City;
- To identify the water cycle in Mekelle for GI;
- To sort out structures for Green Infrastructure;
- To design typical Green Infrastructure component that can enhance the status of GI in the city.

1.4. Question

1. How to integrate/develop Infrastructure network of Mekelle City?
2. What mechanism can be used to harvest rain water in the city?
3. What are the structures for GI in Mekelle?
4. What type of GI components can be enhanced the existing situation of the city?

1.5. Scope

The research area is about 2,205.5 hectare that covers urbanized area of the city, and this doesn't include the current boundary which includes rural villages and two small towns. It only focus on the Green Infrastructure component of Mekelle city. These are green wall, green network, impervious area and WSUD

1.6. Limitation

The research encounters limitation of; money and time. Regarding to money, the budget given by the University is not enough to hire manpower to search the study area, as the study highly relies on the field data. Time wise, the study area is very large and it is difficult to cover details of the study area in this short time.

1.7. Significance

The research will contribute to many part of the community. For researchers, it can be a takeoff for farther study, students can use it as reference to build Green Infrastructure knowledge for similar study in this area. For policy maker and the municipality, they can use the research as a guidance for urban environment policy.

1.8. Methodology

GI deals with the existing of green space/structure/sub-structure of a city. To describe the GI of Mekelle city qualitative and quantitative data has been used. In order to make close investigation of GI, the research area was divided in to 56 blocks and collected data, by surveying methods through observation and GIS analysis. Full sample of the research area was used and collected the data from every blocks, by field work, about buildings, streets and green spaces. Data was also collected from primary and secondary document sources of the research area and other sources. Extensive literature was used to have wider understanding about GI in the research area .

1.8.1. Methods of Data Collection

GI data depends on physical information of the research area and to collect these physical data, field work observation and surveying method was used to extract data from individual blocks (research area 56 blocks) through the techniques of photographing, sketching, sorting, counting, measuring and classification of buildings, plots, green space and streets.

Table 1 Data Collection methods and techniques

No.	Data Type	Sources Type	Methods	Techniques
1.	Primary	Base map (CAD)	GIS Analysis	Shape file
		Maps	GIS Analysis	Shape file
		Google Earth Map	GIS Analysis	Shape file
		Field Works	Surveying	Counting
				Classifying
				Sorting
			Observation	Photographing
Sketching				
2.	Secondary	Books	Scanning and skimming	citing
		Reports		
		Journals		
		Articles		
		Magazines		

(Source; Own)

1.8.2. Data sources

Primary and secondary data was used. Primary data for GI were maps (Google and aerial) and 56 block of the research area and Secondary data were master plan reports, books, CAD files and Internet search engines.

1.8.3. Sampling

The research area was divided into 56 blocks to control and manage data from the research area and to properly handle it. Full sample was used from the blocks and the data was extracted from block to block. Figure 1 shows division of research area into blocks.

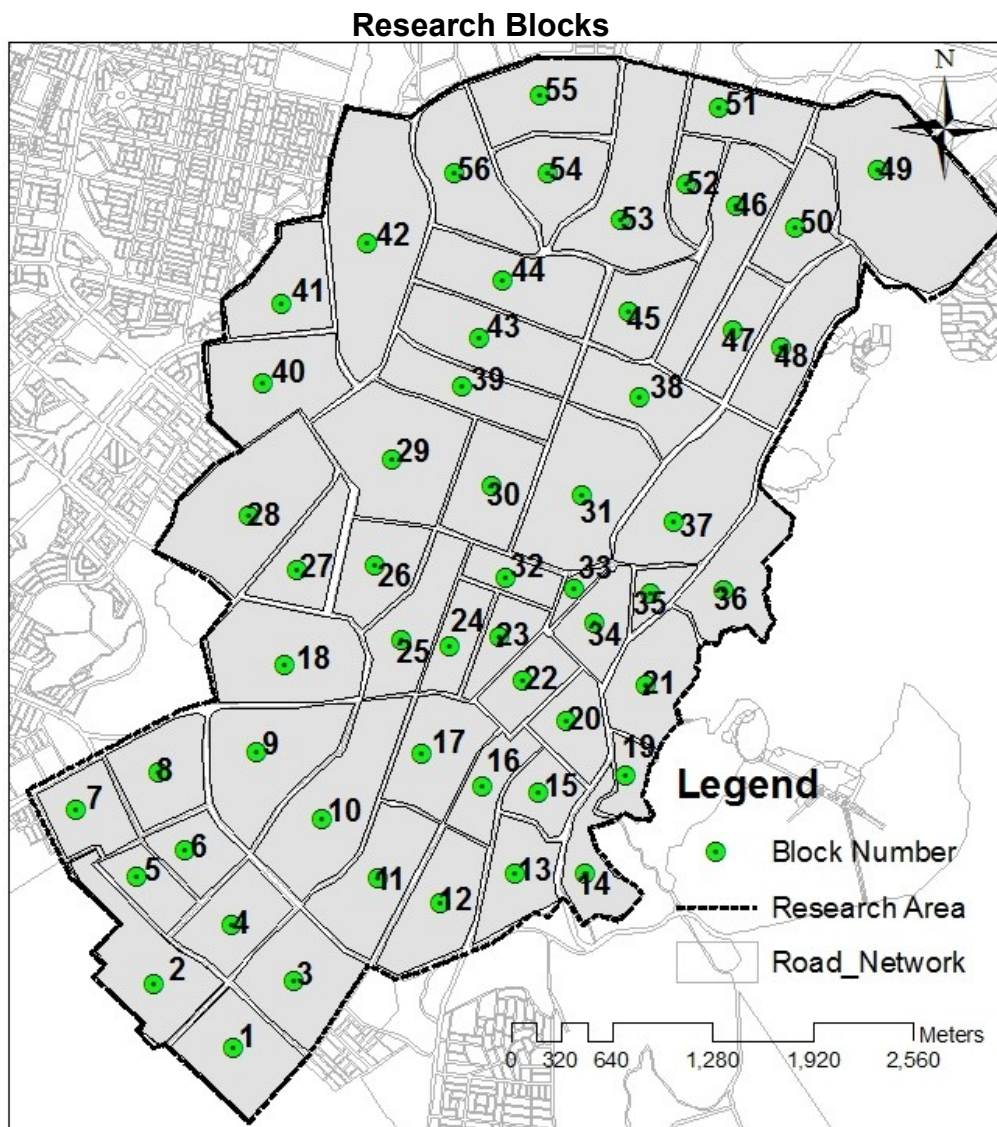


Figure 1 Division of Research Area Blocks (Source; Own)

1.8.4. Research Design

Field work data and GIS map analysis has designed to be tools for describing GI of the research area by conducting field work survey of building (story, wall material and roof type), plot (plot area, built-up area and open space area), street and green spaces from the research area. Figure 2 shows research plan diagram.

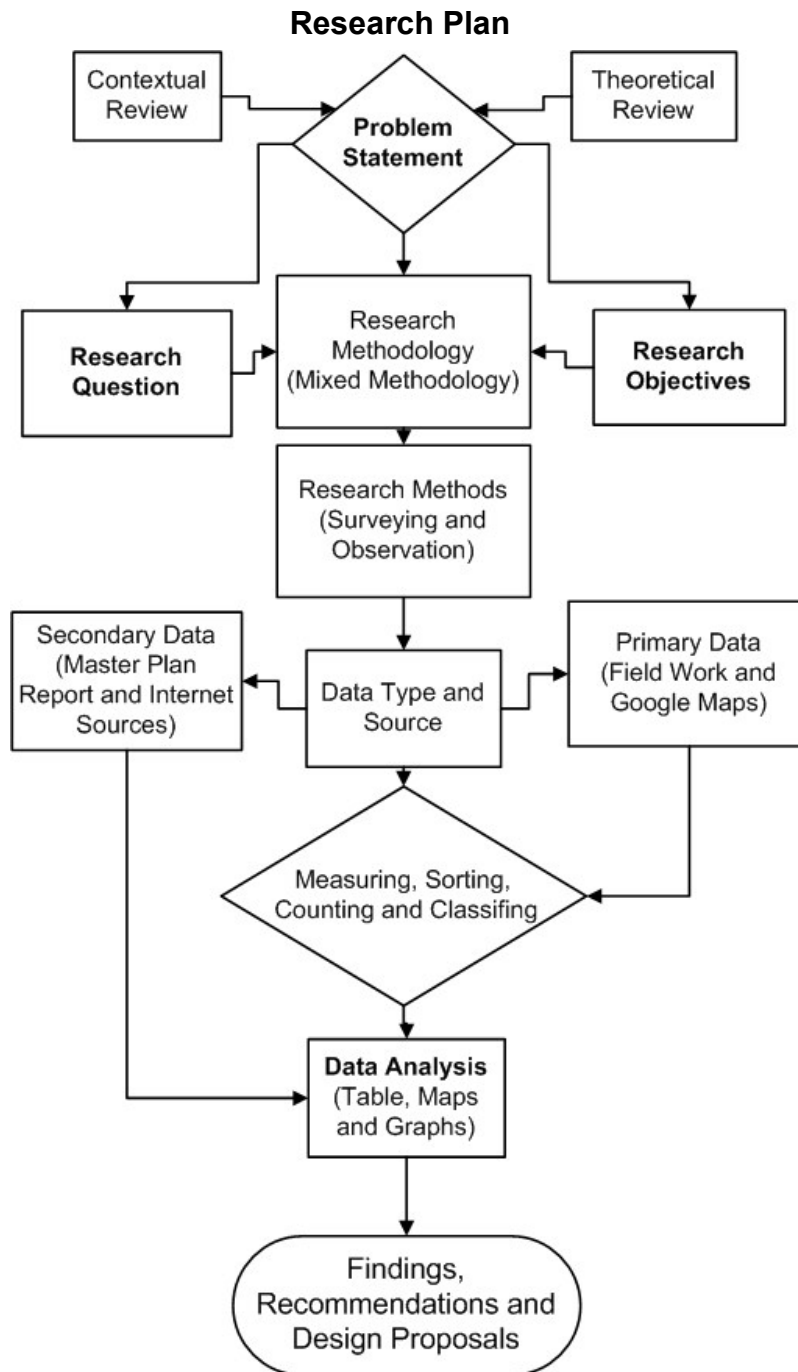


Figure 2 Research Design Diagram (Source; Own)

1.8.5. Data Analysis

The collected data from primary and secondary has been analyzed in qualitative and quantitative data forms. Maps (Google and areal) and CAD files have been analyzed by GIS into shape file and shown in maps and tables. Building, plot, open space, green space and street area was analyzed by GIS into maps and tables. Generally, the data was analyzed using different software in maps, graphs and tables. Table 2 shows the analysis of data by different software.

Table 2 Software Used for Analysis

No.	Software type	In put	Out put
1.	GIS	Maps of Google and Areal CAD files	Maps
			Graphs
			Tables
2.	SPSS	Raw Data	Tables
			Graphs
3.	Excel Words	Raw Data	Graphs
			Tables

(Source; Own)

CHAPTER TWO

2. Theoretical Review

2.1. Green Infrastructure (GI)

Green refers to nature (Moughtin & Shirley, 2005) and Infrastructure is a network of structure and sub-structures (Brad et al. 2001); engineered green infrastructures which mimic nature (Rutherford, 2007) and advocates design with nature. Generally, GI is defined as the network of green space, engineered green structure and sub-structure in a city and consists of natural and developed systems of parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sport fields and cemeteries (Martin and Pitman, 2012).

Different scholars have adopted the definition of GI differently in relation to the contexts and concern of different countries. It is defined as 'a network of natural systems in urban areas' (Fawn and Chau, 2009). Emphasizing networking green area is a strategic plan which integrates different green spaces and enhance biodiversity (Mell, 2011). This helps to maintain the health of the ecosystem. Beyond the working of GI to connect green, it recreates systems of declined and destroyed natural habitats (Lucius, et al., 2011). In some area it is a network of decentralized storm water management (Center for Neighborhood Technology, 2010), and to some other country, GI is a hierarchy of network of hydrological techniques and projects of a city (Sexton, 2009), the engineered projects mimic natural system to mitigate climate challenges (North Michigan Council of Government, 2008). It is a rehearsal works to the environment that has been aggravated and dominated by man.

Generally, GI is a system of connected natural and manmade structures of urban areas that creates harmony of green networks and green systems, which accommodates biodiversity in the urban areas.

2.2. History

Green Infrastructure 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 were 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 were 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).

In the contrary, modern theory behave differently from the above mentioned history, it is a fashion in city opposite to country side, in which cities viewed as physical manifestation of humanities separation from and controlling nature (Brazy and Dumpelmanm, 2011), due to this reason city is considered as “second nature”(Heynen et al., 2006). Modern practice is engineering oriented mega structures, which subdued over nature governing by the theory of “freedom from nature” (Pickett et al., 2013).

In respond to modern theory and practice, contemporary theory has break out to solve urban problems. 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. Function

Everything in the earth survives according to ecological processes (Youngquist, 2009). However the process is greatly destructed in cities. the level of destruction is measured by green infrastructure yardstick. In this respect, it enhances connectivity for species and maintain bio-diversity (Lawton, 2010). The function of GI is mainly stipulated as follows: land scape setting and contextual development to integrate development area with the existing urban areas and surrounding natural areas; habitat provision and access to nature, by maintaining key habitats (hedgerows, tree belts, ponds, water courses and ditches) and flood controlling mechanisms which incorporates water bodies (FCM, 2001). GI paves the way to integrate with liner park, multi modal public right of way, green corridor, recreation/sport areas, play areas, tree lined street and water shed. Conservation of habitat of retained tree and hedgerows, wild areas and wild life corridors, restored water bodies and wetland environment (Crown, 2010). Food production and productive landscape of community garden, community park, allotment and plans organic farms. Flood attenuation and water resource management, in this case GI works to manage the issues by using SuDS (sustainable urban drainage system) system in woodland and hedgerows, public squares, long-distance footpath and green roof (Rutherford, 2007). Countering heat island, mitigates the situation by providing green building and other greeneries of the urban areas (Watkins et al., 2010).

Generally the function of GI is to maintain natural systems, by creating connection and integration with the existing nature and restoring the nature by conservation works in the degraded environment. The work of GI is extended to wards bio-diversity formation and habitat protection in urban areas.

2.4. GI Index

It is a list of GI components in urban areas (Rutherford, 2007). The presence and mismanagement of many urban forms (structures) and functional systems affect greenness of urban area. The index includes: impervious area, water sensitive urban design, green networks and green buildings. The comment of GI are more than the aforementioned, but the scope of the research is only the above one.

i. Impervious Area

Land covers of urban area that prevent infiltration of water in to the soils are called impervious areas (Novotny and Chester 1981). These surfaces are covered with building roofs and roads that lower the capacity of infiltration of the natural ground in to zero (Hill et al., 2003). Sidewalks, patios, bedrock outcrops and compacted soils are also categorized as impervious surfaces (Arnold et al., 1996). Figure 3 shows level of infiltration in natural area and urban areas. Urban areas altered the hydrology cycle due to impervious areas.

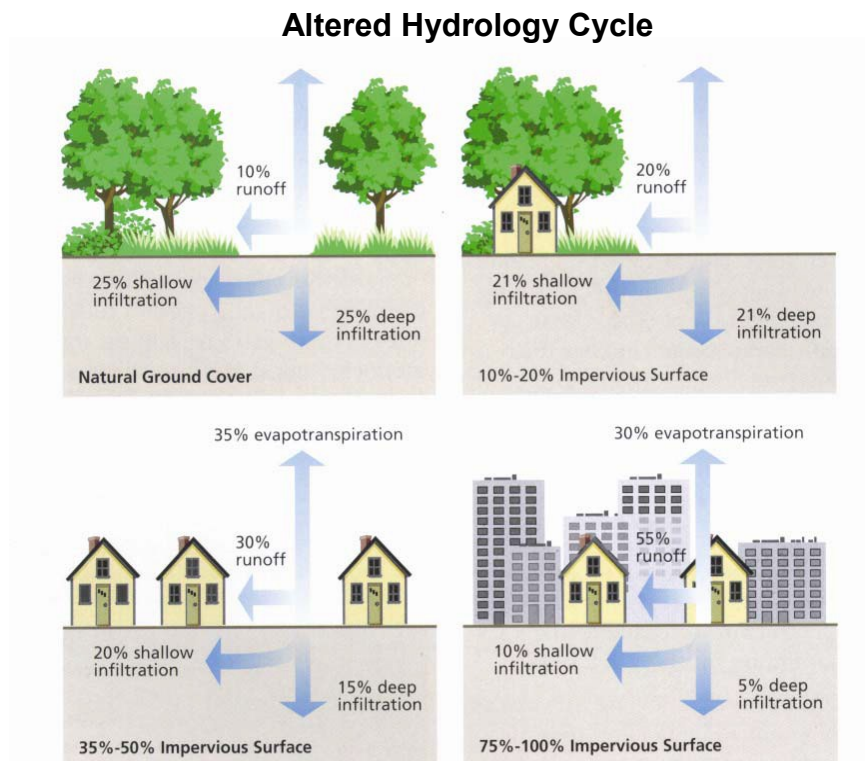


Figure 3 Altered Hydrology Cycle (Source; TRPC, 2003)

Many scholars use different methodologies for mapping impervious areas. Some use aerial photographs of high resolution to detect different impervious land covers and map it out on GIS (Johnson, 2004). Others use land use maps with field observation to estimate the impervious area in GIS (TRPC, 2003). Generally, the detection of impervious area is done by using GIS software based on either aerial photograph, or land use map to figure out the exact impervious area of a given urban area.

Calculation methods of impervious area have been developed for different urban areas using different conditions. The most common methods are total impervious area and effective impervious area (USEPA, 2011), the former uses for calculation of runoff water to design drainage canals in urban areas and it is a given standard (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). Table 3 shows the condition of (DCIA) and (IDCIA). DCIA means when rain water flows from roof (gutter...) into a street and IDCIA means also when rain water flows from roofs in to some area (infiltrates) before reaching the street.

$$IA_{Lui} = Total\ Area\ (Lui) * \%IA \dots \dots \dots (1) \text{ (Source; USEPA, 2011).}$$

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

$$TIA = \sum_{i=1}^n IA_{Lui} \dots \dots \dots (2) \text{ (Source; USEPA, 2011).}$$

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 Impervious Area Condition

No.	Watershed Selection Criteria	Assumed Land Use	Equation (where $IA(\%) \geq 1$)
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	$DCIA = 0.1(IA)^{1.5} \dots\dots(1)$ Where, DCIA= Directly Connected Impervious Area IA=Impervious Area
2.	Highly connected: Same as above, but residential rooftops are connected	High density residential	$DCIA = 0.4(IA)^{1.2} \dots\dots(2)$
3.	Totally connected: 100% storm sewered with all IA connected	--	$DCIA = IA \dots\dots\dots(3)$
4.	Somewhat connected: 50% not storm sewered, but open section roads, grassy swales, residential rooftops not connected, some infiltration	Low density residential	$DCIA = 0.04(IA)^{1.7} \dots\dots(4)$
5.	Mostly disconnected: Small percentage of urban area is storm sewered, or 70% or more infiltrate/disconnected	Agricultural; Forested	$DCIA = 0.01(IA)^2 \dots\dots(5)$

(Source; USEPA,2011)

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

$$EIA = 0.1(TIA)^{1.5}, TIA \geq 1 \dots\dots\dots(3) \text{ (Source; Roger and Sutherland, 1983).}$$

$$EIA = 0.4(TIA)^{1.2}, TIA \geq 1 \dots\dots\dots(4) \text{ (Source; Roger and Sutherland, 1983).}$$

$$EIA = TIA, TIA \geq 1 \dots\dots\dots(5) \text{ (Source; Roger and Sutherland, 1983).}$$

$$EIA = 0.04(TIA)^{1.7}, TIA \geq 1 \dots\dots\dots(6) \text{ (Source; Roger and Sutherland, 1983).}$$

$$EIA = 0.01(TIA)^{2.0}, TIA \geq 1 \dots \dots \dots (7) \text{ (Source; Roger and Sutherland, 1983).}$$

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 (Chambers, 2011). It is collection of rain water that flows to one common converging area (Ministry of Agriculture and Rural Development of Ethiopia, 2005). Water flows from higher position to lower position due to gravitational forces. Figure 4 shows the boundary and direction of flows in watershed area and the dividend line in relation to slope and positional location in the watershed area. Figure 5 shows watershed area components.

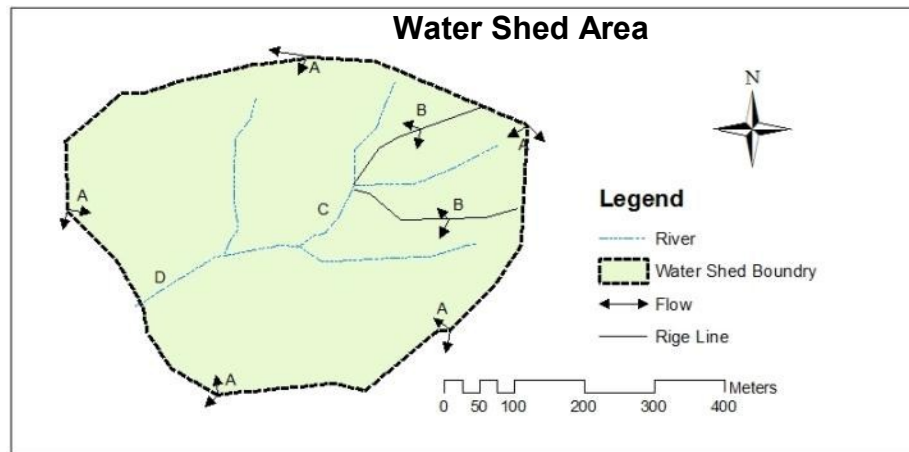


Figure 4 Watershed Area (Source; Ministry of Agriculture and Rural Development of Ethiopia, Watershed manual 2005)

From Figure 4 (A) shows divide large water shed area, (B) shows divided small water shed area, (C) shows water course for the smaller water shed and (D) shows water shed for the large water shed area. Figure 4 is representing water shed of rural area, and for urban water shed it can be represented drainages.

Naturally, water quality could be safe when the hydrological cycle is not changed by a certain development (Barnes et al., 2002). But the watersheds in urban area are affected by impervious surfaces (Petrosky, 2009) and create problems in the greenness of city. The water quality of watershed area is measured in relation to

effective impervious surface coverage (area)percent that means protected (0-10%), impacted (10-30%) and degraded more than (30%) (ibid). Generally, the quality of water is related to the directly connected impervious area or effective impervious areas in urban areas. Figure 5 shows the relationship of impervious surface percentage and water quality. As the coverage increases the quality of water decreases (degraded).

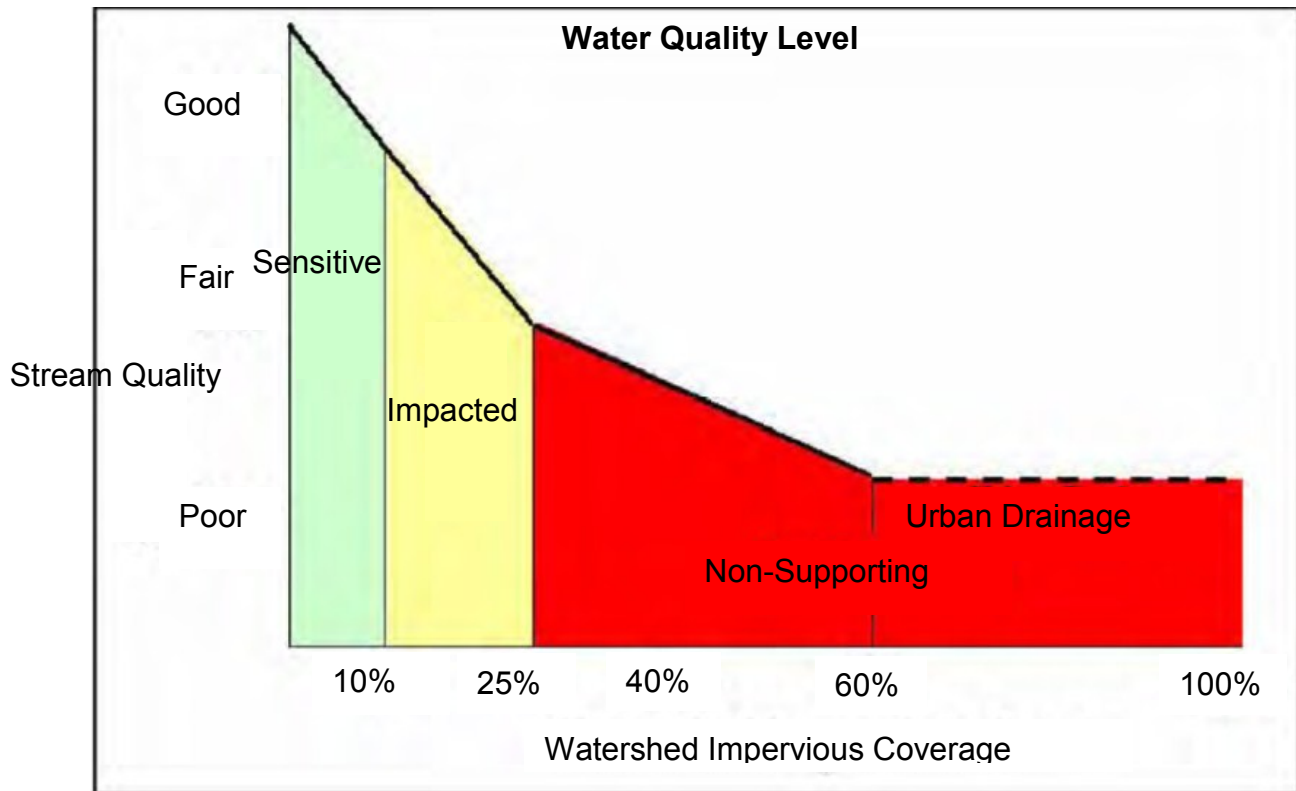


Figure 5 Water Quality Level (Source; Schuler, 2000)

ii. 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, and 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.

Sediment Basin is used to retain coarse sediment (0.25mm size) from runoff. It is the first treatment used to protect the downstream from being loaded with sediments in the water bodies. This mechanism is used in inlet of wetland (ponds). The type of maintenance required are dewatering and dredging collected sediments in every 5 years.

Design Procedure of Sediment Basin: the design include designing of appropriate sediment basin size, minor flow design and major flow design. For the design of minor and major flow design Rational Method is used. In this method the flow is calculated for rain fall intensity, impervious area and catchment area.

$$Q = 0.00278 * I * C * A \dots \dots \dots (8) \text{(Source; Allison and Francey, 2005)}.$$

Where, $Q = \text{Flow} \frac{m^3}{s}$

$$I = \text{Rain Fall Intensity} \frac{mm}{hr}$$

$$C = \text{Impervious Area (Runoff Coefficient)}$$

$$A = \text{Drainage Catchment Area ha}$$

Size and shape of the sedimentation basins is calculated as follows.

$$R = 1 - \left(1 + \frac{1}{n} * \frac{V_s}{Q/A}\right)^{-n} \dots \dots \dots (9) \text{(Source; Allison and Francey, 2005)}.$$

Where $R = \text{Fraction of target Sedimentation removal}$

$$V_s = \text{Settling velocity of target sediment (m/s)}$$

$$Q/A = \text{Flow (m}^3/s) \text{divided by basin surface area (m}^2\text{)}$$

$$n = \text{Turbulence or short – circuiting parameter}$$

The shape of the basin has large impact on effectiveness of the basin or retain sediment. Generally, the length to width ratio should be 3:1 (Allison & Francey, 2005). The required volume of sediment storage (S) can be estimated using equation (10).

$$S_t = C_a * R * L_o * F_r \dots \dots \dots (10) \text{ (Source; Allison and Francey, 2005).}$$

Where, $S_t = \text{Volume of required storage (m}^3\text{)}$

$C_a = \text{Catchment area (ha)}$

$R = \text{From equation (9)}$

$L_o = \text{Sediment loading rate } \left(\frac{\text{m}^3}{\text{ha}}\right)$

$F_r = \text{Required clean – out frequency (year)}$

Hydraulic Structures are constructed at the inlet and outlet of a sediment basin. Its function is for conveyance and ensuring energy dissipation at the inlet structure(s), extended detention at the out let and over flow path for above design conditions.

Inlet and Outlet structures are structure in sediment basin that controls particles and discharges respectively. The inlet structure conveys directly in to the sediment basin the storm water through pipe or open channel. It is the first treatment train to happen and recommended to have gross pollutant trap (GPT) as part of the inlet. Outlet structure, consists of out let pit and discharge control structure to control the rate of discharge from the basin under normal operation. Outlet pit is also part of the out let structure used to control discharge with different mechanisms over flow weir, riser out let and floating slotted pipe. The construction techniques is 150mm top soil depth to support planting, with edge slope 1:3, 1:5 and 1:8 and treated with rocks and submerging plants. Figure 6 overviews the design element of sediment basin design and the consideration in the structure.

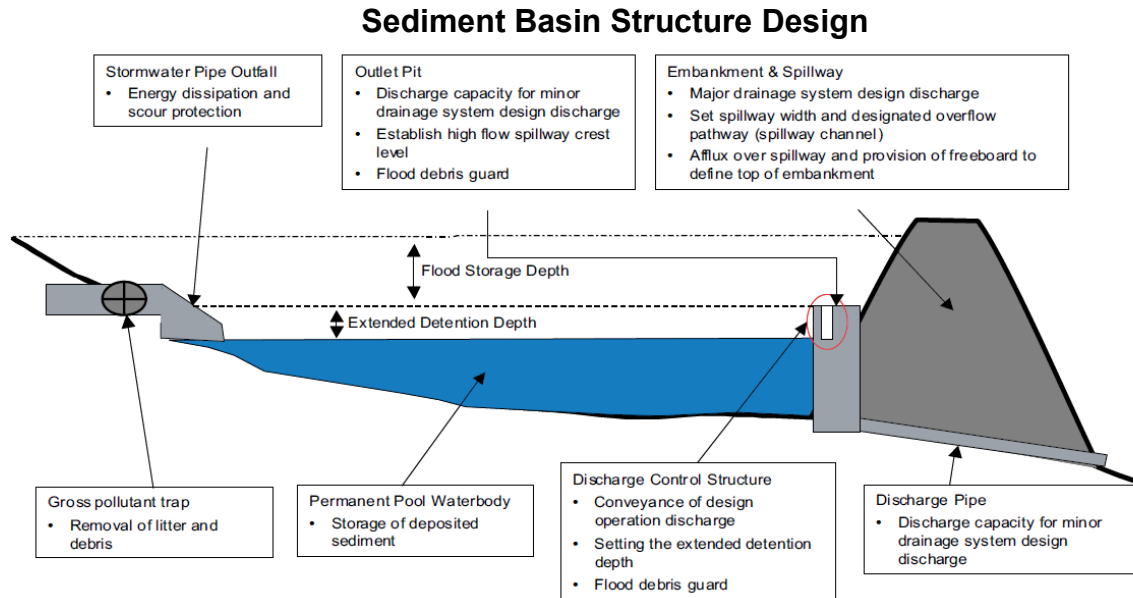


Figure 6 Design Element of a Sedimentation Basin and Main Design Consideration (Source; Allison & Francey, 2005)

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 7 shows bio-retention plan and section of median, and Figure 8 shows detail section of bio-retention swale.

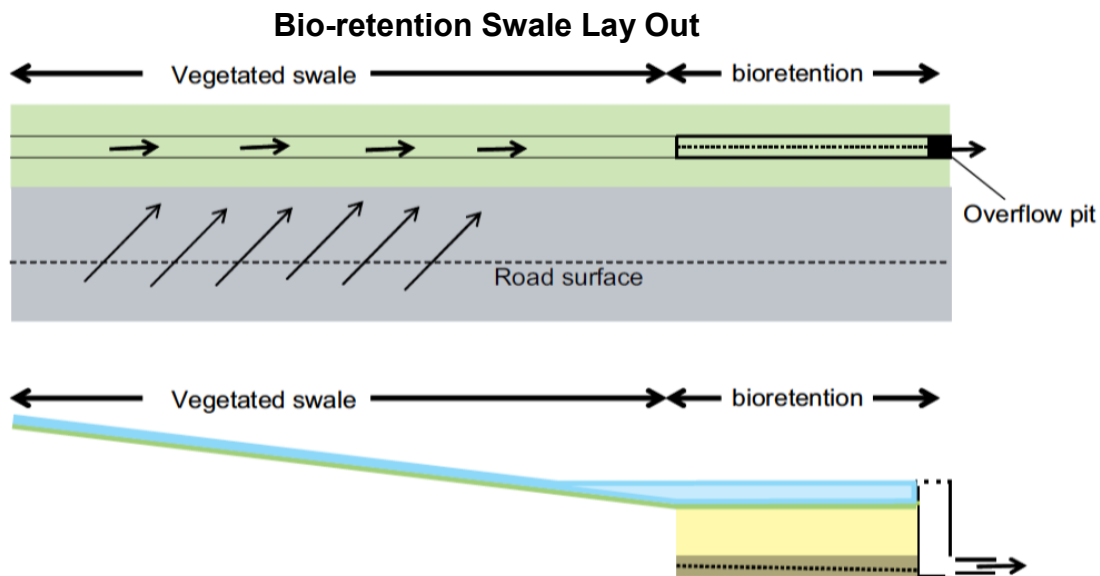


Figure 7 Bio-retention Swale Lay Out (Source; Allison & Francey, 2005)

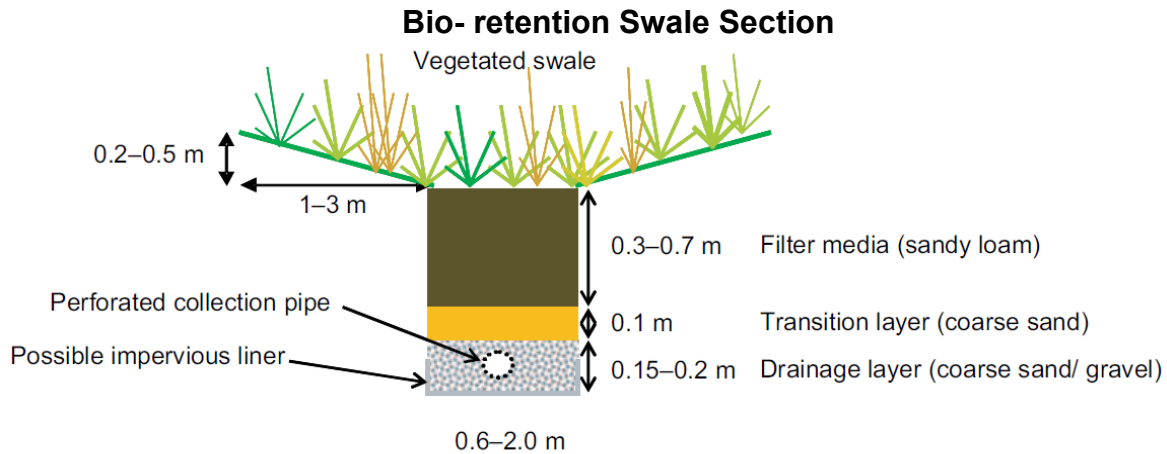


Figure 8 Typical Bio-retention Section Source (Allison & Francey, 2005)

Bio-retention Basin is used to maximize the volume of runoff treated through filtration media by employing ponding above. The treatment is similar to that of bio-retention 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 9 shows bio-retention basin (a) plan and (b) section

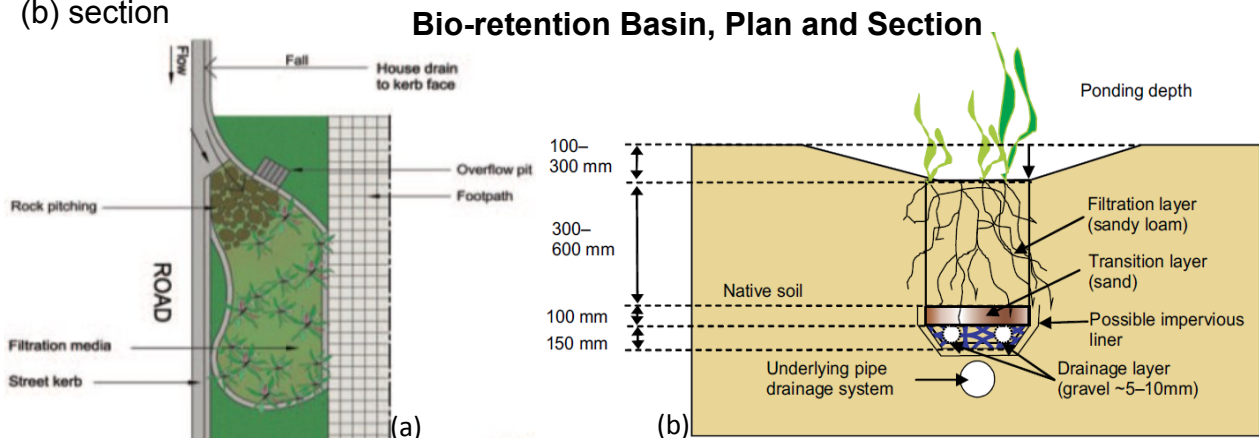


Figure 9 Bio-retention Basin Typical Plan and Section (Source; Allison & Francey, 2005)

Sand filters is similar to bio-retention in treating of sediments and other contaminants, however sand filter does not support vegetation, due to the fact that sand filter area often dries out and plant could not grow. It is very useful treatment for heavy urbanized and built-up areas, also there are some other filter medias use to filter sediments, such as peat, mulching and gravel.

Swales and Buffer Strips is the system that uses over flow and mild slopes to slowly convey water downstream. The interaction between flow and vegetation along swales facilitate pollutant settlement retention. Buffer strips are areas of vegetation through which runoff passes, while traveling to a discharge point. They reduce sediment loads by passing a shallow depth of flow through vegetation which tends to slow velocities and coarse sediments would be retained. Buffer could be served as edge of swales to effectively handle the flow for retention settlement.

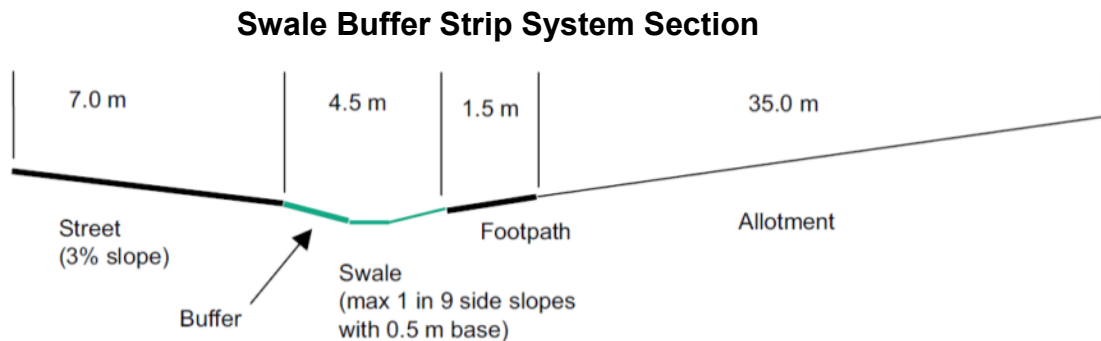


Figure 10 Swale Buffer Strip System Section (Source; Allison & Francey, 2005)

Constructed wetland is extensively vegetated shallow water bodies which is used to improve sedimentation, fine filtration and pollutant trapping process to remove pollutants from storm water. Wetlands consist 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 (11).

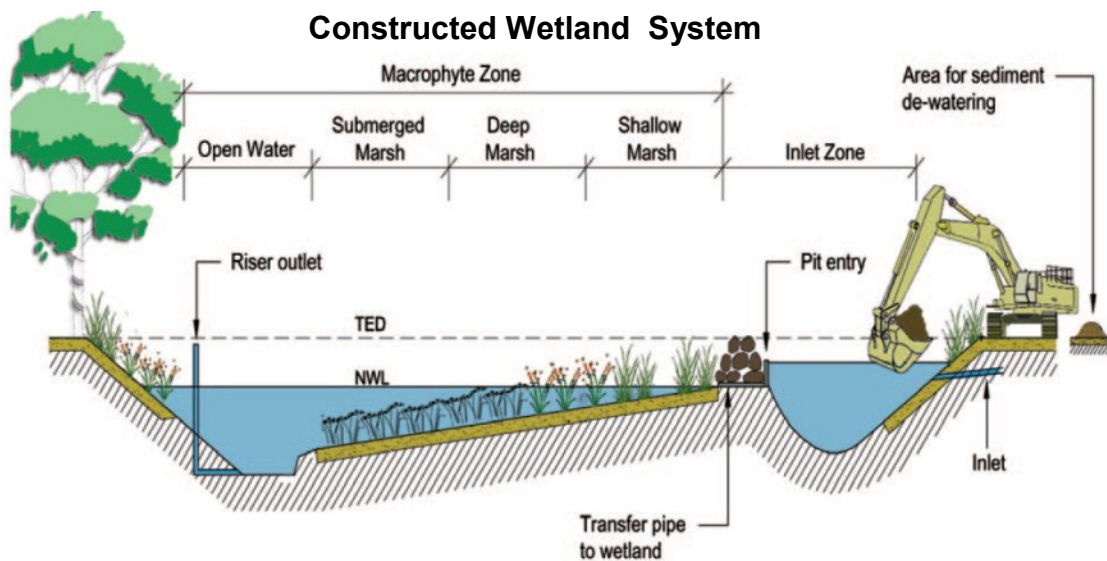


Figure 11 Constructed Wetland System (Source; Allison & Francey, 2005)

Ponds and Lakes: are open water bodies and formed by simple dam wall and a weir outlet. The depth of these water body is greater than 1.5m to hold of fluctuation of water levels within the system. An aquatic vegetation has a great role in controlling water quality in this regard. They are parts of the flood-retarding system and the designing requirements are associated with hydraulic structure for flow conveyance and flood attenuation.

Infiltration measures: encourages storm water to infiltrate in to the existing area and depends on local soil nature that suited with sandy soil deep ground water infiltration. The system focuses on protection of storm water to avoid clogging and to protect ground water quality, and they also reduce volume and magnitude of peak flow from impervious area. Figure 12 shows infiltration measures for a plot levels. (a) plan (b) section plan and (c) cross section.

Infiltration Techniques

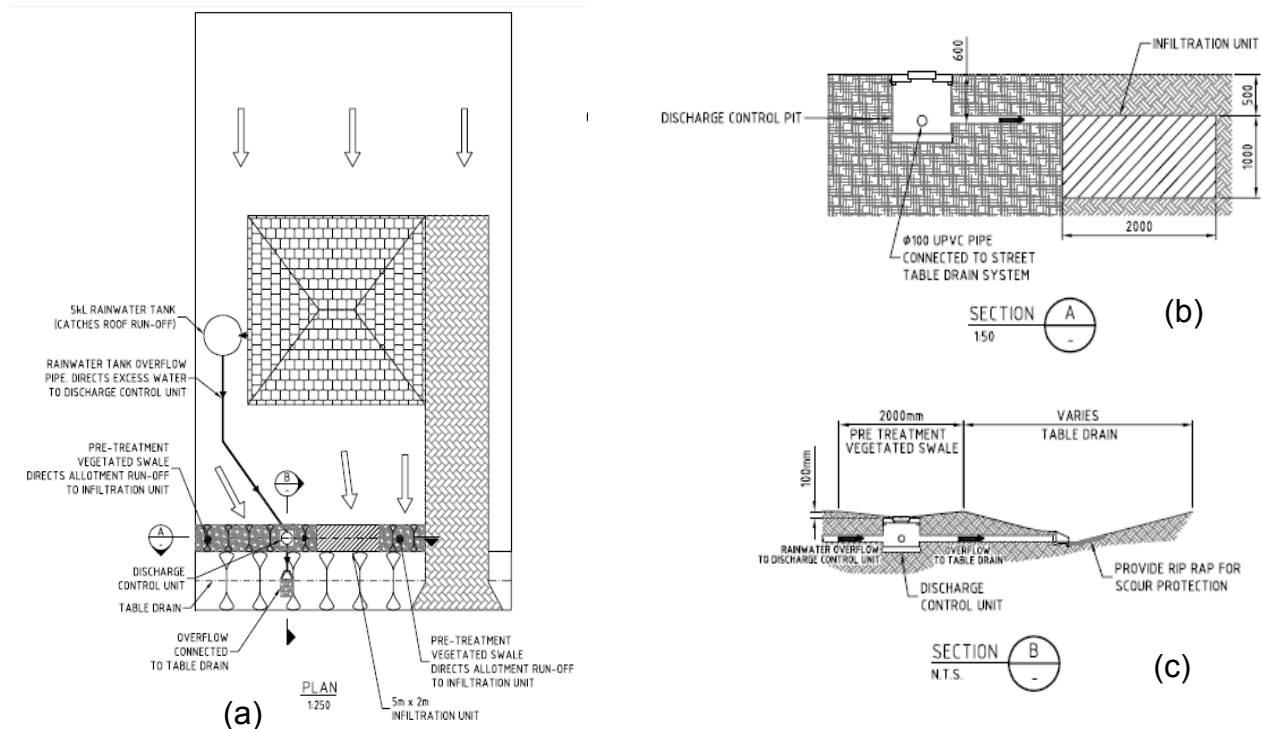


Figure 12 Infiltration Measures in Plot Level (Source; Allison & Francey, 2005)

Rainwater Tank is used to conserve main water and protect urban stream by reducing storm water runoff volume, from water pollutants reaching downstream water ways . The harvesting of rain and storm water on individual plot is important to deliver potable water conservation purposes and use mean annual rainfall (Worn & Hattum, 2006). Figure 13 shows the mechanism of rain water harvesting starting from site to drainage line; harvesting for garden(irrigations) and infiltration of rain waters in different parts of site or city.

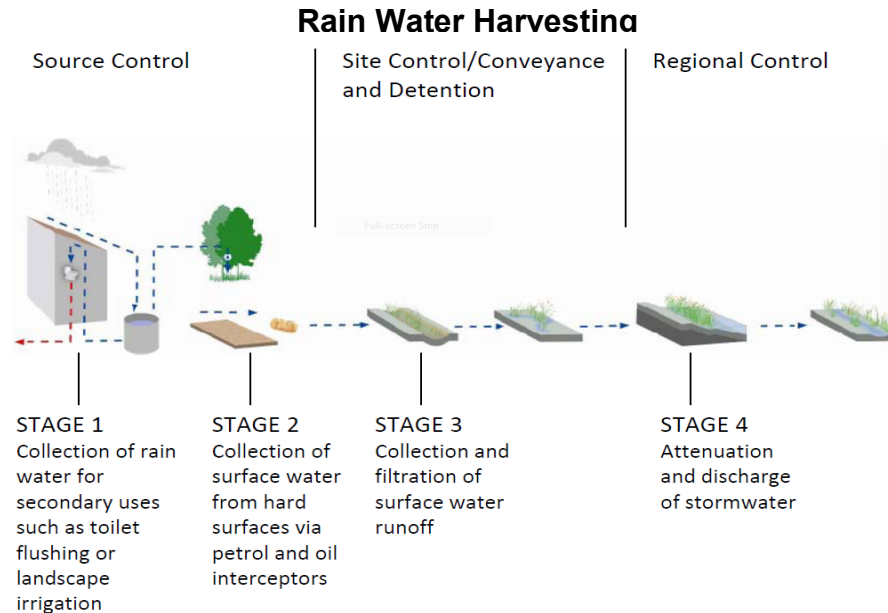


Figure 13 Rain Water Harvesting System (Source; Queensland, 2007)

Aquifer Storage and Recovery: mechanism of enhancing water recharge to underground aquifer by either pumping or gravity feed. It is a method of storing excessive water produce from urbanization during wet periods. This system can use to retrieve the stored water under the ground during dry periods. Diversion structure from stream or drain is an example.

