Improving Stormwater Management Capacity of Cobblestone Paved Local Streets through Green Infrastructure Design and Technologies (*The Case of Resedential District in the Eastern and North Eastern Part of Addis Ababa*)

Thesis Submitted to the Ethiopian institute of Architecture Building construction and City Development for the Partial Fulfillment of the Requirements for the degree of Master of Science in Urban Design and Development

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This thesis is submitted to Ethiopian Institute of Architecture, Building Construction and City Development (EiABC) and to the school of Graduate Studies of Addis Ababa University in partial fulfillment of the requirement for the Masters degree in Urban Design and Development.

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DECLARATION

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

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CONFIRMATION

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

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Semptember 2016

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ACRONYMS

AACRA	Addis Ababa City Road Authority
AAWSA	Addis Ababa Water and Sewerage Authority
BCPDO	Bole sub-city Community Participation Development Office
CBGB`	City Beautification and Greening Bureau
CLUVA	Climate Change and Urban Vulnerability in Africa
CPCO	Cobblestone Project Coordination Office
CPDA	Community Participation Development Agency
CPDO	Community Participation Development Office
CSWM	Conventional Stormwater Management Techniques
EPA	Environmental Protection Authority
ERA	Ethiopian Road Authority
FAO	Food and Agriculture Organization
GI	Green Infrastructure
GIS	Geographical Information System
GS	Green Street
MUDC	Ministry of Urban Development and Construction
MWUD	Ministry of Works and Urban Development
NMA	National Metrology Agency
OAAOSZIDP	The Office of Addis Ababa and the Surrounding Oromia Special Zone Integrated Development Plan
SI	System International
SSWM	Sustainable Stormwater Management
US	United States

USEPA	United Sates Environmental Protection Agency
YCPDO	Yeka sub-city Community Participation Development Office

LOCAL TERMS

Ato	Local word for Mr.
Woreda	Local administrative unit
Sefer	Local term for Neighborhood

ABSTRACT

Addis Ababa is currently undergoing city wide transformation with respect to its built environment and provision of basic infrastructure services. Local street construction with cobblestone pavement is one of the infrastructure development implemented in every part of the city. However, the constructed local streets in many parts of the city are deteriorating within a short time after construction. Therefore, the main objective of the study is; to device green infrastructure design and technologies for the local streets of Addis Ababa in order to reduce the impact of stormwater runoff and at the same time to enhance environmental quality of the city neighborhood.

In order to accomplish the objective, research methods were developed for each specific objective. Case study method is then used in the research, by selecting two areas in Addis Ababa that are found in the same local watershed, based on appropriate criteria. Consequently, the existing situation of local streets and impact of stormwater runoff in the study areas is analyzed.

Based on the research findings, the research proposes site specific green street design and technologies for the local streets of the study area. Moreover, the research tested and illustrated the upscale effect of green infrastructure practices on watershed level using Arc GIS platform.

Key words: Cobblestone pavement, local watershed, green Street, upscale effect

ORGANIZATION OF THE THESIS

This thesis is organized into seven chapters.

Chapter one contains brief introduction of the research problem, objectives, research question significance, scope and limitation of the Study.

Chapter two presents the research methods and methodologies chosen for this specific study, and why it is chosen is briefly discussed, based on the objective of the research.

In the third chapter literature on the subject of green infrastructure, Stormwater management related to Local Street, factors influencing applicability of Green Street practices and modeling tools for measuring the impact of GS technologies is discussed in detail.

Chapter four covers contextual study of streets, stormwater management, GS practices and factors dictating GS practice in the city in general.

Chapter five of this thesis describes the characteristics of the watershed area and detail analysis of the two case study areas in the framework of the literature review.

Chapter six presents, the data obtained from the primary and secondary data sources.

The Final chapter briefly summarizes findings of the study, conclusions and design recommendations. The recommendation includes different site specific designs that can improve the local street drainage systems. Additionally, the effect of this design on the watershed level is also presented.