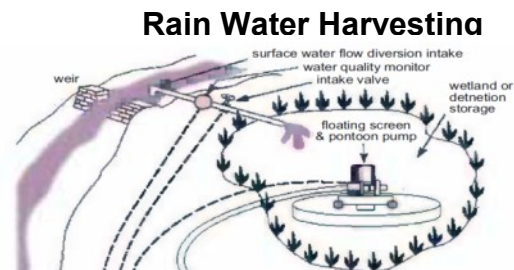


Figure 14 Aquifer Storage Mechanism(Source; Allison & Francey, 2005)

iii. Green network

It is defined as the matrix of natural and developed open green spaces (Ada Development Service, 2006) or natural, semi-natural and urban green spaces (Matthew, 2012). The network reference to the connection (corridors) among the green space matrix (Ely and Pitman, 2012). The provision of green spaces in urban area is different for different countries. In the developed country 40m² per capita and 140m² per capita is provided in urban and suburb respectively (Singly, et al., 2010). The minimum standard of green spaces provision by WHO and FAO in urban area is, 9m² per person (Singly, et al., 2010). Generally, green space network is an interwoven space (green or open spaces) of natural and developed space in the urban area. The connection of green space is vital for people to relax and engage with nature and develop suitable biodiversity in the urban system (Moseley et al., 2013).

Green infrastructure network consists of hubs, links, sites and buffers (Lauzen, 2013). Hub may be large or small core area for green infrastructure network and provides space for local plants and animals. It is a center of attraction for wildlife, people and ecological process. Links include linkages, corridors and green ways, that connect hubs and bind the system together encouraging green infrastructure network processing and maintain biodiversity as well. Sites are small areas of green spaces that produce important ecological and social values. However it may not be physically link to the network established by hubs and links. And buffers are strip area needed to protect critical resources such as important habitats. The provision of buffer depends on the sensitiveness of habitat, it is 25-300ft (Lauzen, 2013).

Habitat is defined as the element of land surfaces which could be consistently defined spatially in the field (Bunce et al., 2008); connection refers to the degree of landscape that facilitates /impedes movement of organisms among resources patches (Tailor et al., 1993), and fragmentation is the entire process of habitat loss and isolation. Pattern fragmentation is the reduction of habitat amount and increase in number of patches, decrease in their size, and increase in isolation of patches (Fahrig, 2003). Figure 15 shows the connectivity of hubs, A, B and C are habitat and

P_{AB} , P_{AC} , and P_{CB} are probability of distance connectivity of the patches, the probability tells the shortness of distance to create connection with the patch. Figure 16 shows (a) habitat connection degree and (b) habitat buffer provisions.

Probability Distance between Patches

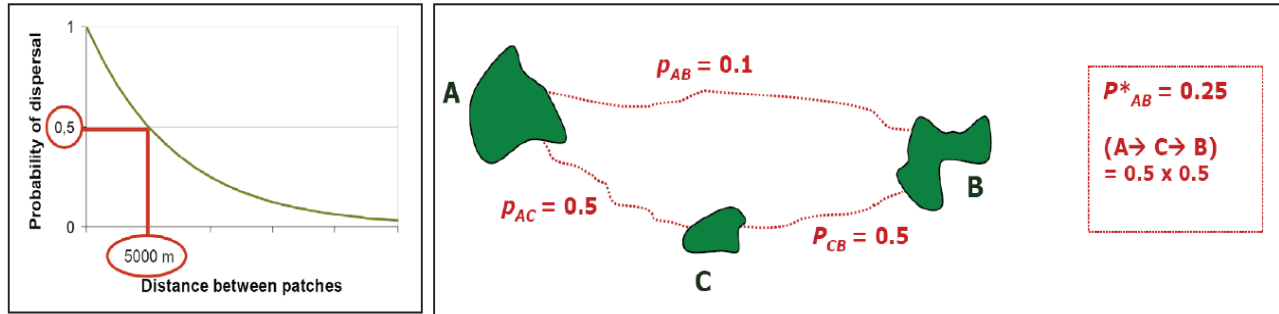


Figure 15 Probability Distance of Patches (Source; Estreuil, et al., 2012)

Habitat connection and Buffers

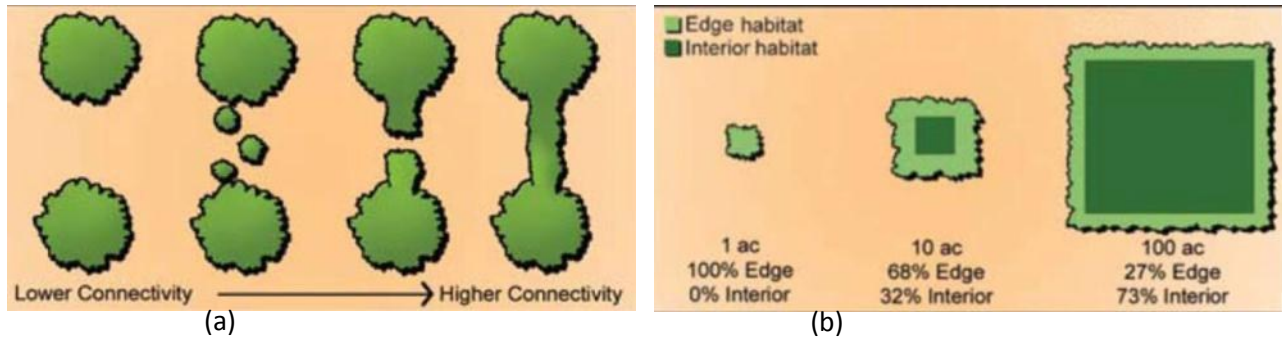


Figure 16 Degree of Habitat Connection and Buffers (Source; Lauzen, 2013)

Green Infrastructure Network

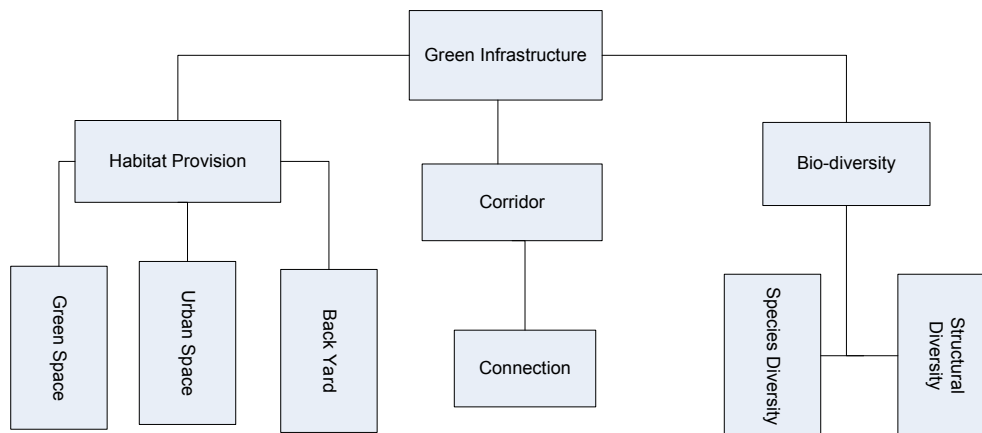


Figure 17 Green Infrastructure Network Diagram (Source; Ely and Pitman, 2012)

Table 4 Green Infrastructure Categories

Green Space (Open Spaces)	
Natural Green open Spaces	Developed Green open Space
Wood land	Irrigated and Maintained Green Spaces
Native Vegetation	Pedestrian/Bicycle Circulation System
Geologic Land Forms	Open Play Areas and Play Fields
Historic/Cultural/Archeological Sites	Play Grounds
Water Bodies/Wetland/Riparian Areas	Picnic Sheltering and Seating
Hill Side Slopes	Architectural features/Buildings
Wild Life Habitat	Informal Recreation Spaces
Ridgeline	Housing Green Spaces
Scenic Buffer Areas	Domestic Gardens
Rangelands	Community Gardens
Agricultural Lands	Roof Gardens
Trails	High Way Trees and Verges
Grass Lands	Living Roof and Walls
Brown Field Site	Civic Spaces
Nature Reserves (statutory and non-statutory)	Cemetery and Churches
Allotments, City Farms, Orchards, and Suburban and Rural Farmland	Green Corridors (River and Canals)
	Parks and Gardens
	Hedges
	Functional green space such as sustainable drainage schemes (SuDS) and flood storage areas

(Source; Ada Development Service, 2006)

Figure 17 shows the network of green infrastructure of natural and developed green in urban area. Table 4 shows the categories fall under natural and developed green/open spaces.

Developed Green space: it is a landscape approach green infrastructure, which entails a design vision that translates planning strategy in to physical reality, by

respecting the ecological characteristics of a particular local, either large or small site (Rouse and Bunster, 2013).

Planning and designing principles: Six principle inform the planning and design of green infrastructure across different discipline and scale of professional practice. Thus include (1)multi functionality, (2)connectivity, (3)habitability, (4)resilience, (5)identity and (6)return on investment(Rouse and Bunster, 2013).

Multi-functionality: conceptualized as the triple bottomline- the environment economic and social benefits.

Connectivity: meaning green infrastructure is most effective in providing services and benefits, when it is part of a physically connected system across the land scape.

Habitat: developing of visible space that provides outdoor habitat for people, fauna and flora in healthy condition.

Resiliency: it is the ability to recover from or adapt to disturbance and change. Green infrastructure can play roles, such as tree and green buildings for heat islands, maintaining flood absorption, permeable pavement etc.

Identity: it is a design element to create a perceptible identity and sense of place. Green infrastructure has the potential to engender the unique of place by employing landscaping.

Return on investment: in time of scarce financial resources green infrastructure can reduce cost and yield positive financial outcomes, like increasing land value, lessening energy consumption etc.

Scale of green infrastructure: to realize the triple bottom-line benefits at different scales in different contexts. These area regional, local government, subarea/district/neighborhood and site(Rouse and Bunster, 2013).

Regional scale: urban revitalization and increase opportunity for walking, biking and transit use.

Local scale: incorporate parks, green ways, urban forest, green street and boulevards into the physical of existing and new development.

District scale: green street scape community parks and gathering places.

Site scale: private and public buildings and others should be in corporate green storm water, green roof, living walls etc.

a. Green Street

It uses permeable surface coverage (New York City Department of Transportation, 2009) and good storm water management by means of natural water way and vegetation (Faha and King, 2007). In addition green street is defined by its attraction of tree-line, open space character and emphasis on the environmental quality and the connection with parks, open space, natural area and with social-service areas (DELSCANCorporation, 2008).The design of green street incorporates, different design elements Permeable Pavement, Storm Water Management Design, Street Tree Plantation and Infiltration (Luke and Kloss, 2008). Generally, it focus on reduction of gases by tree and greeneries, infiltration of water with permeable pavement and bio-retention and amenities for social interaction by providing attractive and qualitative spaces. Figure 18 shows green street which have bio-swale, permeable street pavement, liner parks and tree pit to manage storm water and accommodate pedestrian with in the green space part of it.

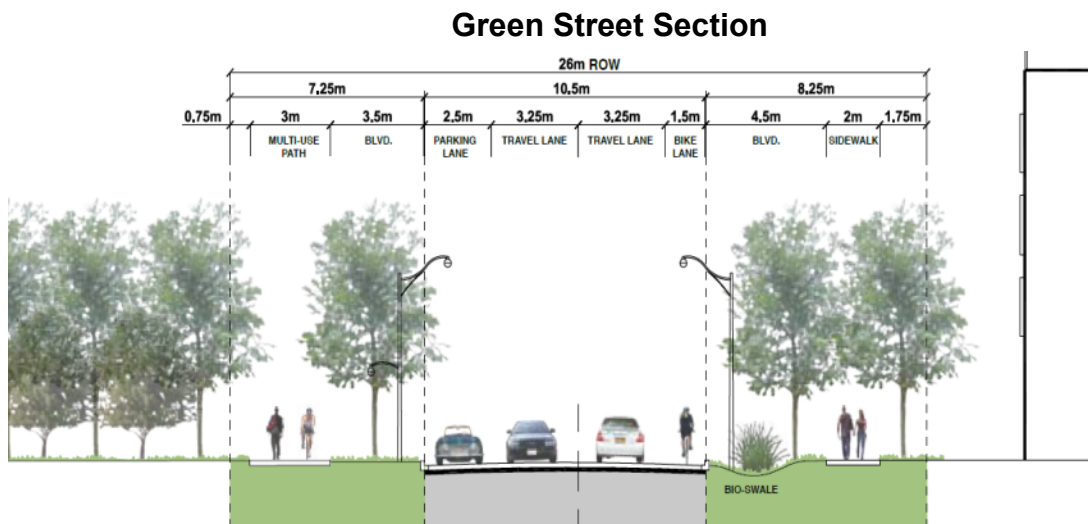


Figure 18 Green Street Typical Section (Source; Michele, 2011)

Tree Plantation: Plantation of tree has high position in Green Street. There are many criteria regarding to trees species, specification, cost, aesthetic and engineering solutions to planting tree on street (Harris and Dines, 1998). The excavation of tree trench is vital for both water management and tree protection. Generally, the planting of tree focuses on the design of planter and substrates to survive water issue and urban development pressure on the trees. Table 5 shows specification of street tree plantation. Figure 19 shows detail of tree pit plantation guidelines with (a) shows tree pit detail of stacking and edging (b) shows tree pit guard position and dimensions (c) shows tree pit root ball details and (d) shows detail of tree pit materials and positions of tree in the pit.

Table 5 Tree Planting Guidelines

No.	Tree plantation part	Description
1.	Site condition	Site of the pit tree should check underground conditions of utility lines, 3m minimum depth and 5m depth for main water and drainages.
2.	Pit size	1.2mX3m or 1.5mx3m and .76m - .9m
3.	Tree selection	Selection is based on height and spread, small- 10m, medium-15m and large>15m
4.	Tree support	Stacking and guying use to anchor the tree and stabilize the root ball
5.	Tree guard	Use to protect tree from damage and fixe rigidly vertically
6.	Soil volume	8.5cu.m – 12.75cu.m
7.	Watering	25L/ Tree immediately after planting
8.	Tree planter	Silva-cells, vault, raiser planter and structural soil
9.	Drainage	Surface drainage, with stone consisting of 200mm deep of clean 50mm aggregate nominal size in the base of the pit topped with a geotextile blanket

(Source; Bloomberg and Benepe, 2008)

Tree Pit Detail Sections

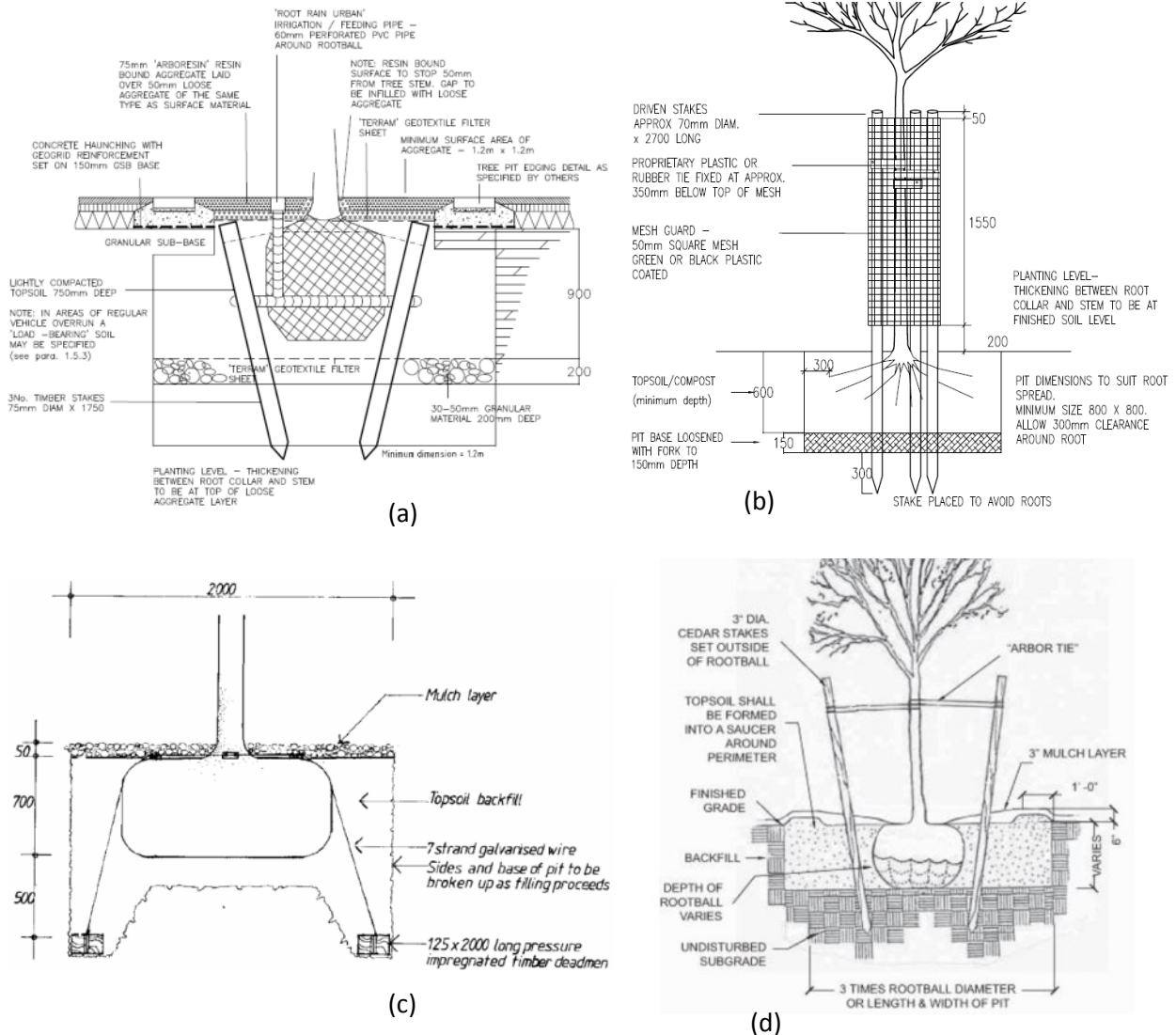


Figure 19 Tree Pit Details (Source; Bloomberg & Benepe, 2008)

Storm water management: Storm water is a hydrological event that happens on the raining seasons, and it is the hydrological cycle that governs the process through landscape. The cycle consists of evaporation, condensation, precipitation, runoff and infiltration (Nicholas and Kyle, 2001). Therefore urban development disturbs the process of natural hydrological cycle and creates runoff problems and other related challenges. The management of storm water in city has vital role in protection, infiltration, harvesting and pollution protection (Brown et al., 2001). The design includes water shed area delineation, volume of rain water calculation, land covers and slope, soil character and the design of appropriate channel.

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 rain water intensity, impervious area (runoff coefficient), regional factors and time of concentration and assumes uniform rain fall intensity throughout the drainage areas.

$$C = \frac{\sum(C_x A_x)}{A_{\text{total}}} \dots \dots \dots (13) \text{ (Source; Denies and Kyle, 2001).}$$

Where, C = Sumation of all individual landuse impervious area percent

C_x = Impervious area percent of single land use plot

A_x = Area of single plot

A_{total} = Total area of all land use plots

This formula is used for calculation of impervious areas (runoff coefficient) of urban drainage area to estimate the amount of storm water coming from the surrounding uses (residential, commercial, street....). the percent of imperviousness of the uses are given standard and shown in Table 6. Table 6 shows the standard of impervious area percent of single plot uses.

$$I = \frac{K}{K + b} \dots \dots \dots (14) \text{ (Source; Denies and Kyle, 2001).}$$

where, I = Rain fall intensity

K + b = Regional coefficient storm frequency design

$$Q = KCIA \dots \dots \dots (15) \text{ (Source; Denies and Kyle, 2001).}$$

Where, Q = Peak discharge flow (m^3/s)

C = Runoff coefficient (impervious area percent) step (13)

K = Constant number (0.0028 SI unit)

I = Rain fall intensity step (14)

A = Area of the catchment drainage

Equation (15) overview the calculation for storm water volume that produce in the catchment area of the drainage line and designed to manage the storm water by constructing channel (pipe or culver).

Table 6 Total Impervious area percent of individual land use plot standards

No.	Surfaces		Impervious Area (%) or (C) value	
			Min.	Max.
1.	Street Asphalt		0.70	0.95
2.	Street Concrete		0.80	0.95
3.	Drives and Walks		0.75	0.85
4.	Roof		0.75	0.95
5.	Pervious Area 'A' Soil	0-1% Slops	0.04	0.09
		2-6% Slops	0.09	0.13
		Steep Slops	0.13	0.18
6.	Pervious Area 'B' Soil	0-1% Slops	0.07	0.12
		2-6% Slops	0.12	0.17
		Steep Slops	0.18	0.24
7.	Pervious Area 'C' Soil	0-1% Slops	0.11	0.16
		2-6% Slops	0.16	0.21
		Steep Slops	0.23	0.31
	Pervious Area 'D' Soil	0-1% Slops	0.15	0.2
		2-6% Slops	0.2	0.25
		Steep Slops	0.28	0.38
Composite Values				
8.	Business Down Town Areas		0.70	0.95
9.	Business Neighborhood Area		0.50	0.70
10.	Residential	Single Family Detached	0.30	0.50
		Multi-Unit Detached	0.40	0.60
		Multi-Unit Attached	0.60	0.75
		Suburb Lots <0.5 Acre	0.25	0.40
		Suburb Lots >0.5 Acre	0.30	0.45
11.	Apartment /Condominium Dwelling Areas		0.50	0.70
12.	Industry	Light	0.50	0.80
		Heavy	0.60	0.90
13.	Parks and Cemetery		0.10	0.20
14.	Play Ground		0.20	0.40
15.	Rail road Yard Area		0.20	0.40
16.	Unimproved Area	Pasture (Flat-Steep)	0.10	0.42
		Cultivated (Flat-Steep)	0.31	0.44

(Source; Denies and Kyle, 2001)

iv. Green Building


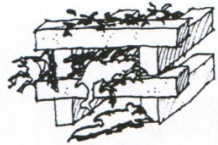
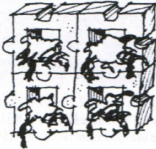

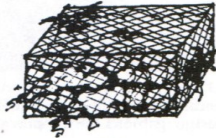



It is not a new phenomenon but has been used throughout the history of urbanization. The pronouncing of green building in recent time is related to global warming and energy crisis (Chamber, 2011). Green building is a system of practice to green the conventional building with vegetation as part of the green infrastructure model in urban area. It serves as an opportunity to gain green space in scarce green space and congested areas (Thompson and Sorving, 2008). The component of Green buildings (structures) are green wall (living wall), green roof.

a. Green Wall

It is also called living walls, vegetable walls, vertical gardens, green façade. It is a vertically vegetated wall (Bjerre, 2011). The vegetating of green walls depends on the façade of buildings; verticality or plain walls, horizontality or balcony, staged or stepped buildings (Sheweka & Mogdy, 2011). There are various techniques to cover the vertical walls with vegetation; block, crib wall, frame, trough, gabion, mesh, cell, sandbag(Thompson and Sorving, 2008), are some to mention.

Green walls can be categorized into three type of building, in relation to walls shape and to apply vegetation in to it, as climbing wall, hanging down wall and modular wall (Thompson and Sorving, 2008). Climbing wall is plain wall and covered with climbers (self-climber-no support need, twining climber-support need and rambling shrubs-trained) with either on container soil or fixed ground. Hanging down type wall is with balcony or podium and vegetation will install on the balcony or podium and hanged down from the container soil of balcony or podium. Finally modular can apply on both wall by fixing into the wall, the pre planted mat or module into the wall. Table 8 shows the construction technique of green wall that could apply to the aforementioned type of walls.

Table 7 Construction Technique of Green Wall

No.	construction technique type	Description	Sketch
	Block	engineered with gaps where plants root through the wall	
	Crib wall	concrete or wood elements stacked "log cabin" style	
	Frame	stacked interlocking O-or diamond shape masonry	
	Though	stacked soil-filled tubs (retaining of free standing).	
	Gabion	stone filled wire baskets, strong but permeable	
	Mesh	like mini gabions, holding a thin layer of soil to a surface	
	Cell	flexible strong honey comb filled with soil also use horizontally	
	Sand bag	geotextile wrapped around soil formally called "vegetated geo-grid".	

(Source; Thompson and Sorving, 2008)

The construction methods and material for green wall varies among professionals, particularly the modular wall. They develop different type of construction techniques

and methods. Optigreen organization uses substrate filled aluminum cassette. The aluminum suspension rail or mesh bolted in to a wall and install the plant's pot. Generally, the cassette is made up of aluminum rail 100cm by 60cm size and 6cm width with 3cm plus for suspension rail and 50kg per cassette weight and use drip irrigation. Figure 20 shows green wall module (a) aluminum suspension rail filled with substrate (b) placement of plant pot (c) installing of plant and (d) growing up of plant.

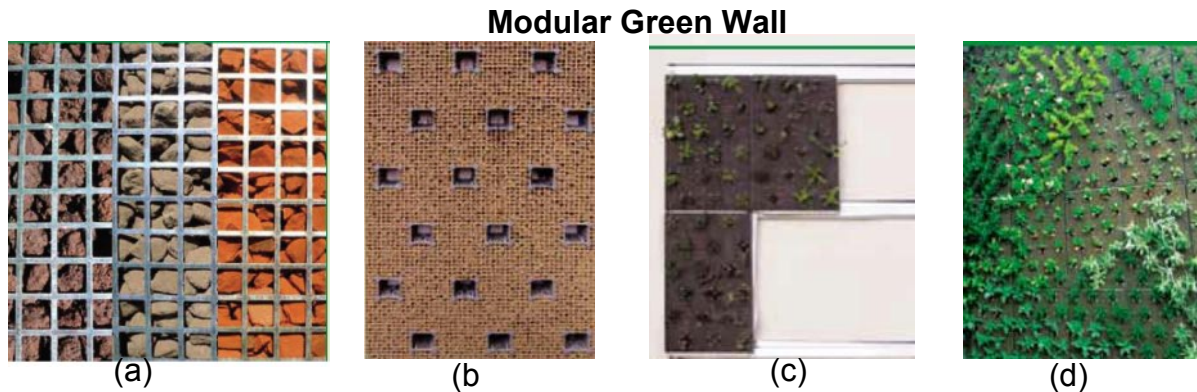


Figure 20 Modular Green Wall (source; Sheweka & Mogdy, 2011)

Florafelt organization uses pleated pocket design either fixed or hanged. It is designed with light weight nylon of 2.8g/m^2 , the size of the pocket is $250\text{mm} \times 150\text{mm} \times 80\text{mm}$ and use drip irrigation (using of pipe line). Figure 21 shows modular green wall of (a) pocket design (b) plant position on the pocket and (c) growing plant on pocket.

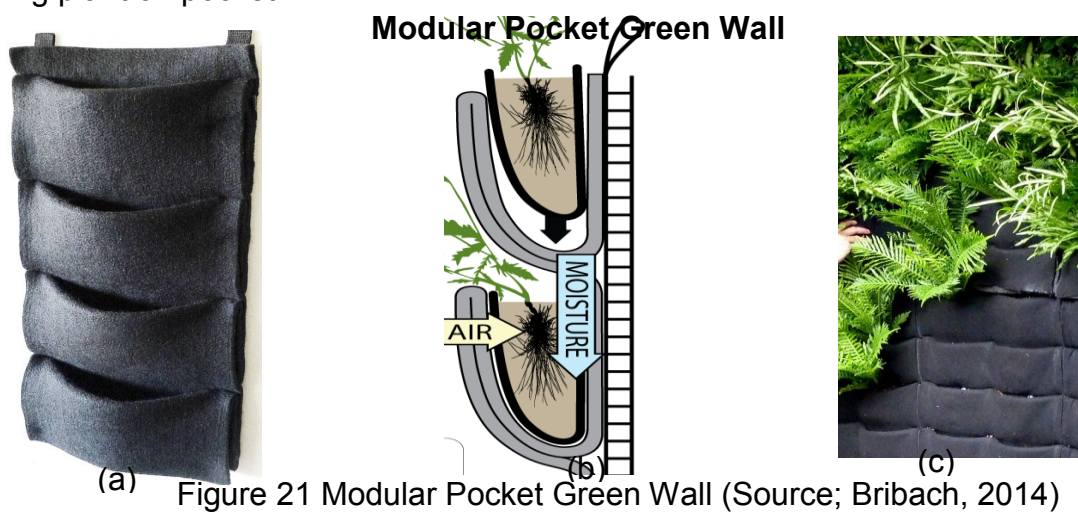


Figure 21 Modular Pocket Green Wall (Source; Bribach, 2014)

Green wall uses some important trees to cover with, climbers are among the many and divided in to three categories based on the species ability to climb facades self-

climber, twining climber and tendril and leaf twining climber (Sheweka & Mogdy, 2011). Self-climber are plants that have strong tendency to grow up and climbs with areal roots or climb with suckers and doesn't need support to climb walls of facades. Twining climbers the main stem twist with a helical motion around wire or other supporting system and needs support to climb a wall. Tendril and leaf twining climber are plants with special leaf/ stem that can twist like a corkscrew to wrap around a support. They need both support and training.

Table 8 Green Wall plant classification

Green Façade Classification	Green Wall		
	Fixation principles against the façade	Characteristic features	Plant types and Systems
Rooted in to the ground	Direct (use the façade as guide to grow upwards)	Self-Climbing Climbers	Aerial Roots
			Suckers
	Indirect (distance between climbing plant and façade via an supporting system or spacer)	Self-Climbing Climbers	Aerial Roots
			Suckers
		Climber with Supporting Systems	Twining Climber
			Tendril Climber
Scrambling Climber			
Rooted in artificial substrates adopting soil Mixture	Direct (use the façade as guide to grow upwards)	Self-Climbing Climbers	Aerial Roots
			Suckers
		Natural Wall Vegetation	Herbaceous Plants and Woody Plants
	Artificial Created Wall Vegetation (grow able concrete)	Herbaceous Plants	
	Indirect (distance between climbing plant and façade via an supporting system spacer, planter boxes, substrate which is used as guide to cover the façade)	Climber with Supporting Systems	Twining Climber
			Tendril Climber
			Scrambling Climber
		Living Wall Systems	Herbaceous Plants and Woody Plants

(Source; Ottele, 2011)

Green walls have some side effects such as moisture problem, maintenance, cost, insect problems, long period to see results and incompatibility of construction

(Sheweka & Mogdy, 2011). Additionally, structural issues, leakage and damage to water proofing and fire hazards (Gedge & Newton, 2008) are problems in relating to green walls.

b. Green Roof

Historically, green roof is a long age practice in history of mankind. It is a structure covered with vegetation and its function is to protect building structure and dweller (Zinco, 2013). There are two types of green roof identified as intensive and extensive. Intensive green roofs support complex vegetation communities in substrate depths greater than 20 cm. They are often designed as roof gardens for human use and usually require irrigation, maintenance and additional structural reinforcement of the roof (Ely and Pitman, 2012). Extensive green roofs have shallow substrate depths less than 20 cm (2-15 cm), require little or no irrigation and are usually planted with low growing drought resistant and fire retardant vegetation (Fifth Creek Studio, 2012). Generally, green roofs have two important parts. Firstly, structure of the roof itself is important to carry the load and secondly, slope of the roof has determinant factor in vegetating and irrigating of the green roof.

Green roof components: green roof has different components of water proofing, protective layer, drainage, filter, root barriers, growing media and plants (Townshend, 2007). Water proofing protects leakage and is water tight; protective layer protects water proofing from damage by drainage materials; drainage uses to drain excess water and prevent prolonged saturation; filter as its name implies that it filter fine soil material from entering to drainage layer; root barrier protects root out grow and confined it; growing median is soil which support the growth of plant and the soil should be light weigh material to solve loading problems. Finally plants are supposed to be draught retardant to solve water problem in the case of extensive roof, but in intensive roof irrigation and varieties of plant are used. For both green roof system plant weight is calculate and added to the live load of the building to protect the safety of the structure.




Table 9 Comparison of Extensive and Intensive

Atypical details	Extensive roof	Intensive roof
Brief description	Thin soil (25mm – 150mm)	Deep soil (200mm – 2000mm)
	Little or no irrigation	Irrigation
	Low maintenance (\$0.8-\$ 2.25/m ² /year)	Normal maintenance (\$6.5-\$44/m ² /year)
advantages	Light weight (80-150kg/m ²)	Divers utilization of roof (recreation, growing food and open space)
	Low maintenance	Great diverse of plants and habitat
	Suitable for retrofit project	Good insulation properties
	Relatively inexpensive (\$400-1000/m ²)	Can simulate a wildlife garden on the ground
	Suitable for large area	Can be made very attractive
	Suitable for roof 0-30 ⁰	Often visually accessible
Disadvantage	More limited choice of plants	Relatively high coast (1000-5000/m ²)
	Usually no access for recreation or other uses	Greater weight (300-1000kg/m ²)
	May be unattractive to some during dry season	Need for irrigation and drainage systems, hence greater need for energy, water, material et.

(Source; Townshend, 2007)

Table 9 shows the comparison of intensive and extensive green roof in terms of advantage and disadvantage. Table 11 shows the components of green roofs.

Table 10 Green Roof Components

Green Roof Components	Description
<p>1. Waterproofing Membrane</p> 	<p>A high tensile strength, root-resistant (FLL rated) ethylene vinyl acetate and PVC terpolymer thermoplastic sheet waterproofing membrane with a proven 30 year world-wide performance track record. Has excellent elongation and puncture resistance, is highly resistant to UV, rot and soil-borne chemicals and microbial organisms.</p>
<p>2. Drainage Modules</p> 	<p>Lightweight, high strength, interlocking modules that capture and transport high water volumes and protect the waterproofing membrane. Ideally suited for use in intensive green roof systems where load weight bearing capacity and efficient drainage is important.</p>
<p>3. Water Retention & Drainage Trays</p> 	<p>A lightweight, cost-effective water management tray used below the growing media that functions to store and drain water and to protect the waterproofing membrane. The high water storage capacity of the cells coupled with high discharge capacity ensures effective capillary irrigation, eliminates the possibility of waterlogging, reduces irrigation frequency and minimizes fertilizer runoff and usage.</p>
<p>4. Geotextile Filter Fabric</p> 	<p>A needle-punch geotextile filter fabric placed onto either VersiCell® or VersiDrain® 25P prevents fine particles in the growing media from entering and causing clogging. A > 50mm layer of coarse washed sand is positioned on the geotextile in intensive green roof systems before the addition of lightweight growing media. The geotextile also acts as a 'capillary wick' when positioned onto VersiDrain® 25P.</p>
<p>5. Cellular Confinement Cells</p> 	<p>Lightweight, expandable, high strength and flexible thermoplastic strips that are ultrasonically bonded to form a strong, dimensionally stable and inert honeycomb structure that both contains and prevents, growing media movement on sloped roofs.</p>
<p>6. Lightweight Growing Media</p> 	<p>The lightweight mix, as recommended by the specifier, should incorporate expanded clay aggregate or vermiculite and other lightweight, high water storage capacity components such as peat moss, composted sawdust and bark fines, coco peat, washed sand and recommended fertilizers and water retaining crystals.</p>
<p>7. Plant Species</p> 	<p>Species, as recommended by the specifier, should include plant varieties selected for greening quality, adaptability to growing media, irrigation regimes and local environmental conditions.</p>

(Source; Elmich, 2014)

The Challenges of green roofs are load bearing conditions, cost, transportation (construction) of materials to the high-rise buildings, selection of the right plants, irrigation, soil selection and maintenance are among.

Green Roof development requires some important considerations about vegetation species type, primary use of roof, storm water management, temperature, aesthetic, recreational and scarce water issue.

Plant selection considers heat, humidity, exposure to sun, wind, and shade and temperature fluctuation. The plant for green roof should have shallow root system to survive in harsh conditions. Vegetation plantation into the green building uses the method of seed (direct sowing), cutting, plugs, nursery containers, vegetated mat and modules. Type of plant for green roof depends on load bearing condition, medium composition, depth, and roof slope. Figure 22 shows the comparison of extensive and intensive roof type.

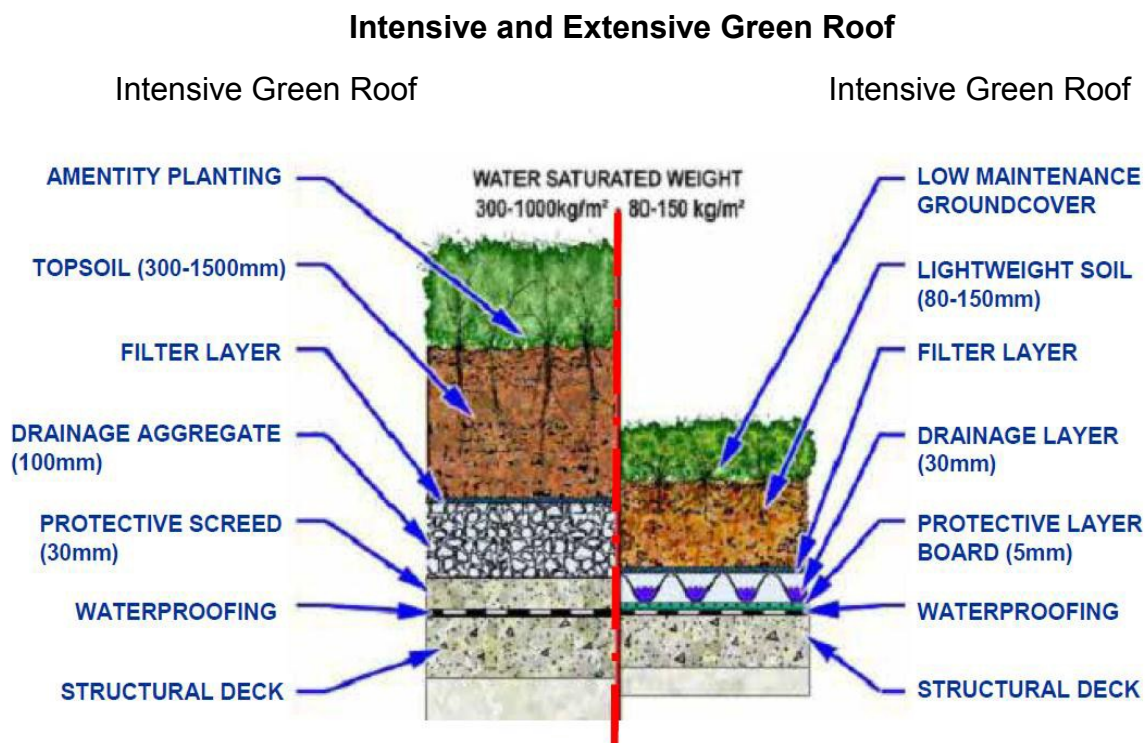


Figure 22 Intensive and Extensive Green Roof Comparison (Source Townshend, 2007)

Conclusions

In the review discussion chapter two, it can be conclude that GI is the network of green space and green structures of urban areas. The definition of GI is related to context and vision of countries to many scholars. The historical development of GI was traced back, but its scale of development is recent phenomenon in respond to global warming which was ignited by contemporary theory and practices.

GI compenents are impervious area, green space, green street, green buildings and WSUD. Imperviuos area has key measure of urban environmental degradation with its coverage percent in urban area; green space is about interconnecting of natural green area and developed green area to maintain ecosystem; green street deals with management of rain water by using vegtation and pervious surface; green building also deals with managing rain water and increment of green area in urba area and finally, WSUD deals with maintaning of ecological functions by protecting and managing rain water pollution by natural systems and maximazing infiltration and utilization of rain water in urban areas. Generally GI is important for ecological system and bio-diversity in urban areas.

CHAPTER THREE

3. Case Study

3.1. Hong Kong

Hong Kong and its 260 territorial islands and peninsulas are located in the South China Sea, at the mouth of the Pearl River Delta (Encyclopedia, 2013). The reason of choosing this city is that, it is known for using GI to maximize its greenness and it is known with this practice worldwide and the study wants to take this experience to makelle city.

3.1.1. Greening Policy

In Hong Kong government's greening policy, targets to enhance the quality city living environment through active planting, and proper maintenance and preservation of trees and vegetation on their planning projects.

3.1.2. Green Roof

In Hong Kong green roof is either intensive or extensive the difference is in soil depth and character, accessibility and vegetation type. intensive is accessible with widely variety of vegetation and deep growing media, but extensive is shallow growing media, few vegetation species and in accessible. Green roof includes green podium, green terraces and sky garden (Source: Townshend, 2007).

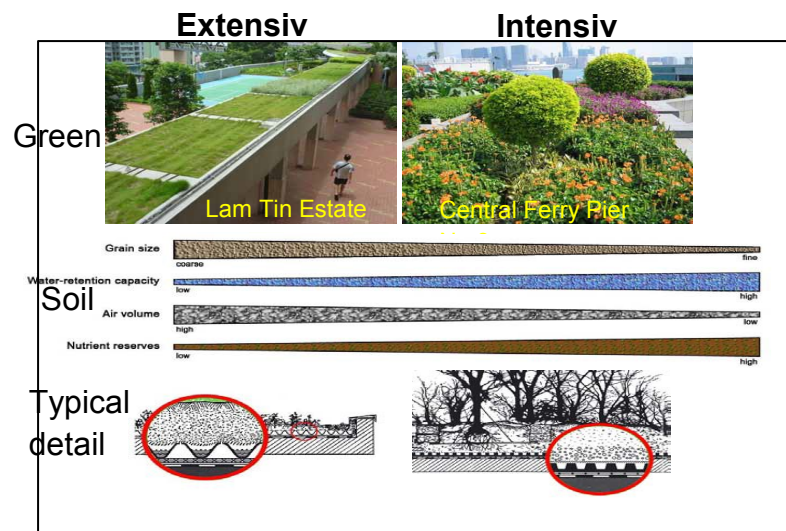


Figure 23 Green Roof Comparison Between Extensive and Intensive (Source; Townshend, 2007)

Table 11 Green Roof Comparison between Extensive and Intensive

Description	Extensive	Intensive
	Thin soil (50-150mm)	Deep soil (200-2000mm)
	No irrigation	Irrigation
	Low maintenance (\$0.8-\$2.25/m ² /year)	normal maintenance (\$6.5-\$44/m ² /year)
	Extensive application over large area for optimal environmental benefit	Intensive capital and maintenance input for optimal benefit

(Source; Townshend, 2007)

Green Roof Components

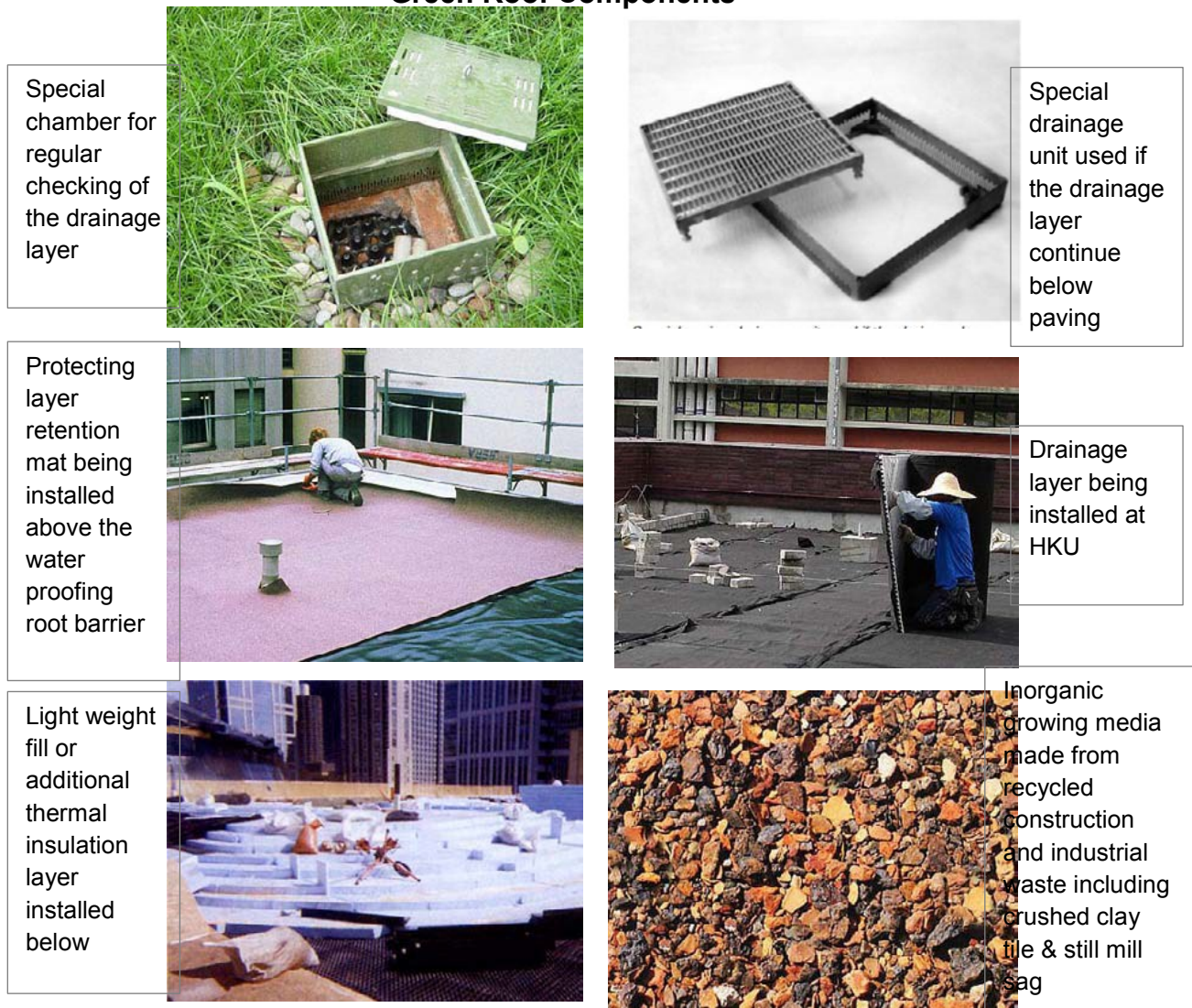


Figure 24 Green Roof Components (Source; Townshend, 2007)

Table 11 shows the comparison between extensive and intensive green roof. Figure 24 shows green roof components.

3.2. Hawassa City

Hawassa is a city in Ethiopia, located 275 km south of Addis Abeba. It is the capital of South Nations, Nationalities, and Peoples Region. The city is found on the shore of Lake Hawassa in the Great Rift Valley. This lake measure 16 km long and 9km wide, with a surface area of 129 square kilometers has a maximum depth of 10 meters with an elevation of 1,708 meters. (Tadesse Fetahi, 2012). The choosing reason is that it is the green city in Ethiopia and the research wants to compare it's greenness with the research area Mekelle city.

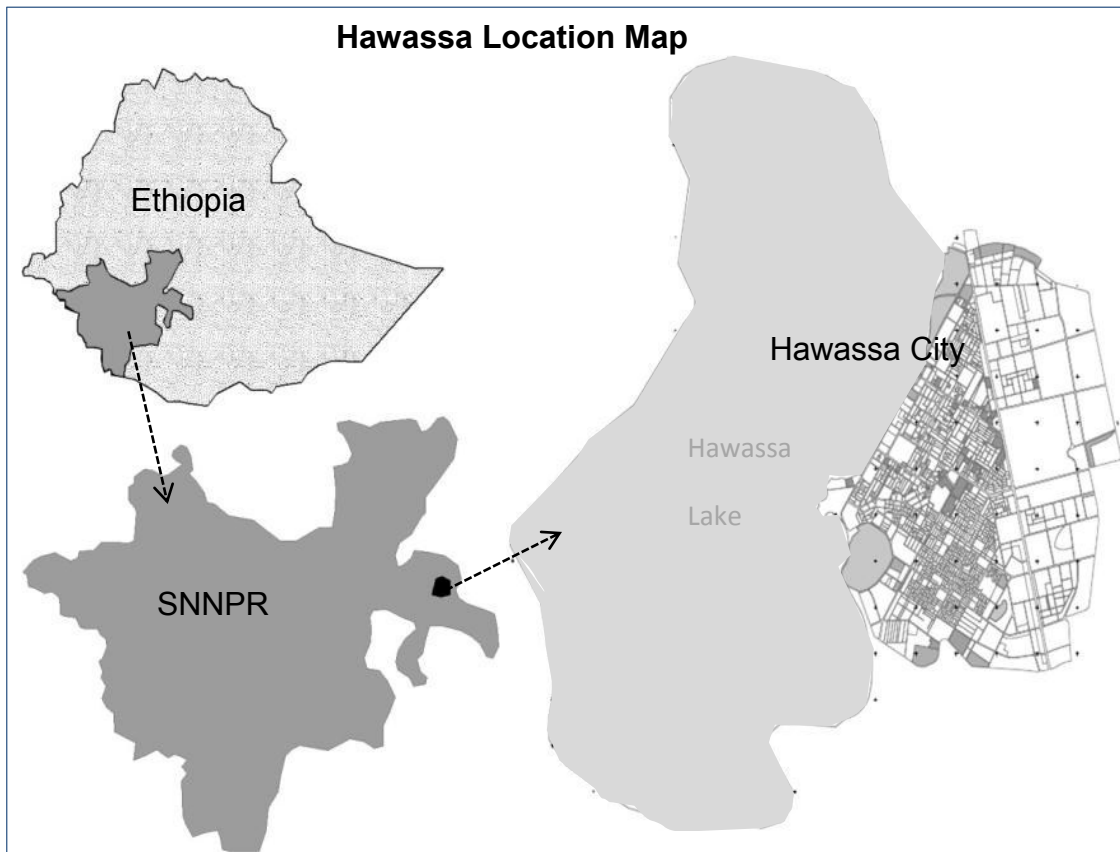


Figure 25 Location Map of Hawassa City (Source: Own)

In Ethiopia, green infrastructure is not in practicing yet, the research has chosen Hawassa to show natural green that it is blessed with lake and natural vegetation. According to the research calculation from master plan of Hawassa 42% of the existing land use is covered with green areas and it is not difficult to imagine how green Hawassa is. Even though, Hawassa city is green no GI practice in the area. Figure 25 shows location map of Hawassa city.