CHAPTER ONE

INTRODUCTION

1.1. Introduction

Recently, people are living in and migrating to cities at high rate throughout the world. This continuous movement to cities has resulted in extension of urban boundaries which causes more damage to the environment. Over time, the development of high-density urban areas with residential and commercial developments has resulted in an increase in paved (impervious) areas and a reduction in green spaces (previous areas). As a result, during the storm event there is an increase in peak flows where more runoff is generated and flows faster into the conventional drainage system over a shorter period of time. This stormwater that runs over the impervious areas in cities is called stormwater runoff. It is recognized as a major source of flooding: which causes damage to infrastructure in many parts of the urban communities worldwide (Pazwash, 2011).

During the past decade, Addis Ababa the capital of Ethiopia, has exhibited to be one of the rapidly developing cities of Africa. The city has undergone several transformations with respect to its built environment and provision of basic infrastructure services. According to Hayal et al. (2003) "this rapid development has resulted in the removal of vegetation, forests and converting green spaces into built environment". This in turn has a negative impact on the general environment and existing infrastructures (Hayal et al., 2011).

URAdapt 2013 report (On the strategic agenda for adaptation to urban water-mediated impacts of climate change in Addis Ababa) the existing road infrastructure of the city is more vulnerable to flooding due to the likely increase in intensity of rainfall and under-design of drainage systems. Out of the current road networks of 4148 km in the city, about 1,662 km of road is vulnerable to the impacts of stormwater runoff as this was not considered during the design (URAdapt, 2013). Therefore, this study tried to focus on how Addis Ababa can reduce local street deterioration through integration of green infrastructure development.

1.2. Problem Statement

The process of urbanization not only destroys the vegetation cover, but also alters the natural course of water flow. The increase in urbanization leads to the construction of more roads, sidewalks, and buildings. This results in reducing natural permeable surface that can infiltrate water into the ground. As a result, the impermeable surface will create flooding and more stormwater runoff (Pazwash, 2011).

Addis Ababa, the capital of Ethiopia, is also currently undertaking citywide construction of infrastructure, buildings, parking lots, etc. This has changed the land use from being largely unbuilt to a built-up area. The total current area of Addis Ababa is approximately 518 km2 with built up area of 169.02 km2. Road coverage constituting 15.64% of the built up area. Out of the current road networks of 4148 km in the city, about 2002 km is paved with asphalt and 727km is paved with cobblestone (AACRA, 2015).

Recently, local street construction with cobblestone pavement is one of the infrastructure developments implemented in many parts of the city. This road construction appears to bring social, economic and environmental benefits at the local and national level. Lots of jobs created for the people. It is cost-effective compared to concrete or asphalt roads. It makes town and cities more beautiful and benefits residents. Moreover, it is easy to maintain and has a much longer lifespan than asphalt roads (MUDC, 2012).

However, in the design as well as construction of cobble stone paved local streets in Addis Ababa, some environmental aspects seem to be neglected (MUDC, 2013). For example, these streets appear to lack shade (like trees) and proper integration of stormwater drainage facilities. As a result, it is common to see local streets that are significantly damaged by overflowing during high rain event and heat stress during dry seasons. Consequently, these streets appear to deteriorate or decrease in their quality within a short time after construction. If appropriate measure is not taken, the problem could create further damage to the infrastructure and the environment. Therefore, this study has tried to focus on integration of green infrastructure technologies to local street design. It also tried to develop designs that can guide future local street developments in the city.

1.3. Objectives

General objective

- To device GI design and technologies for the local streets of Addis Ababa in order to reduce the impact of stormwater runoff and at the same time to enhance environmental quality of the city neighborhood

Specific objectives

- To identify the major factors that dictate the applicability of GI practices
- To analyze the existing situation of local streets
- To find out the impact of stormwater runoff within the study areas
- To identify and design appropriate GI technologies for the local streets within the study area
- To test the upscale effect of the designed technologies in the watershed area

1.4. Research question

Main question

- What are the appropriate GI design and technologies that can be integrated in the local streets of Addis Ababa in order to minimize the impact of stormwater runoff and enhance environmental quality of the city neighborhood?