CHAPTER FOUR

4. Contextual Review

4.1. Description of the Study Area –Mekelle City

Mekelle, the capital city of the present Tigray Regional State, has emerged from the small agrarian villages. These were Enda Meskel, Gonay Daero, May Degene, May Liham, Chomea, Enda Gabr, Enda Anania, Enda Gufaf, and May Gufaf (Rumi, 2009). Figure 26 shows how the city was green with scattered village and surrounded by green areas but now every green is gone and becomes fragmented like the village was and on the course of time development had been reversed the situation that green area has receded from the city while built-up area has merged and filled the whole city.

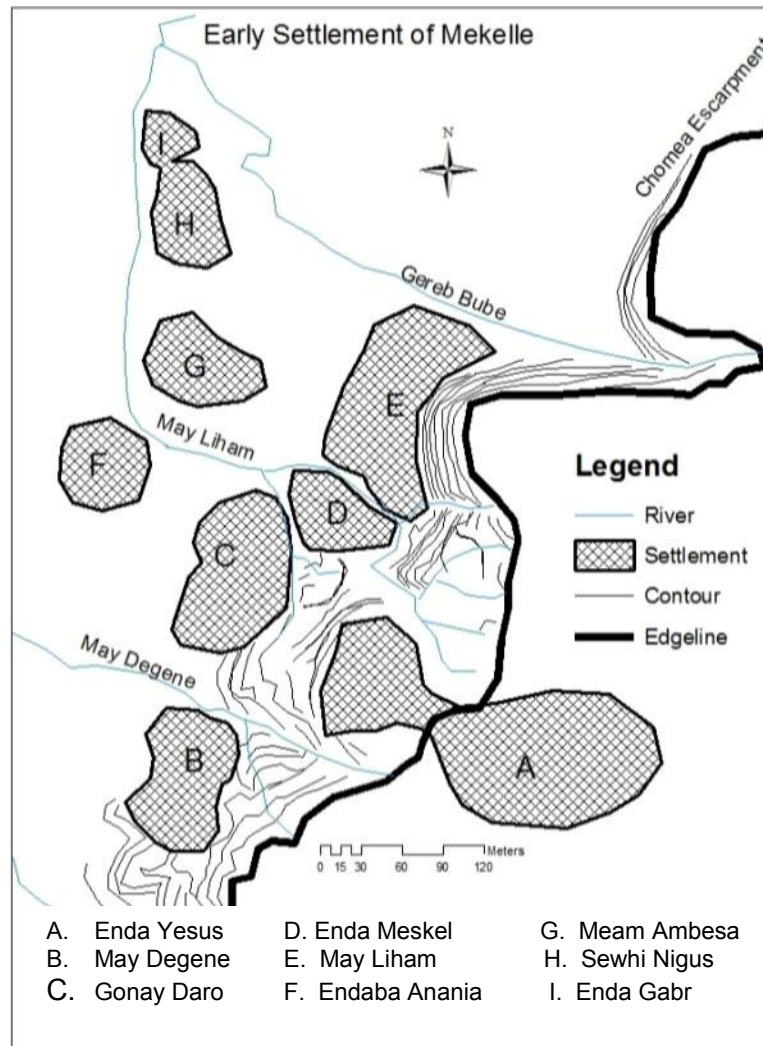


Figure 26 Early Settlement Villages of Mekelle City (Source; Rumi, 2009)

The city has been named differently before it got the present name 'Mekelle', one of the high priest who had divided the city to each of his church students for the sake of collecting foods. It was named Enda Meskel to commemorate its being a stopover for the delegation of bearer of the true cross from their journey from Jerusalem to Gishen. Later named Meam Ambesa, since it was a village amidst a large dense forest, which in habitats many wild animals such as lion. This name recall the greenness of the settlement. The founder of the village was Aba Absadi (Mekelle Municipal, 2006). This village had expanded during the time of Atse Seyfe Arad and Atse Zera Yakob and has got its present urban form by Atse Yohans-IV. The word 'may' associated with the village denotes the presence of streams for each village and how the area was green enough. Now these streams have vanished due to high intensity of settlement (dense settlement). Figure 27 shows location map of Mekelle.

Mekelle is located at 777 km drive north of national capital city, Adiss Ababa. Geographically, it is located between $13^{\circ} 24'30''$ to $13^{\circ} 36'52''$ Latitude and $39^{\circ} 25'30''$ to $39^{\circ} 38'33''$ Longitude. Figure 26 shows the location map of the research area.

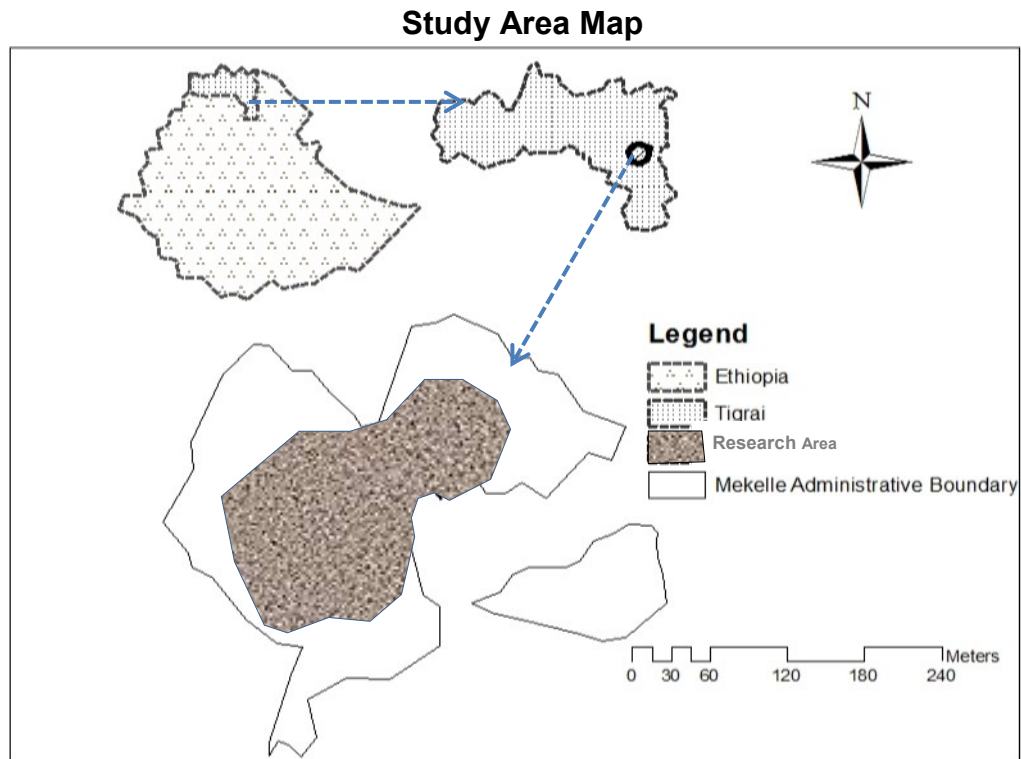


Figure 27 Study Area Description Map (Source; Own)

According to CSA (2007), the population of Mekelle city was 215,914 and its average house hold size was 3.4. The projected city population size for 2014 was 321,200 (Mekelle Municipal, 2006). Spatially, the city covers 19,200 hectares after the expansion of Mekelle into Addihawsi-Addiquote, Serawt, Addida'ero-Addikolomoy, Addishumduhun and Addiha, Lachi-Addichu'endog, Addikidana-Felegdaro and two small towns Quiha and Aynalem. In 1984 it had covered 1600 hectares of land (Mekelle Municipality, 2006). Table 14 shows the population size and its density in different years. This has done base on the built-up area and administrative boundary, built-up area includes urbanized areas, where as administrative boundary area includes non-urbanized area (expansion area) or non-built-up areas.

Table 12 Population and Density of Mekelle City (1974-2014)

No.	Year (G.C)	Surface Area in		Population	Density (built-up area/population)	Density (boundary area/population)	Green/Open Space
		Built-up Area	Administrative Boundary Area				
1.	1974		-	42130	-	-	
2.	1984	1600	1600	65583	2.4	2.4	
3.	1994	1600	2034	96938	1.65	2.09	
4.	2004	2304	10240	207308	1.11	4.9	0.15
5.	2006	3000	19200	264887	1.13	7.24	0.14
6.	2014	4500	19200	321,200	1.4	5.98	0.13

(Source; Mekelle Municipal, 2006)

Mekelle City has weyna dega (temperate) climate. Its monsoon is from July to October with average of 618mm. Its average maximum and minimum temperatures are 24.1c⁰ and 11.11c⁰ respectively. The city attain its maximum temperature (29.9c⁰) in June 1969 and its lower temperature 1.6c⁰ in January 1987 G.C. Its average wind per month is 5m/sec. The wind blows from east to west direction from September to June and changes it direction from west to east from July to August with and average yearly speed of 3m/sec. the maximum average wind speed so far registered per day is 14m/sec in June 1996 E.C.

The city has got four master plan. The first was prepared by Italian in 1937 during Italian occupation, the second was prepared during the reign of Emperor Haile Selassie by Italian Architecte called Arturo Mezzedimi, the third one is prepared by NUPI in 1993 and the fourth one was by Municipal of Mekelle city in 2006 (Rumi, 2009). Figure 27 shows the first master plan of Mekelle in 1937.

Master plan of Mekelle city in 1937



Figure 28 Master Plan of Mekelle City in 1937 (Source; Rumi, 2009)

4.2. Physical Infrastructure in Mekelle

Social services of urban area are being facilitated by the existence of proper infrastructures and suitability to the environment for proper functions and social development these include buildings, water supply, drainage, street, etc.

4.3. Green Infrastructure(GI) in Mekelle

As it is defined on the literature review that GI is the green network of natural/man-made structure/sub-structure, and open space of an urban area. In Mekelle GI is found in the form of natural and developed green spaces. The research has analyzed Mekelle city in the eyes of GI components green space, green roof, green wall, green street and WSUD.

4.3.1. Green Space(GS)

The green spaces on the research area includes developed (man-made/or touched) and natural (non-manmade/or untouched). Natural area includes river buffer, hillside, open land, agricultural land and forest area. Developed includes median, hedge, backyard, garden, recreation area, open space, social service area and street side. The natural area includes Chomoa mountain, river buffer (Gereb tsedo, Mydegene, Gerebbubi, Mygufaf and Hawelt), sewhinigus (open grass land) and Myduba forested area. Developed green areas are Hawelt sematat, Yohans-VI palace, Abrha castle, parks (Degen, Lucyand Endarasi), Rufael church and Mekabr aslam, St. Mary church, Teklehaymanot church, Kidanemhirt church, Gebremenfeskdus church, and Medhanialm church. Naturaly green area are not accessible rather they have scenic value because they are not integrated with the city space (not articulated for use). The developed habitable (recreational) green area also are not enough for the city, they are small in area and number Degen has 3500m², Lucy 4500m² and Endarasi 36000m². They are parks in name but practically, they are owned by investors and have no fauna and flora to amaze and recreate the public. Most of the natural area are covered by Equiliptous tree and local bushes. The old churches like Medhanialem and Teklehaimanot and Endarasi park has indotic species of trees. Generally, green space in Mekelle are confined to public place and retreat to area where people could not access. Therefore, people could not enjoy themselves to the natural world to refuge themselves with, from the urban abiotic dominant harsh condition and heavy (polluted) air inhalation. Figure 29 shows main natural green area and developed green area of Mekelle city and Figure 30 shows name of the main green spaces.

Green Space

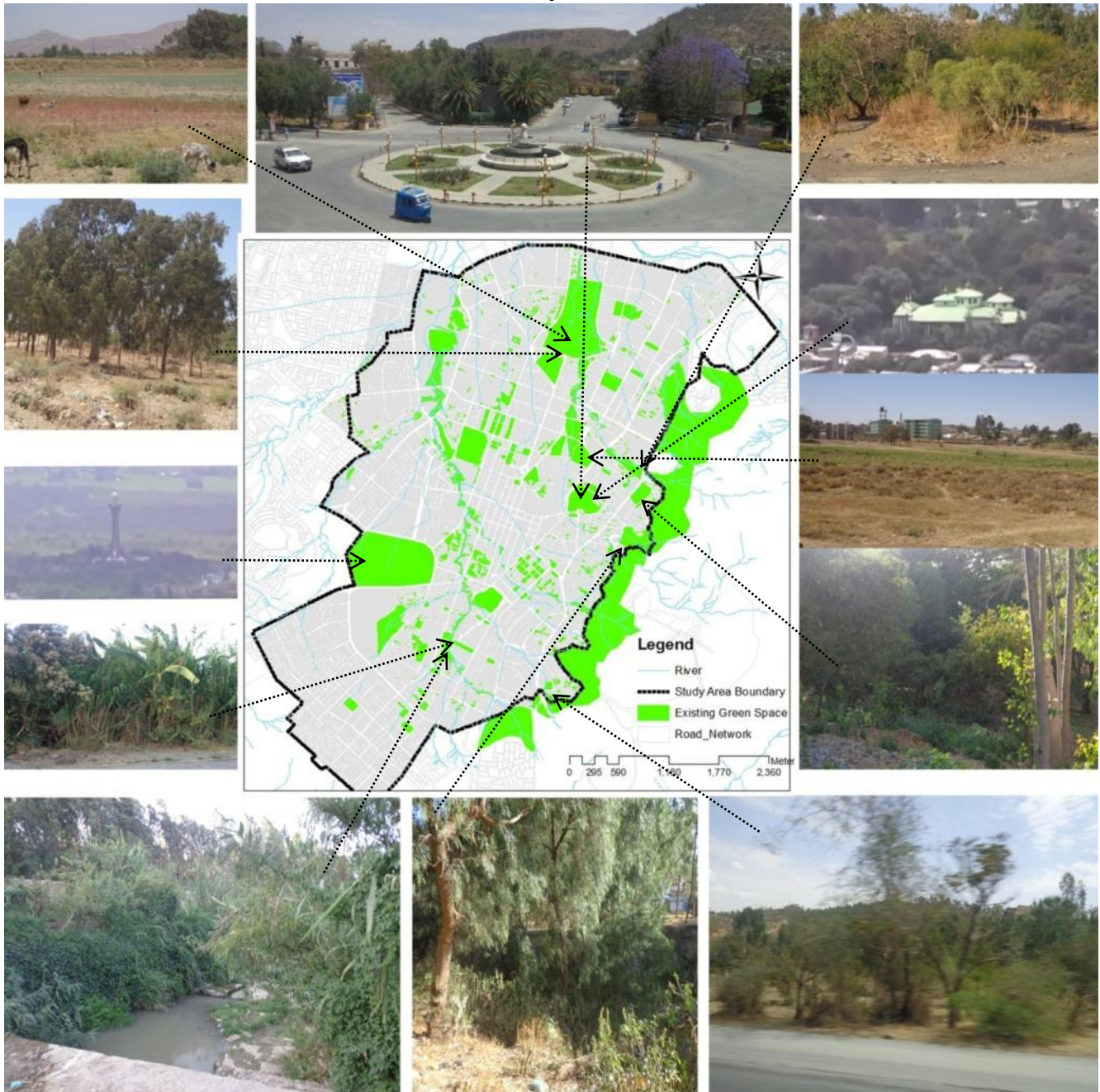


Figure 29 Green Space (Source Own)

Table 13 Green Space Coverage percent

No.	Green/open space	Areas (m2)	Percent (%)
	Green space (vegetated space between buildings)	2602877	26%
	Open space (any space between buildings)	170773	1%
	Total	6022748.4	27%

(source; Own)

Green Area Names

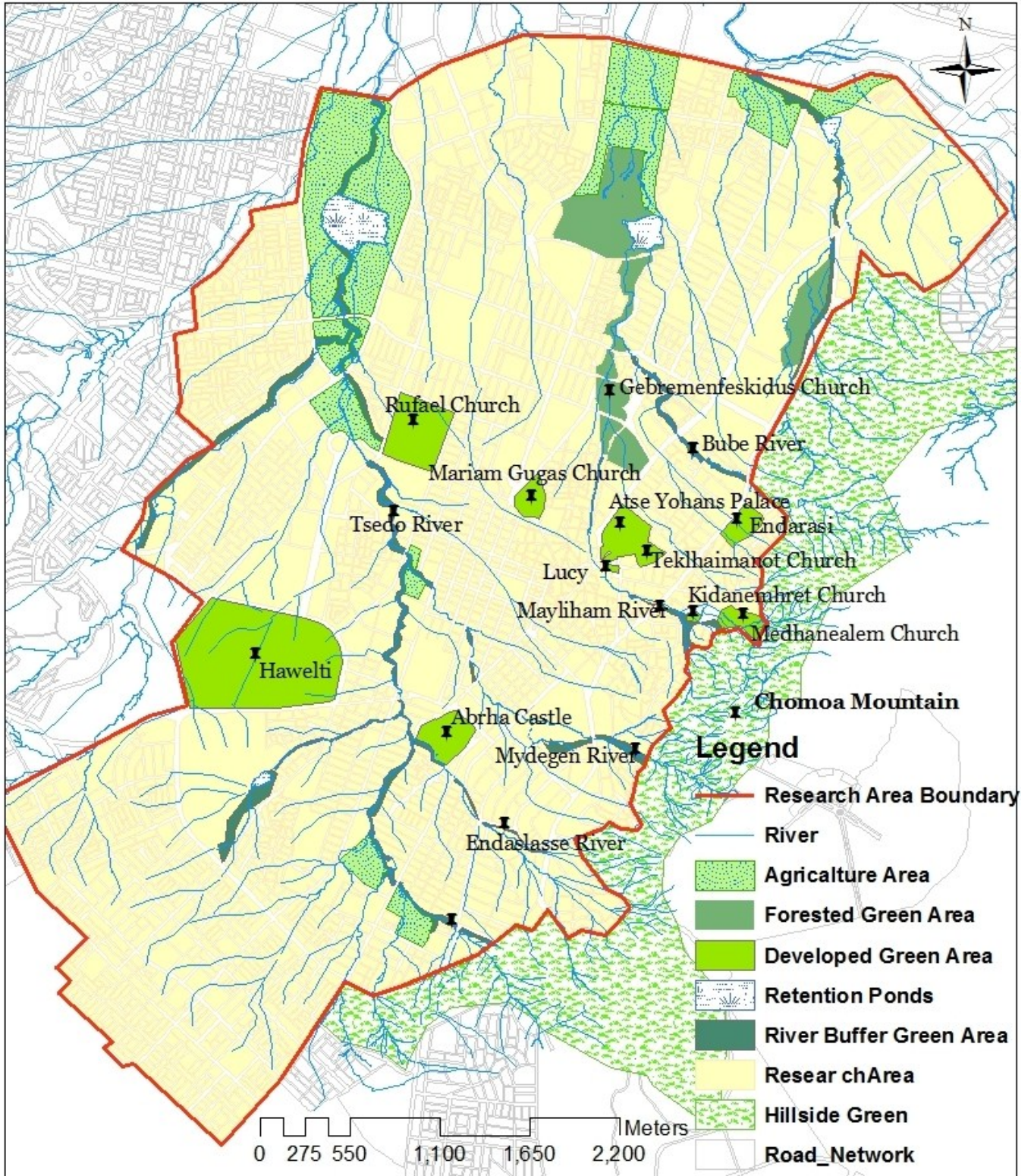


Figure 30 Green Space Name (Source; Own)

Green area has fragmented because of city development has been pushed them apart and deteriorate in connectivity and capacity. Green area has changed from interior habitat into edge habitat and patterns. In Mekelle natural green was along river valley and small mountains, now rivers has chopped by development and increase the number of patterns thereby loss habitat capacity, and the small hill side has occupied by public buildings because of strategic elevation. These include Yohanse-VI palace, Abrha castle, Hawelti and churches.

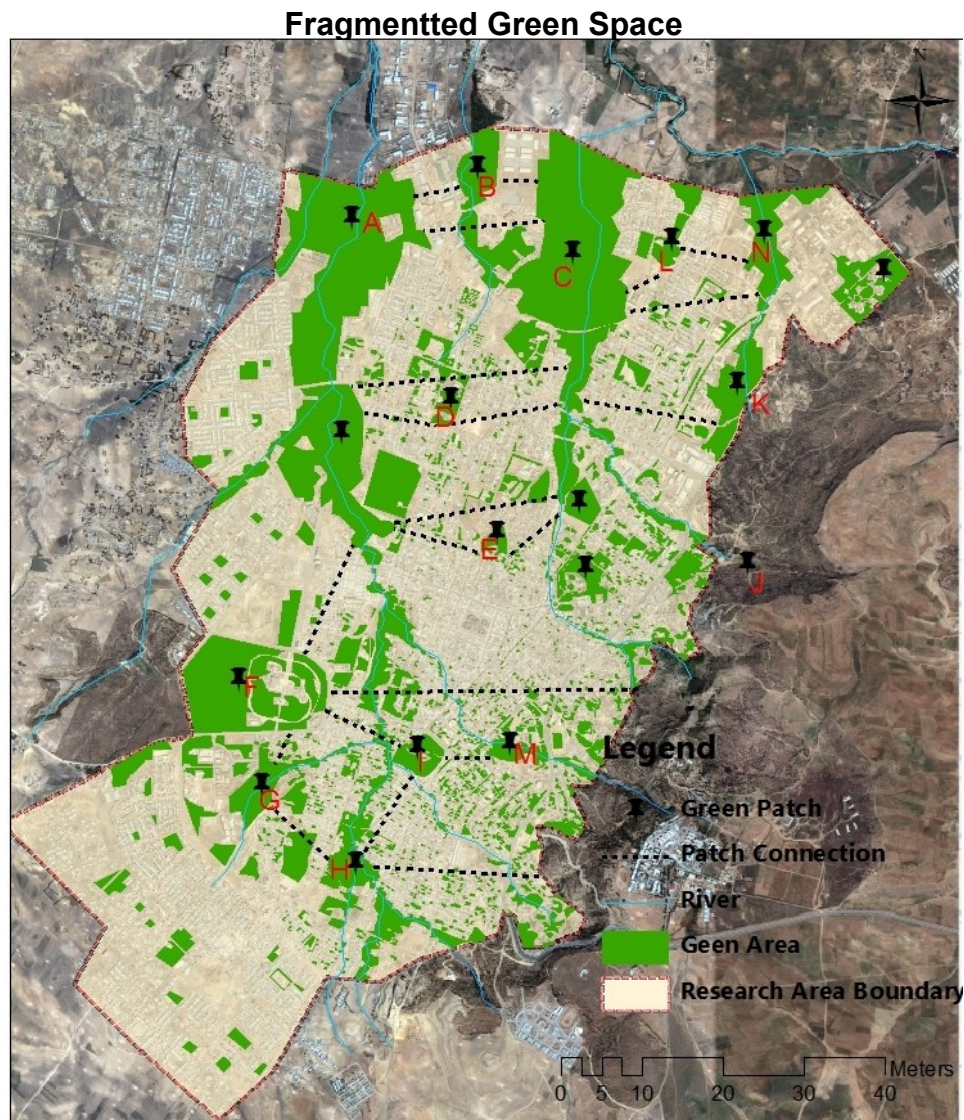


Figure 31 Fragmented Green Area Represented by letters (Source; Own)

Figure 31 shows fragmented green area represented by letters and possible connection paths.

Table 14 Probability Distance Dispersion

patches	distance	Probability distance	P*	patches	distance	Probability distance	P*
A&C	2.2km	AB=.8km BC=.9km	P^*_{AC} A->B->C .72km	AJ	4.4km	AE=1.3km EJ=2.9km	P^*_{AJ} A->E->J .79km
C&K	2.3km	CL=1.1km LK=1.55km	P^*_{CK} C->L->K .78km	FJ	4.57km	FI=1.8km IJ=.25km	P^*_{FJ} F->I->J .45km
A&C	3.km	AD=1.3km DC=1.4km	P^*_{AC} A->D->C .52km	FH	2.2km	FG=.9km GH=.9km	P^*_{FH} F->G->H .81km

(Source: Own)

Table 14 shows the direct distance, probability connectivity (PAC...) and maximum probability connectivity (P^*_{AC} ...). P^*_{AC} ... is the result of two patch distance product.

I. Plot

Urban land is divided into plots, in the research area there are about 19868 plots, the plot area varies from 65 to 544655m². The size of old settlement plot of the city have small plot sizes and varies with use types. The green area (open space) of plot is done by division that 30% of plot area is open and green area decrease on the small plots which was seen on the old settlement of the city that there is no green area on the small plots. Table 15 shows plot area classification.

Table 15 Plot Size number

No.	Category of plot by area(m ²)	Number of plots
1.	65-100	610
2.	101-200	7689
3.	201-300	4106
4.	301-500	4486
5.	501-1000	1978
6.	1001-2000	498
7.	>2001	501
8.	Total	19868

(Source: Own)

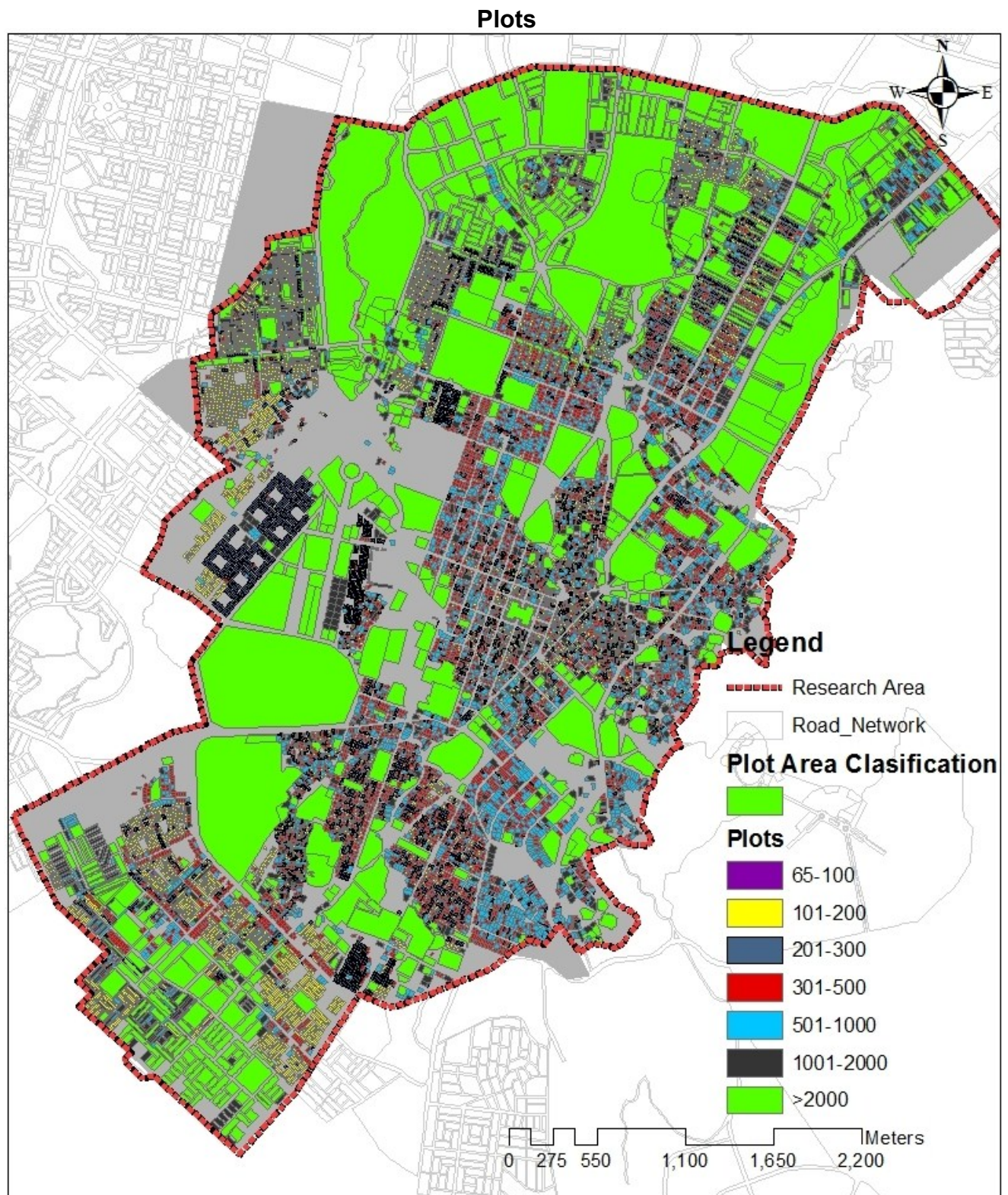


Figure 32 Plot Area Classification (Source: Own)

Figure 32 shows plot area of public and privet plot of different size represented by colors corresponding to plot size.

II. Plot Built-up Area

It is the place where buildings built-up (installed), according to thumb rule 70% of plot is built-up area and 30% is green area.

Table 16 Plot Built-Up and Green Space area of Blocks (1-17)-A

Block Code	Plot Code	Plot Area Range (m ²)	Number of plots	Built-up Area(m ²)	Green /Open area (m ²)
1	1.1	160-170	182	120-144	20-26
	1.2	180 - 190	350	125-130	55-60
	1.3	200-300	285	98-145	102-155
	1.4	350-28807	60	140-2575	210-26232
2	2.1	160-170	251	115-120	45-50
	2.2	180-190	496	128-137	52-53
	2.3	200-300	217	110-145	90-155
	2.4	350-17853	73	120-1150	230-16703
3	3.1	140-160	600	97-100	43-60
	3.2	170-180	144	101-110	69-70
	3.3	200-350	43	84-153	116-197
	3.4	400-15380	83	115-1052	285-14328
4	4.1	140-170	273	86-90	154-80
	4.2	180-200	47	113-115	67-85
	4.3	250-400	62	140-166	110-234
	4.4	450-22557	100	211-3904	239-18653
5	5.1	140-300	15	71-165	69-135
	5.2	300-400	23	147-229	153-171
	5.3	450-15121	106	150-1068	300-14053
6	6.1	140-170	242	87-115	53-55
	6.2	180-200	137	93-110	87-90
	6.3	250-400	92	112-135	138-265
	6.4	450-2047	66	160-375	290-1672
7	7.1	120-125	65	98-102	22-23
	7.2	150-180	260	82-110	68-70
	7.3	200-300	256	94-145	106-155
	7.4	350-5369	57	123-1457	227-3912
8	8.1	140-170	206	83-108	56-62
	8.2	180-250	117	89-150	91-100
	8.3	300-450	56	146-205	154-245
	8.4	500-63676	82	270-3056	230-60620
9	9.1	100-140	65	65-79	35-61
	9.2	170-250	85	78-123	92-127
	9.3	300-450	92	167-215	133-235
	9.4	500-413702	47	209-12000	291-401702
10	10.1	100-140	101	65-73	35-67
	10.2	150-200	216	83-103	67-97
	10.3	250-350	415	98-132	152-218
	10.4	400-61126	197	154-2300	246-58826
11	11.1	100-140	138	70-103	31-37
	11.2	150-250	118	68-112	82-138
	11.3	300-350	96	145-156	155-194
	11.4	400-52487	115	174-5055	226-47432
12	12.1	140-170	96	63-90	77-80
	12.2	180-200	55	95-110	85-90
	12.3	250-350	309	101-147	149-203
	12.4	400-39602	91	161-1662	139-37940
13	13.1	200-300	95	133-190	67-110
	13.2	350-400	75	190-210	160-190
	13.3	450-500	35	193-265	157-235
	13.4	550-26270	130	210-1938	340-24632
14	14.1	168-400	70	65-175	103-225
	14.2	450-700	25	187-217	263-483
	14.3	750-13334	37	302-1184	448-12150
15	15.1	210-400	69	103-253	107-147
	15.2	450-550	43	234-272	216-278
	15.3	600-15225	89	287-2414	313-12813
16	16.1	120-170	27	80-120	40-50
	16.2	180-300	130	96-202	84-98
	16.3	350-500	131	136-269	214-231
	16.4	550-1661	61	222-863	328-798
17	17.1	120-190	98	67-135	53-55
	17.2	200-300	260	87-147	113-153
	17.3	350-400	56	129-205	221-195
	17.4	450-60862	78	167-1689	283-59173

(Source; Own)

Table 17 plot Built-up and Green Space Area of Blocks (18-37)-B

Block Code	Plot Code	Plot Area Range (m ²)	Number of plots	Built-up Area(m ²)	Open area(m ²)
18	18.1	544655	1	19488	437904
19	19.1	160-400	25	123-141	37-259
	19.2	401-500	37	132-198	269-302
	19.3	550-10398	47	298-604	252-9794
20	20.1	130-350	4	91-205	39-145
	20.2	650-70974	15	401-11999	249-58975
21	21.1	100-180	66	55-89	45-91
	21.2	190-300	108	65-139	125-161
	21.3	350-450	52	109-201	241-249
	21.4	500-26164	126	190-2241	310-23923
22	22.1	100-180	66	55-89	45-91
	22.2	190-300	108	65-139	125-161
	22.3	350-450	52	109-201	241-249
	22.4	500-26164	126	190-2241	310-23923
23	23.1	65-140	137	60-125	45-91
	23.2	150-250	120	130-198	125-161
	23.3	300-400	95	240-276	241-249
	23.4	450-2390	55	287-704	310-23923
24	24.1	120-200	58	72-130	5-15
	24.2	250-350	53	109-189	20-48
	24.3	400-33793	85	260-6710	60-124
25	25.1	100-300	67	63-205	163-1686
	25.2	350-400	42	189-291	48-70
	25.3	450-27792	55	287-2640	141-161
26	26.1	120-200	107	101-150	140-27083
	26.2	250-300	114	107-201	37-95
	26.3	350-450	23	197-256	161-109
	26.4	500-17478	67	206-3054	113-25152
27	27.1	2294-87708	13	670-12000	19-50
28	28.1	120-170	183	89-130	143-150
	28.2	180-200	215	107-140	153-196
	28.3	250-300	498	121-163	294-14424
	28.4	350-17358	55	187-1430	1624-75708
29	29.1	140-300	45	89-209	31-40
	29.2	350-133534	63	204-3012	73-80
30	30.1	100-200	68	67-151	129-137
	30.2	250-300	133	135-180	115-120
	30.3	350-450	122	198-270	152-180
	30.4	500-24873	144	204-2106	296-22767
31	31.1	65-140	181	52-106	13-34
	31.2	150-200	224	78-123	72-77
	31.3	250-350	141	146-201	104-149
	31.4	400-52300	191	187-6194	187-46106
32	32.1	66-140	108	54-120	12-20
	32.2	150-200	55	112-160	38-40
	32.3	250-350	45	160-250	90-100
	32.4	400-14627	66	205-9605	195-5022
33	33.1	65-140	73	60-132	5-8
	33.2	150-250	72	121-215	29-35
	33.3	300-1992	18	209-1192	91-800
34	34.1	65-140	203	60-126	5-80
	34.2	150-200	166	110-150	40-50
	34.3	250-350	86	186-256	64-94
	34.4	400-13468	74	245-3320	155-10148
35	35.1	65-140	43	60-121	5-19
	35.2	150-250	45	101-200	49-50
	35.3	300-400	52	206-298	94-102
	35.4	450-7304	33	209-2583	241-4721
36	36.1	100-250	62	63-143	37-107
	36.2	300-400	111	150-230	150-170
	36.3	450-550	34	187-276	263-274
	36.4	600-39540	78	305-1602	295-37938
37	37.1	100-200	81	55-143	45-57
	37.2	250-300	134	154-189	96-111
	37.3	350-400	74	179-234	144-166
	37.4	450-6409	146	232-2856	218-3553

(Source; Own)

Table 18 plot Built-up, and Green Space Area of Blocks (18-37)-C

Block Code	Plot Code	Plot Area Range (m ²)	Number of plots	Built-up Area(m ²)	Open area(m ²)
38	38.1	100-250	63	45-121	55-129
	38.2	300-400	83	162-230	138-170
	38.3	450-500	132	201-267	249-233
	38.4	550-39037	66	262-1358	288-37679
39	39.1	100-200	156	40-104	60-96
	39.2	250-300	106	107-154	143-146
	39.3	350-400	55	169-190	181-210
	39.4	450-8408	181	189-854	261-7554
40	40.1	100-140	67	55-79	45-61
	40.2	150-200	819	86-125	63-175
	40.3	250-300	75	181-201	69-99
	40.4	350-8273	63	221-1120	129-7153
41	41.1	125-140	94	65-95	60-45
	41.2	150-170	445	87-101	63-69
	41.3	180-200	260	94-110	86-90
	41.4	250-18030	66	120-1300	30-16730
42	42.1	17086-332983	5	250-18606	14536-314377
43	43.1	100-170	78	45-75	55-95
	43.2	180-250	74	67-125	113-125
	43.3	300-450	56	120-230	180-220
	43.4	500-159001	164	210-14514	290-144487
44	44.1	100-170	195	47-78	53-92
	44.2	180-200	130	80-90	100-110
	44.3	250-400	185	129-230	121-170
	44.4	450-88527	113	202-4410	248-44117
45	45.1	100-170	89	40-78	60-92
	45.2	180-250	42	55-120	125-130
	45.3	300-400	115	120-201	180-199
	45.4	450-15106	101	125-1003	325-14103
46	46.1	100-170	93	68-120	32-50
	46.2	180-250	135	82-150	98-100
	46.3	300-350	260	150-190	150-160
	46.4	400-37276	130	186-2130	214-16146
47	47.1	100-300	60	45-230	55-70
	47.2	310-350	130	200-238	110-112
	47.3	400-500	58	201-287	199-213
	47.4	550-11549	55	230-4086	320-7463
48	48.1	100-750	13	56-378	44-372
	48.2	1533-65389	17	1034-7908	499-57481
49	49.1	100-140	45	35-87	65-53
	49.2	150-400	49	67-120	83-280
	49.3	450-900	39	124-234	326-666
	49.4	950-80643	82	145-2003	805-78640
50	50.1	100-300	51	30-167	70-133
	50.2	310-350	50	125-150	185-300
	50.3	360-30932	27	164-4270	196-26662
51	51.1	130-170	65	69-100	61-70
	51.2	180-200	39	110-120	70-80
	51.3	250-138077	20	125-8100	125-129977
52	52.1	145-170	57	78-100	67-70
	52.2	180-250	43	87-155	93-95
	52.3	300-59525	39	171-3820	129-55705
53	53.1	3379-4373	2	345-412	2967-3961
	53.2	18687-434053	2	130-2321	18557-431732
54	54.1	115-575	49	58-312	57-263
	54.2	600-32801	56	235-1256	365-31545
55	55.1	1993-135226	12	532-18801	1461-1116425
56	56.1	70-250	55	65-165	5-85
	56.2	251-450	68	97-215	154-235
	56.3	500-40011	72	206-4350	294-35661

(Source; Own)

Table 16, 17 and 18 shows plot built-up and green (open) space area of block (1-17)-A, block (18-37)-B and block (38-56)-c. figure 33 show the relationship between

plot area and built-up area and so it show the small the plot, the small the small the built-up area will be and vice versa.

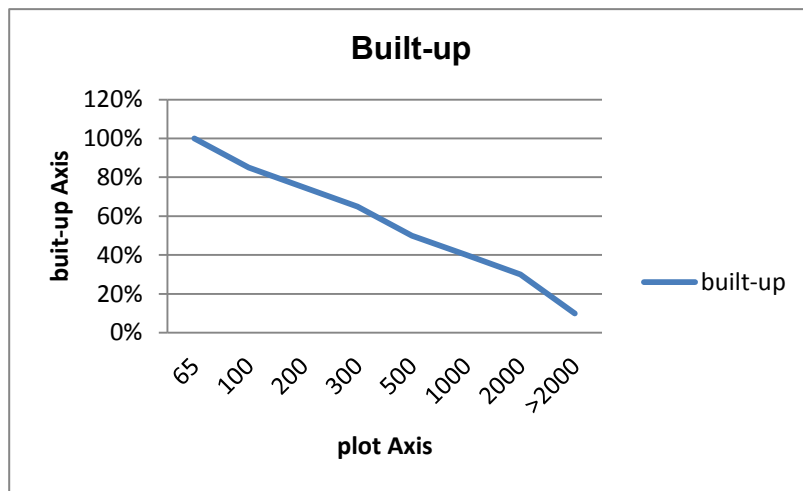


Figure 33 Plot Area versus Built-up Area (Source; Own)

4.3.2. Impervious area

It is an area of repelling infiltration of rainwater into the ground, by impervious surfaces. These include roof, street and pavement.

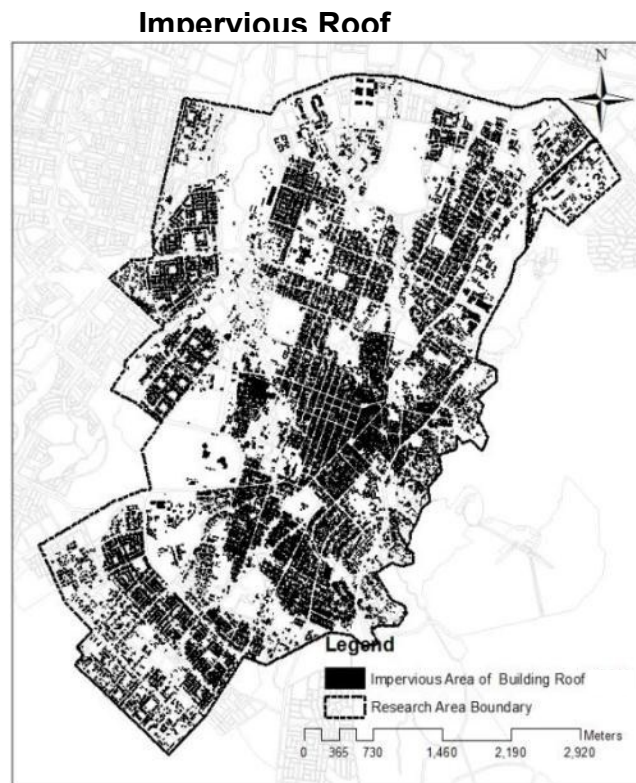


Figure 34 Impervious Area of Roof (Source; Own)

Impervious Street Area

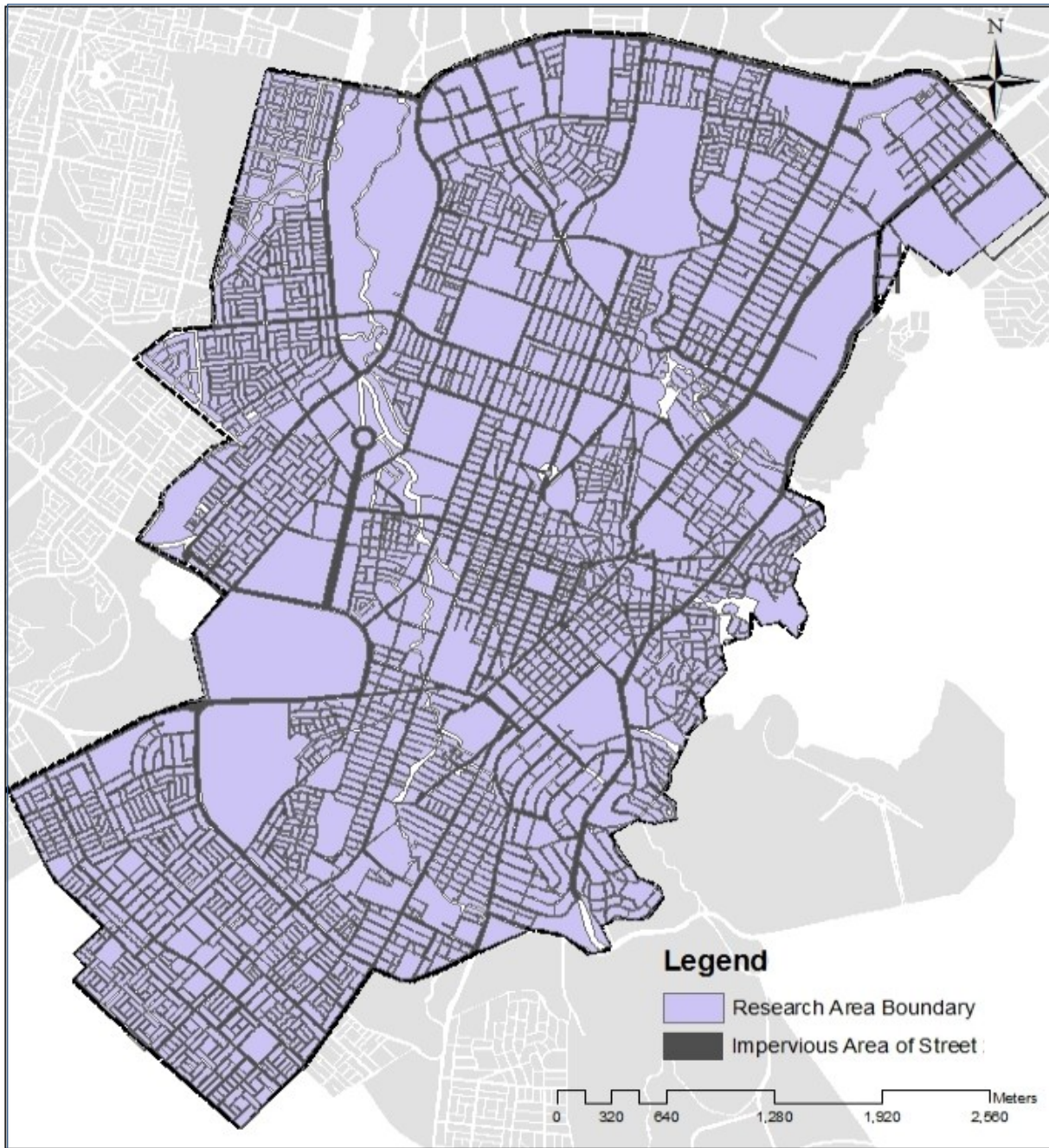


Figure 35 Street Impervious Area (Source; Own)

Figure 37 shows built-up area covered by roof, Figure 38 shows impervious area of streets (asphalt, concrete, gravel, cobble stone and rammed soil/ earth). All these streets are impervious areas and Figure 39 shows pavement (cobble stone, concrete and asphalt) impervious areas.

Impervious Pavement Area

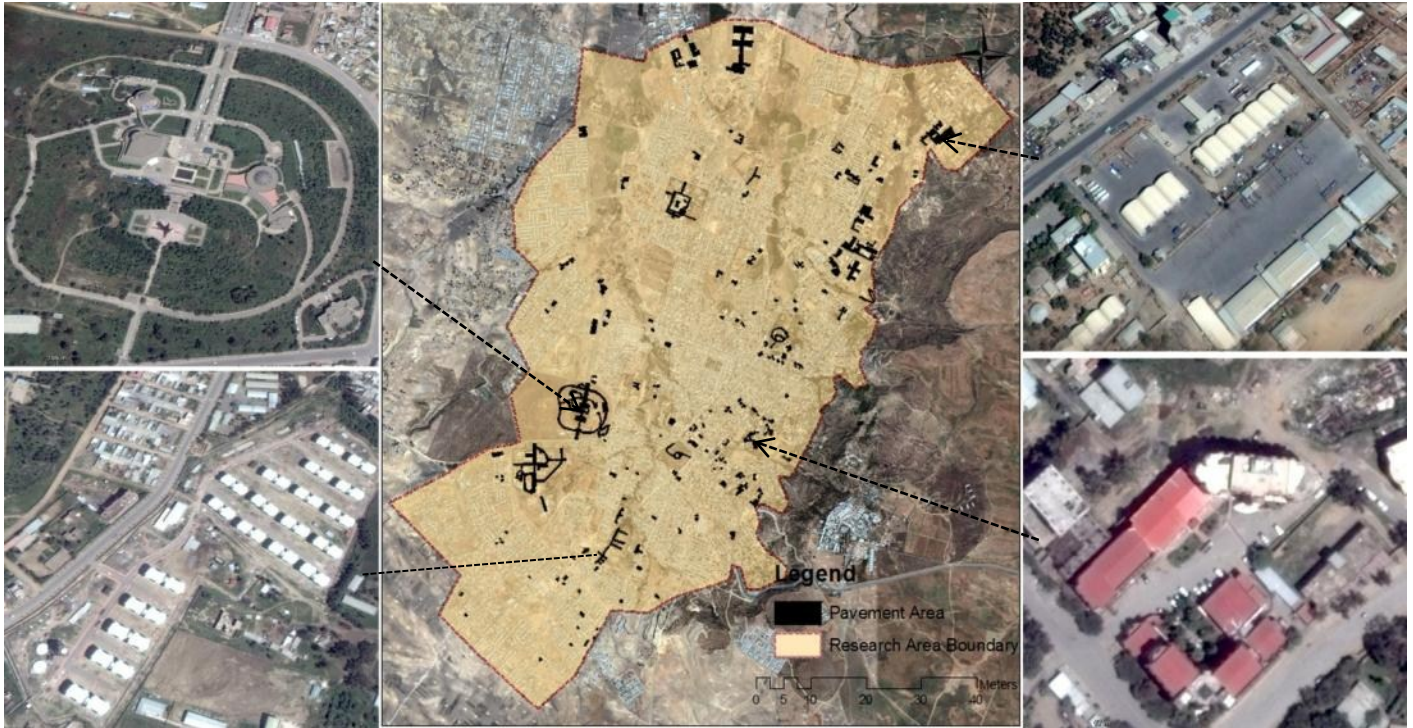


Figure 36 Pavement Impervious Area (Source; Own)

Table 19 Impervious area Coverage

No.	Pavement category	Area (m ²)	research area coverage %
1.	Built-up roof	3025648	14%
2.	Street	5282989	24%
3.	Pavement	1446391	6.5%
4.	Total	9755028	44.5%

(Source: Own)

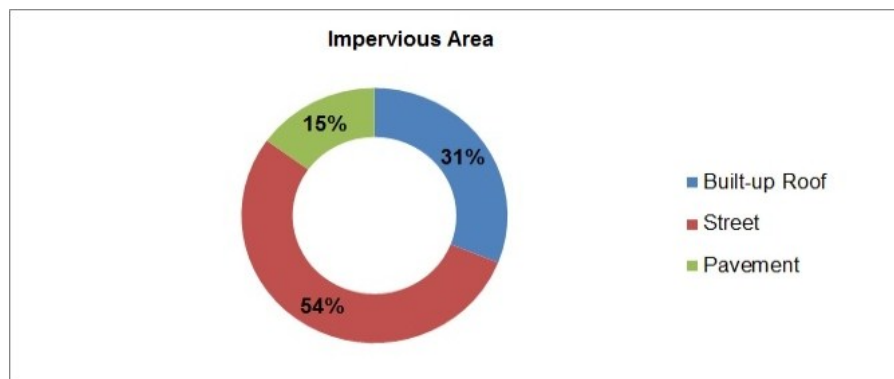


Figure 37 Impervious Area Graph (Source; Own)

I. Effective Impervious Area

This term holds special consideration of impervious area pertaining to pollution and degradation of environments, as it is stipulated on chapter two. Effective impervious area is governed by indirectly connected and directly connected impervious area rules. This rule has formulas which corresponds to each and every condition of impervious area in the research area. The formula is ratified on Table 2. Figure 41 shows directly connected and indirectly connected impervious area of the research area.

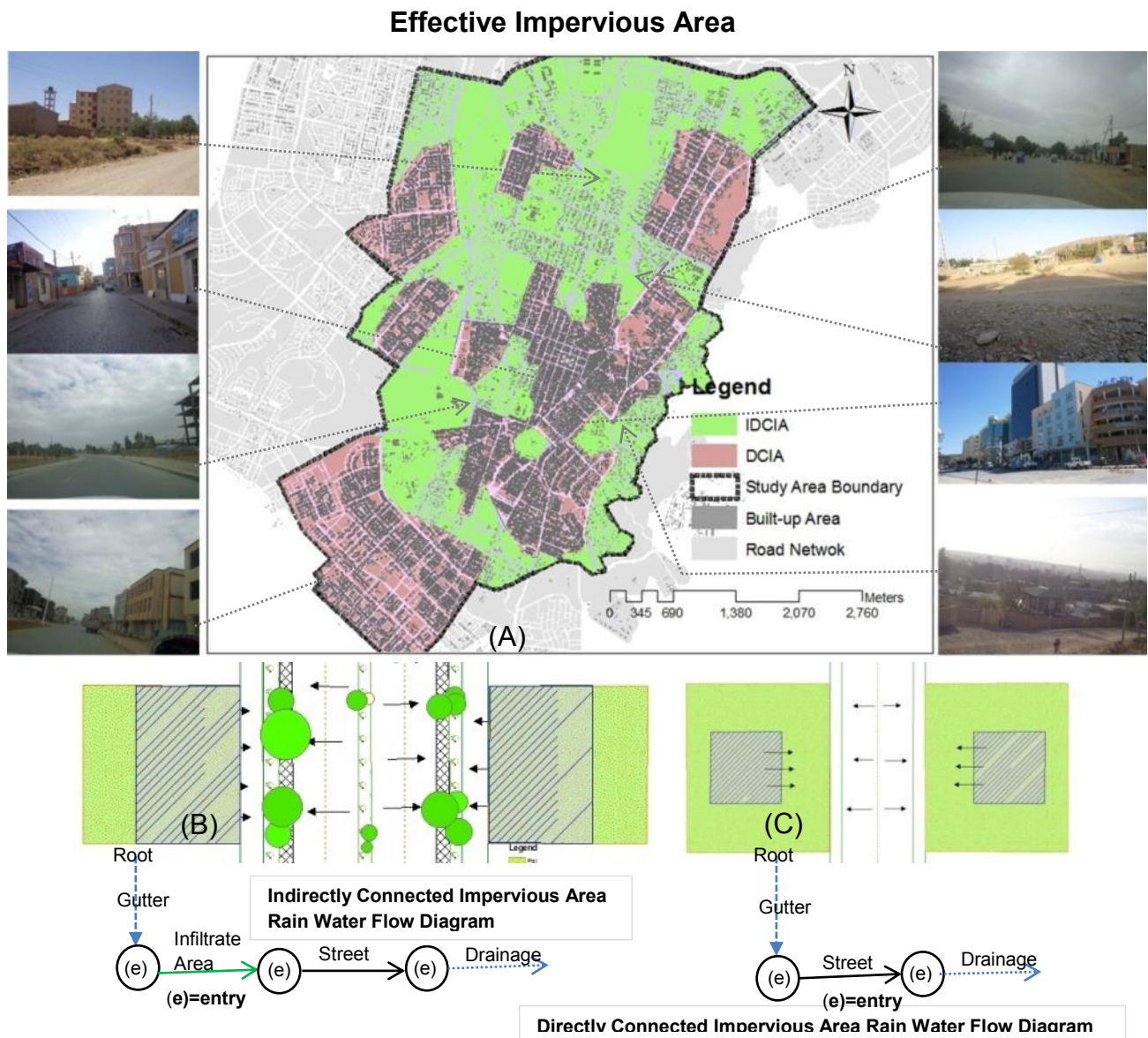


Figure 38 Effective Impervious Areas (Source; Own)

Figure 41 shows (A) directly connected impervious area and indirectly connected impervious area, (B) shows sample of directly connected and (C) shows indirectly connected impervious area. Table 20 shows effective impervious area calculation formula and selection criteria for the research area.

Table 20 Effective Impervious Area formula

No.	Water Shed Selection Criteria	Land Use	Used Equation	Effective Impervious Area (m ²)	%age
1.	Directly Connected	Asphalt Street	$DCIA = IA$	954104.04	95.39%
		Concrete Street		3250.44	
		Cobble stone Road		402907.48	
		Gravel Pavement Road		1230480.94	
		Earth Road		2691946.25	
		Commercial		1721679.19	
		Mixed residence		1110149.51	
		Industrial		1813985.93	
2.	Directly Connected	Recreational	$DCIA = 0.1(IA)^{1.5}$	602	4.59%
		Condominium		18620.7	
		Residence		6683	
		Administrative		104969.1	
		Service		347276	
3.	In Directly Connected	Play field	$DCIA = 0.01(IA)^2$	85.1	0.02%
		Green Open Space		73	
		River Buffer		153.2	
		Agriculture		297	
		forest		188.5	
		Vacant lot		216.9	
		Undefined Uses		68.3	
4.	Total			10407736.6	100%

(Source; Own)

Table 20 shows the calculation of effective impervious areas of the study area by using the recommended equation of calculation of effective impervious areas shown on Table 4. Effective impervious area accounts 10,407,737m² and 47% of the total research area. Effective impervious area measures environmental degradation Figure (6). Therefore, protected (0-10%), impacted (10-30%) and degraded (>30%). Thereafter, the study area falls under degraded.

Table 21 Impervious area (EIA, TIA and IA)

No.	Categories	Area (m ²)	Percent (Out of Total Area)
1.	Total Impervious Area (TIA)	15187474.5	68.86%
2.	Effective Impervious Area (EIA)	10407736.6	47.19%
3.	Impervious Area	5569984	44.5%
4.	Research Area	22055054.5	

(Source; Own)

Table 21 shows impervious area of TIA, EIA and IA. Total impervious area (TIA) is calculated from standard of land use value Table (5).

4.3.3. Streets

In the research area the street represents different type of streets arterial, sub-arterial, collector and local streets. Street is consisting of right-of-way, median, walkway, furniture area and drainage canals. In the research area, green is found on medians, furniture area (tree pits) and in some part between walkway and front setbacks.

In Mekelle, there are about five type of streets based on surface cover. These are asphalt, concrete, coble stone, gravel and earth. The greenness of the street depends on infiltration capacity of rain water asphalt and concrete are impervious surface. The cobble stone, gravel and earth surface streets are semi-impervious, because they are being compacted and get pounded every day by commuters and vehicles. Table 22 shows street type by surface and length. Figure 42 shows the different type of street pavements in the research area.

Table 22 Classification of Streets

No.	Street Type	Area (m ²)	Area Percent (%)
	Asphalt	954104.04	18%
1.	Concrete	3250.44	0.6%
2.	Cobble	402907.48	7.4%
3.	Gravel	1230480.99	23%
4.	Earth	2691946.25	51%
5.	Total	5282989.15	100%

(Source; Own)

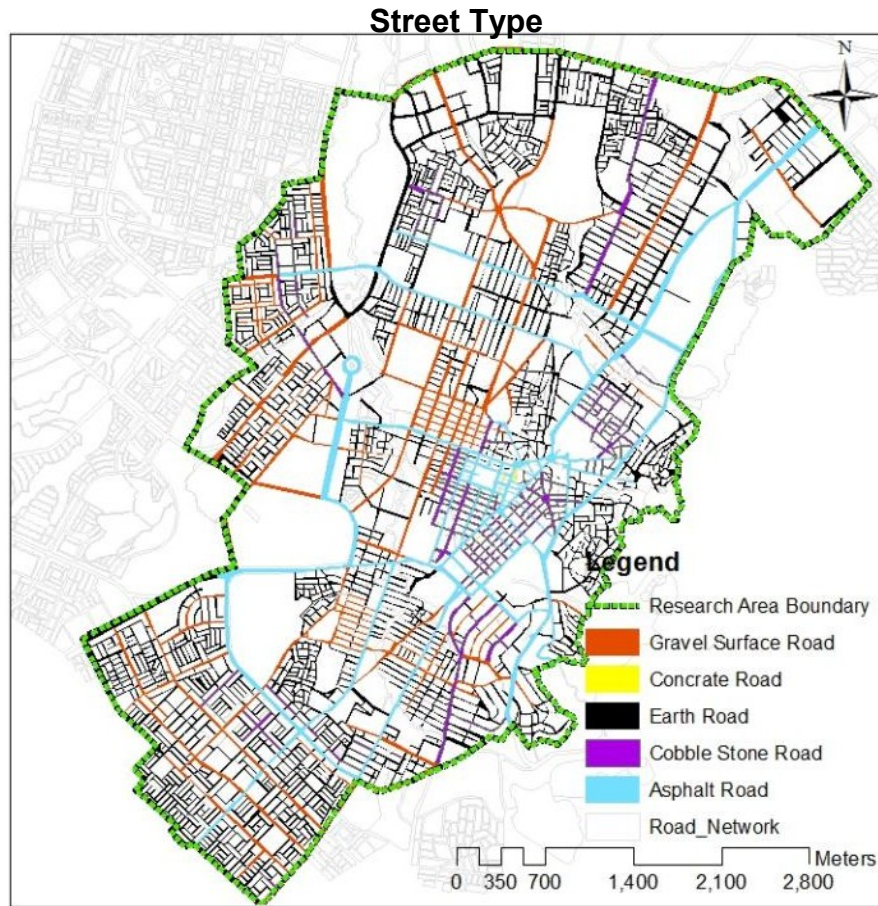


Figure 39 Different Street Types (Source; Own)

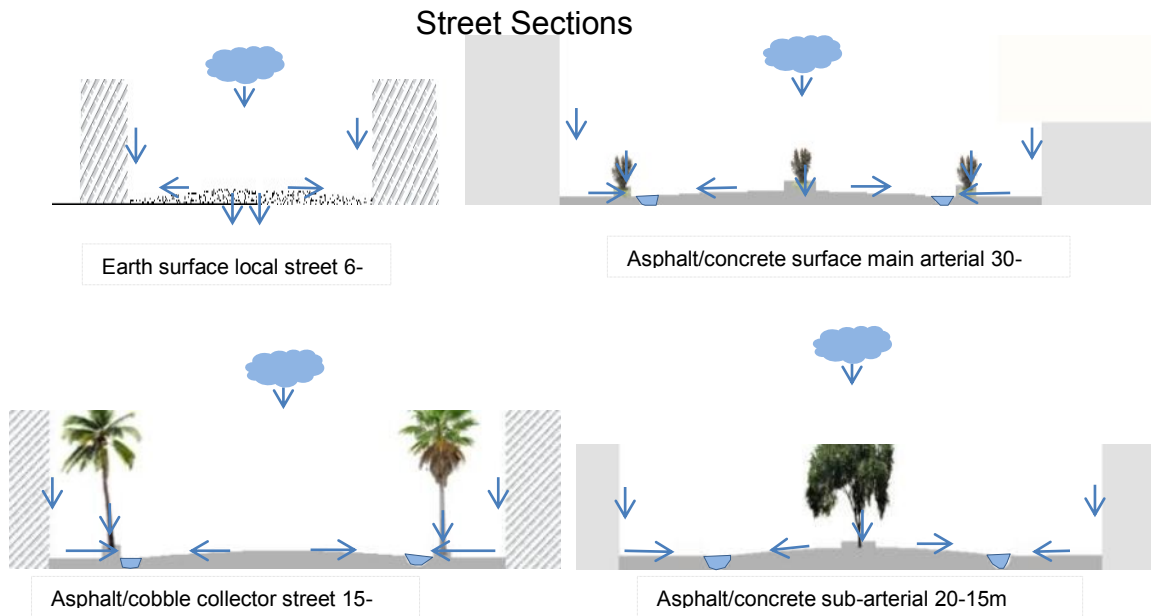


Figure 40 Street Sections (Source; Own)

I. Median

Median is part of the street that supports green in the middle of streets. But it is not well designed, it only serves as marks, which divided the street in two opposite lanes. The median is a little bit elevated from the carriage way and could not accommodate rain water that flows from the street. In the city, there are more than eight streets that have medians and they are all arterial street. The width of median is 1 to 2m and its total area becomes 4835m². The median is important and it should be maintained, in such a way that rain water should be infiltrate there. Figure 44 shows the street which have medians.

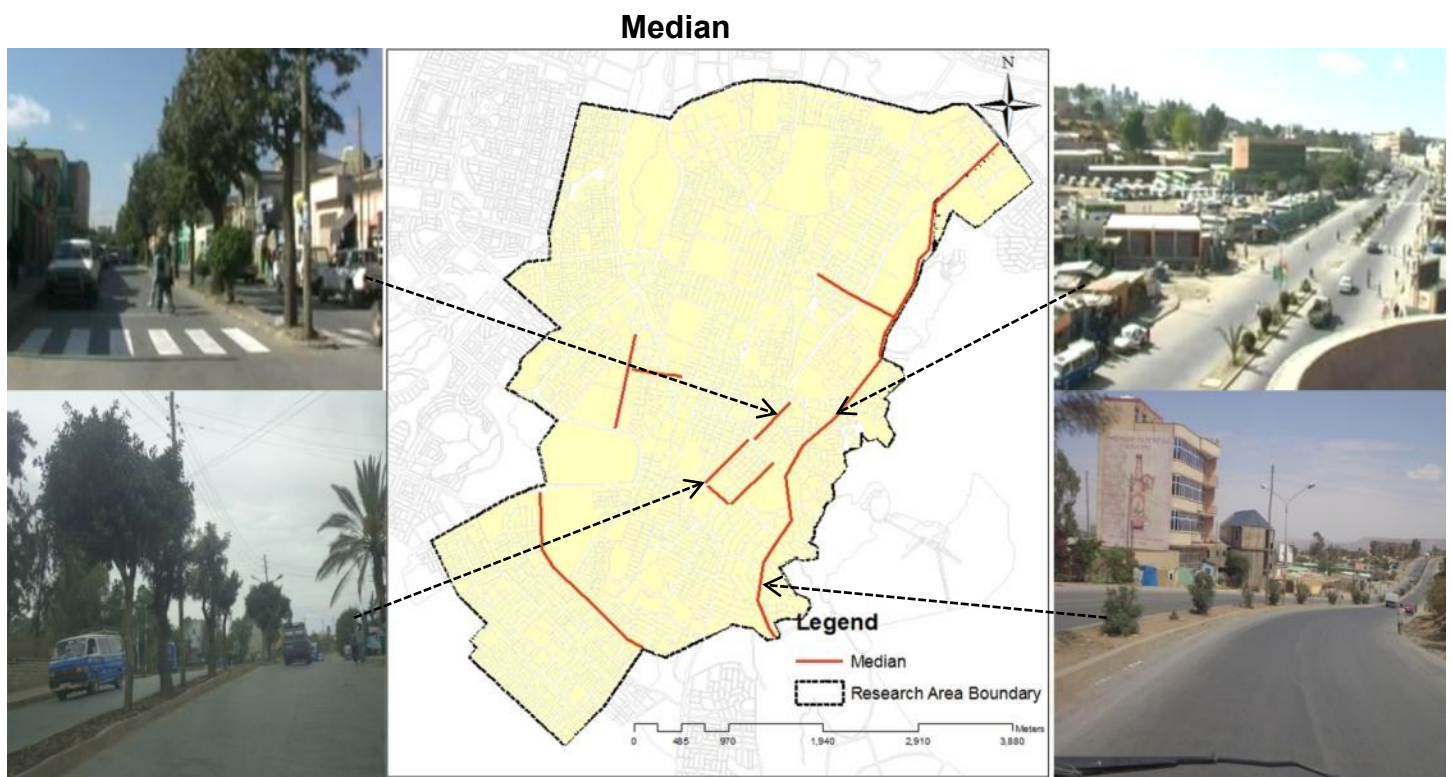


Figure 41 Median (Source: Own)

II. Walkway

It is a paved part of a street used it for walking. In the research area, the walkways are paved with different materials such as stone, tile, concrete and gravel and its size ranges from 2m-5.5m. It is found on arterial and sub-arterial of the city. Figure 45 shows walkway plan on the street.

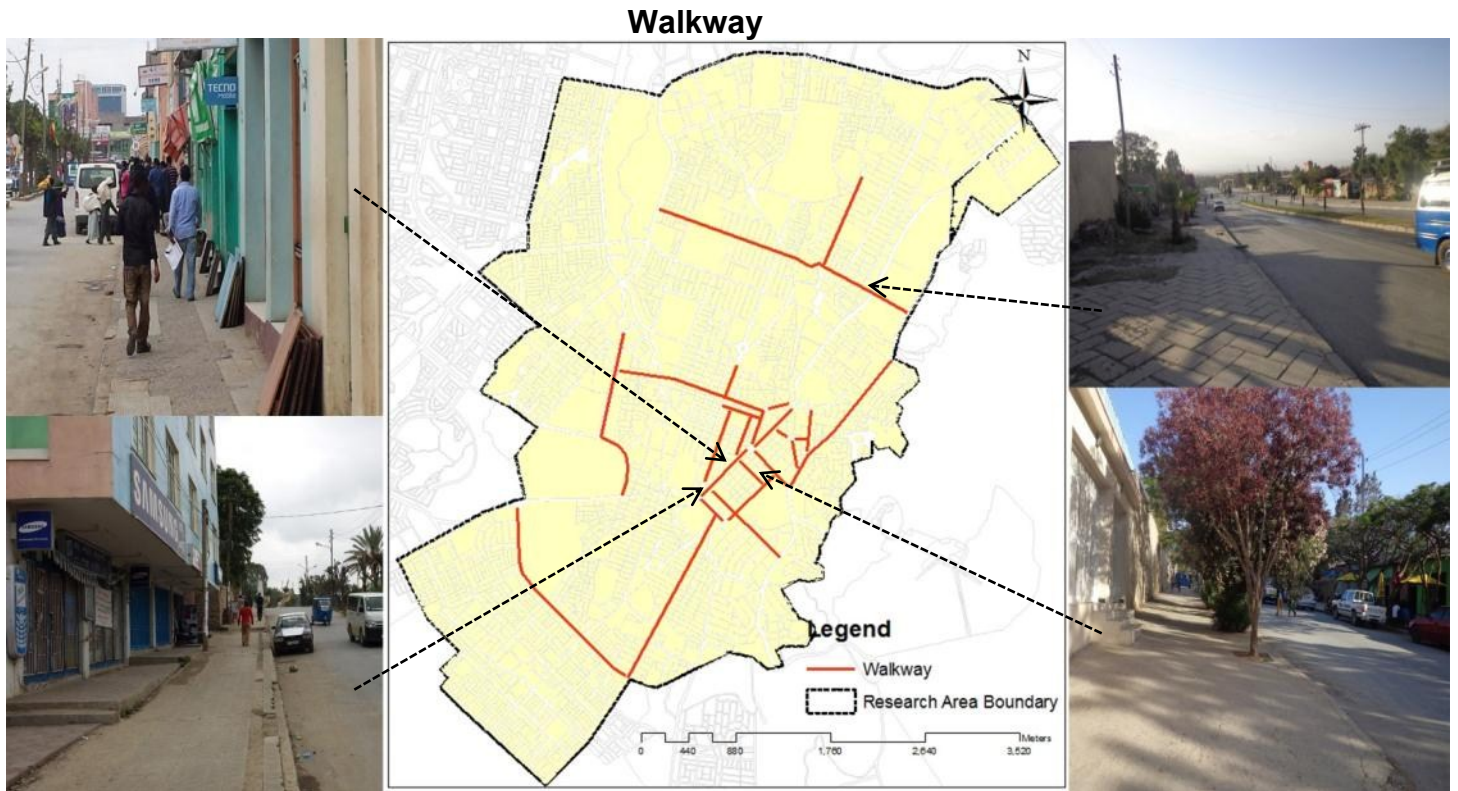


Figure 42 Walkway on street (Source; Own)

III. Drainage

In urban area storm water are remove through drainage line. They are found on arterial and sub arterials streets and are made of impervious materials. Drainage line consists of concrete pipe, inlets and out lets. Concrete pipe is a kind of drainage laid on the ground to transport storm waters, while inlet and outlets are, entry of storm water to the sewer line and out pouring of storm water out of the concrete pipes respectively. Two type of drainages are found, closed and open which are made-up of concrete and masonry and has different sizes, diameter 0.6m-1.5m and height 0.3m-1.5m. There is no mechanism of bio-swale, bio-retention with in the drainage and the storm water which is polluted by siltation, car oil and other debris are directly discharge into the environment. Figure 46 shows sewerage line sections and Figure 47 shows drainage line.

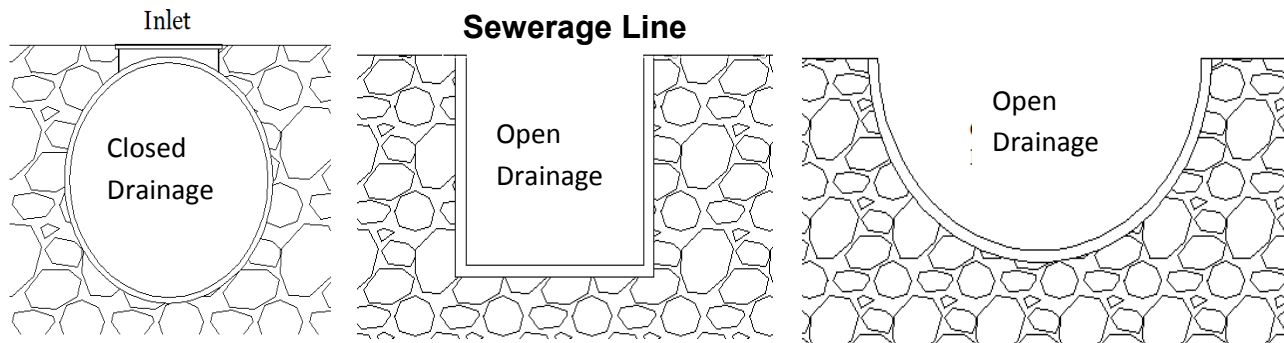


Figure 43 Sewerage Line Sections (Source; Own)

Drainage Line

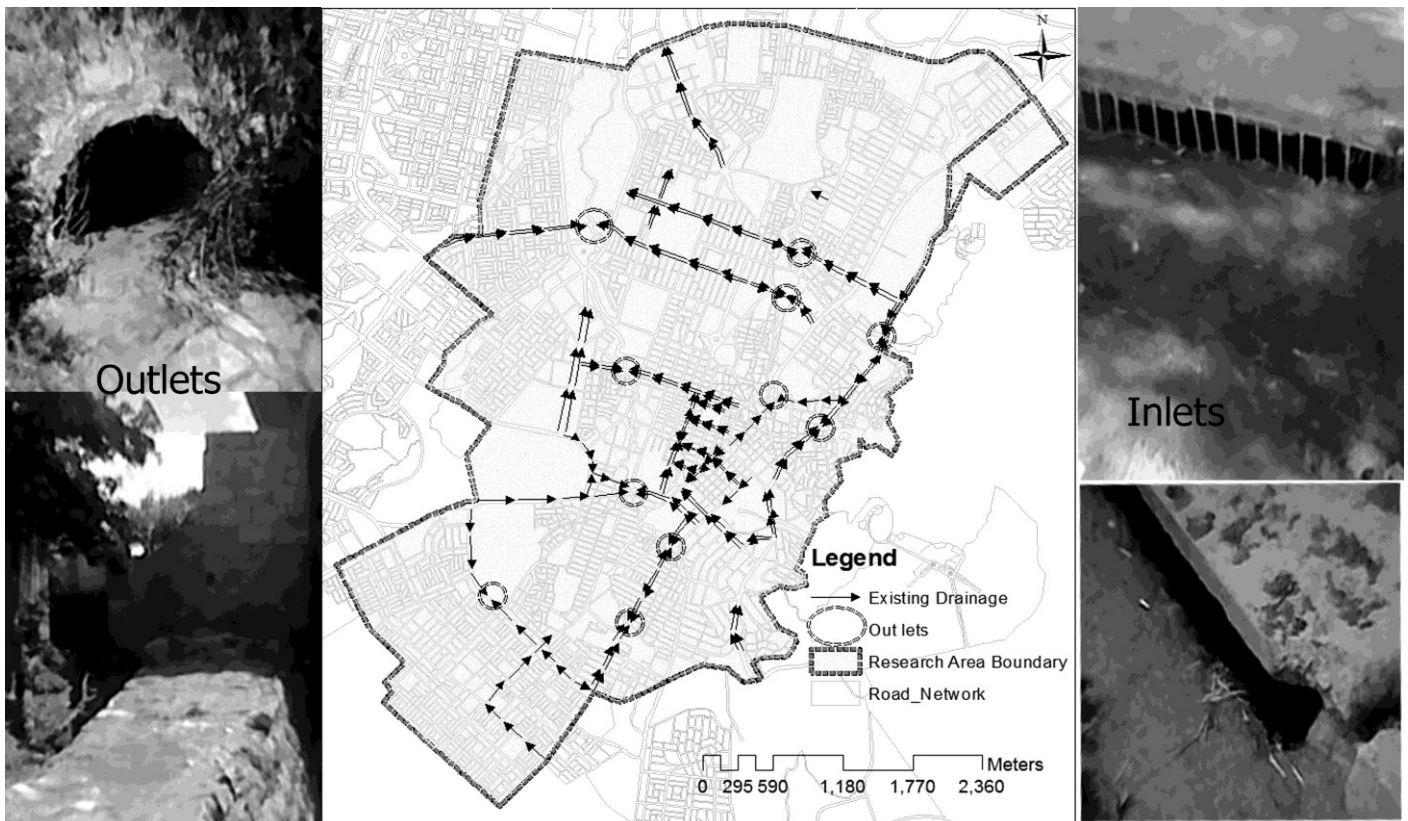


Figure 44 Drainage Line Sewerage (Source; Own)

IV. Tree and tree pits

In the research area, trees are planted on different street parts of the walkways (furniture area) and medians. The tree lines are planted at a distance of 2 to 10m minimum and maximum respectively. The tree on the side of the streets are functional. People need shades during dummy time and gathers around café that has trees on its front street side and enjoys fresh air. The trees are planted either on single planter or liner horizontal planters. Figure 48 shows street with tree.

Street Plants



Figure 45 Street Trees and Location(Source; Own)

Table 23 Street Tree Name Figure 47

No.	Street tree	Scientific /common name
1.	(a)	Gravillea Robusta
2.	(b)	Platanus
3.	(c)	Acacia Melonoxylon
4.	(d)	Callisteman
5.	(e)	Jacaranda
6.	(f)	Delonix regia
7.	(g)	Acacia Xyphocarpa
8.	(h)	Mognolia Grandiflora
9.	(i)	Palm tree
10.	(j)	Ash
11.	(k)	Cedar of Lebanon
12.	(l)	Schinus Molle

(Source; Own)

4.3.4. Buildings

Building serves as ground for GI, as it was mentioned on chapter two. In the research area there are about 47,297 buildings, with areas from 3 to 5805m². The building parts use for GI applications are walls, roofs and fences. In the research area there are three type of buildings; horizontal, vertically emphasized and stepped buildings. Horizontal buildings (horizontality) have balcony, in which the GI could be placed, vertically emphasized buildings have plain façade and the GI can placed on ground as climber or modular wall and stepped building have podium, which is a place for GI. In Mekelle no GI practice was found.

Building Forms




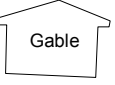



Building Forms



Figure 46 Horizontal, Podium and Vertically Emphasized Building Forms (Source; Own)

Figure 46 shows (a) horizontal, (b) podium and (c & d) vertically emphasized buildings.

Table 24 Block Summary of Wall, Roof and story

Wall			roof			story			Sketch
Building construction materials	Total no. of buildings	%age	Roofing type	Total no. of buildings	%age	Building stories	Total building stories	%age	
Stone	26704	56.4%	Hidmo	164	0.3%	$G^{+0}-G^{+1}$	35885	76%	
Concrete Block	20475	43%	Gabled	46740	98.86%	$G^{+2}-G^{+4}$	111558	23.2%	
Metal	204	0.4%	Hut	22	0.04%	$G^{+5}-G^{+7}$	787	1.66%	
Mud	104	0.2%	Flat	96	0.2%	$>G^{+8}$	21	0.04%	
			Barrel vault	275	0.5%				
Total	47297	100%	Total	47297	100%		47297	100%	

(Source; Own)

Table 26 shows summarized building findings, building construction stone (56.4%), concrete block (43%), metal (0.4%) and mud (0.2%). Roofing hidmo (0.3%), gabled (98.86%), hut (0.04%), flat (0.2%) and barrel (0.5%). Building stories $G^{+0}-G^{+1}$ (76%), $G^{+2}-G^{+4}$ (23.2%), $G^{+5}-G^{+7}$ (1.66%) and $>G^{+8}$ (0.04%). Figure 47 shows graph of Table (26).

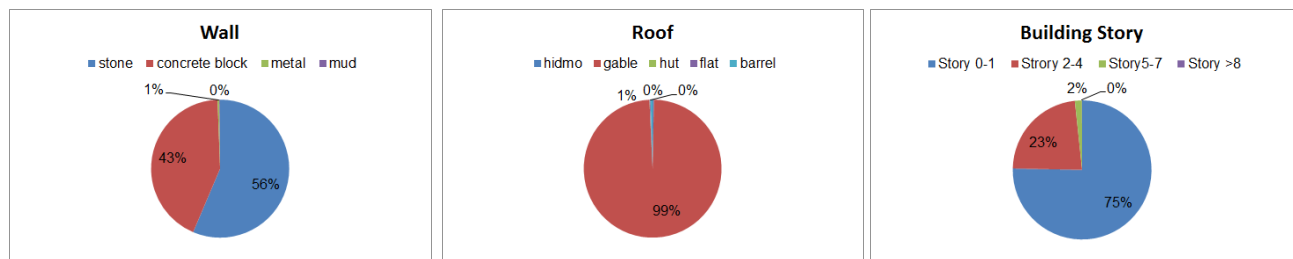


Figure 47 Graph of wall, Roof and Story (Source; Own)

I. Walls

Green walls are categorized as climbing, hanging down and modular wall. Climbing wall is covering of wall with climbing tree and grows either in planter box or on ground, hanging down wall a vegetation creeps down from balcony to wall and modular wall vegetation grows on cassette module and fixed (line) to the wall. No green wall was found on the research area. Construction techniques of walls are for stone mud and cement mortar, mud wall, mud is plastered on a wood wall, concrete

block wall cement mortar and plaster with cement screed and metal wall nail or bolt is used.

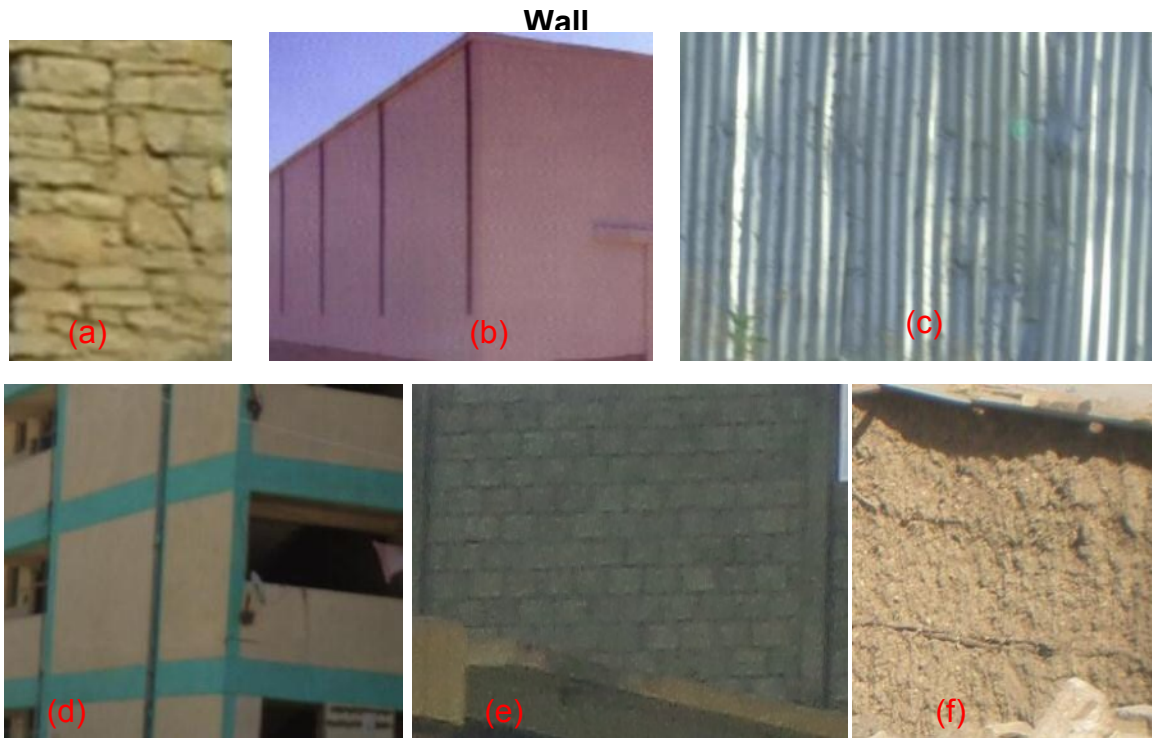


Figure 48 wall type (Source; Own)

Figure 48 shows (a) stone, (b&c) metal, (d&e) concrete block and (f) mud walls.

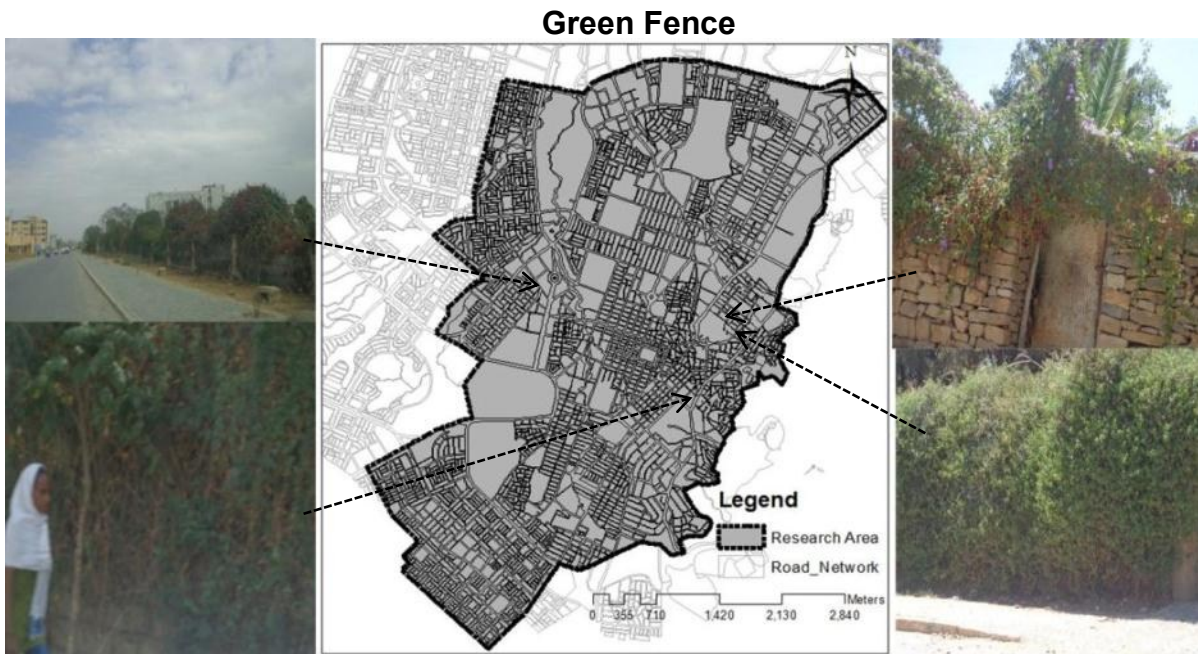


Figure 49 Green Fences (Source; Own)

Figure 49 shows green fences, but not to the standards.

II. Roof

As it was mentioned on chapter two that the weight of plants (age, height, crown size, foliage type and density) and planting materials (soil, water...) are the most important elements in calculation of green roof structures. In the research area there are about five type of roofs. These are barrel vault, hut, gable (sloped roof), hidmo and flat roofs and their slope varies accordingly. Hidmo and flat roof have lower degree of slopes ($2-6^{\circ}$), gabled (sloped) roof has about $10-30^{\circ}$ roofing slopes, hut roofing has higher slope degree ($25-45^{\circ}$) and barrel vault has 45 degree of roofing system. Some vernacular green roof was found on the research area. The structures of the roof needs to be inspected about their bearing capacity to apply GI. Figure 53 shows different roofing systems.

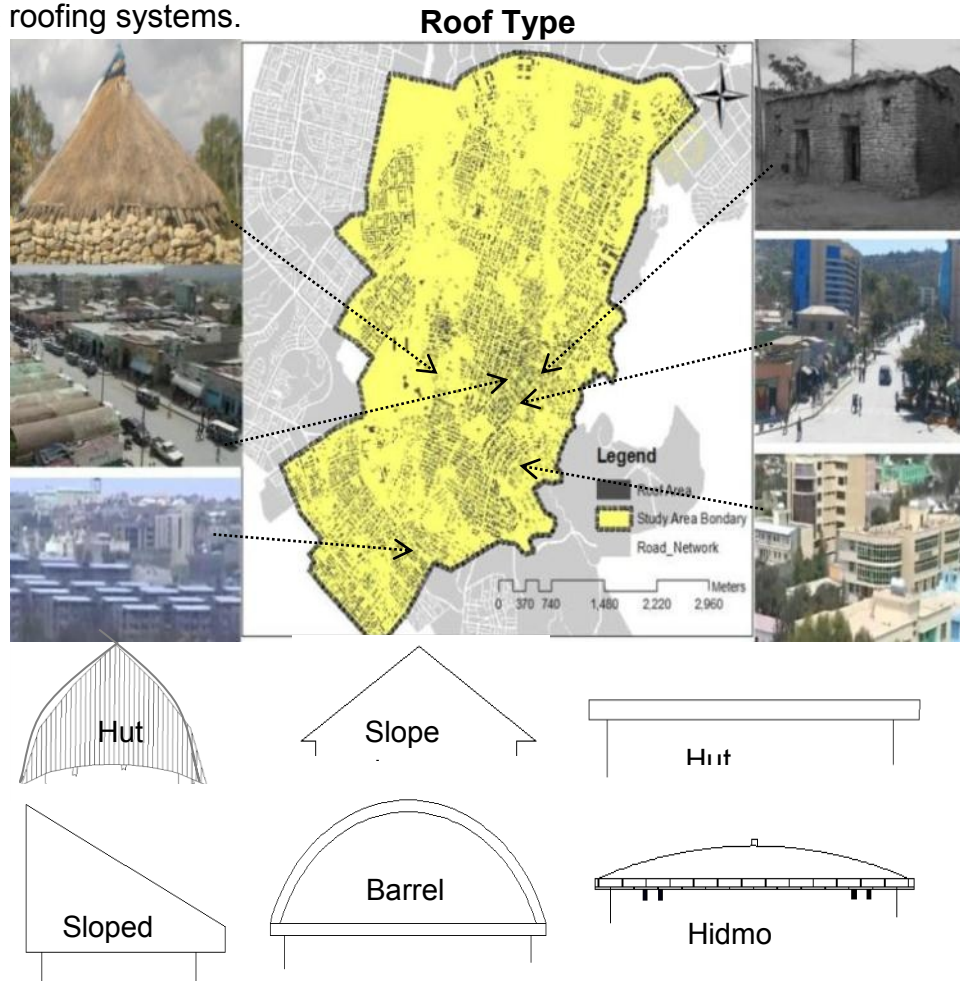


Figure 50 Green Roof (Source; Own)

4.3.5. WSUD

It is a techniques developed for environmental benefits and improvements, in the area of water consumption, water recycling, waste minimization and environmental protection, and employed urban landscape, reducing pollutant export, retarding storm flow and reducing irrigation requirements. In the research area, this technique is not used yet that there is water (river) pollution. This pollution happens when wastes of sediment, oil from car and other wastes enter to the river body by the canals, beside to this Mekelle city is located on a sloppy land and become prone to flooding and erosions.

Slope and Flood Affected Area

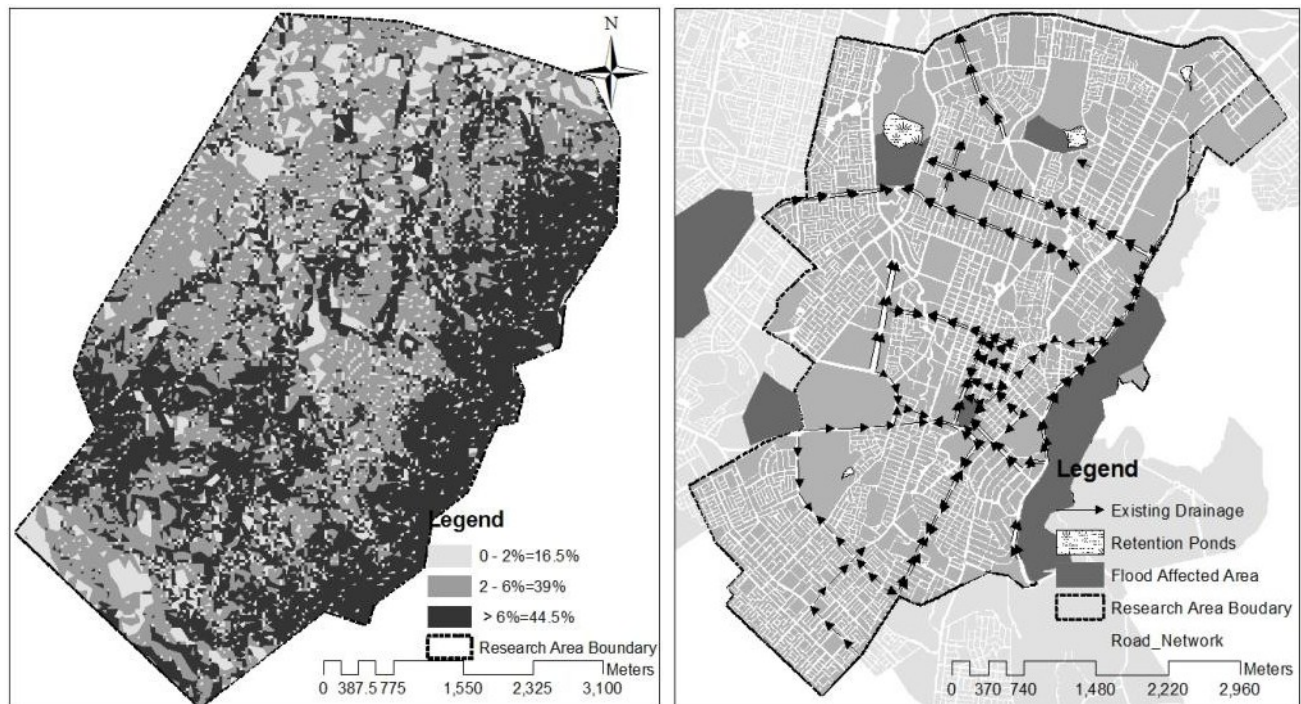


Figure 51 Slope, Flood Affected Area and Retention Pond (Source; Own)

I. Water supply

Water for the city is supplied from ground water bore holes found outside of the city boundary and supplied by pipe line and distributed. There are about 18 water production well 13 of them are located in Aynalem area (Mekelle Municipal, 2011). The daily production and demand is 17260m^3 and $41,000\text{m}^3$ respectively. There is a persistent shortage of water in the city, as borehole/well production capacity decline due to ground water recharge interrupted by impervious surface. Consequently, the city is not supplying water demand of the people and some people becomes bono

users. Table 27 shows performance of borehole/well production capacity. Figure 52 shows water supply of Mekelle city.