Sub questions

- What are the major factors that dictate the applicability of GI practices?
- What are the major impacts of stormwater runoff in the study areas?
- What is the existing situation of local streets in the study area?
- How can local street drainage system in the study areas be improved?
- What is the upscale effect of the designed technologies in the watershed area?

1.5. Significance

The study tried to add new ideas in the area of local street drainage and stormwater management. Therefore, it could be used as a guide for professionals like urban designers, planners, etc. working in the area of street and stormwater management. Additionally, it could serve as the basis for making guideline; for the future design and construction of local streets. The findings from this research could also provide valuable information that can be used as an input or reference for further studies in this area. Generally, the beneficiaries from the outcome of this research are academician (could use it as a reference), researchers (could conduct similar or further studies in other areas), government officials (could use it as a guide or an input) and the general public.

1.6. Scope

The thematic scope of this study address issues only related to street stormwater management. The specific focus of this research also includes the design and integration of GI technologies for the local streets of the study area. However, the construction, engineering design and management aspects of local streets are not part of this study.

In order to understand the issue briefly, two case study areas were selected in Addis Ababa. The city is currently divided into 10 sub cities and 116 woredas (local administrative unit). The first case study area is located in Yeka subcity, woreda 9 locally known as Lamberet Abunaregawi sefer and the second case study area is located in Bole Subcity, Woreda 6 locally known as Mekerbetoch sefer.

1.7. Site selection criteria

A. Local streets that have a width between 4m to 15m

   Even though there are different classification of streets based on different criteria for the purpose of this research, local streets are selected based on functional classification.

   Local roads or streets refer to those roads constructed with Cobblestones. This Cobblestone road construction sector is a new emerging practice applied in some selected cities of Ethiopia including Addis Ababa since 2008 and 2009. Furthermore, there is a strategy to scale-up and still scaling-up to other parts of the country.

B. Local strets that fall on the high (>15) and low (0-5) slope classifications

   Addis Ababa is characterized by steep mountains and undulating type of topography. However, for the purpose of this research areas that have slope >15% and areas that is found in 0%- 5% slope is selected.

C. Local streets that have been affected by stormwater runoff

   After selecting areas that fall under the above mentioned criteria, the researcher then tried to identify the local streets that have been affected by stormwater runoff. These streets were identified through the data obtained from the public participation office of the respected sub city.

D. Landuse

Local streets that are found in the residential part of the city or street that primarily provides access to local residences.

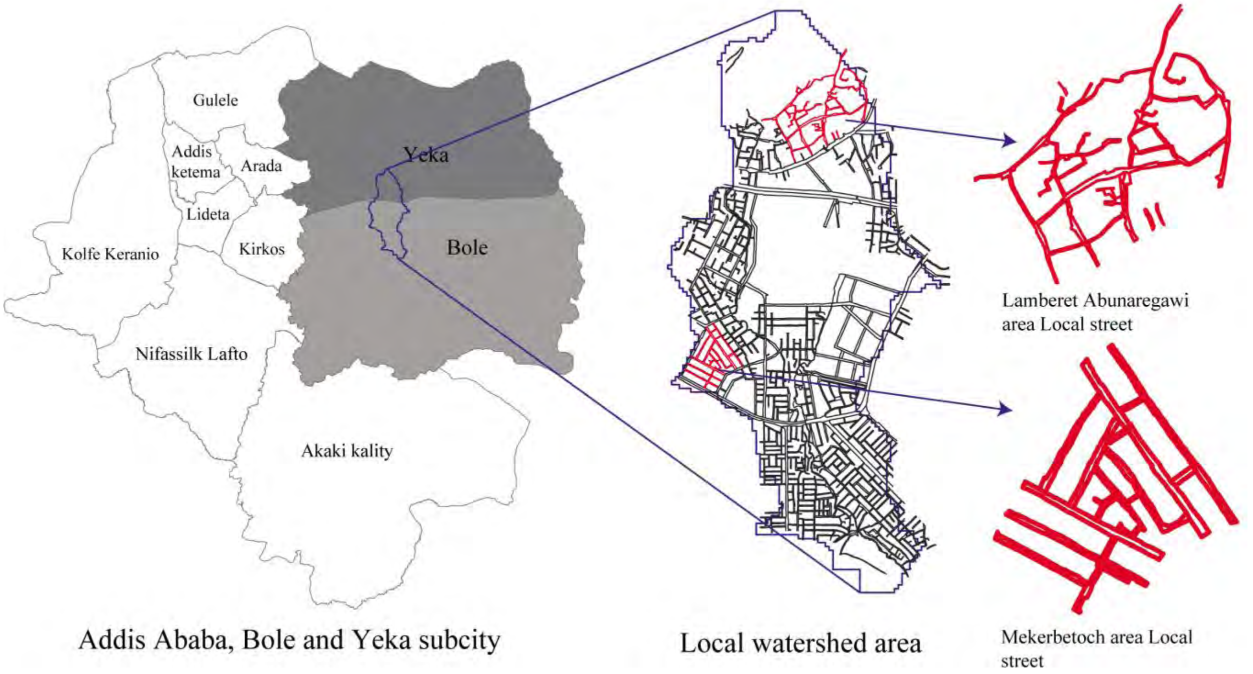


Figure1. 1 Location map of the study area (Source: Author, 2016)

1.8. Limitation of the study

Different challenges had been encountered while conducting this research. Lack of organized data in Yeka and Bole sub city was one of the challenging factors. Moreover, lack of professionals related to the issue being studied was also the main challenge. The researcher also faced lack of focused literature and local researches in relation to local street and cobblestone pavements.

Last but not least was a financial constraint for conducting soil test and lack of compatible software with the available data provided for the analysis was also one of the limitations. Therefore, the researcher was forced to use secondary data sources for soil infiltration test and other related compatible software's for conducting this research.