Table 25 Summary of Borehole/well performance 1998-2001 E.C

No.	Borehole/well index	1998	2000/2001
		Monthly	Monthly
1.	Sewhi Niguss	2735	300
2.	Mekelle/Lachi	1170	910
3.	Mekelle University	13533	13086
4.	TW ₂	20392	16387

(Source; Own)

Water Supply

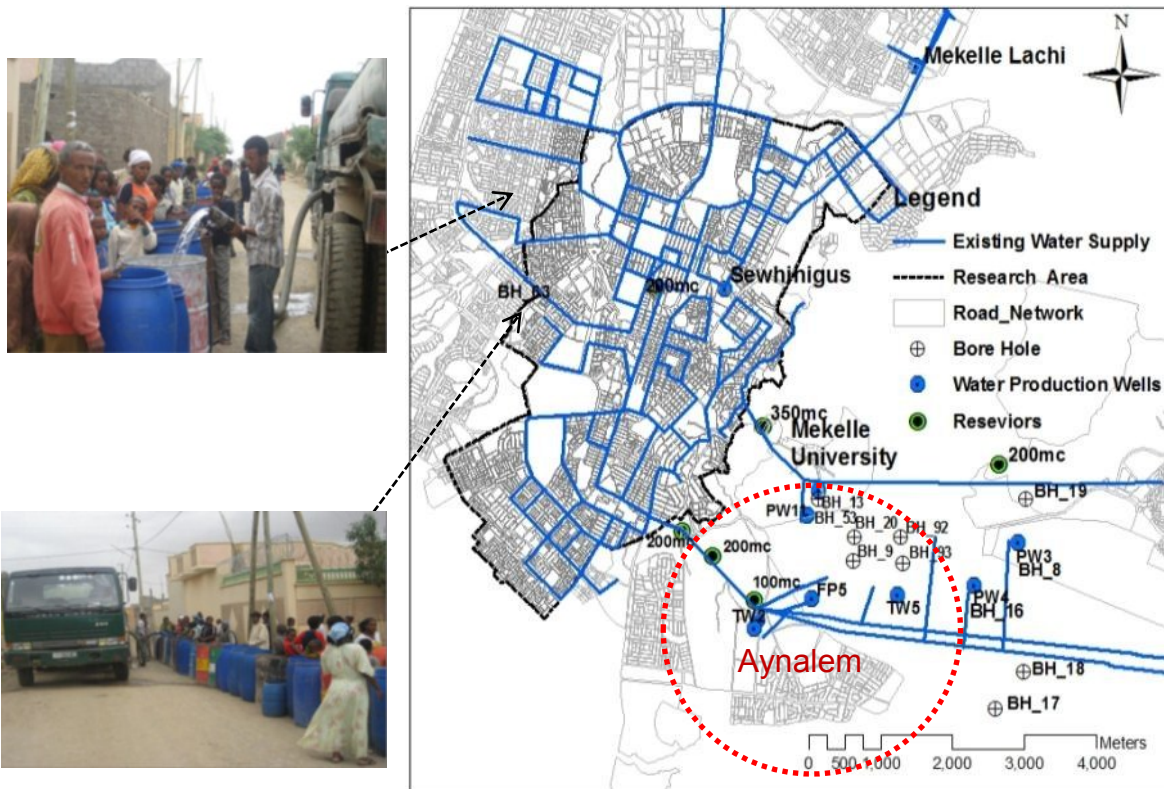


Figure 52 Water Supply Network of Mekelle city (Source; Own)

II. Watershed

In urban area, rain water drains from individual plots and streets into lower area through drainage canals. In Mekelle, rain water drains from individual plots and

streets into the nearby river basin through drainages. no practice of WSUD in the city was found.

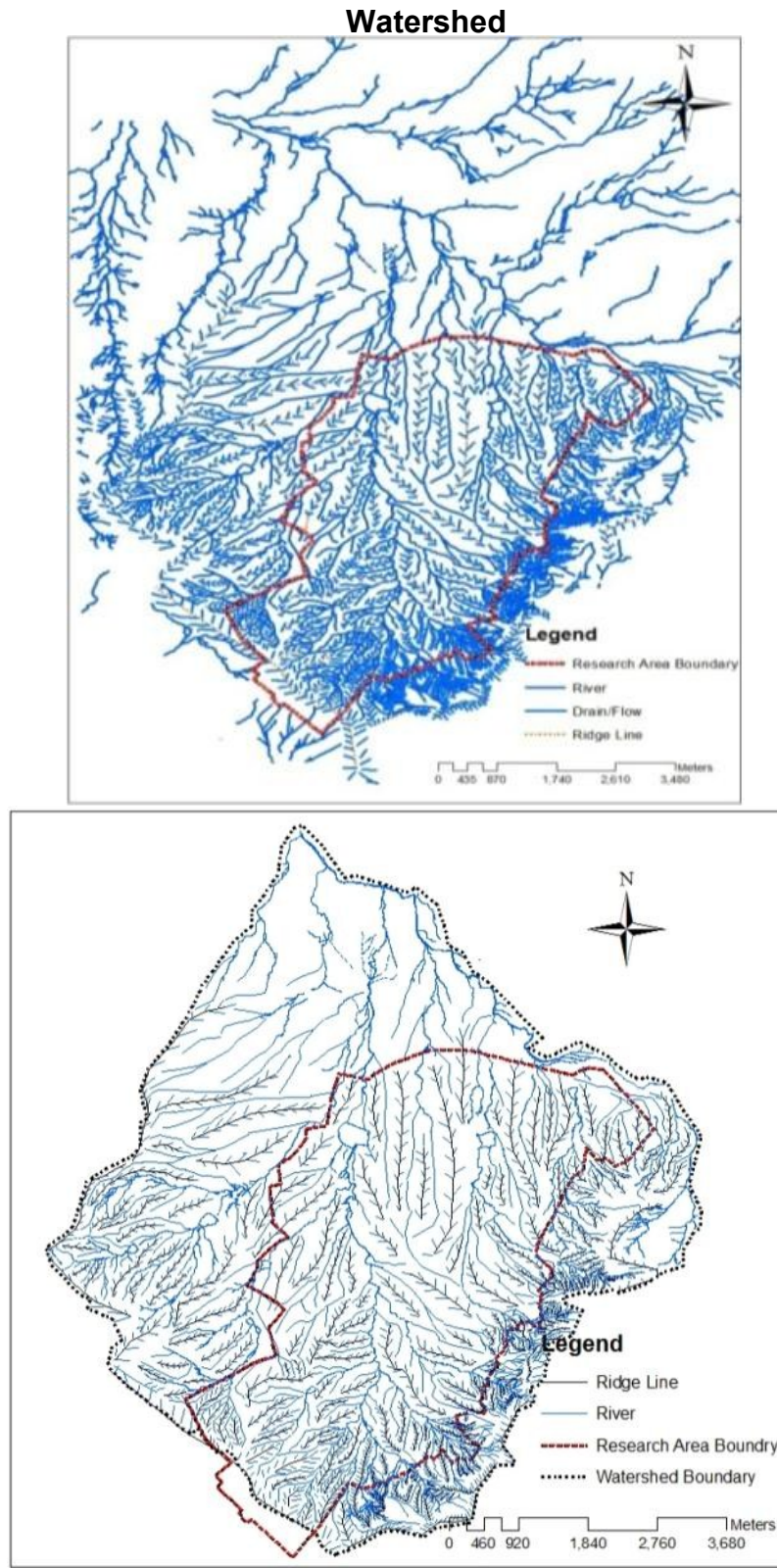


Figure 53 Watershed Area of Mekelle City (Source; Own)

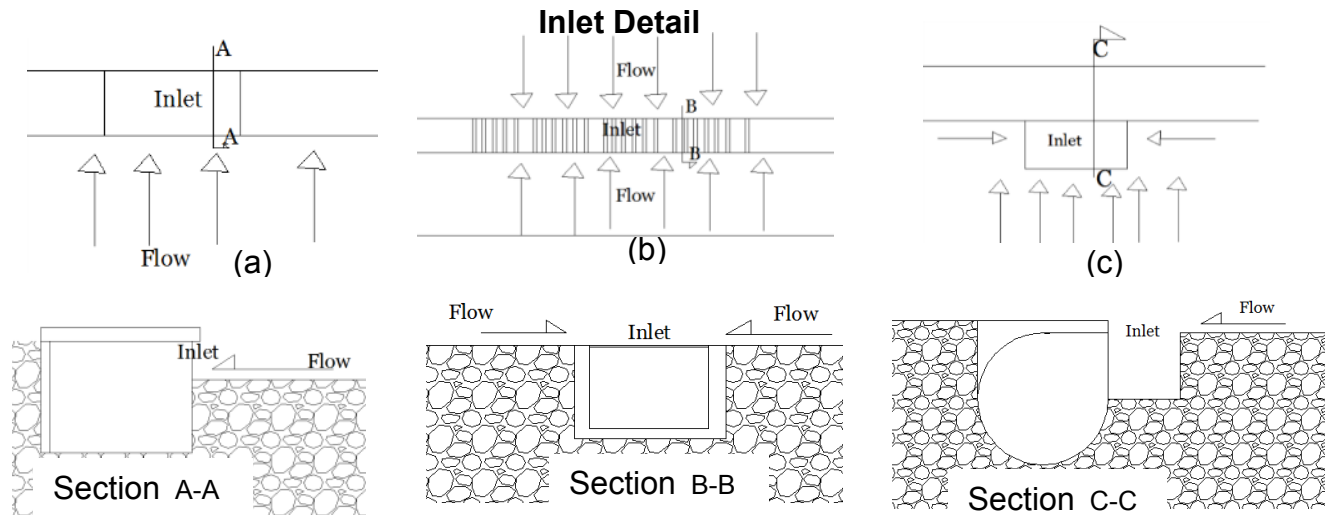


Figure 54 Inlet Detail of the Research Area (Source: Own)

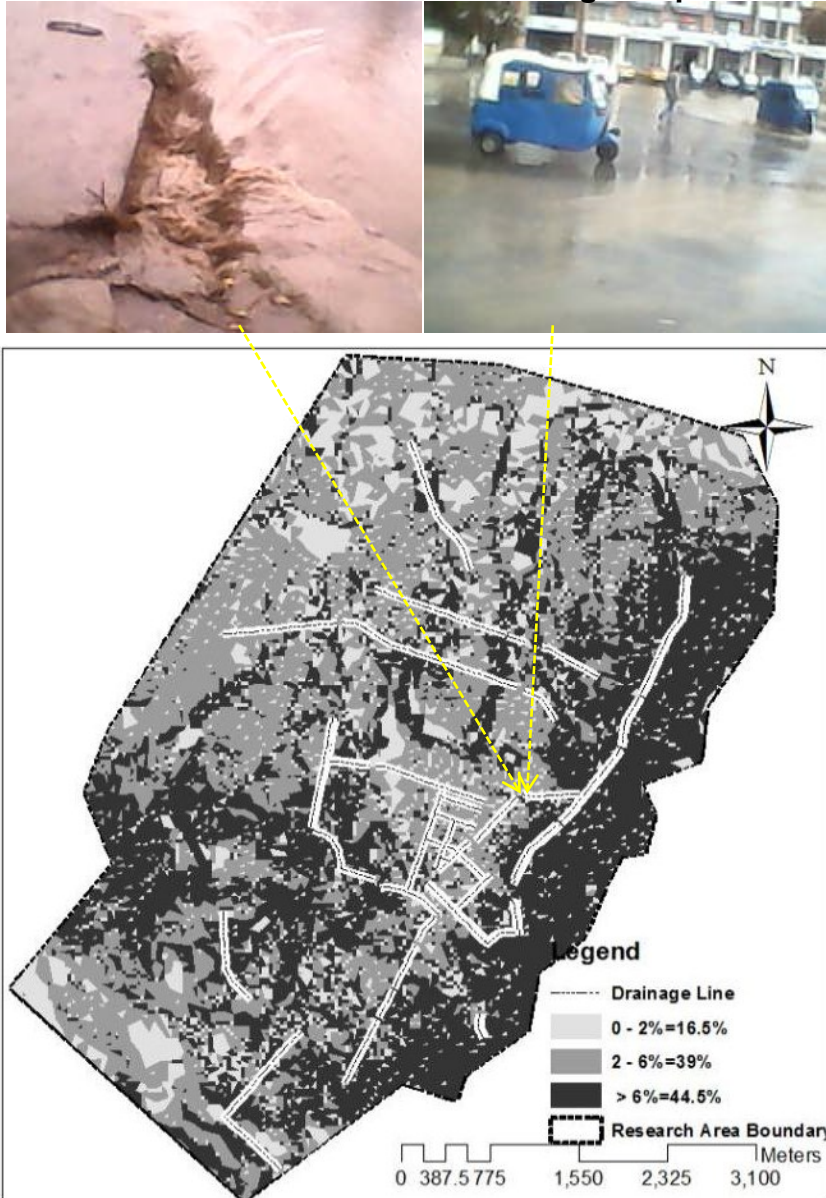
The kind of inlet that are identified on the research area are three types, rain water enter through side hole (inlet) of the drainage from the street Figure 54 (a), second, open and covered by gridded drainage hole which traps larger objects (particles) Figure 54 (b). The third one is a hole type that projected to the street and rain water enter on top of it Figure 54 (c). figure 54 shows typical detail plan and section of inlet found in the research area.

Logging Area



Figure 55 Water Logging Area of Bazar Roundabout (Source: Own)

Drainage Slope



In the research area flooding is a problem and challenges the dweller in their daily life during the raining season. The major problem was, (1) the drainage line wasn't installed appropriately in responding to topography, the pipelines were laid on the ground without due consideration of the different slope variation and this results in stagnation of water on the surface of the street. (2) the design of the pipes were not enough to discharge the storm water with regarded to size, the drainage was designed when the city was small. The study has looked into the overall case of drainage in city and described the case of bazar (near Yohans-IV palace).

Figure 56 Drainage Slope and Logging Area (Source; Own)

Figure 55 shows logging area around Bazar roundabout and Figure 56 shows logging area and slope drainage of the research area.

III. Soil

It 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). In Mekelle the type of soils are clay, silt, sandy (sandy silt) and clay (silty sandy alluvial) (Gebremedhin, 2010). Figure 60 shows soil map of the research area.

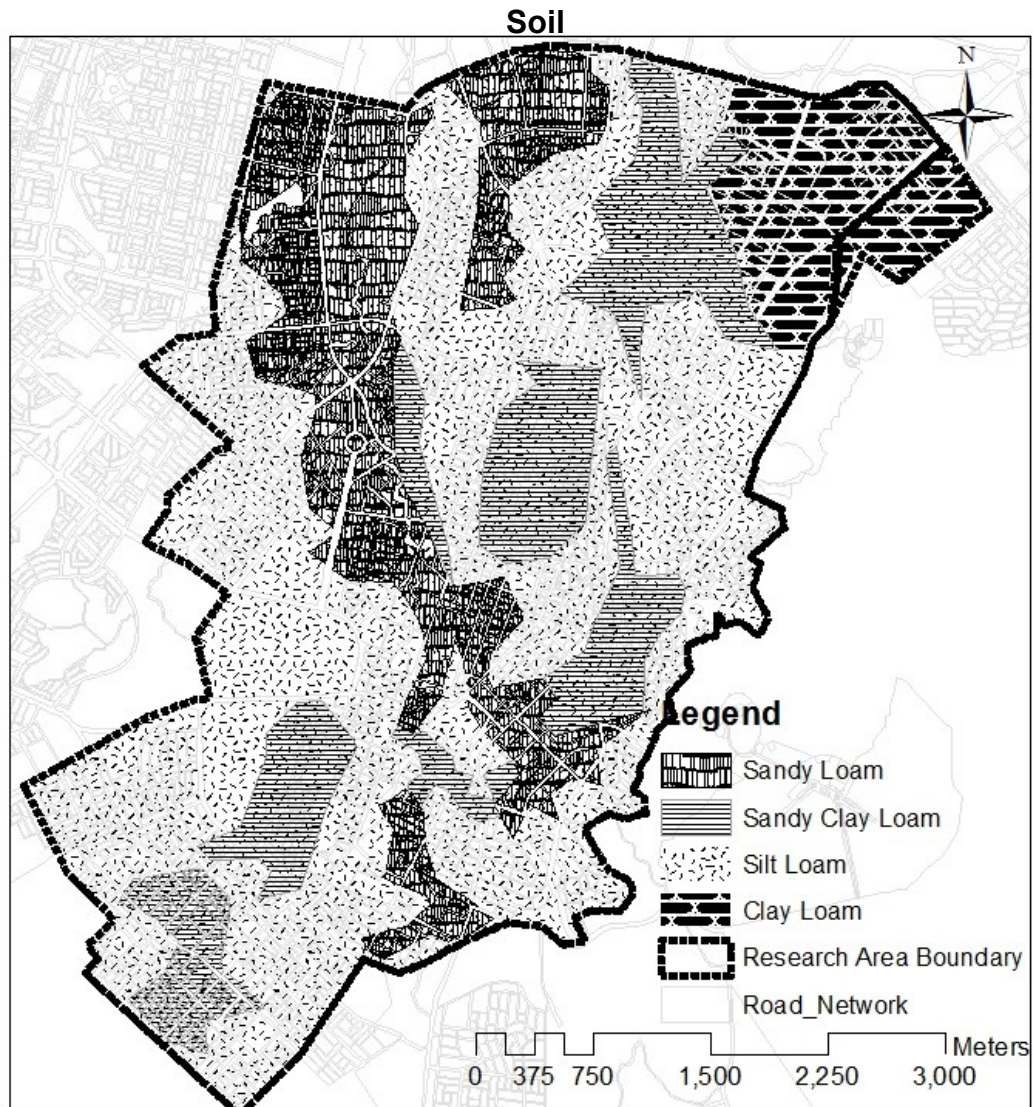


Figure 57 Soil Map of the Research Area (Source: Gebremedhin, 2010)

CHAPTER FIVE

5. Conclusion and Recommendations

5.1. Conclusions

Mekelle city has evolved from small villages, by engulfing agricultural land and green areas. The city had different names in different time and finally got the name Mekelle permanently. Mekelle was established by Yohanse IV in 1864 E.C and got its urban structure during his reign.

Historically, the city has seen about four kinds of master plans. The first one is done by Italian, second by Haileslasse, third by NUPI and the fourth one by Mekelle city municipal. The city density has been increased due to population and construction of infrastructure increase at the cost of green and open spaces.

Green Infrastructure of a city is vested on green street, green space, impervious area, green roofs, green walls and fences and WSUD. In Mekelle city, GI is dominated by grey infrastructures and the research has evaluated the Green Infrastructure components of the city and summarized as follows. Streets are consists of cobble stone (7.4%), asphalt (18%), earth (51%), gravel (23%) and concrete (.6%) area coverage, the green part of street is median and tree pit area, but no GI techniques is practiced. Impervious area is the coverage of hard surface of the city that includes pavement (6.5%), street (24%) and built-up roofs (14%). Total area coverage of impervious area is (44.5%) which shows the city is in the range of degradation. Wall consists of different building construction material stone (56.4%), hollow concrete block (43%), metal (.4%) and mud (.2%), no green wall practice was found on the research area. Roof also has different material of roof structure hidmo (.3%), hut (.04%), gabled (98.86%), barrel (.5%) and flat (.2%), there is a vernacular green roof but not to the standard of GI in the city. Finally, WSUD includes drainage, retention and conveyance. Drainage includes rain water canals of river, sewer line, inlets and out lets and protect pollution of rainwater by siltation, car waste oil, debris and other suspended particles by GI techniques of bio-swale, bio-retention and other refinement mechanisms to safeguard the environment. Wetlands include in the research area dry ponds and retention ponds and GI technique uses to protect the

health of the wetlands. Rain water harvesting includes infiltration into ground and rain water storage techniques. No GI technique was applied on the city, that means drainages are silted; rain waters are being polluted. Wetland has no proper inlet and outlet design provisions and improperly edge design. Rain waters are being wasted due to lack of GI techniques practice in the city, but it is known that the city suffers from shortage of water supply while it has 618 mm annual rain fall, so harvesting of rain water is advisable in the city.

Generally, the research has identified that streets, walls, roofs, impervious areas and WSUD of the city are the potential of GI of the city. Even though, no practice of GI has been seen on the research area at all.

5.2. Recommendations

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. Lack of potable water supply in the area as there is high impervious area that minimize ground water recharge. Green area fragmentation and shortage of green areas, inaccessible and improperly handling of green spaces. Pollution of urban environment and less developed green spaces in the research area. Generally the research has recommended the following techniques to alleviate the research area problems.

- a) Green Roof, the top part of the building of the research area is important to develop green areas of hidmos, huts, gabled, barrel and flat roofs to solve the shortage of green areas of the city and to improve environmental condition of the area for the city dwellers by making the green roof accessible and scenic values based on the structure of the roofs.
- b) Green Wall, the different type of walls' construction materials which are stone, mud, metal and hollow concrete blocks of the research area are important to make green walls by using GI techniques such as modular, hanging down and climbing walls, to increase green area index of the city and to improve environmental condition of the city.

-
- c) Green Street, GI technique can applied on streets of cobble stone, asphalt, earth, gravel and concrete of the research area. Green street uses to manage rain water through tree pits and increase green areas of the city that uses to improve and increase outdoor activities of the public spaces of the research area.
 - d) Green Area Networks, the fragmented green areas of developed and natural areas can be inter connected through green corridors and this can increase accessibility.
 - e) Use of WSUD techniques in drainage line, wetlands, flood affected areas and rain water harvesting mechanisms. Sewerage lines are silted through inlets and outlets, so bio-swale, bio-retention and refining mechanisms is recommended to use at the entry canals. Harvesting of rain water in plot levels which uses to control flooding and siltation, the harvesting of rain water uses to sustain green infrastructure at the dry seasons by storing water on water tanks for green and domestic uses.

CHAPTER SIX

6. Design Proposals

It is a thesis based project, which shows how the existing gray infrastructure of the research area changes in to Green Infrastructure by using GI techniques. So the following are some selected case structures to show how Mekelle city can be changed in to GI.

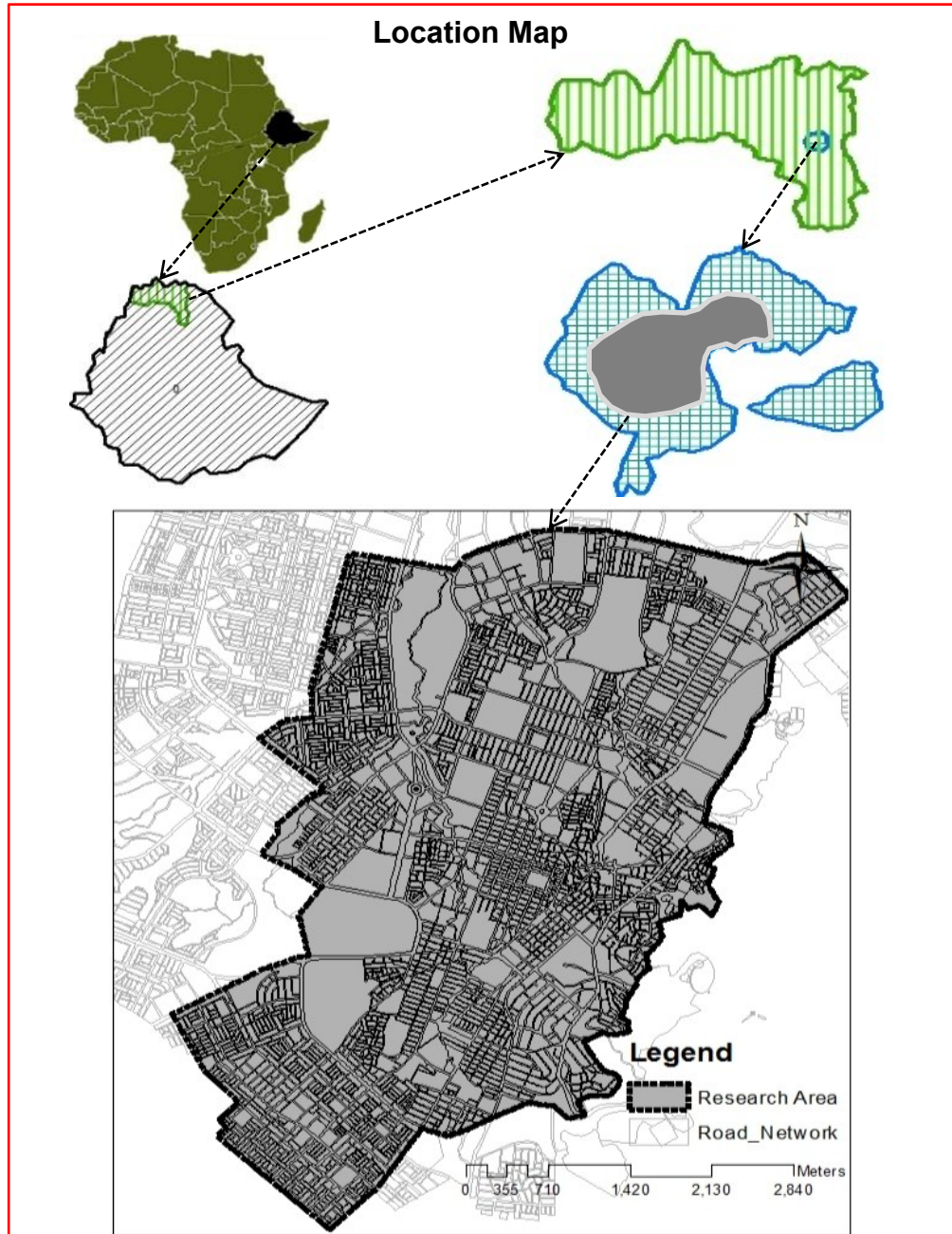


Figure 58 Location Map (Source: Own)

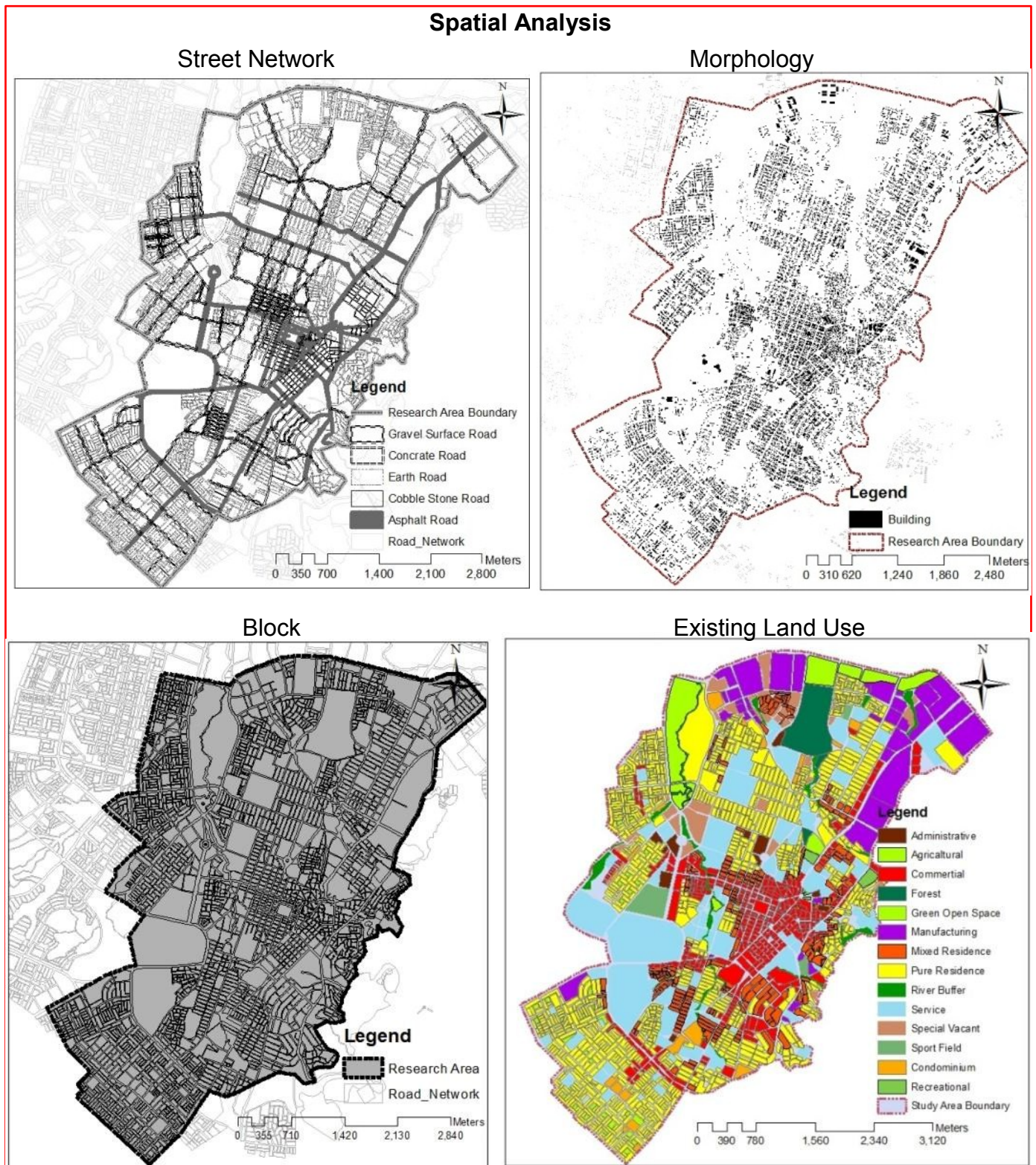


Figure 59 Spatial Analysis Map (Source: Own)

6.1. Programs

- A. Green Wall
- B. Green Roof
- C. Green Street
- D. Green Plot
- E. Green Network
- F. WSUD

6.2. Design Principles

- 1. Connectivity
- 2. Sustainability
- 3. Permeability
- 4. Integrity
- 5. Accessibility
- 6. conservation

The existing walls are made of stone, concrete plaster, metal and mud. Picture 60 shows sample walls of the project area. The aim of Green wall is to cover the walls with Green Infrastructure by using GI techniques.

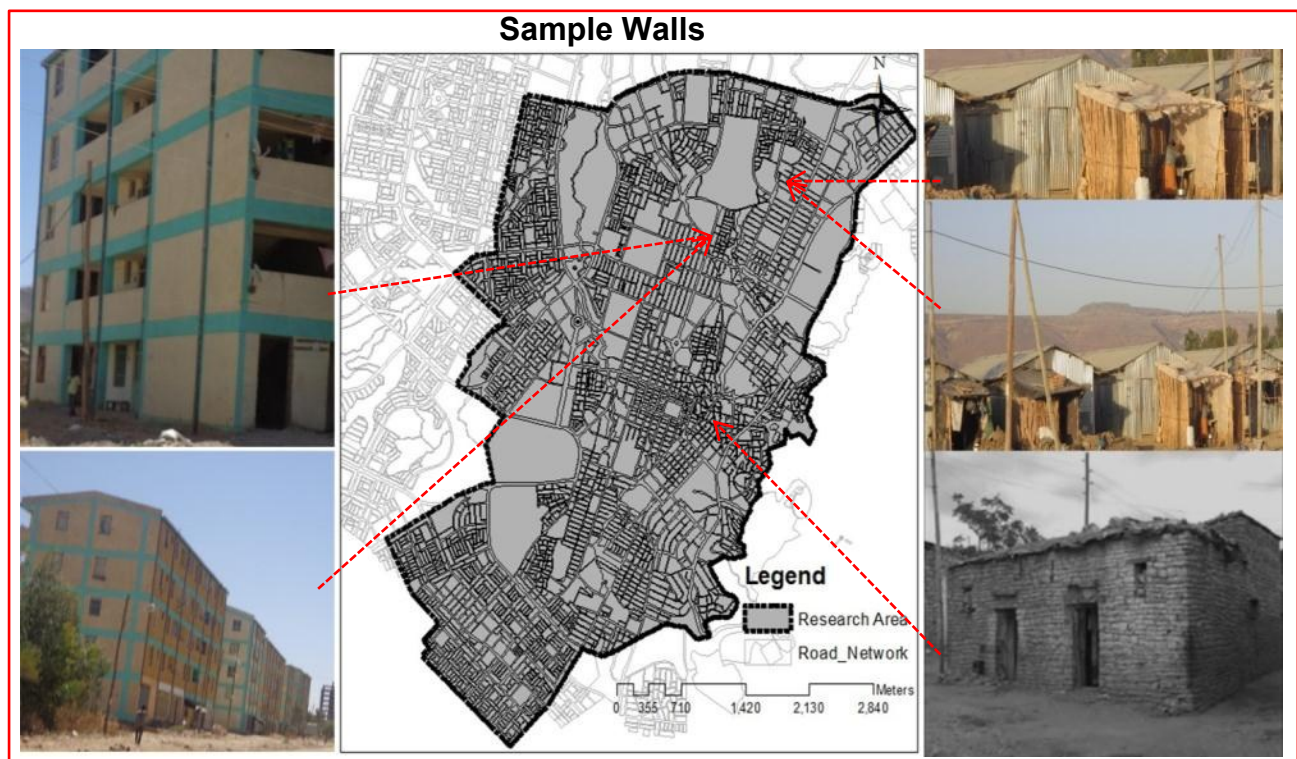


Figure 60 Sample Walls of the Site (Source: Own)

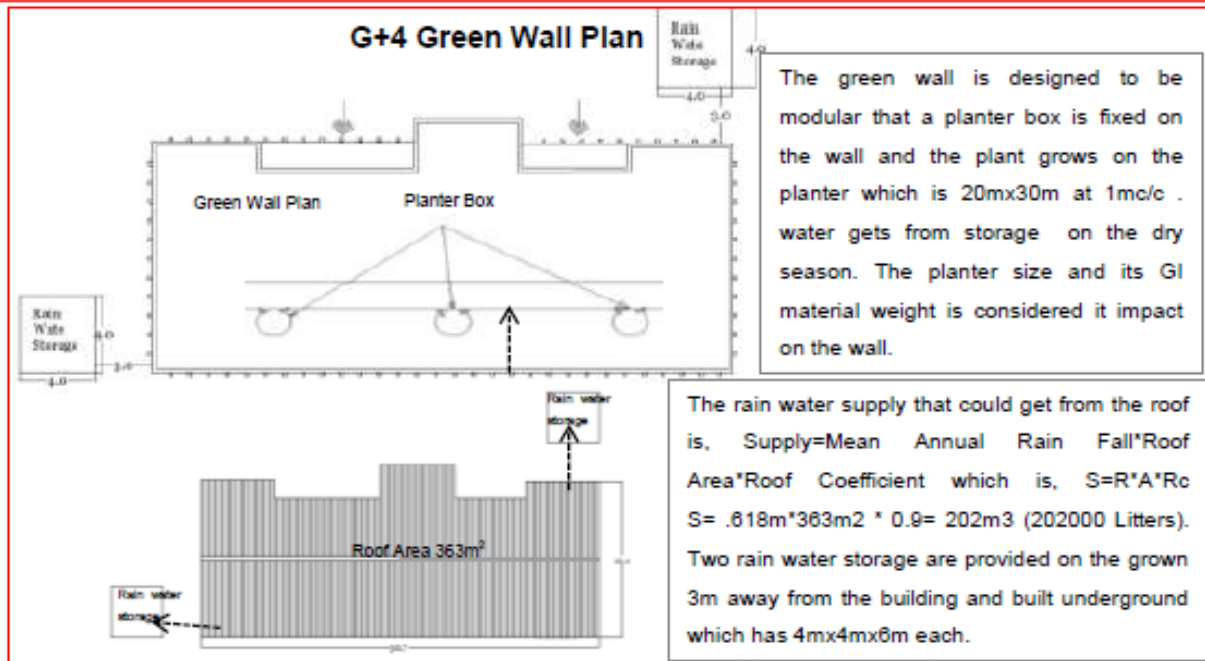
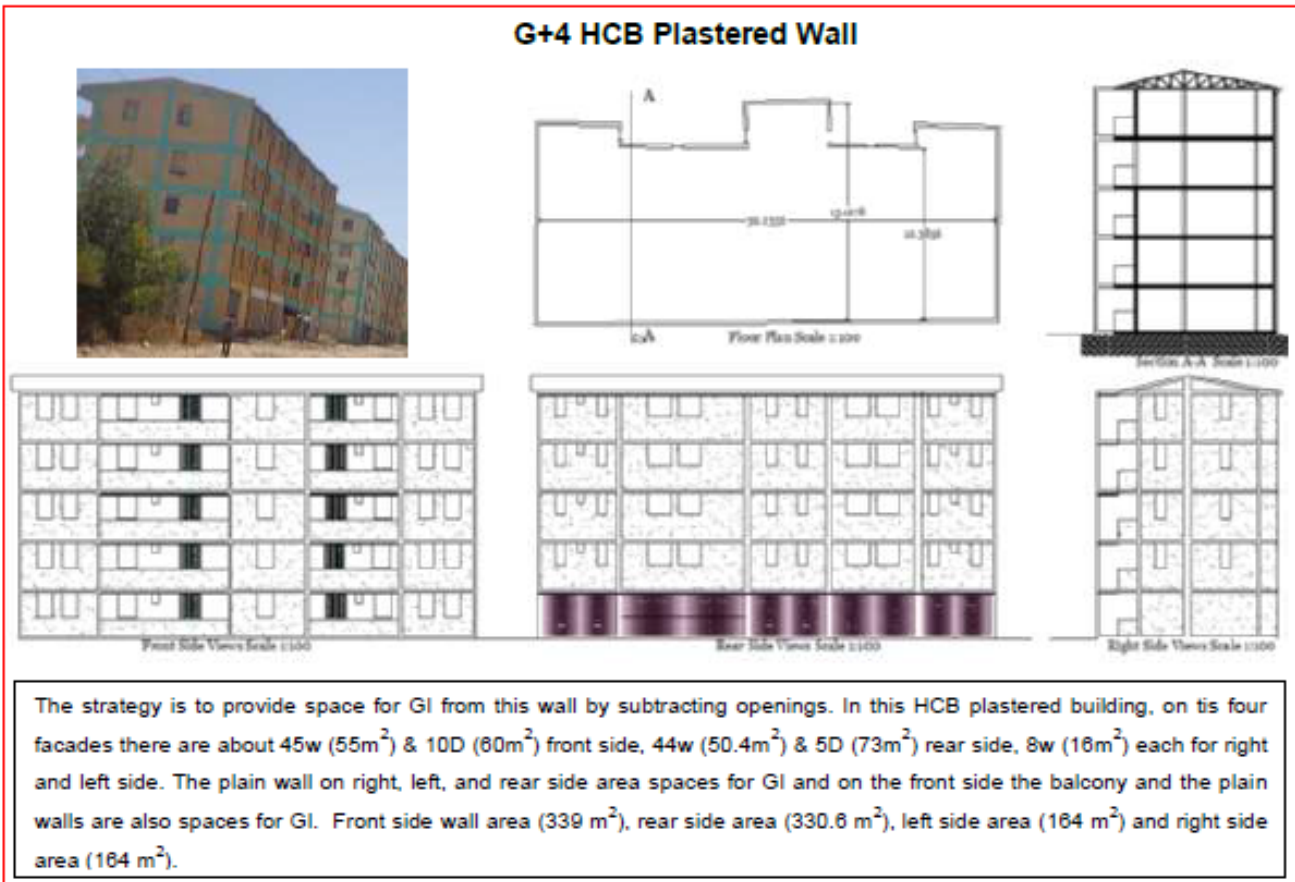


Figure 61 HCB Wall (Source; Own)

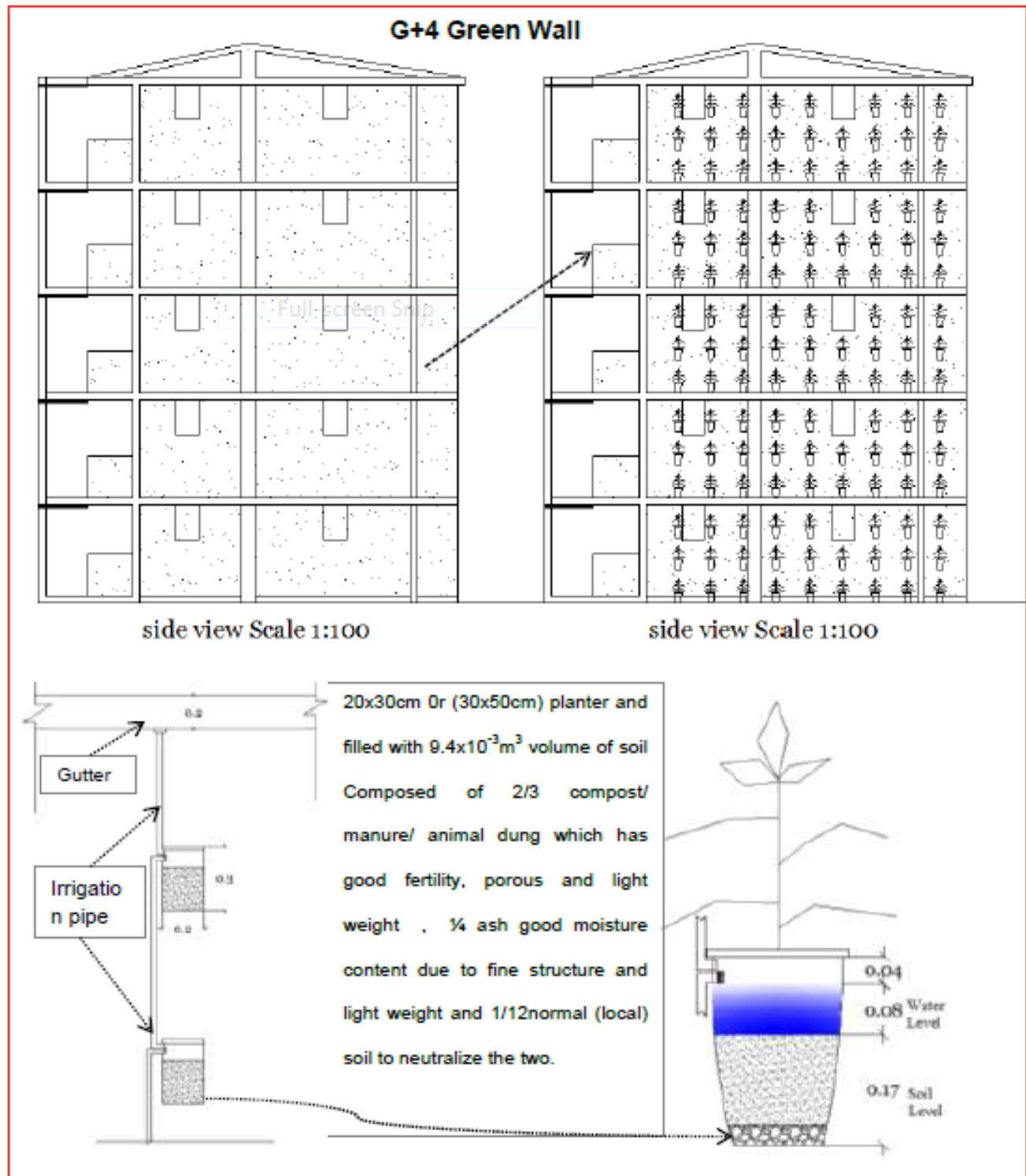
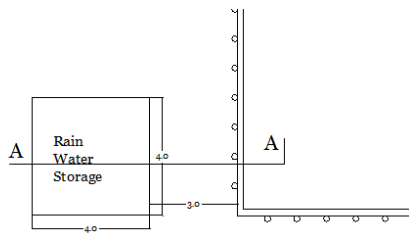
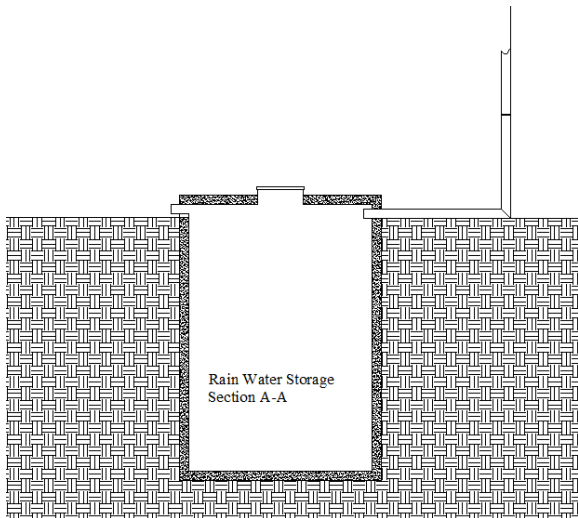


Figure 62 Green Design of HCB Wall (Source; Own)

G+4 Green Wall



The rain water storage stores about 202000 Liters of water which can water the plant for 9 month dry seasons. One planter box takes 0.5 Litter every day and 202000 Litter can water 1496 planter for the dry seasons. The water will pumped from the storage to the gutter by moter engine and down to planter irrigation pipe



'Money (Epipremium Qureum) plant is very common plant; preferably grows in hydroponic. It is excellent plant for removing formaldehyde and other VOC's (Volatile Chemical) in the air' (Bhawan, 2013).

The circulation of rain water is from roof to rain water storage via gutter and from storage water to gutter for distribution by generator pipe line and from gutter to irrigation pipe, then to planter box and move in the same manner to next planter.