1.9. Research design

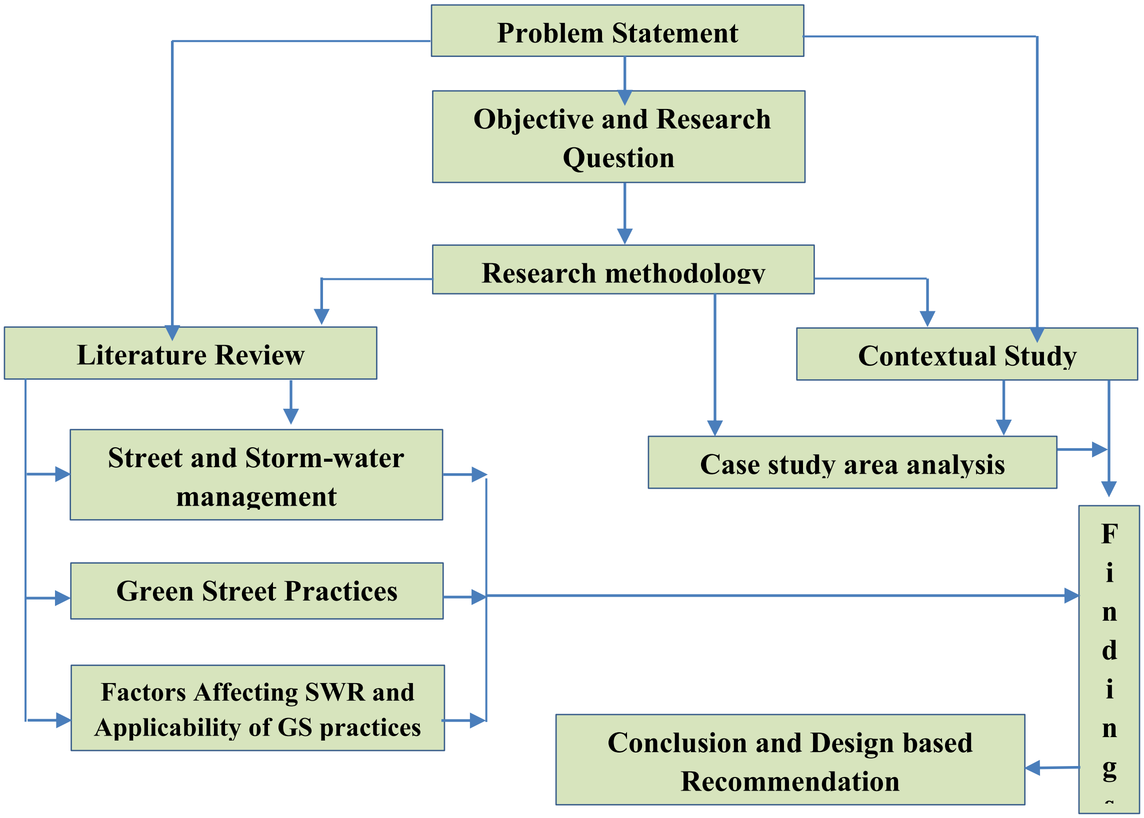


Figure1. 2 Study flow chart (Source: Author, 2016)

CHAPTER TWO

RESEARCH METHODS

2.1 Research methods

2.1.1. Type of study

The researcher has selected case study as a method. Because, this method is open to the use of theory or conceptual categories that can guide the research and analysis of data. Additionally, it gives an opportunity to see the holistic view of the process. Moreover, case study method reveals more about a particular subject than any other methods. Therefore, the researcher has selected two case areas based on appropriate criteria as discussed in chapter one.

2.1.2. Data type and source

After the case study areas were selected; the data required for this thesis has been gathered through interviews and observations (primary data) accompanied with secondary data through reading and scanning.

Primary data

Interviews with the officials were conducted in the selected office like officials of AACRA, MUDC, CPDO, and CPCO. In addition to conducting interviews in offices and local residents on-site observations were made with special focus on existing major problems related to drainage, vegetation and slope. Photographs were also taken during the observation and are presented in this thesis.

Secondary data

Secondary data collection was also performed through reading of books, researches, journals, articles and web based source that were related to the research objectives.

2.1.3. Methods of data collection and analysis for each objective

The data collection techniques and methods of data analysis for each objective are briefly discussed as follows.

Specific objective one: To analyze the major factors that dictates applicability of GI practices

Data collection

- Quantitative and qualitative Data were collected from different purposefully selected office like OAAOSZIDP, EPA, CBGB, NMA and MUDC. Different related researches, journals and articles related to the objective were also referred.

Data analysis

- Maps were analyzed in Arc GIS and table, charts, sketch and explanatory diagrams were used to identify the streets that are vulnerable to the impact of stormwater runoff.

Specific objective two: To analyze the existing situation of local streets and impact of stormwater runoff in the study areas

Data collection

- Primary data were gathered from selected sites using personal observations (taking photographs) and formal and informal interviews with the local community within the study areas. Secondary data were also gathered from different reports, similar researches and studies on the issue in Addis Ababa.

Data analysis

- The data that were obtained from interview, observation, reports, researches etc. The collected data were analyzed qualitatively in the framework of the major factors dictating the applicability of GI practices and influence the flow of stormwater.

Specific objective three: To identify and design GI technologies for the study area local streets

Data collection

- Qualitative data from different books like street stormwater management, Porous pavements, green street, and etc. were referred. In addition, concepts obtained from different green infrastructure and stormwater management manuals were also included.
- Quantitative data were constructed from data that were obtained from an Ethiopian metrology agency like (rain fall data), OAAOSZIDP (soil map, water depth map, land use map, street network map) and MUDC (street standards, guidelines and construction manual).

Data analysis

- The collected data like the soil map, landuse map, waterdepth map and contour map were analyzed in the Arc GIS software (by using spatial analyst tool) and excel integrate with the rainfall data. Finally the results were presented in charts, maps and tables.