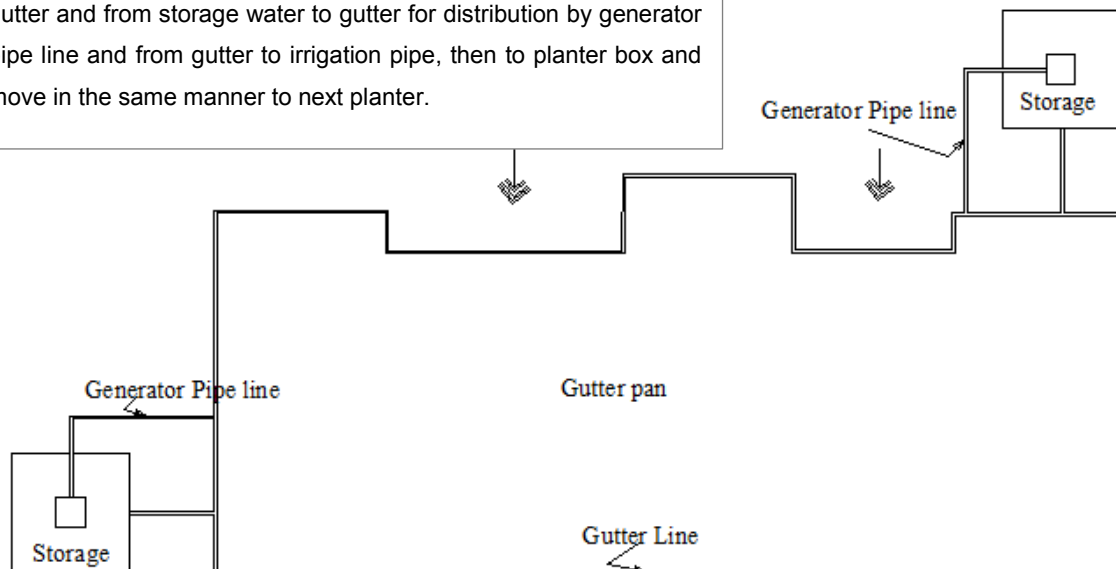


Figure 63 Green Wall Plan (Source: Own)

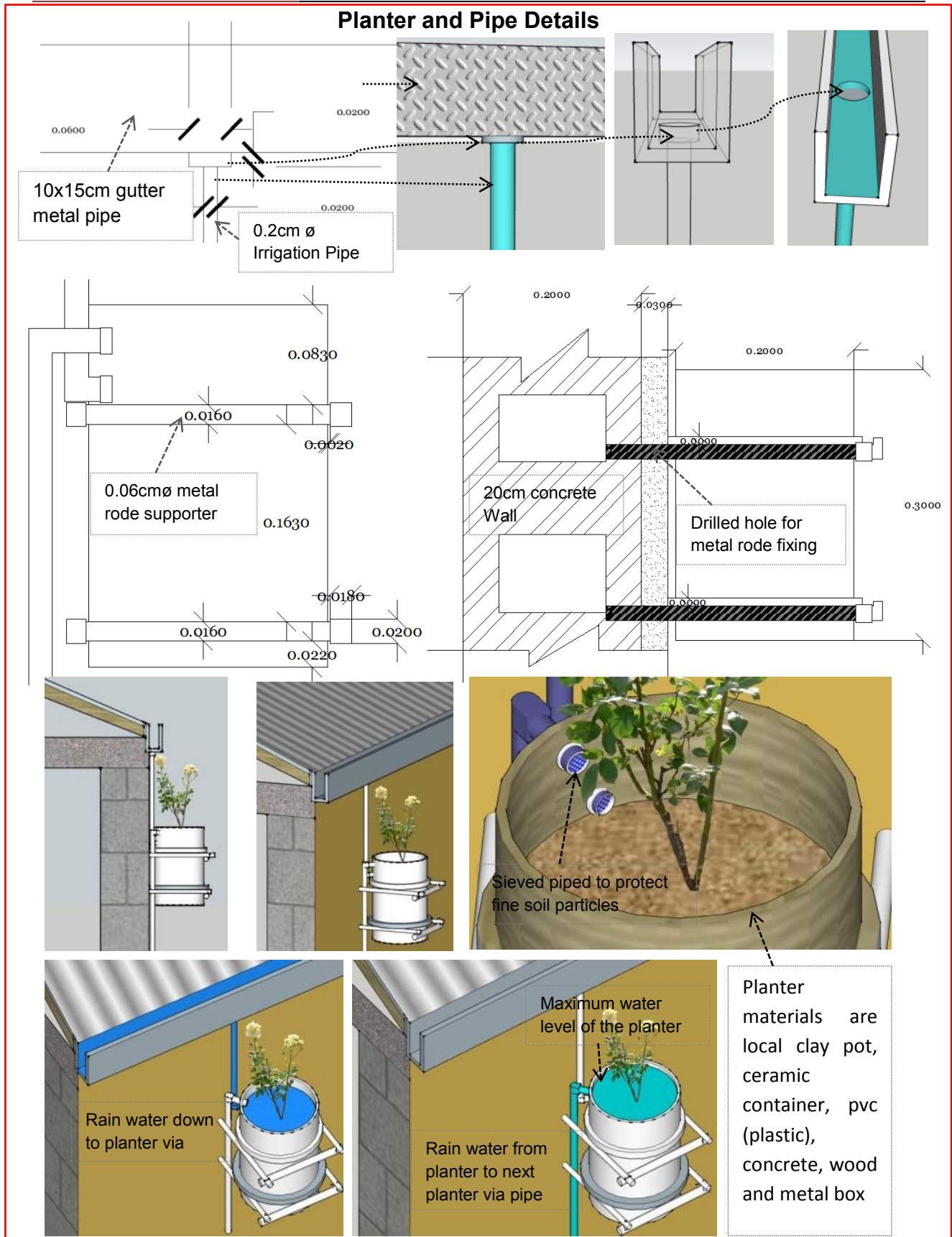


Figure 64 Detail of Green Wall (Source: Own)

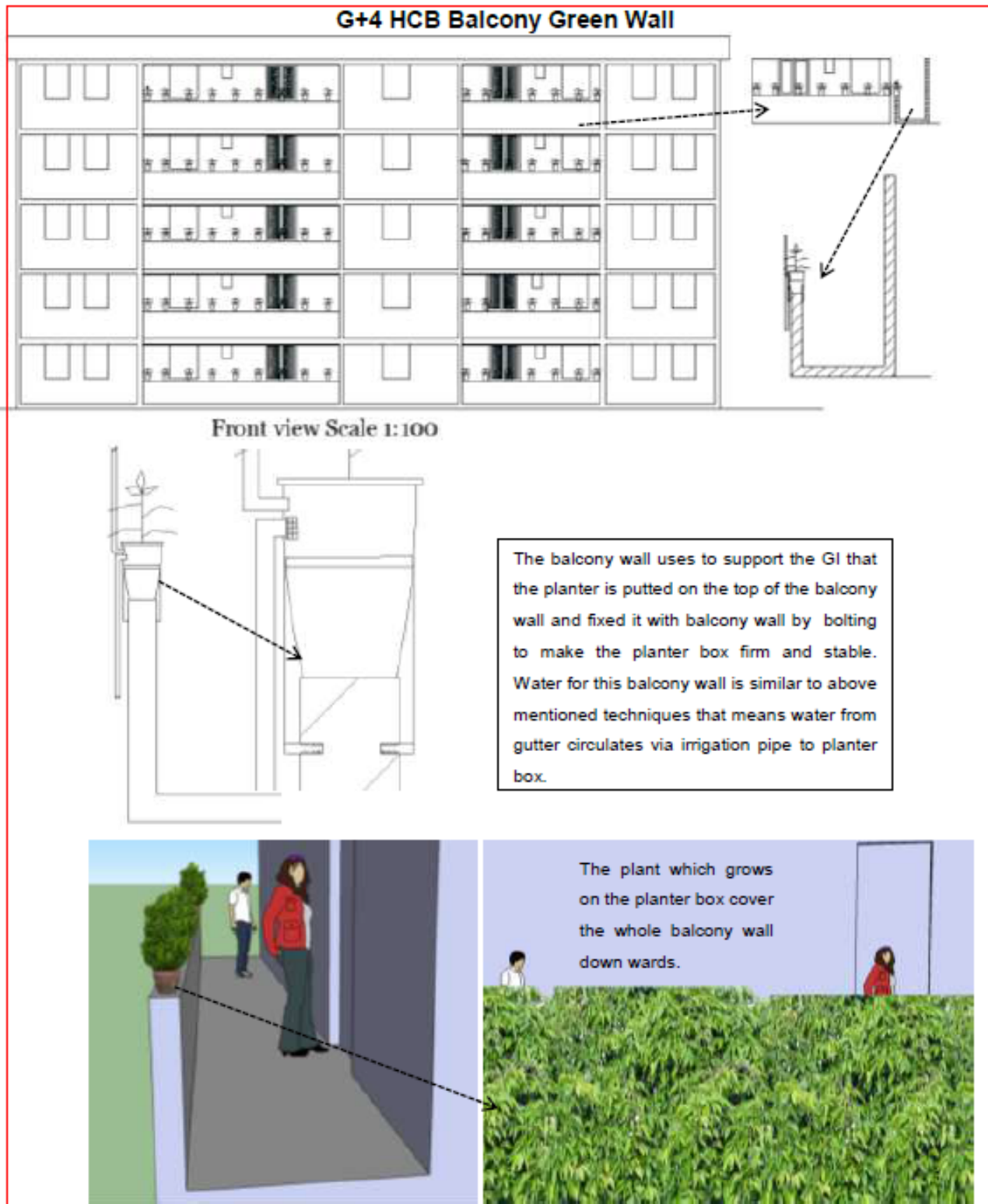
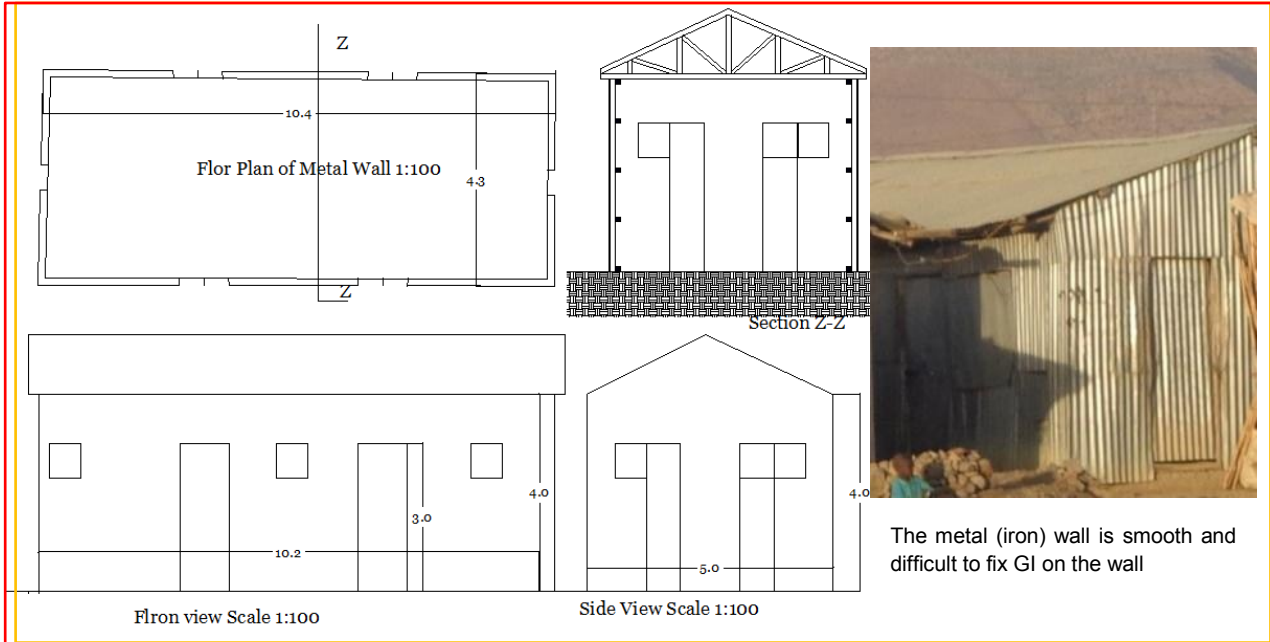


Figure 65 Balcony Green Wall (Source; Own)

Metal Wall



Green Wall

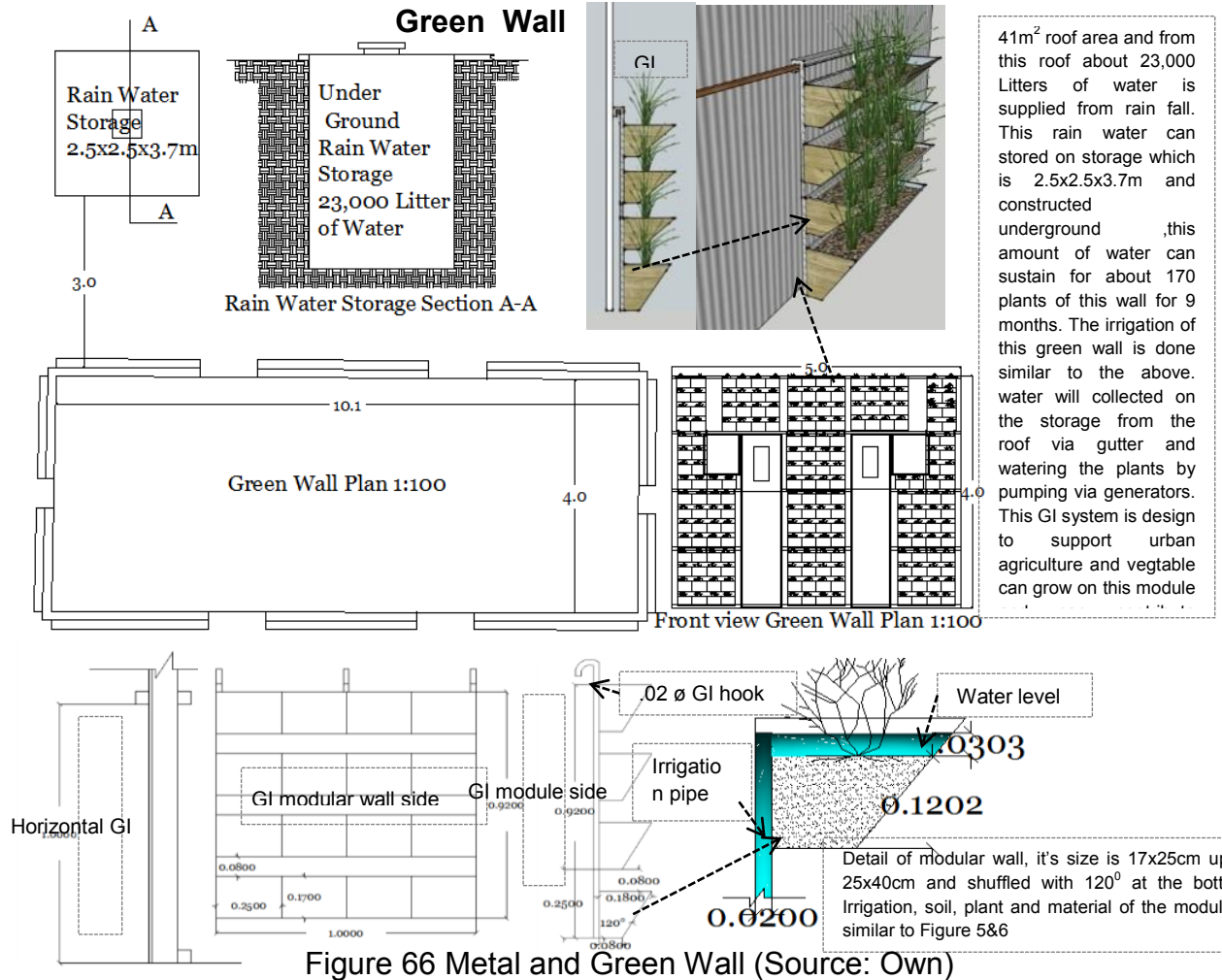


Figure 66 Metal and Green Wall (Source: Own)

Stone Wall

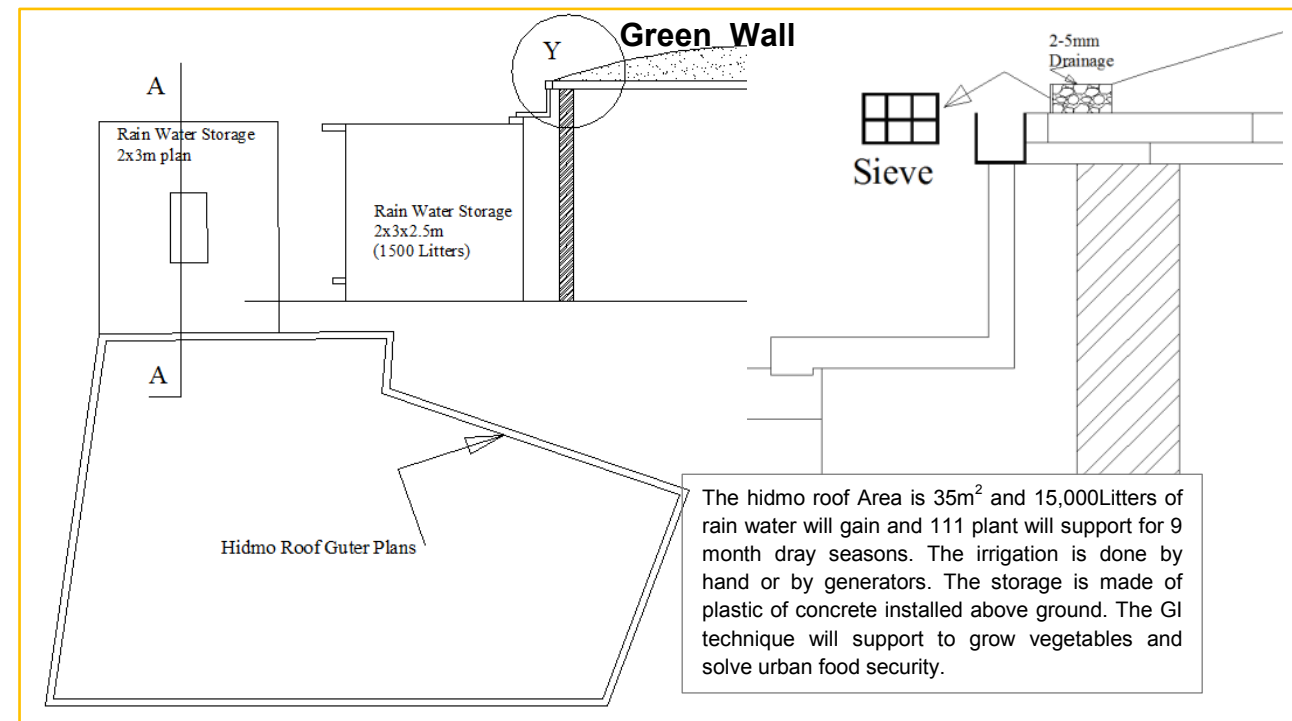
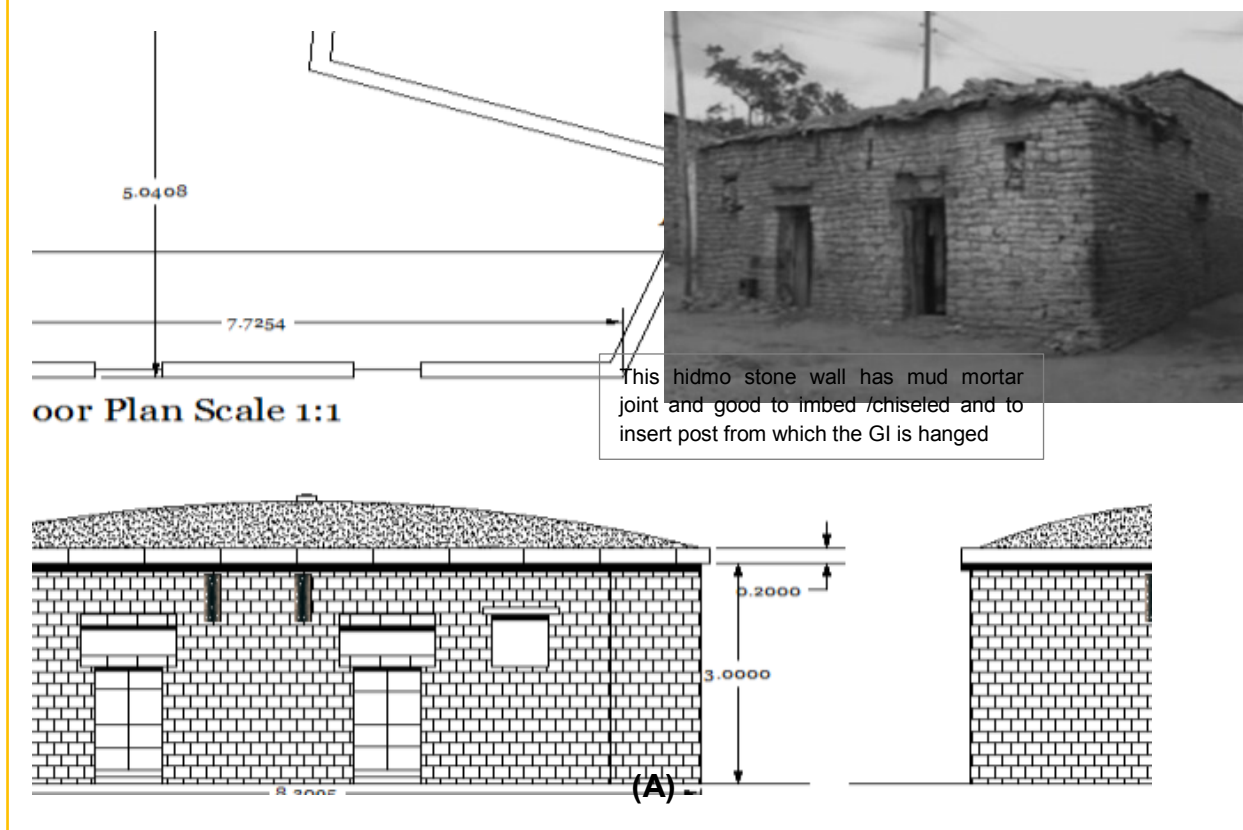


Figure 67 Stone and Green Wall (Source: Own)

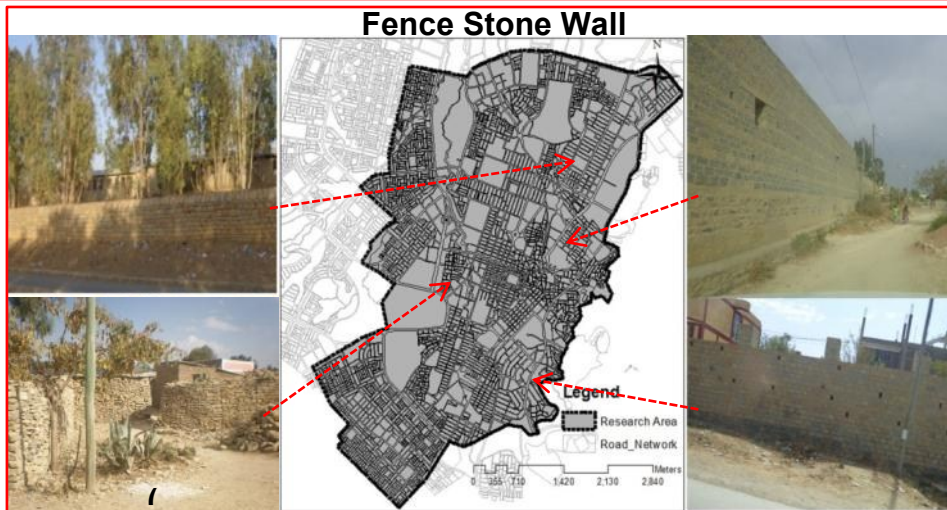
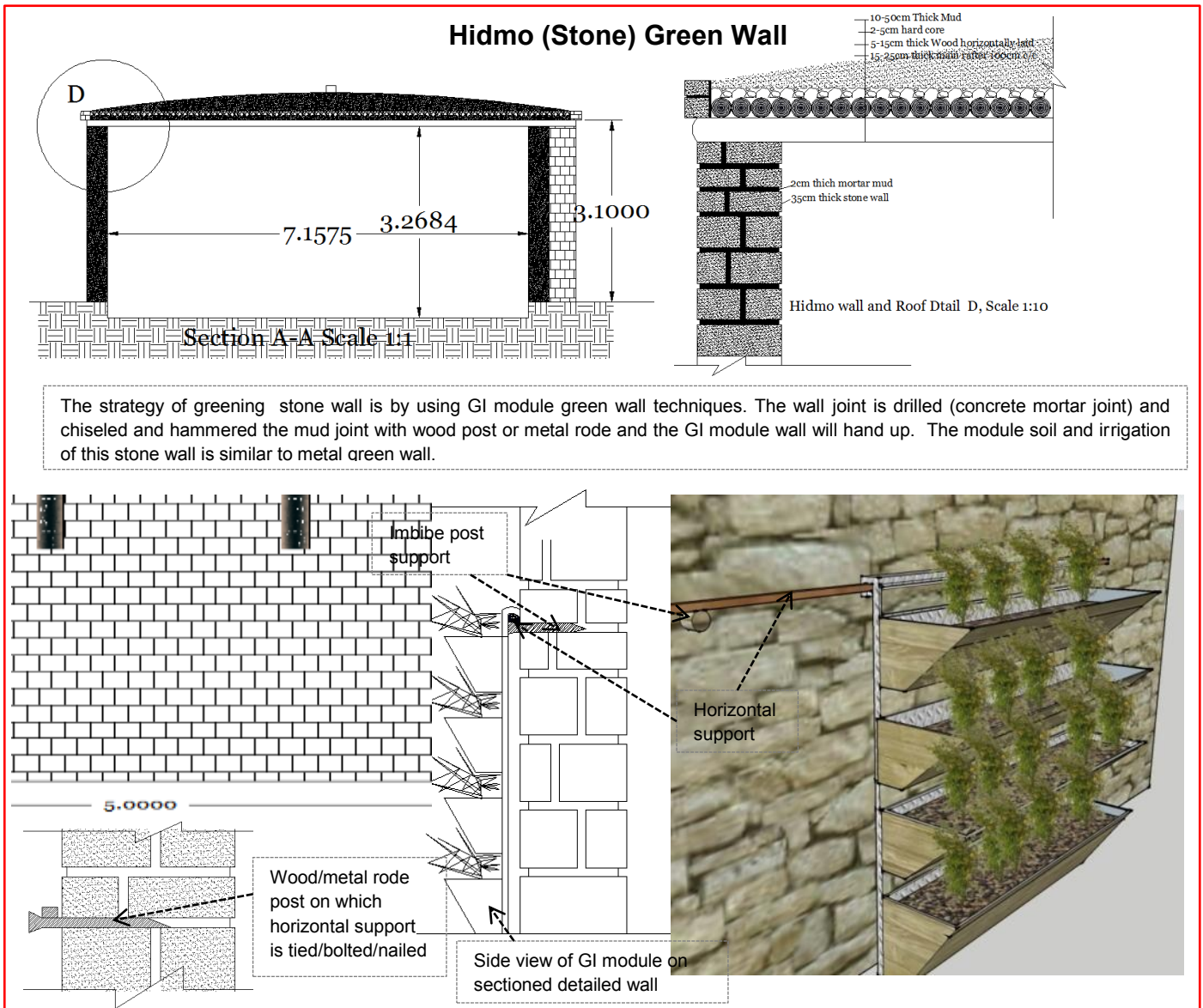


Figure 68 Stone Green Wall and Roofs (Source: Own)

Fence Stone Green Wall

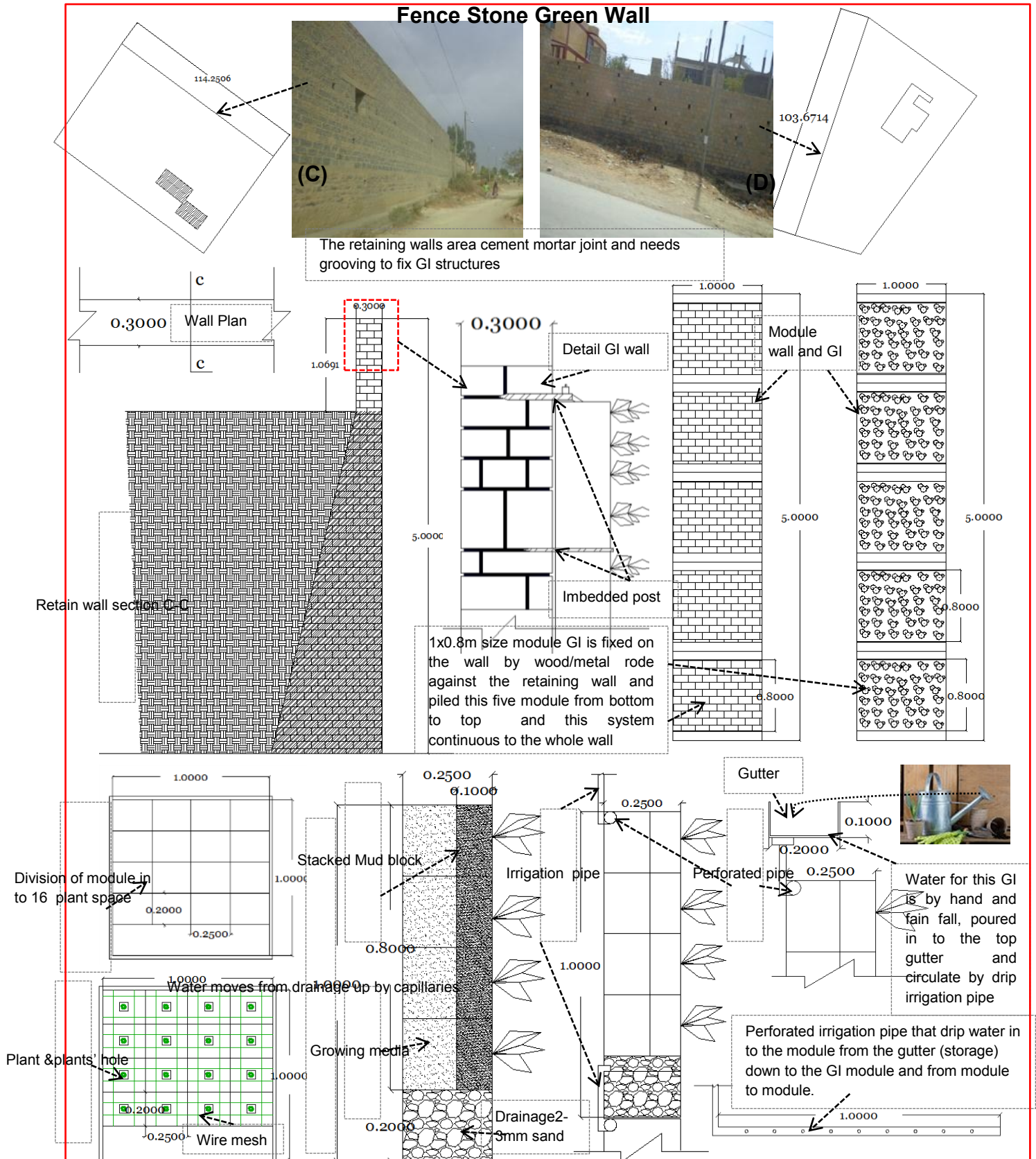


Figure 69 Green Fence Wall (Source: Own)

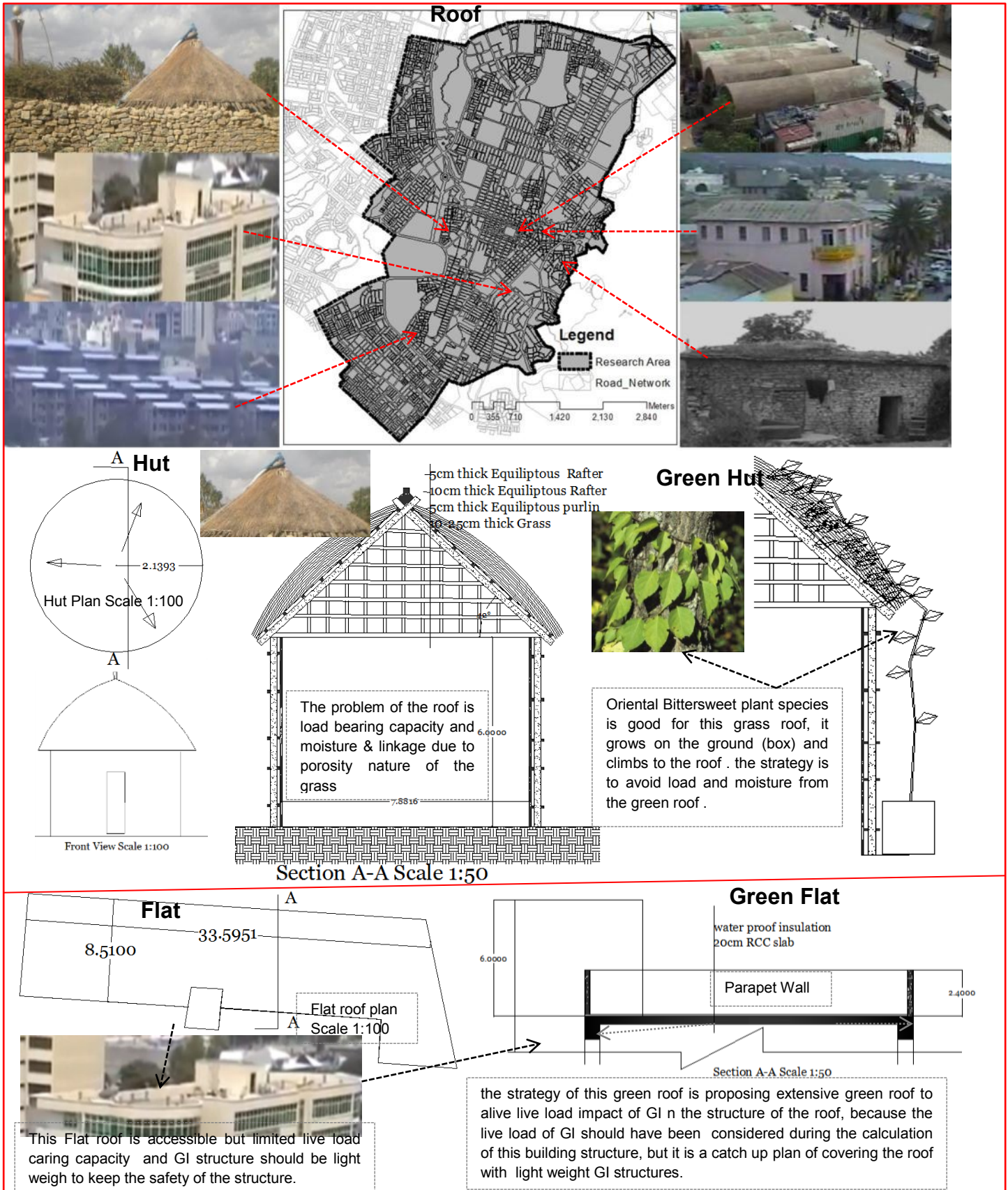


Figure 70 Roof and Green Roofs (Source: Own)

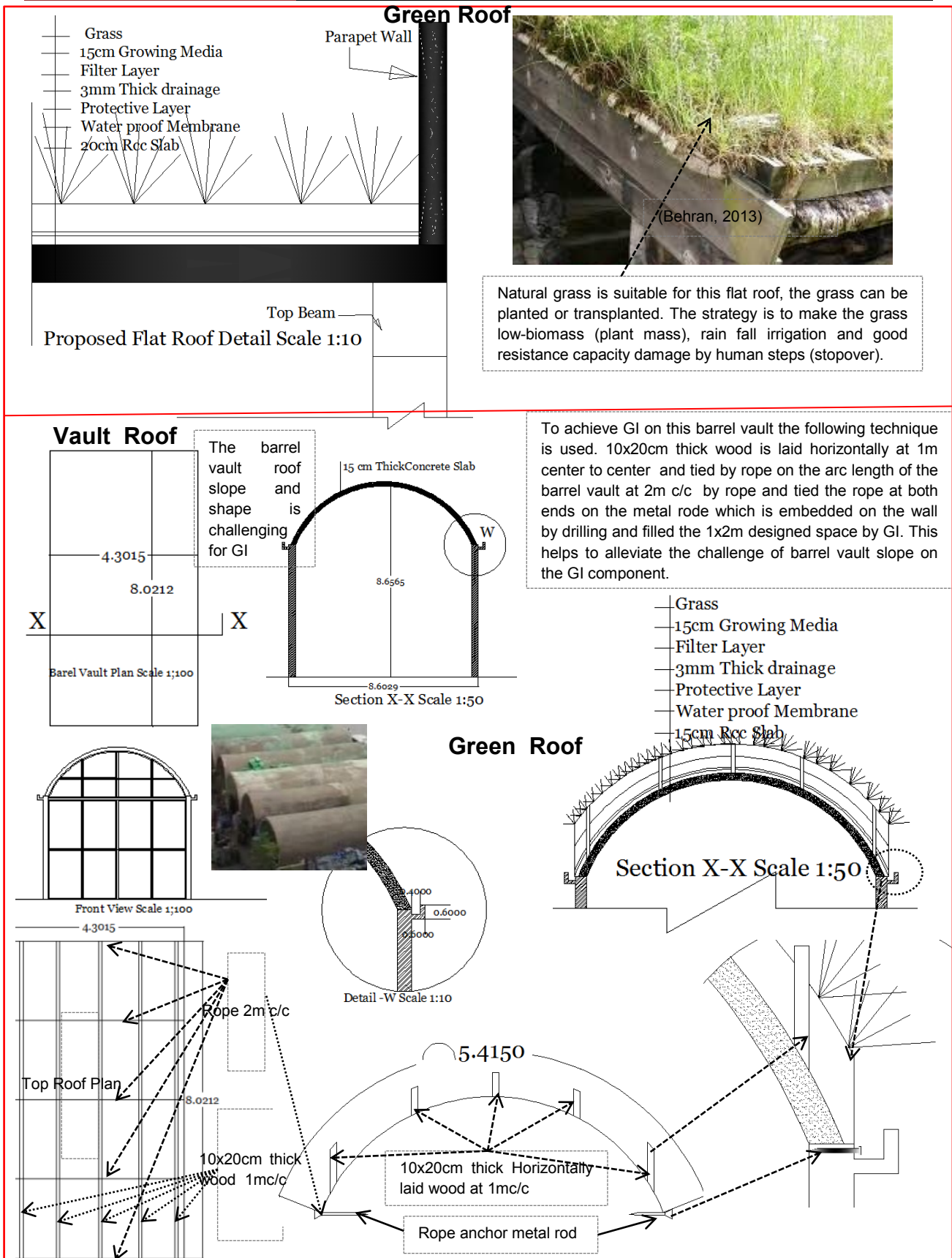


Figure 71 Barrel and Green Roofs (Source: Own)

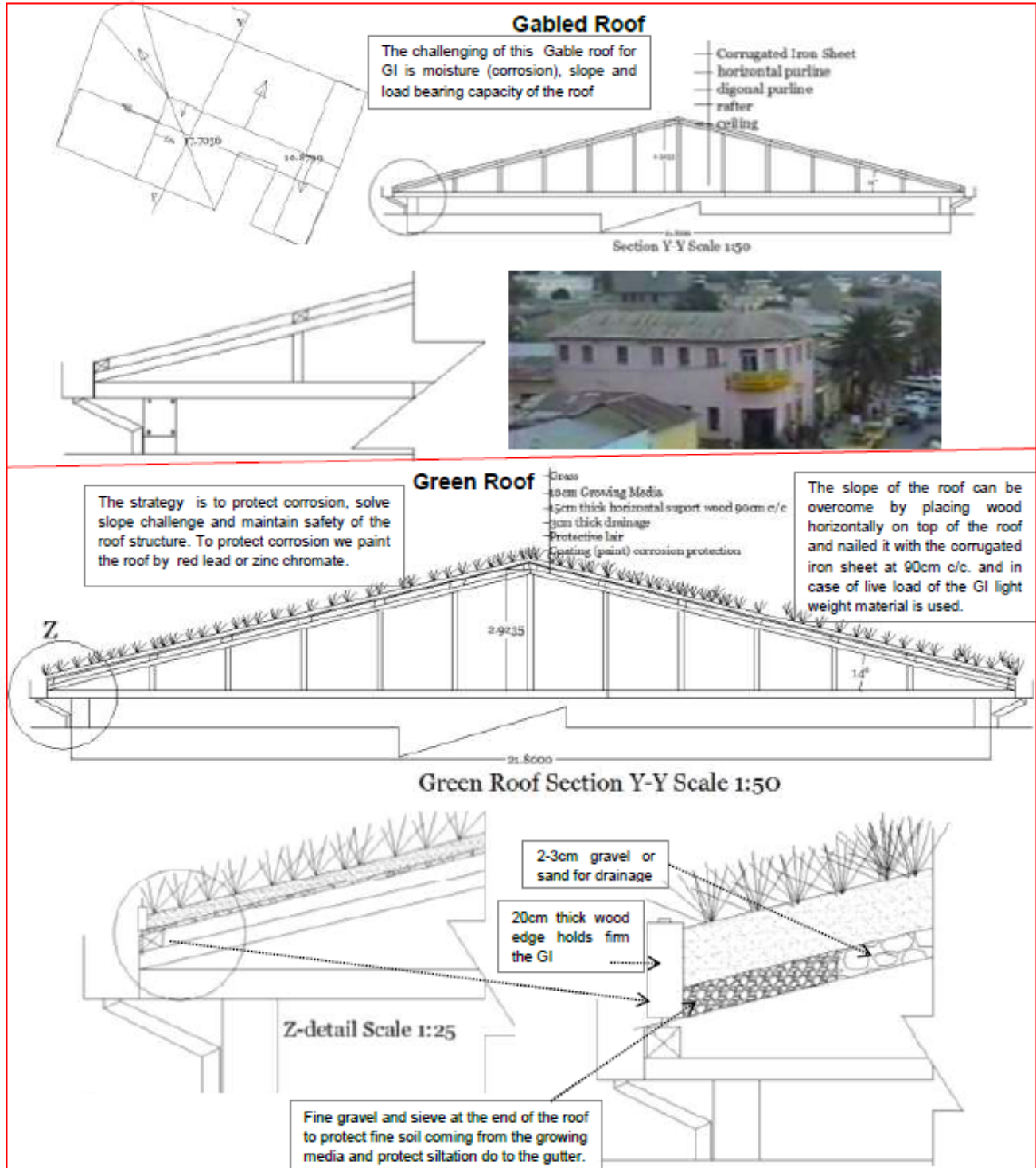


Figure 72 Gabled and Green Roof (Source: Own)

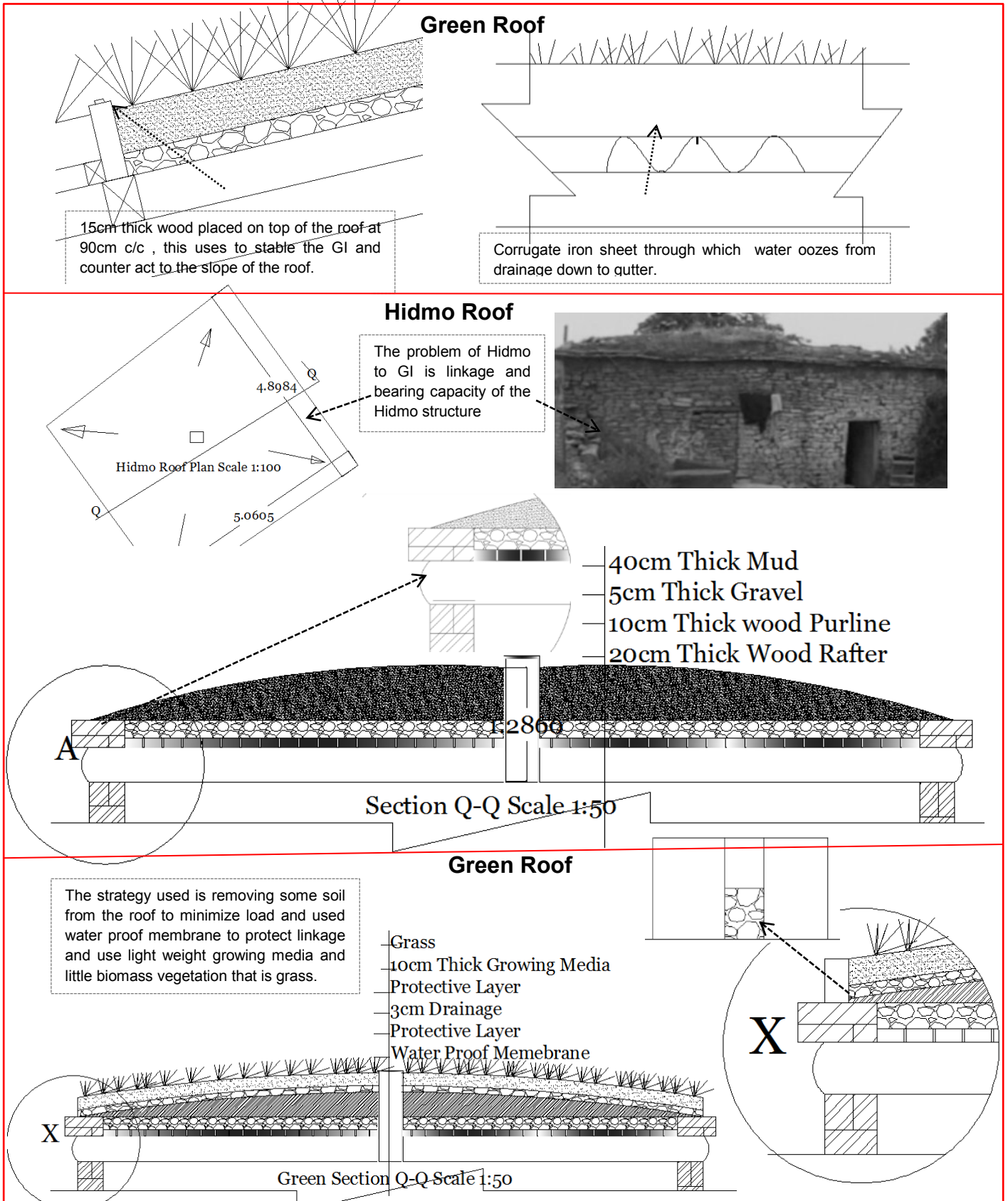


Figure 73 Hidmo and Green Roof

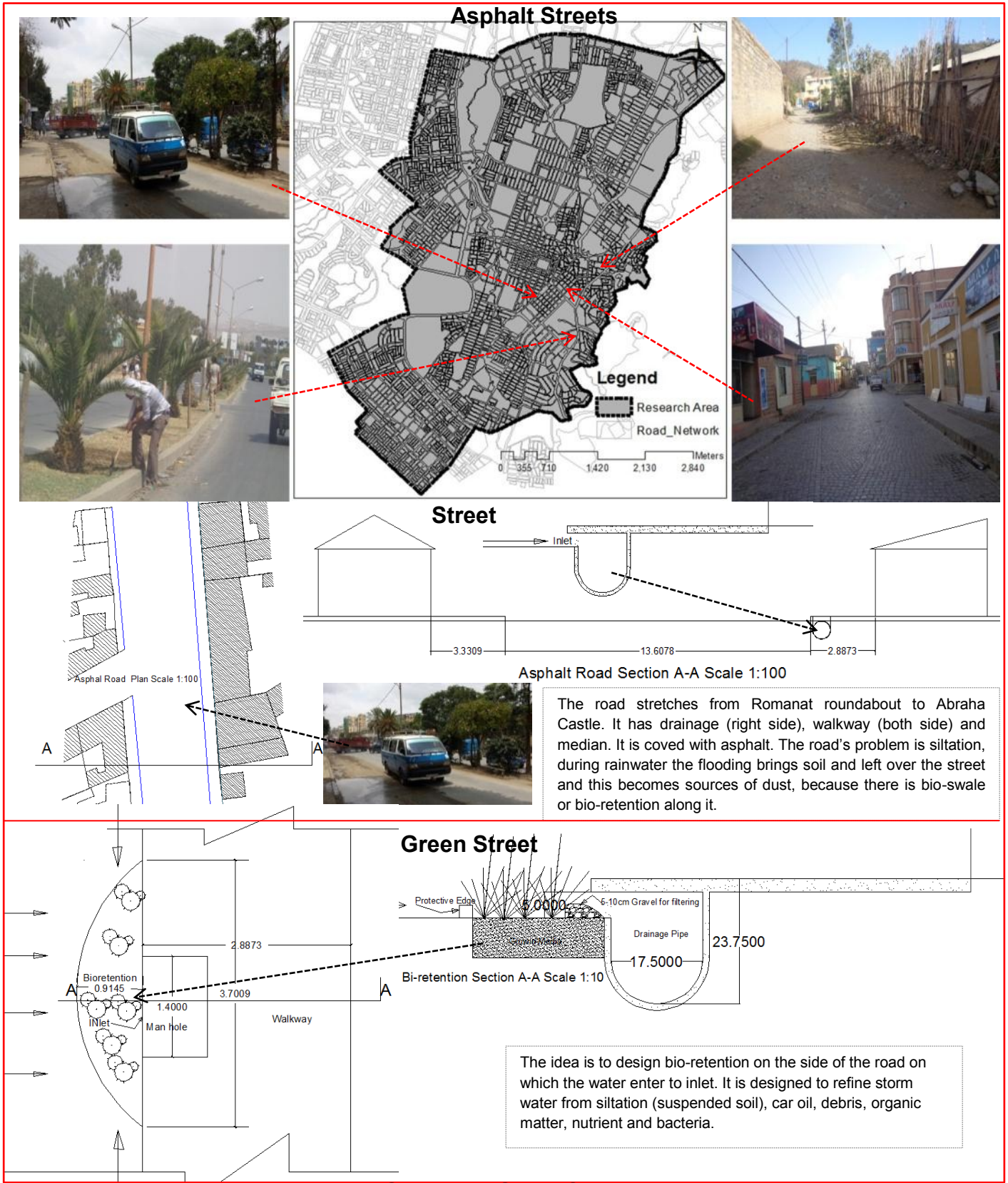


Figure 74 Street and Green Street

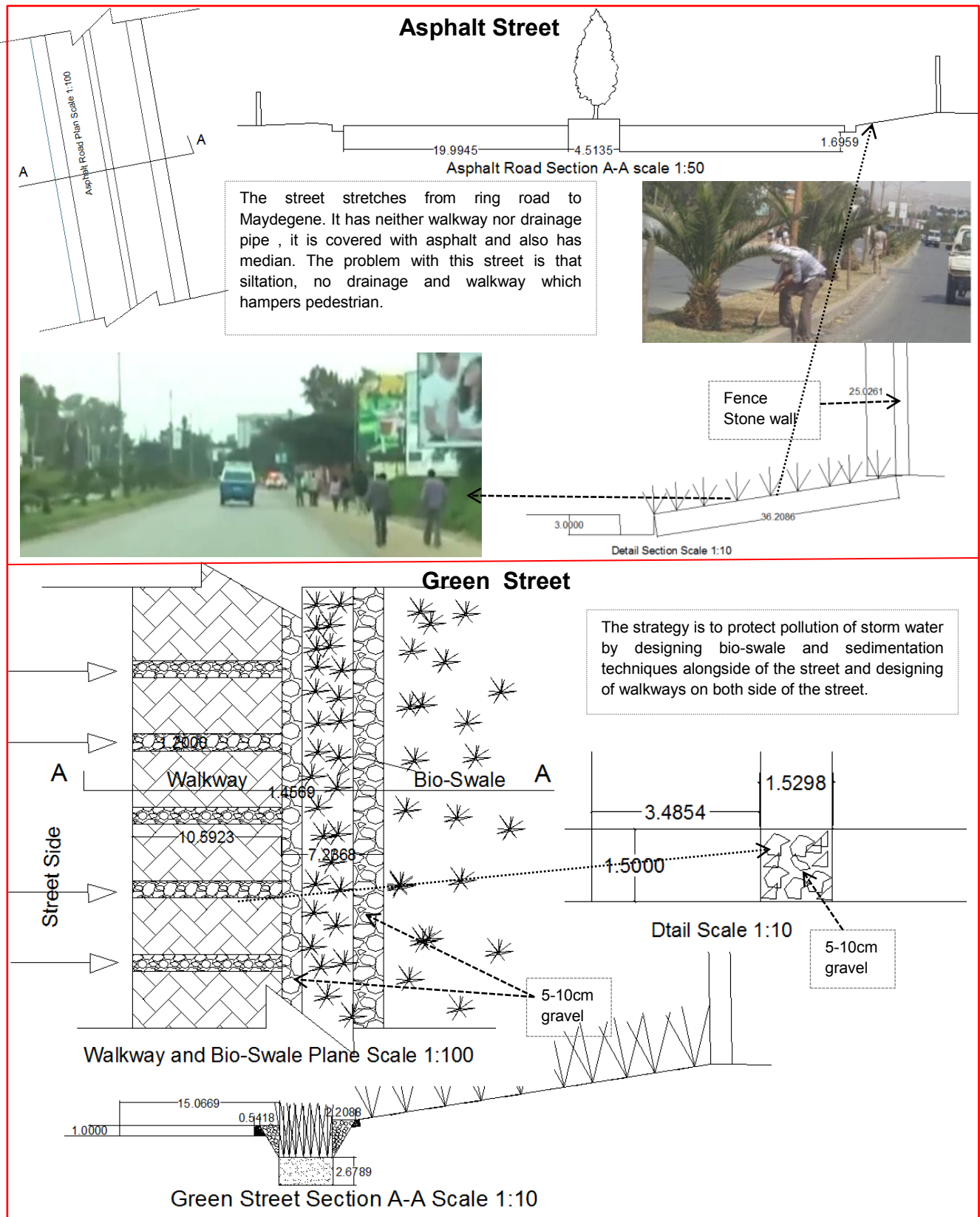


Figure 75 Asphalt and Green Street (Source: Own)

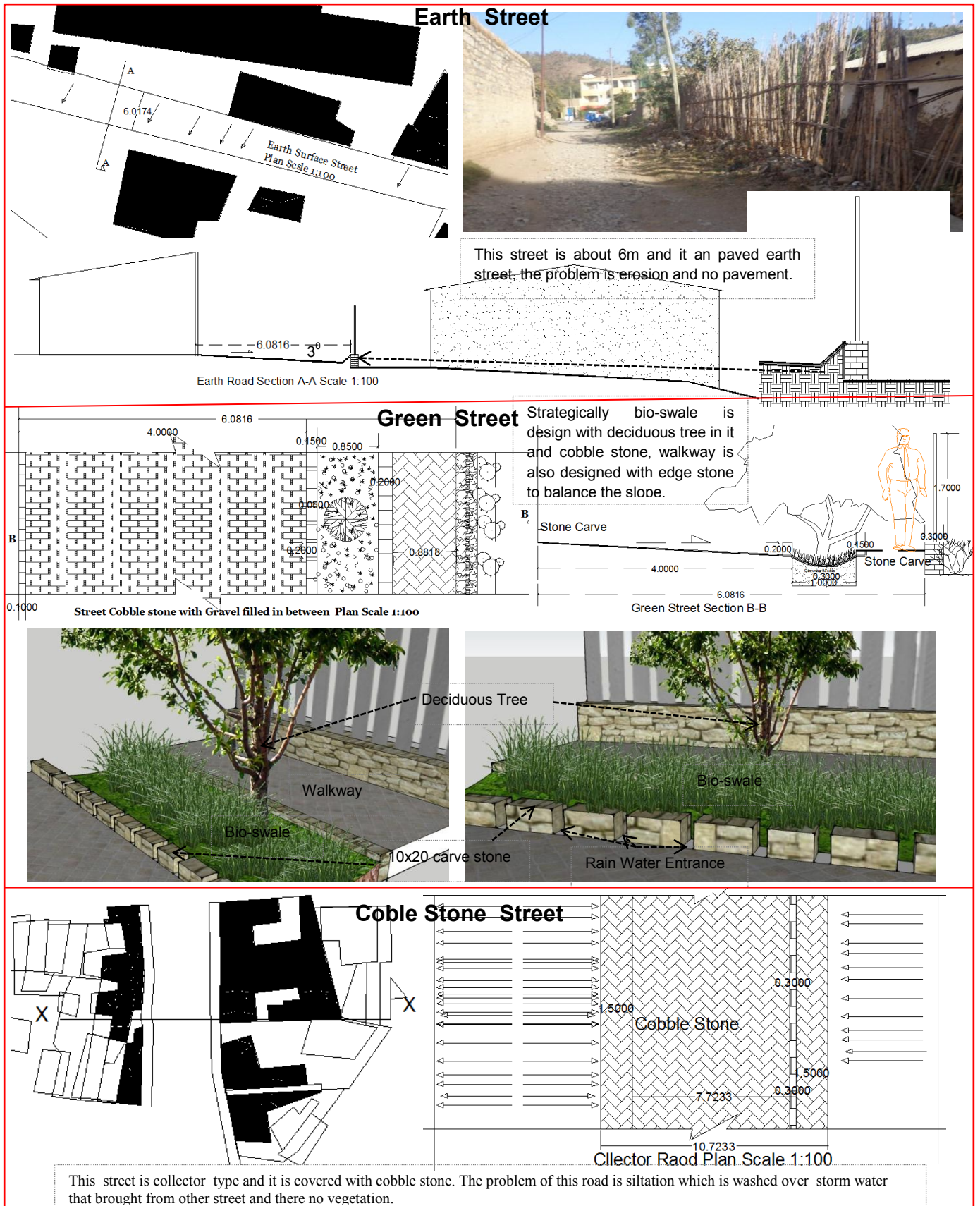


Figure 76 Earth, Green and Cobble Stone Street (Source: Own)

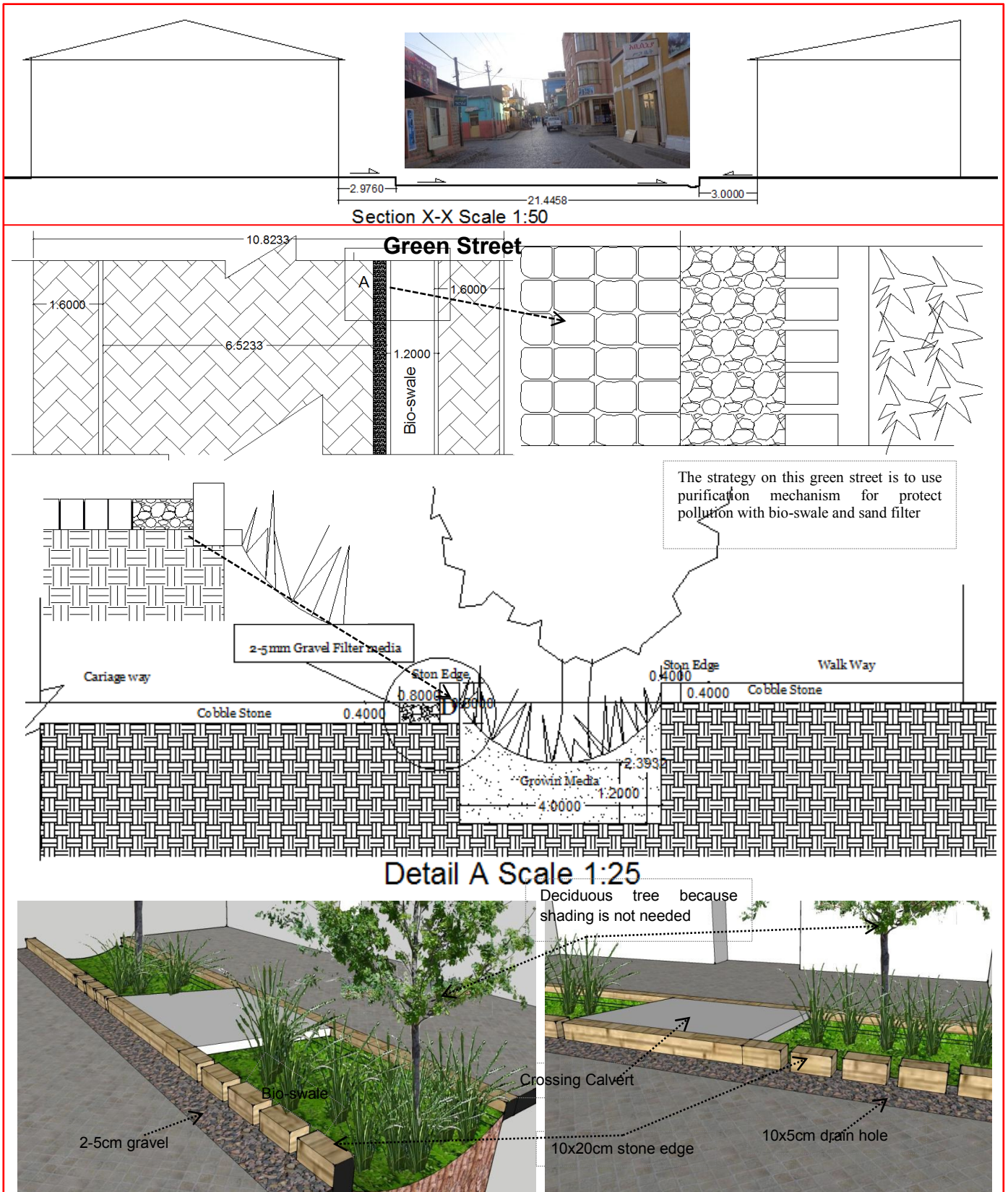


Figure 77 Green Streets (Source: Own)

Plot

The harvesting of rain water is essential for GI in the plot level. The research intends to retain the supply of water from rain using storage and infiltration mechanism with in the plot itself. As safety factor overflow pipe is design to flow out of the plot during emergency to the street and on the street there is harvesting of rain water by bio-retention and bio-swale. There are about seven plots which are taken from the research area, this was done based on their size and these include 65 m², 200 m², 300 m², 500 m², 1000 m², 2000 m² and 8000 m².

Table 26 Plot Area and Runoff coefficient

No.	Plot area (m ²)	Built-up (roof)area (m ²)	Open Space area (m ²)	Plot Pervious area			Roof	
				Slope	Soil group	Runoff coefficient	Material type	Roof runoff coefficient
1.	65	14	51	0.13%	C	0.11	Corrugated iron sheet	0.75
2.	200	32	168	0.2%	A	0.04	Corrugated iron sheet	0.75
3.	300	97	203	0.06%	B	0.07	Corrugated iron sheet	0.75
4.	500	29	471	0.05%	B	0.07	Corrugated iron sheet	0.75
5.	1000	152	848	0.08%	B	0.07	Corrugated iron sheet	0.75
6.	2000	332	1668	0.2%	B	0.07	Corrugated iron sheet	0.75
7.	8000	372	7628	0.13%	C	0.11	Corrugated iron sheet	0.75

(Source; Own)

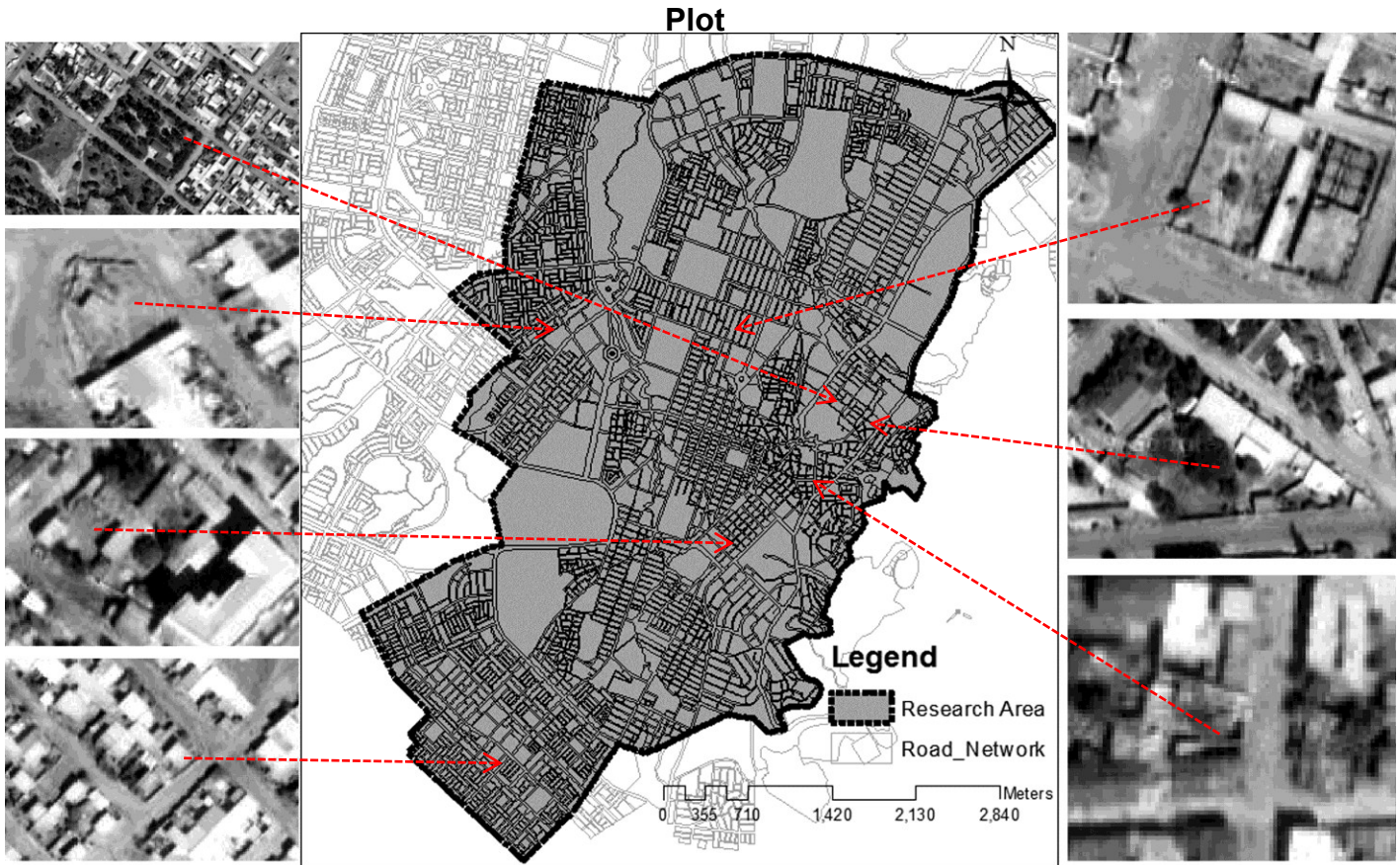


Figure 78 Sampled Plot with Area of (65, 200, 300, 500, 1000, 2000 and 8000m²)
(Source; Own)

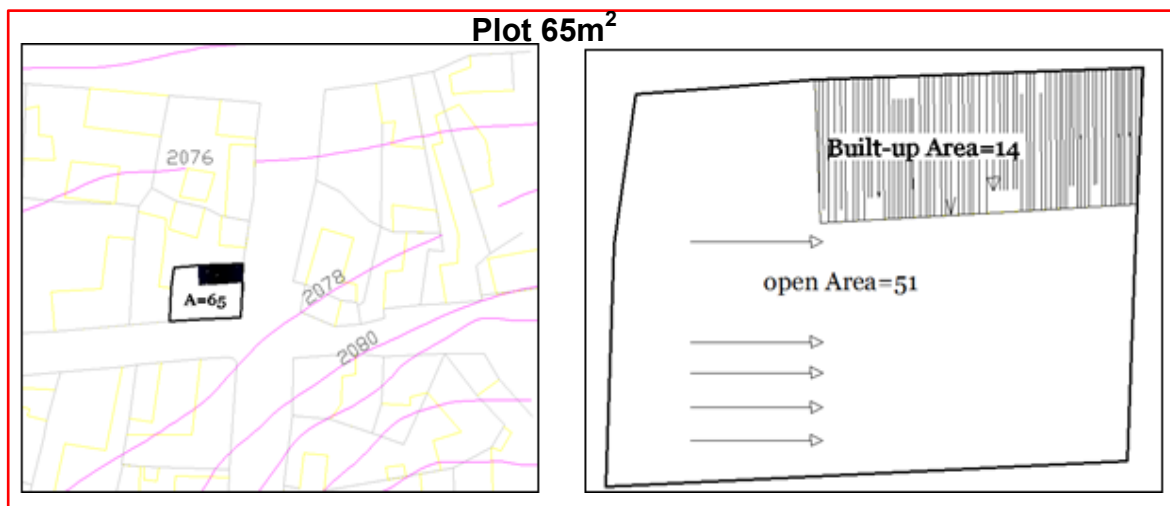


Figure 79 Plot with 65 Square meter area (Source; Own)



Figure 80 Plots with Areas of 200, 300 and 500 Square meter (Source; Own)

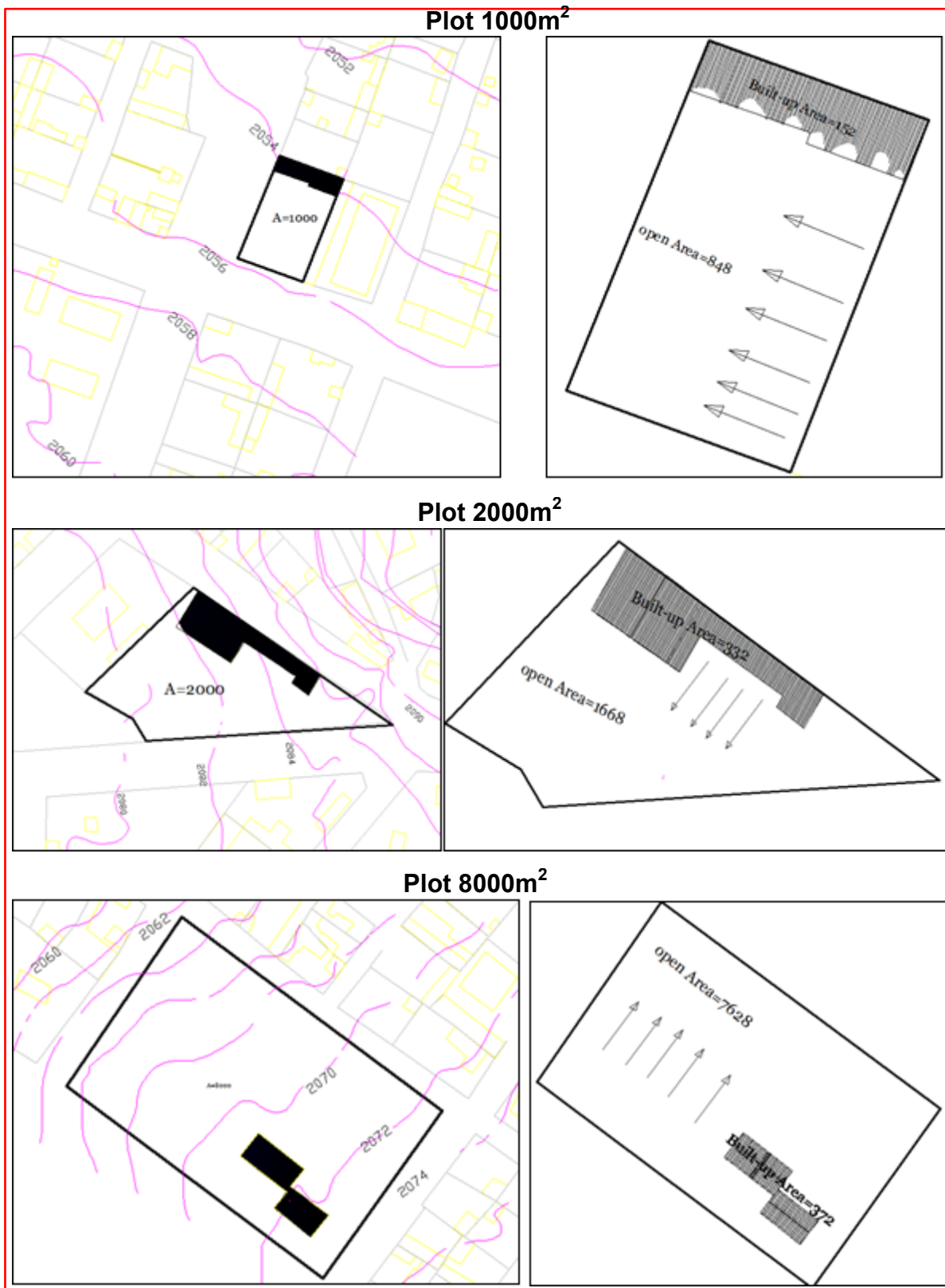


Figure 81 Plot Area of 1000, 2000 and 8000 Square Meter (Source; Own)

Table 27 Green Plot Rain Water Harvesting System

No	Green Plots									
	Pervious area rain fall harvesting					Roof area rain fall harvesting				
	Plot open area (m ²)	Pervious area runoff coefficient	Mean annual rain fall	Plot supply of rainwater (open area* runoff coefficient* mean annual rain fall) m ³	Infiltration volume (width*length* depth) m ³	Roof area (m ²)	Roof runoff coefficient	Mean annual rain fall	Roof supply of rainwater in m ³	Storage size (width* height* length)
1.	51	0.11	618mm	3.47	1.73*2*1	14	0.75	618mm	6.49	2*3.25*1
2.	168	0.04		4.15	2*2.07*1	32	0.75		14.83	3*5*1
3.	203	0.07		8.78	2.93*3*1	97	0.75		44.96	4*5.6*2
4.	471	0.07		20.37	2.54*2*2	29	0.75		13.44	3*4.48*1
5.	848	0.07		36.68	3.6*5*2	152	0.75		70.45	5*7*2
6.	1668	0.07		72.16	5*7.2*2	332	0.75		153.88	5*10*3
7.	7628	0.11		518.55	10*20.7*2.5	372	0.75		172.42	5*11.5*3

(Source; Own)

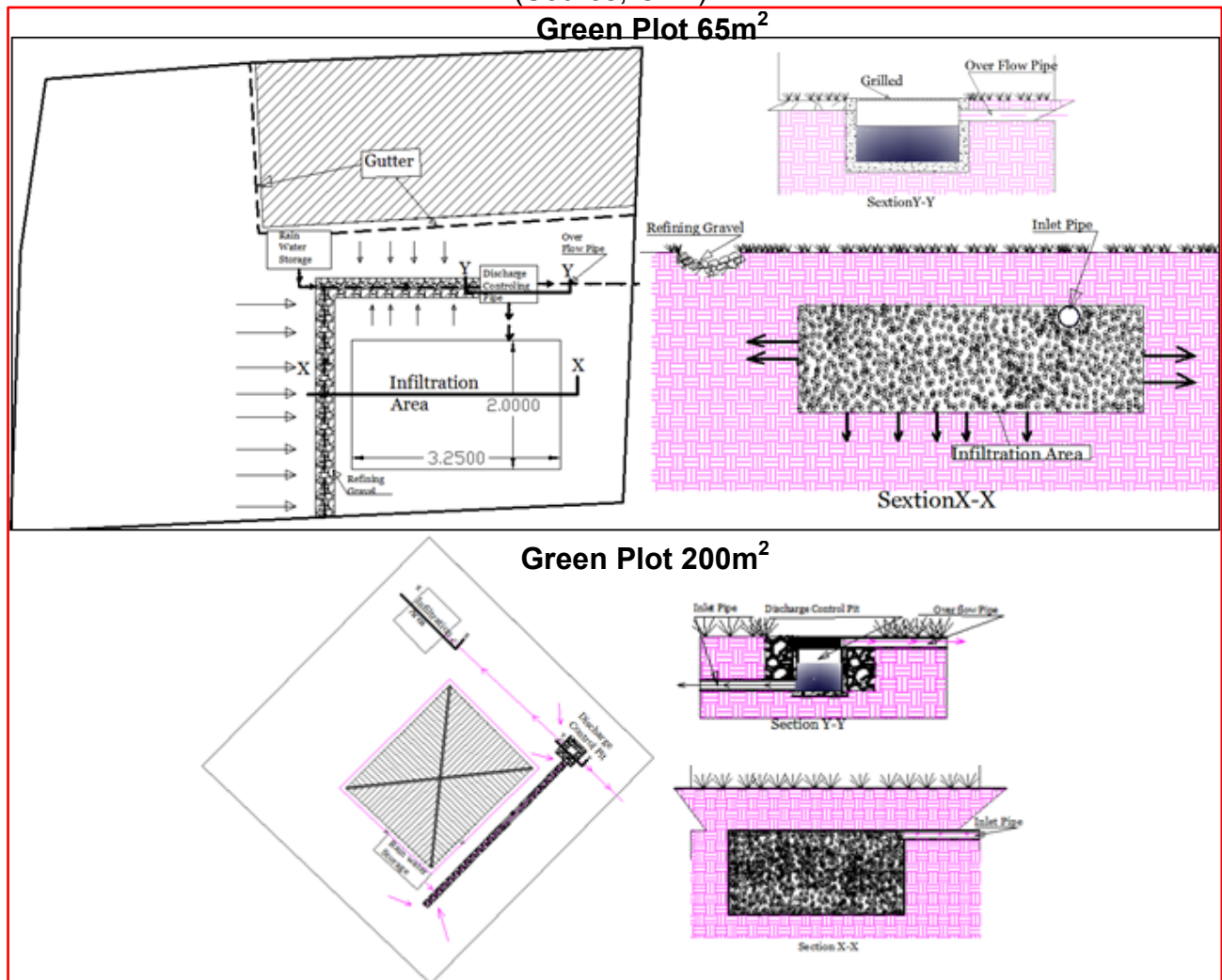


Figure 82 Green Plot Areas of 65 and 200 Square Meters (Source; Own)

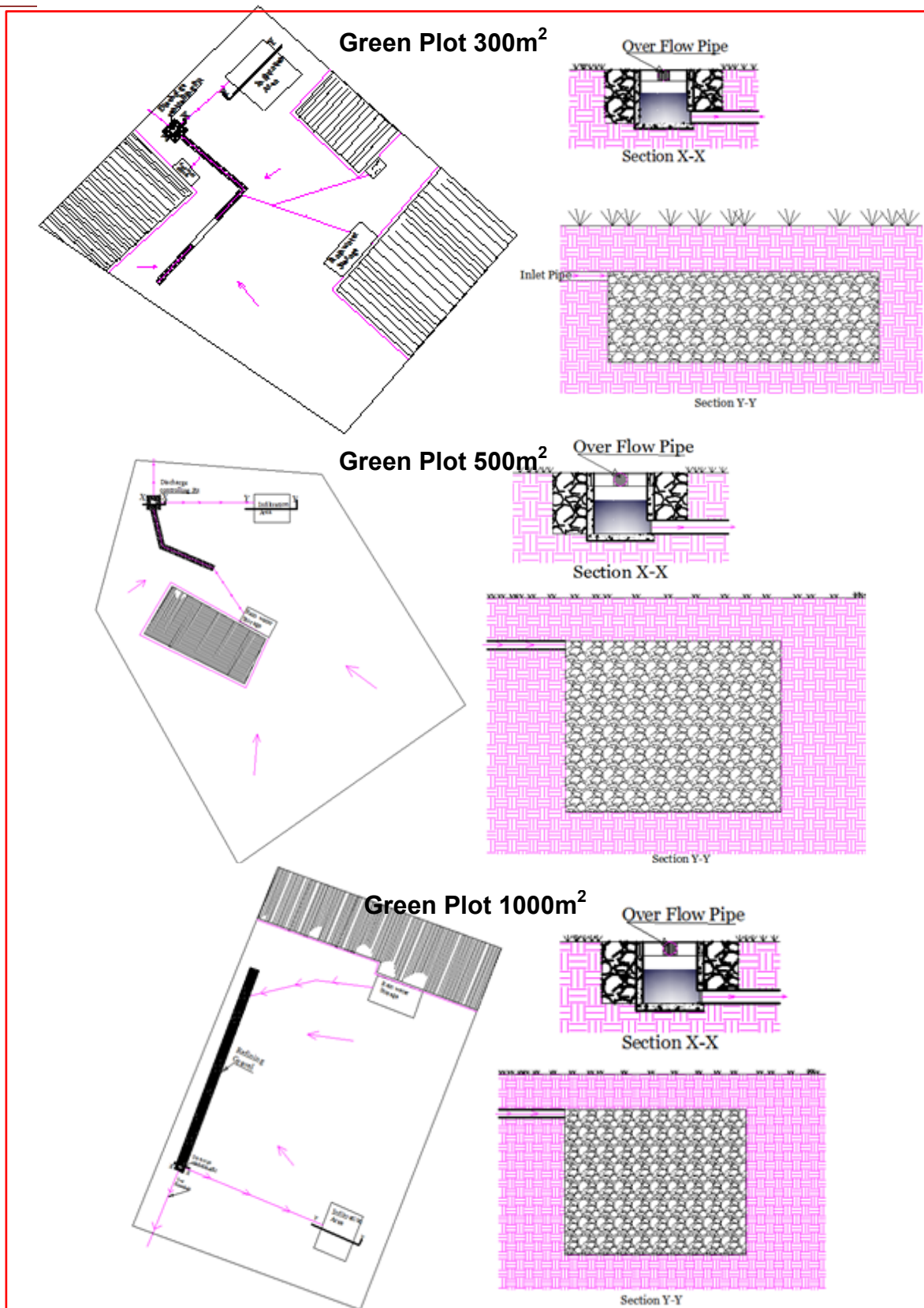


Figure 83 Green Plot Area of 300, 500 and 1000 Square Meters (Source; Own)

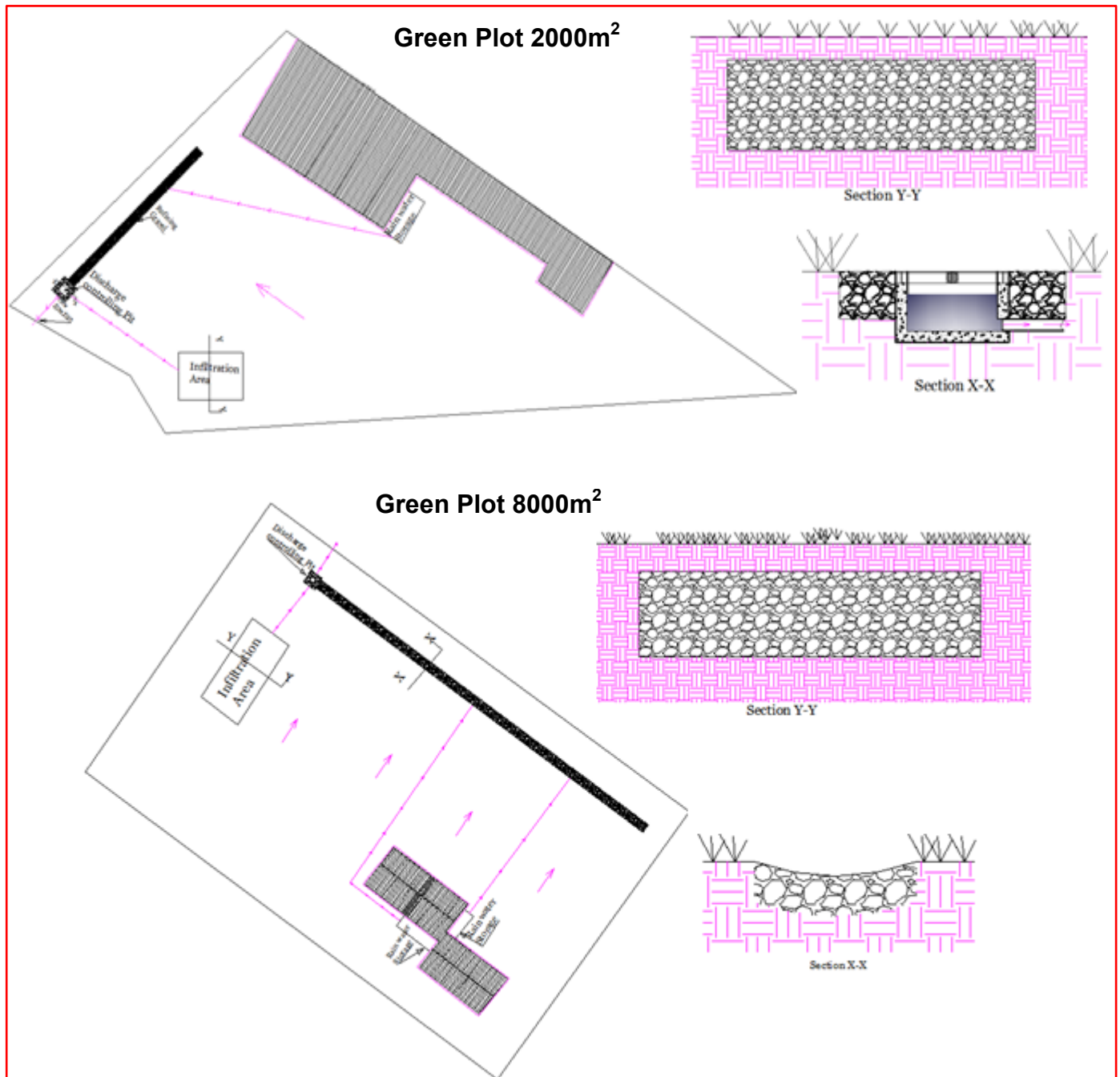


Figure 84 Green Plot Area of 2000 and 8000 Square Meters (Source; Own)

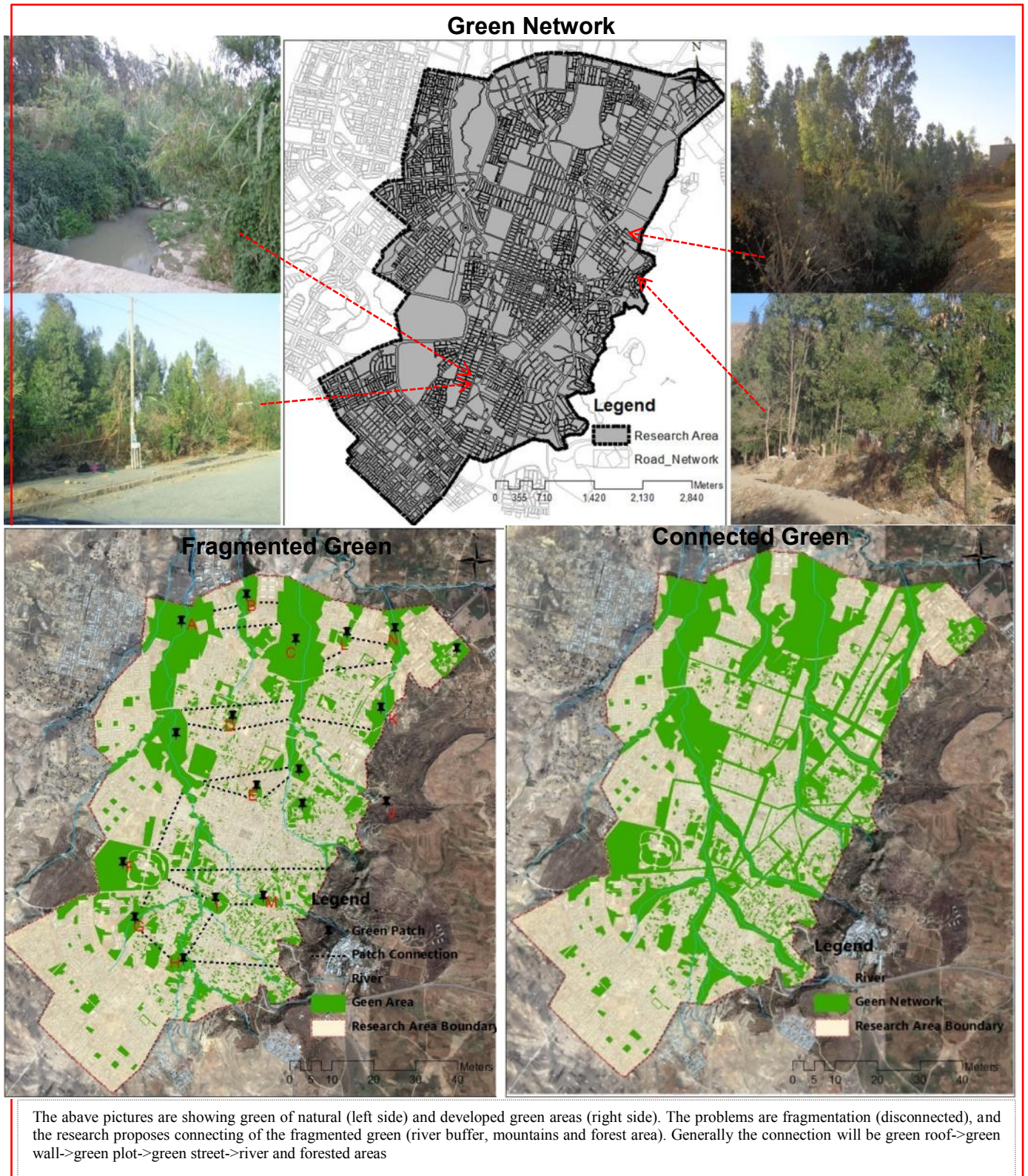


Figure 85 Fragmented and Connected Green Areas (Source; Own)

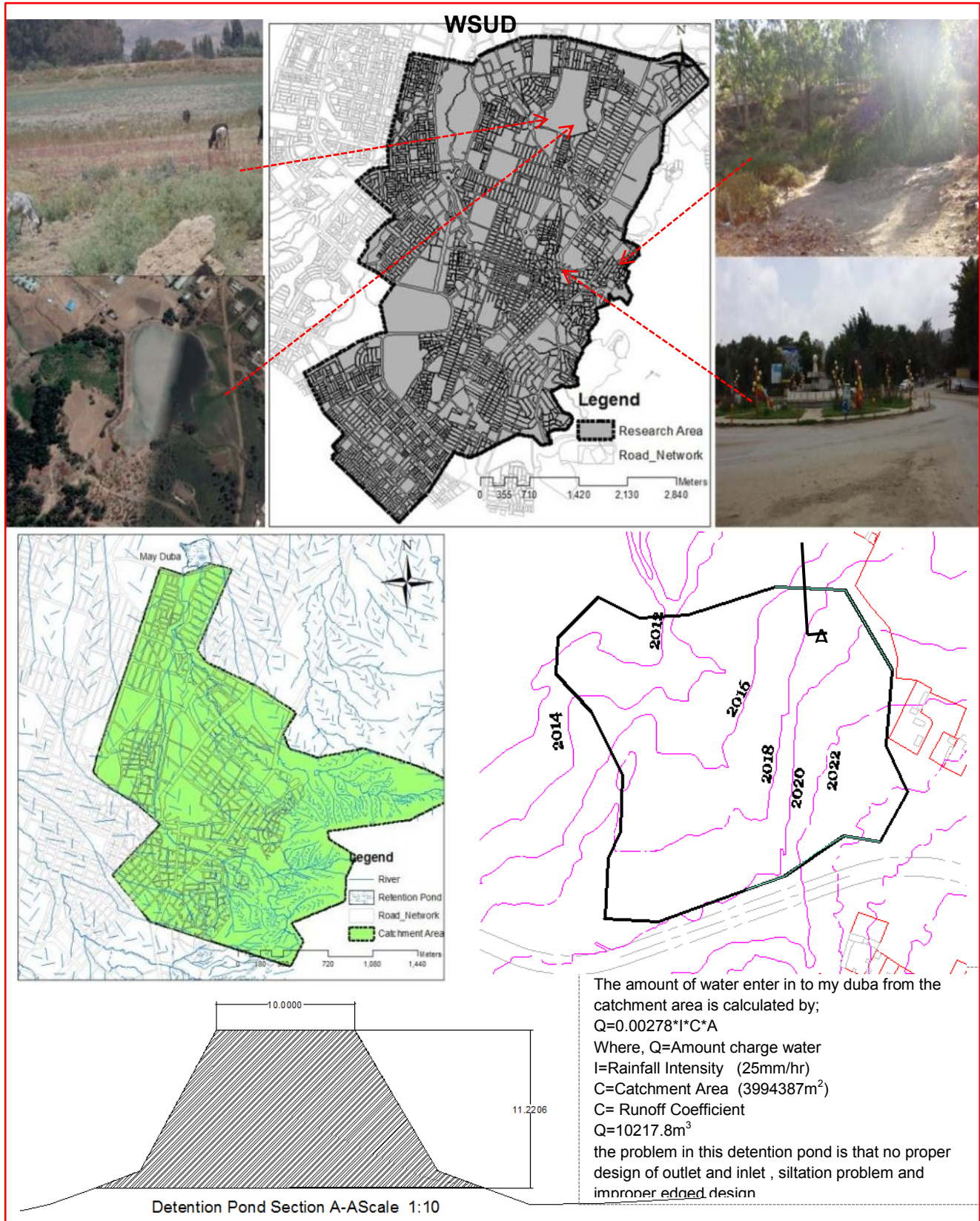


Figure 86 WSUD of Wetlands (Source; Own)

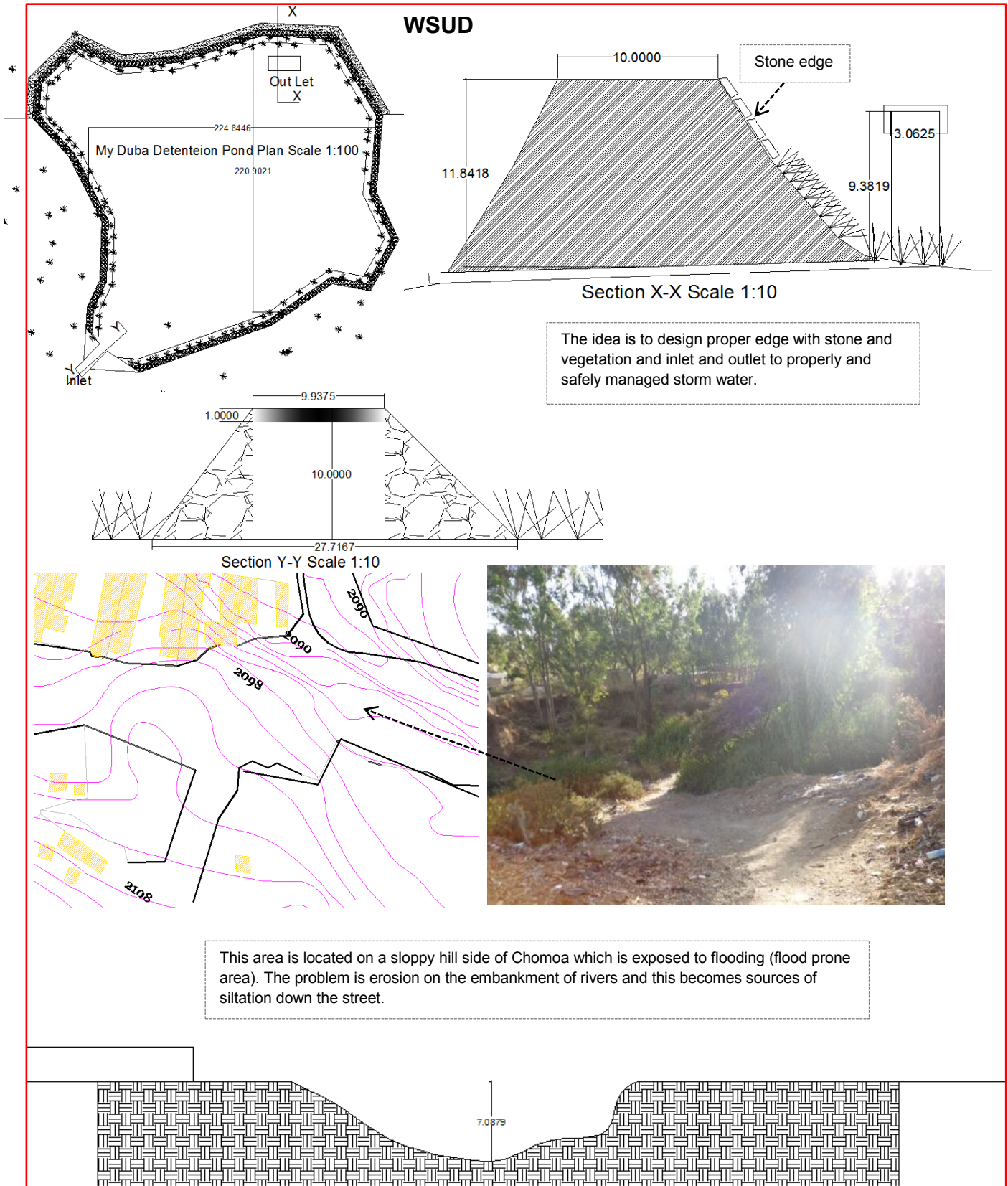


Figure 87 WSUD of Erroded Areas (Source; Own)

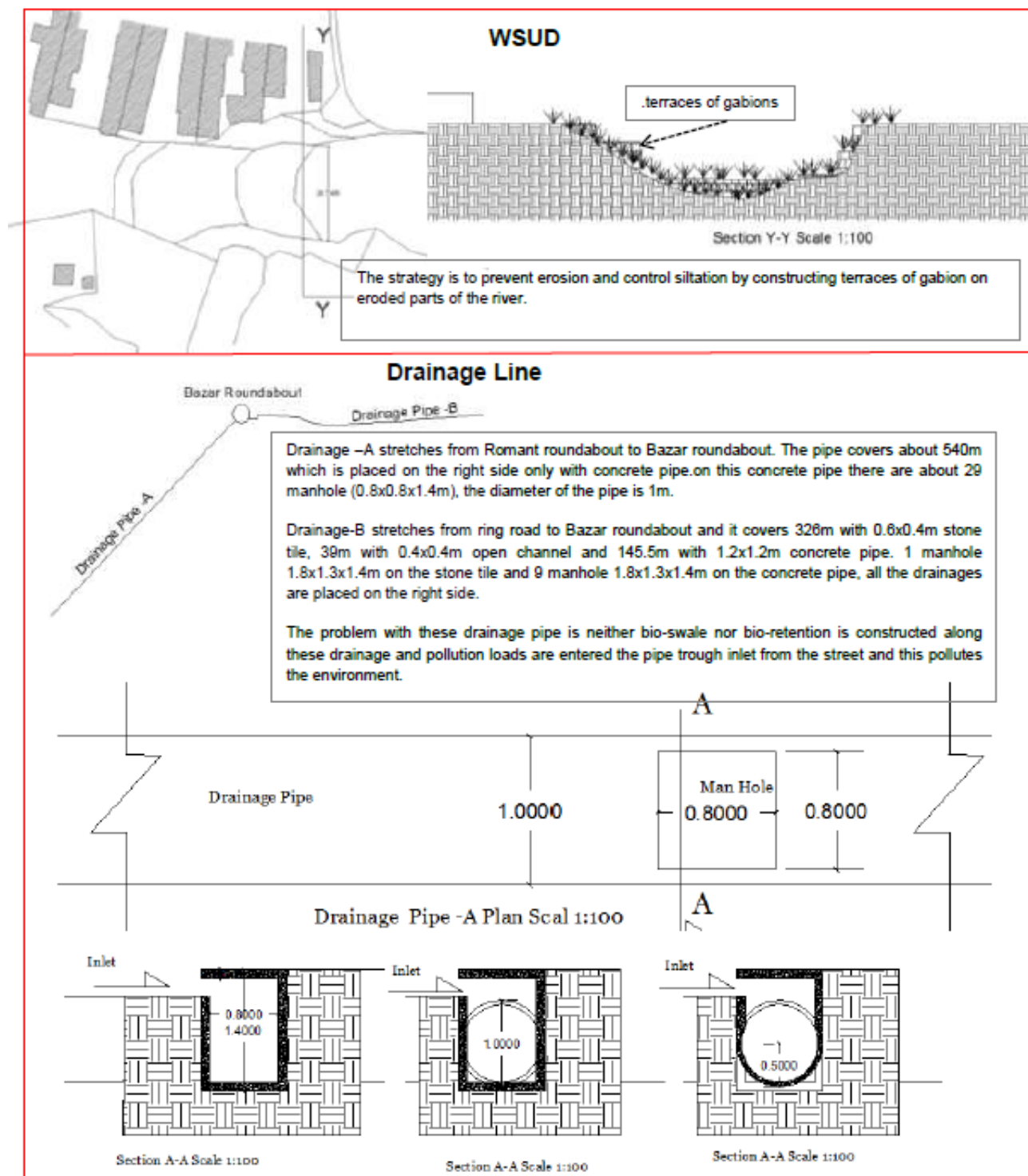


Figure 88 Drainage Line (Source: Own)

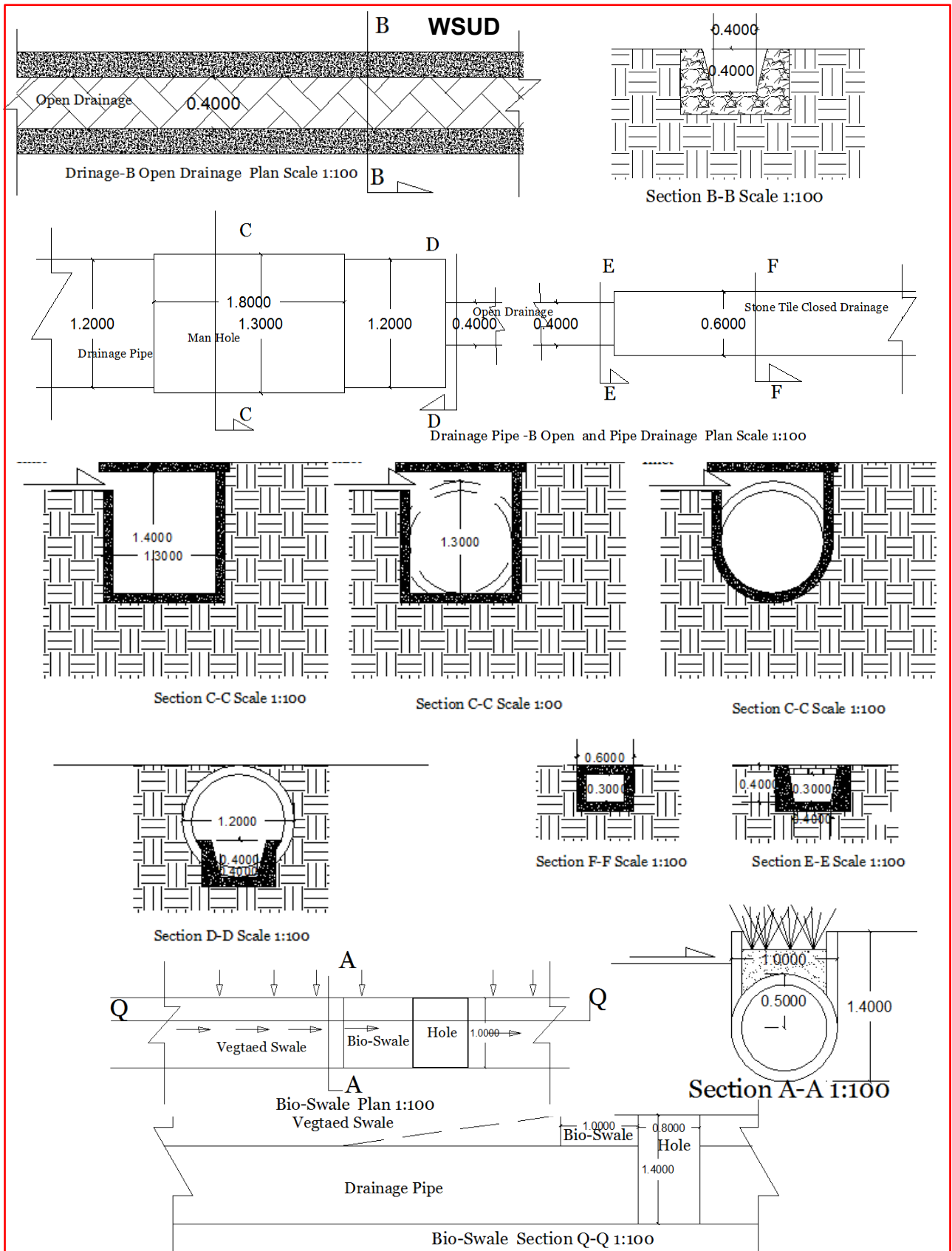


Figure 89 Drainage Line WSUD(Source: Own)

6.2. Implementation

In applying this proposal three important things are needed. These are finance, manpower and construction materials. Finance case loan micro finance. Manpower organizing local people with cooperative manner or small scale industry cooperative organized by local administrative and other responsible governmental body (kebelle, woreda and municipal of Mekelle) or volunteer entrepreneur. Construction material case local materials are used. These are ash, manure (dung of animal) from local villages, stone from local quarry sites, gabion, plastic box and irrigation pipe from Bruh Tesfa Plastic factory in Mekelle, pot caly (clay box) local art work in Gembela area and Ceramic tile from Addigrat-Quiha Tile factory in Mekelle. By the above mentioned mechanisms green infrastructure can be applied. All the above mentioned sites and villages are accessible by car.