Specific objective four: To test the upscale effect of the designed technologies in the watershed area

Data collection

- The green street design that was made for the selected local streets were used as an input

Data analysis

- In Arc GIS software the researcher tested the upscale effect of implementing green infrastructure design at watershed level.

2.1.4. Methodological framework

In order to look the problem in depth the researcher has selected triangulation as methodology. Triangulation is a type of methodology which is made by combining both qualitative and quantitative type of research (Dawson, 2007). The study began by selecting representative case study areas based on appropriate criteria's. After that primary and secondary data were collected. The qualitative data collected were used to construct the methodological framework. This framework was used as a methodological tool; to identify the factors that affect the applicability of GI practices and to perform a contextual and case study analysis. The developed methodological framework helped to understand the research problem in a holistic manner at the city level (macro scale) and watershed level (meso scale). Additionally the case study areas (micro scale) were also analyzed in detail based on the framework.

The Quantitative data obtained from rainfall, soil, runoff, and the slope was also analyzed in detail with the software's like Arc GIS and SWMM. Finally, based on the results obtained from the quantitative and qualitative analysis, recommendation and conclusion are drawn.

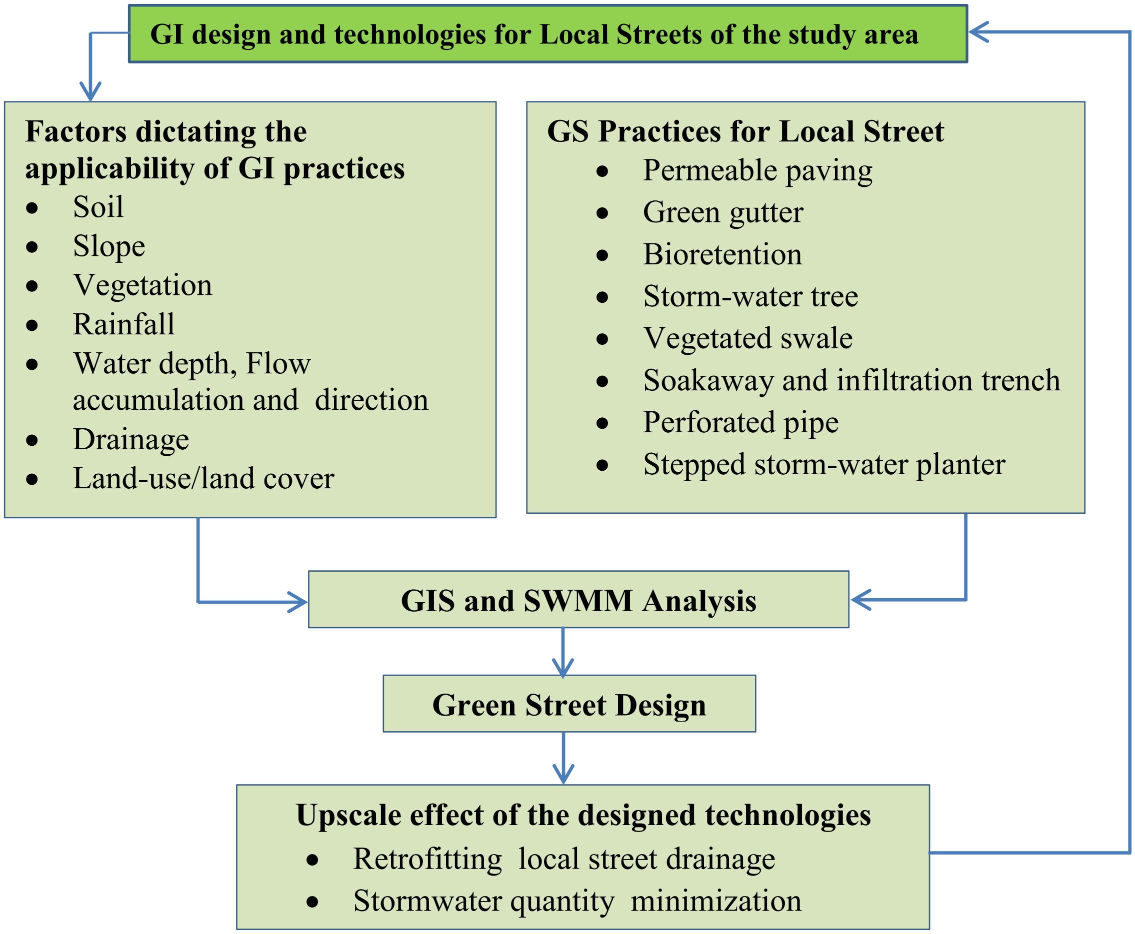


Figure 2. 1 Methodological framework (Source: Author, 2016)

Table 2. 1 Summary of data Collection methods and techniques (Source: Author, 2016)

Specific Objectives	**Description**	**Type of Data**	**Data source**	**Conceptual Framework**	**Data collection**	**Analysis**	**Result**
Objective 1	Major factors that influence the flow of stormwater and dictate the applicability of GI practices	Books, Report, journals, researches, articles	AACRA, OAAOS ZIDP, MUDC CPCO, Internet, EPA,	Soil, Drainage, Vegetation, Rainfall Water depth, Flow accumulation and direction Land-use/land cover	Reading, Scanning, copying and writing	Conceptual framework VS Data	Summary of Major factors that affect stormwater and dictates applicability of GI practices