Table 28 Resource Area Location Distannce

No.	Sources of Construction material villages and sites	Distance from Mekelle city(km)	No.	Sources of Construction material villages and sites	Distance from Mekelle city (km)
1.	Debri	8.5	7.	Mymekden	11
2.	Grakili	3	8.	Aynalem	3.66
3.	Srawat	5.1	9.	Gergembez	6.42
4.	Messebo	9.4	10.	Shafat	5.8
5	Gembela	7.74	11.	Fellegdaro	7.01
6.	Dagia	6.7	12.	Lachi	9

(Source: Own)

6.3. Management

To change the design proposals in to ground, management is very essential to facilitate the process and to make efficient. The management can be done by different governmental bodies (hierarchically) will manage it. They include mekelle city beautification bureau, mekelle urban agriculture, environmental protection agency, Tigrai water enterprise and mekelle municipality.

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APPENDICES

Appendix I Walkway and Drainage Data

a. Walkway

Walkway-Name	Position	Walkway-pavement-Type	Curve-Type	Length	Width
Zeselase Adebaby-Transe Adebabay	Left Side			0	0
Higher Court -Team garage	Left Side			0	0
Higher Court -Teame Garage	Right Side			0	0
Zeselase Adebaby-Transe Adebabay	Right Side			0	0
Demti Weyane -Dejen memehedar	Right Side	Concrete	Concrete	0.67	4.85
Mesfen-Referral Hospital	Left Side	Concrete	Concrete	2.403	4
Mesfen-Referral Hospital	Right Side	Concrete	Concrete	2.403	4
Mekelle Universty-Elala	Left Side	Concrete	Concrete	3.05	2
Mekelle Universty-Elala	Right Side	Concrete	Concrete	3.14	2
castel Adebaby- 18 Taxi	Left Side	Concrete	Concrete	1.403	5
castel Adebaby- 18 Taxi	Right Side	Concrete	Concrete	1.403	5
Demti Weyane -Dejen memehedar	Left Side	Concrete	Concrete	0.68	4.65
Castel Adebabay -Teame garage	Right Side	Concrete	Concrete	370	3.5
castel Adebaby Adebabay -Teame garage	Left Side	Concrete	Concrete	380	8
Hawezian-Encodo mesemer	Left Side	Tile	Concrete	1.403	5
Romanat -castel Adebaby	Right Side	Tile	Concrete	538	2.3
Romanat -castel adebaby	Left Side	Tile	Concrete	538	3
Zeselase Adebaby-Romanat adebabay	Right Side	Tile	Concrete	420	2.2
Romanat -Atsey Yowhanns	Left Side	Tile	Concrete	431	5.5
Romanat -Atsey Yowhanns	Right Side	Tile	Concrete	431	4.4
Hawezian-Encodo mesemer	Right Side	Tile	Concrete	1.403	5
Zeselase Adebaby-Romanat Adebabay	Left Side	Tile	Concrete	420	2.3

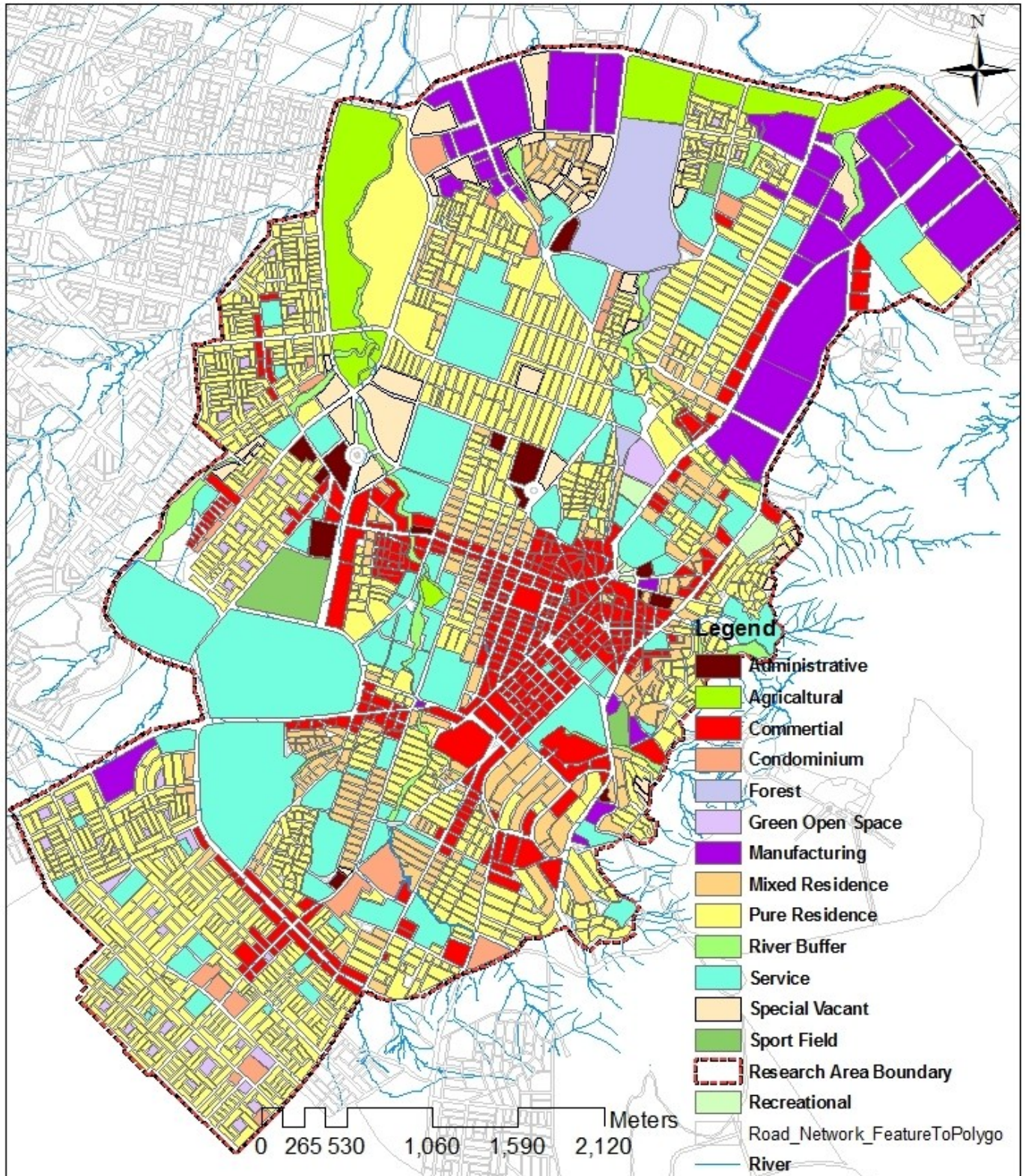
(Source: Mekelle City, Municipality, 2011)

b. Drainage

Drainage Location	Drainage Categories	Drainage position	Length (m)	Diameter(m)	Height (m)
Aberha castel Adebabay-Teame garage	Concrete Pipe	Lifside	175	1.05	1.05
Aberha castel Adebabay -Teame garage	Concrete Pipe	Lifside	150	0.8	0.8
Aberha castel Adebabay-Teame garage	Concrete Pipe	Lifside	285	0.8	0.8
haweziiane Adebabay-Encodo(dedebt Micro Finance)	Concrete Pipe	Lifside	1000	1.2	1.2
haweziiane Adebabay-Encodo(dedebt Micro Finance)	Concrete Pipe	Lifside	378	0.8	0.8
Hawzen Adebabay - Encodo Bridge	Concrete Pipe	Midian	20	0.6	0.6
haweziiane Adebabay-Encodo(dedebt Micro Finance)	Concrete Pipe	Right Side	378	0.8	0.8
Aberha Castel Adebabay-hawelti bridge	Concrete Pipe	Lifside	197	0.8	0.8
Hawelti Deldel-Dehan Kuni Mekelle	Concrete Pipe	Lifside	3000	1.2	1.2
Hawelti Deldel-Dehan Kuni Mekelle	Concrete Pipe	Right Side	3000	1.2	1.2
Abraha Castle Adebabay - 18 taxi Line	Concrete Pipe	Lifside	1352	0.8	0.8
Abraha Castle - 18 taxi Mecheresha	Concrete Pipe	Lifside	1373	0.8	0.8
Mesfin Industrial - Referral Hospital	Concrete Pipe	Right Side	860.85	0.8	0.8
Sheria Court-Adishundhun	Concrete Pipe	Lifside	3065	1.2	1.2
Sheria Court-Adishundhun	Concrete Pipe	Right Side	3065	1.2	1.2
Semen Eze-Serawt	Open Channell	Right Side	1210	0.8	1.5
Encodo health Office	Concrete Pipe	Right Side	14	0.8	0.8
Encodo- health Office	Masonry Channel	Lifside	195.7	0.8	0.8
Encodo -heath Office	Concrete Pipe	Lifside	14	1.2	1.2
Encodo -heath Office	Stone Tile	Right Side	17	1	0.6
Encodo -heath Office	Concrete Pipe	Lifside	51	1.2	1.2
Transe Ethiopia-Arid Universty	Concrete Pipe	Lifside	16	0.6	0.6
Transe Ethiopia-Arid Universty	Concrete Pipe	Midian	1445	0.6	0.6
Transe Ethiopia-Arid Universty	Concrete Pipe	Right Side	216	0.8	0.8
Transe Ethiopia-Arid Universty	Concrete Pipe	Lifside	143.8	1.05	1.05
Transe Ethipoia -Arid Universty	Masonry Channel	Lifside	424.2	1	0.8
Transe Ethipoia -Arid Universty	Stone Tile	Lifside	191.3	1	0.4
Transe Ethiopia-Arid Universty	Concrete Pipe	Lifside	21	0.8	0.8
Transe Ethipoia -Arid Universty	Masonry Channel	Right Side	223	0.6	0.8
Transe Ethipoia -Arid Universty	Stone Tile	Right Side	214	0.6	0.4
Transe Ethiopia-Arid Universty	Concrete Pipe	Right Side	8	0.6	0.6
Transe Ethipoia -Arid Universty	Concrete Pipe	Right Side	2218	0.6	0.6
Transe Ethipoia -Arid Universty	Open Channell	Right Side	40	0.8	0.9
Trans Adebabay-Lachi	Stone Tile	Lifside	383	1	0.6
TransAdebabay -Lachi	Concrete Pipe	Lifside	29	1	1
Trans Adebabay -Lachi	Stone Tile	Lifside	303.1	0.6	0.3
TransAdebabay-Lachi	Concrete Pipe	Lifside	18	0.6	0.6
TransAdebabay -Lachi	Masonry Channel	Lifside	69	0.6	0.8
Trans Adebabay-Lachi	Stone Tile	Right Side	564	0.8	0.6
Trans Adebabay - Lachi	Open Channell	Right Side	80	0.8	0.8
Trans Adebabay -Lachi	Open Channell	Right Side	136	0.8	0.8
MayeWeyni School-Bussiness College	Concrete Pipe	Lifside	2800	1.2	1.2
MayeWeyni School-Bussiness College	Concrete Pipe	Right Side	2800	1.2	1.2
AyderN kebabian-Keray Abayeti Store	Open Channell	Right Side	0.8	1.5	1

(Source: Mekelle City, Municipality, 2011)

Appendix II Existing Land Use of Mekelle City



(Source: Own)

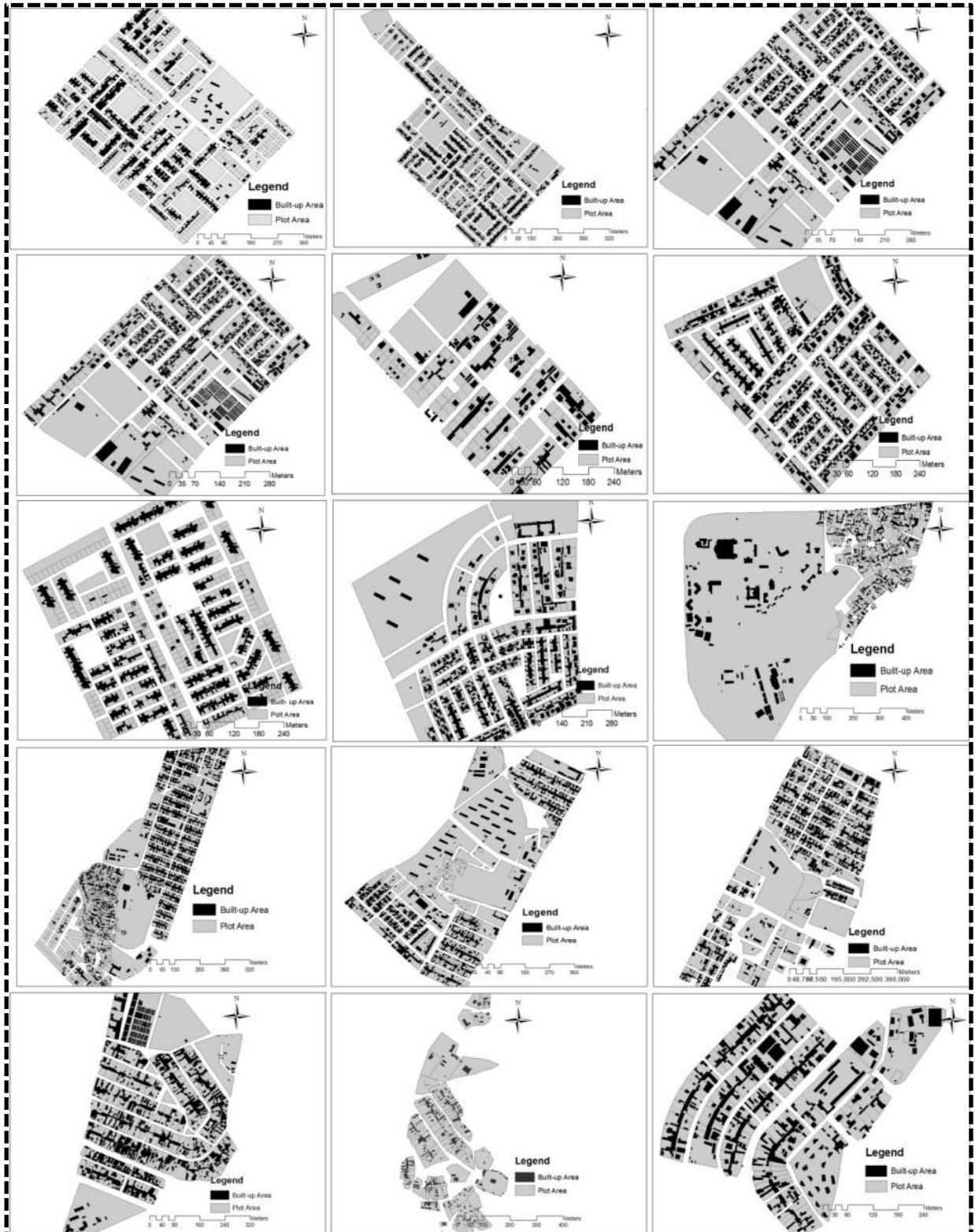
Appendix III Base Map of Mekelle City



(Source: Mekelle City, Municipality, 2011)

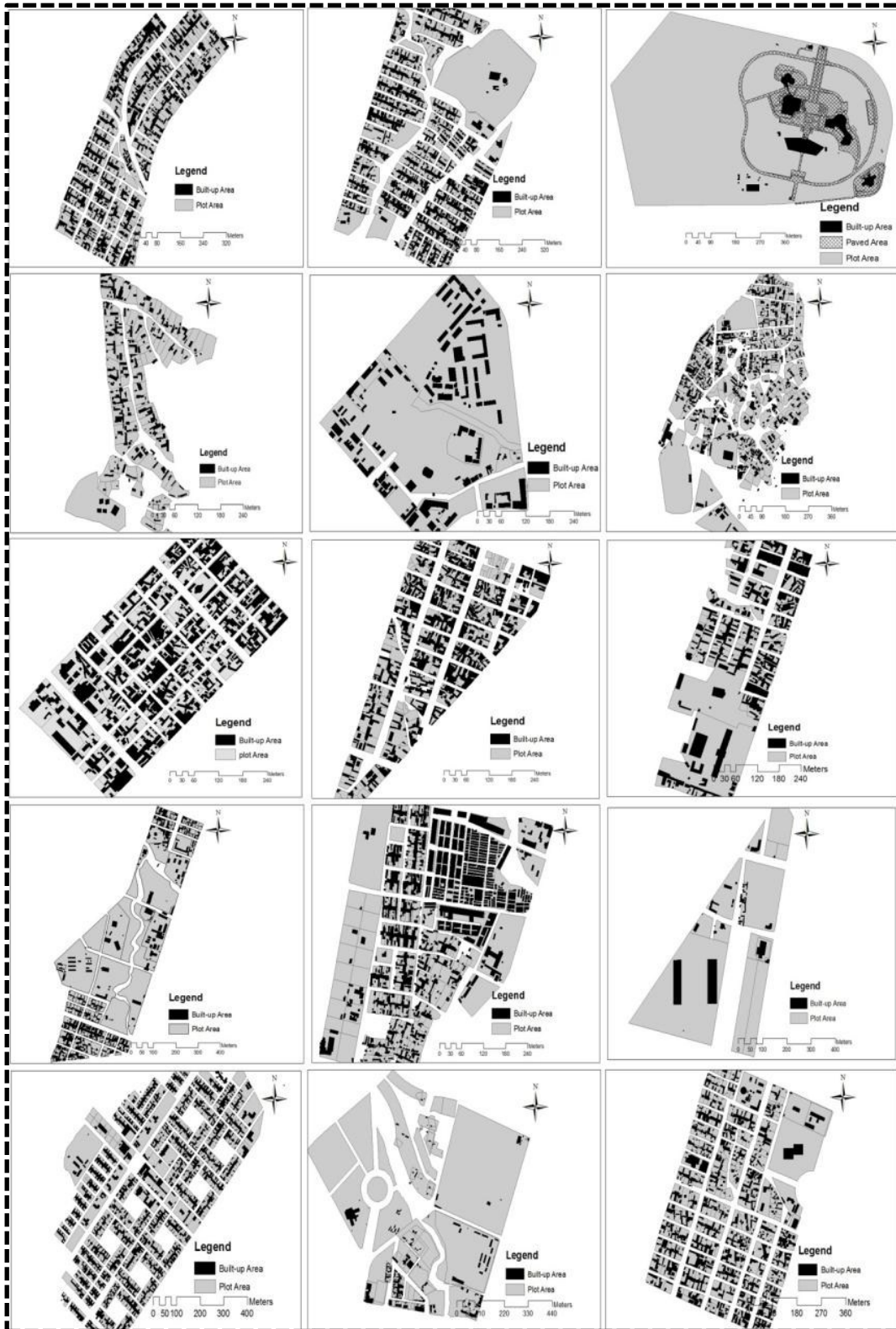
Appendix IV Research Area Block (1-56) Maps

a. Built-up Area Block 1-15



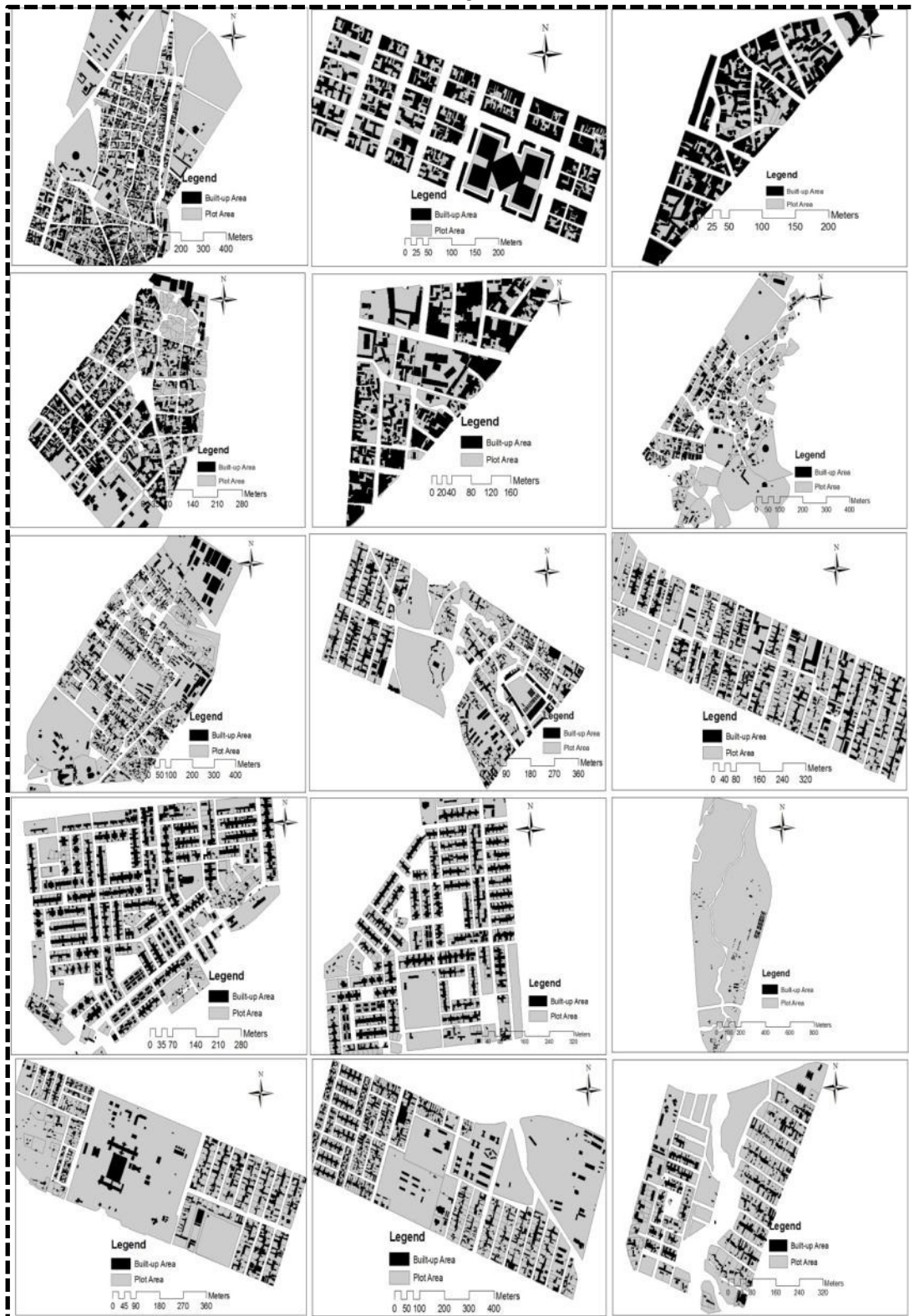
(Source; Own)

b. Built-up Area Block 16-30



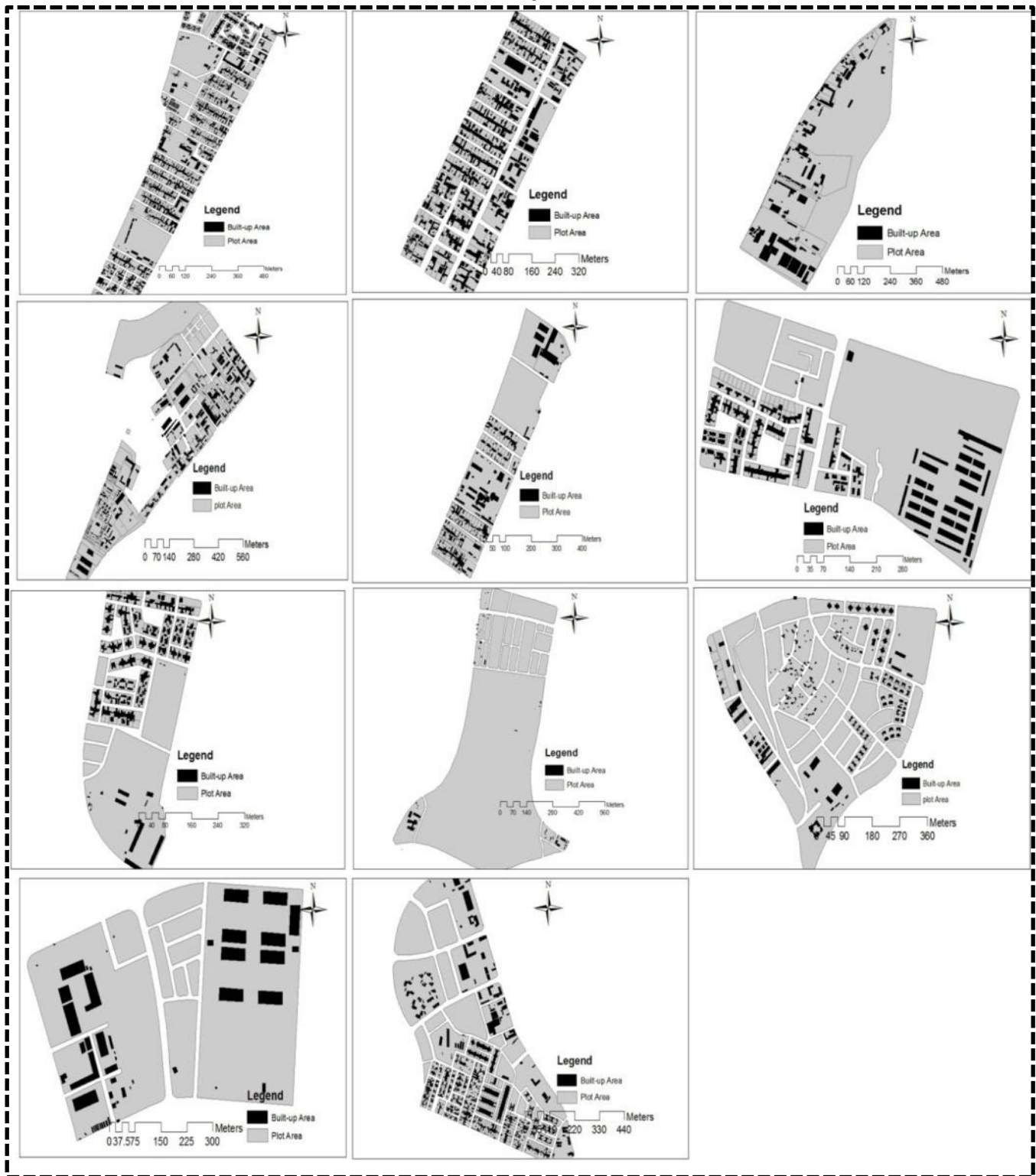
(Source; Own)

c. Built-up Area Block 31-45



(Source; Own)

d. Built-up Area Block 46-56



(Source; Own)

Appendix VI Blocks (1-56) Building Data

a. Building construction material, Roofing and Building Stories Block (1-11)

Block	Construction Material (Wall)		Roofing		Building stories	
	Type	Number of Buildings	Type	Number of Buildings	Type	Number of Buildings
1	Stone	300	Hidmo	0	G ¹⁰ -G ¹	550
	Concrete	500	Flat	0	G ¹² -G ⁴	192
	Metal	0	Gabled	800	G ¹⁵ -G ⁷	58
	Mud	0	Hut	0	>G ¹⁸	0
2	Stone	416	Hidmo	0	G ¹⁰ -G ¹	600
	Concrete	500	Flat	0	G ¹² -G ⁴	253
	Metal	0	Gabled	916	G ¹⁵ -G ⁷	63
	Mud	0	Hut	0	>G ¹⁸	0
3	Stone	752	Hidmo	0	G ¹⁰ -G ¹	1298
	Concrete	807	Flat	10	G ¹² -G ⁴	209
	Metal	0	Gabled	1549	G ¹⁵ -G ⁷	52
	Mud	0	Hut	0	>G ¹⁸	0
4	Stone	382	Hidmo	0	G ¹⁰ -G ¹	674
	Concrete	600	Flat	0	G ¹² -G ⁴	302
	Metal	50	Gabled	1032	G ¹⁵ -G ⁷	56
	Mud	0	Hut	0	>G ¹⁸	0
5	Stone	152	Hidmo	0	G ¹⁰ -G ¹	185
	Concrete	104	Flat	0	G ¹² -G ⁴	53
	Metal	0	Gabled	256	G ¹⁵ -G ⁷	18
	Mud	0	Hut	0	>G ¹⁸	0
6	Stone	460	Hidmo	0	G ¹⁰ -G ¹	820
	Concrete	589	Flat	0	G ¹² -G ⁴	206
	Metal	0	Gabled	1049	G ¹⁵ -G ⁷	23
	Mud	0	Hut	0	>G ¹⁸	0
7	Stone	222	Hidmo	0	G ¹⁰ -G ¹	387
	Concrete	350	Flat	0	G ¹² -G ⁴	186
	Metal	0	Gabled	573	G ¹⁵ -G ⁷	0
	Mud	0	Hut	0	>G ¹⁸	0
8	Stone	388	Hidmo	0	G ¹⁰ -G ¹	834
	Concrete	635	Flat	0	G ¹² -G ⁴	179
	Metal	0	Gabled	1023	G ¹⁵ -G ⁷	0
	Mud	0	Hut	0	>G ¹⁸	0
9	Stone	950	Hidmo	0	G ¹⁰ -G ¹	948
	Concrete	240	Flat	0	G ¹² -G ⁴	217
	Metal	0	Gabled	1190	G ¹⁵ -G ⁷	25
	Mud	15	Hut	0	>G ¹⁸	0
10	Stone	3487	Hidmo	0	G ¹⁰ -G ¹	3834
	Concrete	2100	Flat	0	G ¹² -G ⁴	1753
	Metal	0	Gabled	5573	G ¹⁵ -G ⁷	0
	Mud	35	Hut	14	>G ¹⁸	0
11	Stone	716	Hidmo	0	G ¹⁰ -G ¹	1993
	Concrete	1689	Flat	20	G ¹² -G ⁴	356
	Metal	0	Gabled	2385	G ¹⁵ -G ⁷	56
	Mud	0	Hut	0	>G ¹⁸	0

(Source: Own)

b. Building construction material, Roofing and Building Stories Block (12-23)

Block	Construction Material (Wall)		Roofing		Building stories	
	Type	Number of	Type	Number of	Type	Number of
12	Stone	625	Hidmo	0	G ¹⁰ -G ⁺¹	768
	Concrete	430	Flat	0	G ⁺² -G ⁺⁴	287
	Metal	0	Gabled	1055	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
13	Stone	667	Hidmo	0	G ¹⁰ -G ⁺¹	777
	Concrete	258	Flat	0	G ⁺² -G ⁺⁴	149
	Metal	34	Gabled	973	G ⁺⁵ -G ⁺⁷	47
	Mud	14	Hut	0	>G ⁺⁸	0
14	Stone	197	Hidmo	6	G ¹⁰ -G ⁺¹	276
	Concrete	89	Flat	0	G ⁺² -G ⁺⁴	10
	Metal	0	Gabled	276	G ⁺⁵ -G ⁺⁷	0
	Mud	20	Hut	10	>G ⁺⁸	0
15	Stone	361	Hidmo	0	G ¹⁰ -G ⁺¹	412
	Concrete	153	Flat	0	G ⁺² -G ⁺⁴	86
	Metal	0	Gabled	514	G ⁺⁵ -G ⁺⁷	16
	Mud	0	Hut	0	>G ⁺⁸	0
16	Stone	545	Hidmo	0	G ¹⁰ -G ⁺¹	653
	Concrete	257	Flat	0	G ⁺² -G ⁺⁴	149
	Metal	0	Gabled	802	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
17	Stone	1037	Hidmo	0	G ¹⁰ -G ⁺¹	1170
	Concrete	438	Flat	0	G ⁺² -G ⁺⁴	305
	Metal	0	Gabled	1475	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
18	Stone	1	Hidmo	0	G ¹⁰ -G ⁺¹	0
	Concrete	6	Flat	6	G ⁺² -G ⁺⁴	5
	Metal	0	Gabled	1	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
19	Stone	200	Hidmo	0	G ¹⁰ -G ⁺¹	225
	Concrete	37	Flat	0	G ⁺² -G ⁺⁴	26
	Metal	0	Gabled	251	G ⁺⁵ -G ⁺⁷	0
	Mud	14	Hut	0	>G ⁺⁸	0
20	Stone	44	Hidmo	0	G ¹⁰ -G ⁺¹	96
	Concrete	90	Flat	3	G ⁺² -G ⁺⁴	36
	Metal	0	Gabled	131	G ⁺⁵ -G ⁺⁷	2
	Mud	0	Hut	0	>G ⁺⁸	0
21	Stone	447	Hidmo	10	G ¹⁰ -G ⁺¹	678
	Concrete	264	Flat	4	G ⁺² -G ⁺⁴	56
	Metal	0	Gabled	712	G ⁺⁵ -G ⁺⁷	0
	Mud	23	Hut	8	>G ⁺⁸	0
22	Stone	466	Hidmo	0	G ¹⁰ -G ⁺¹	530
	Concrete	312	Flat	4	G ⁺² -G ⁺⁴	243
	Metal	0	Gabled	774	G ⁺⁵ -G ⁺⁷	5
	Mud	0	Hut	0	>G ⁺⁸	1
23	Stone	488	Hidmo	0	G ¹⁰ -G ⁺¹	533
	Concrete	301	Flat	5	G ⁺² -G ⁺⁴	235
	Metal	0	Gabled	789	G ⁺⁵ -G ⁺⁷	21
	Mud	0	Hut	0	>G ⁺⁸	0

(Source: Own)

c. Building construction material, Roofing and Building Stories Block (24-34)

Block	Construction Material (Wall)		Roofing		Building stories	
	Type	Number of	Type	Number of	Type	Number of
24	Stone	227	Hidmo	0	G ⁰ -G ⁺¹	353
	Concrete	192	Flat	0	G ⁺² -G ⁺⁴	56
	Metal	0	Gabled	419	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
25	Stone	602	Hidmo	0	G ⁰ -G ⁺¹	637
	Concrete	351	Flat	0	G ⁺² -G ⁺⁴	321
	Metal	0	Gabled	960	G ⁺⁵ -G ⁺⁷	12
	Mud	17	Hut	10	>G ⁺⁸	0
26	Stone	188	Hidmo	0	G ⁰ -G ⁺¹	396
	Concrete	230	Flat	0	G ⁺² -G ⁺⁴	67
	Metal	83	Gabled	501	G ⁺⁵ -G ⁺⁷	18
	Mud	0	Hut	0	>G ⁺⁸	20
27	Stone	23	Hidmo	0	G ⁰ -G ⁺¹	26
	Concrete	28	Flat	5	G ⁺² -G ⁺⁴	20
	Metal	0	Gabled	51	G ⁺⁵ -G ⁺⁷	5
	Mud	0	Hut	0	>G ⁺⁸	0
28	Stone	769	Hidmo	0	G ⁰ -G ⁺¹	1086
	Concrete	925	Flat	32	G ⁺² -G ⁺⁴	459
	Metal	0	Gabled	1662	G ⁺⁵ -G ⁺⁷	149
	Mud	0	Hut	0	>G ⁺⁸	0
29	Stone	89	Hidmo	0	G ⁰ -G ⁺¹	109
	Concrete	96	Flat	3	G ⁺² -G ⁺⁴	56
	Metal	0	Gabled	182	G ⁺⁵ -G ⁺⁷	20
	Mud	0	Hut	0	>G ⁺⁸	0
30	Stone	717	Hidmo	0	G ⁰ -G ⁺¹	718
	Concrete	257	Flat	0	G ⁺² -G ⁺⁴	243
	Metal	0	Gabled	974	G ⁺⁵ -G ⁺⁷	13
	Mud	0	Hut	0	>G ⁺⁸	0
31	Stone	1000	Hidmo	98	G ⁰ -G ⁺¹	1013
	Concrete	300	Flat	0	G ⁺² -G ⁺⁴	287
	Metal	0	Gabled	1202	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
32	Stone	200	Hidmo	0	G ⁰ -G ⁺¹	696
	Concrete	620	Flat	8	G ⁺² -G ⁺⁴	124
	Metal	0	Gabled	537	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Barrel vault	275	>G ⁺⁸	0
33	Stone	622	Hidmo	0	G ⁰ -G ⁺¹	1072
	Concrete	600	Flat	8	G ⁺² -G ⁺⁴	150
	Metal	0	Gabled	1222	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
34	Stone	444	Hidmo	50	G ⁰ -G ⁺¹	645
	Concrete	565	Flat	0	G ⁺² -G ⁺⁴	364
	Metal	0	Gabled	959	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0

(Source: Own)

d. Building construction material, Roofing and Building Stories Block (35-45)

Block	Construction Material (Wall)		Roofing		Building stories	
	Type	Number of	Type	Number of	Type	Number of
35	Stone	294	Hidmo	0	G ¹⁰ -G ⁺¹	369
	Concrete	210	Flat	0	G ⁺² -G ⁺⁴	145
	Metal	0	Gabled	514	G ⁺⁵ -G ⁺⁷	0
	Mud	10	Hut	0	>G ⁺⁸	0
36	Stone	256	Hidmo	0	G ¹⁰ -G ⁺¹	356
	Concrete	98	Flat	0	G ⁺² -G ⁺⁴	24
	Metal	0	Gabled	380	G ⁺⁵ -G ⁺⁷	0
	Mud	26	Hut	14	>G ⁺⁸	0
37	Stone	656	Hidmo	0	G ¹⁰ -G ⁺¹	74
	Concrete	366	Flat	5	G ⁺² -G ⁺⁴	48
	Metal	0	Gabled	10117	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
38	Stone	538	Hidmo	0	G ¹⁰ -G ⁺¹	782
	Concrete	256	Flat	0	G ⁺² -G ⁺⁴	12
	Metal	0	Gabled	794	G ⁺⁵ -G ⁺⁷	0
	Mud	10	Hut	0	>G ⁺⁸	0
39	Stone	769	Hidmo	0	G ¹⁰ -G ⁺¹	899
	Concrete	140	Flat	0	G ⁺² -G ⁺⁴	10
	Metal	0	Gabled	909	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
40	Stone	853	Hidmo	0	G ¹⁰ -G ⁺¹	1318
	Concrete	865	Flat	0	G ⁺² -G ⁺⁴	400
	Metal	0	Gabled	1718	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
41	Stone	345	Hidmo	0	G ¹⁰ -G ⁺¹	710
	Concrete	654	Flat	0	G ⁺² -G ⁺⁴	289
	Metal	0	Gabled	999	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
42	Stone	120	Hidmo	0	G ¹⁰ -G ⁺¹	138
	Concrete	10	Flat	0	G ⁺² -G ⁺⁴	0
	Metal	0	Gabled	138	G ⁺⁵ -G ⁺⁷	0
	Mud	8	Hut	0	>G ⁺⁸	0
43	Stone	467	Hidmo	0	G ¹⁰ -G ⁺¹	582
	Concrete	342	Flat	0	G ⁺² -G ⁺⁴	222
	Metal	0	Gabled	809	G ⁺⁵ -G ⁺⁷	5
	Mud	0	Hut	0	>G ⁺⁸	0
44	Stone	778	Hidmo	0	G ¹⁰ -G ⁺¹	1032
	Concrete	386	Flat	0	G ⁺² -G ⁺⁴	132
	Metal	0	Gabled	1164	G ⁺⁵ -G ⁺⁷	0
	Mud	0	Hut	0	>G ⁺⁸	0
45	Stone	423	Hidmo	0	G ¹⁰ -G ⁺¹	341
	Concrete	125	Flat	0	G ⁺² -G ⁺⁴	213
	Metal	0	Gabled	569	G ⁺⁵ -G ⁺⁷	15
	Mud	21	Hut	0	>G ⁺⁸	0

(Source: Own)

e. Building construction material, Roofing and Building Stories Block (46-56)

Block	Construction Material (Wall)		Roofing		Building stories	
	Type	Number of	Type	Number of	Type	Number of
46	Stone	1080	Hidmo	0	$G^{+0}-G^{+1}$	1367
	Concrete	321	Flat	0	$G^{+2}-G^{+4}$	43
	Metal	9	Gabled	1410	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
47	Stone	550	Hidmo	0	$G^{+0}-G^{+1}$	748
	Concrete	254	Flat	0	$G^{+2}-G^{+4}$	56
	Metal	0	Gabled	804	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
48	Stone	40	Hidmo	0	$G^{+0}-G^{+1}$	140
	Concrete	89	Flat	0	$G^{+2}-G^{+4}$	12
	Metal	23	Gabled	152	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
49	Stone	372	Hidmo	0	$G^{+0}-G^{+1}$	707
	Concrete	354	Flat	0	$G^{+2}-G^{+4}$	54
	Metal	43	Gabled	769	$G^{+5}-G^{+7}$	8
	Mud	0	Hut	0	$>G^{+8}$	0
50	Stone	246	Hidmo	0	$G^{+0}-G^{+1}$	352
	Concrete	95	Flat	0	$G^{+2}-G^{+4}$	12
	Metal	23	Gabled	364	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
51	Stone	135	Hidmo	0	$G^{+0}-G^{+1}$	264
	Concrete	120	Flat	0	$G^{+2}-G^{+4}$	23
	Metal	32	Gabled	287	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
52	Stone	200	Hidmo	0	$G^{+0}-G^{+1}$	382
	Concrete	184	Flat	0	$G^{+2}-G^{+4}$	12
	Metal	10	Gabled	394	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
53	Stone	20	Hidmo	0	$G^{+0}-G^{+1}$	40
	Concrete	40	Flat	0	$G^{+2}-G^{+4}$	20
	Metal	0	Gabled	60	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
54	Stone	120	Hidmo	0	$G^{+0}-G^{+1}$	240
	Concrete	120	Flat	0	$G^{+2}-G^{+4}$	53
	Metal	53	Gabled	293	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
55	Stone	13	Hidmo	0	$G^{+0}-G^{+1}$	57
	Concrete	12	Flat	0	$G^{+2}-G^{+4}$	0
	Metal	32	Gabled	57	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0
56	Stone	245	Hidmo	0	$G^{+0}-G^{+1}$	414
	Concrete	256	Flat	0	$G^{+2}-G^{+4}$	130
	Metal	43	Gabled	544	$G^{+5}-G^{+7}$	0
	Mud	0	Hut	0	$>G^{+8}$	0

(Source: Own)