Objective 2	Existing situation of local street in the study area related to environmental issues and impact of stormwater runoff	Soil type, water depth, slope, land use, Street network map, Drainage map reports, researches, rainfall	Yeka sub-city CPCO, key informants, OAAOS ZIDP, CPCO AAWSA, AACRA, ERA, EPA, NMA	Soil, Drainage, Vegetation, Rainfall Water depth, Flow accumulation and direction Land-use/land cover	Physical observation, questionnaires, interview, Reading,	Conceptual framework VS Data GIS, SWMM	Summary of findings on the existing situation of local streets in the study area
Objective 3	Identification and design GI technologies for the study area local streets	Books, Report, journals, similar researches, articles	Internet Websites AACRA, OAAOS ZIDP, EPA, and CPCO	Permeable paving, Green gutter, Bioretention, Vegetated swale Soakaw y and infiltration trench Perforated pipe Stepped stormwater planter	Reading, Scanning, copying and writing	Conceptual framework VS Data GIS, Auto CAD, SWMM	Summary of GI technologies for local streets and Design of local streets integrated with GI practices
Objective 4	Testing upscale effect of the designed technologies in the watershed area	Shape file, DWG file	Result of the GS design	GS design	-	GIS	Watershed level map

CHAPTER THREE

LITERATURE REVIEW

3.1 Street

Streets are not just a path way for transportation from one destination to another. In fact, they are public realms with multipurpose functions (Syms, 2010). For example, local streets are vital constituents in residential areas in changing the overall quality of the environment. But, in order to have quality environment streets need to have environmental comfort (e.g. Shade from sun, wind, etc.) and physical comfort (e.g. Comfortable and sufficient seating, etc.) (Carmona et al., 2003). According to Carmona et al., (2003) Comfort is among the prerequisite of successful public realms. This sense of comfort may also be enhanced by the physical design of the streets and or by its management strategies. "Better-designed streets; therefore, contribute significantly to the quality of the built environment and play a key role in the creation of environmental quality" (Syms, 2010).

Streets are classified into different categories based on their function such as (Local, Collector, Arterial, etc.). These Streets are designed not only to carry traffic, but stormwater runoff as well. The main purpose is for traffic movement therefore, the drainage purpose is passive and must not interfere with the traffic function of the street (Urban Runoff Management Plan, 2010). However, stormwater runoff in the street exceeds tolerable limits and interferes with the primary function, especially at high rain events.

3.1.1. Stormwater management

Stormwater management system is a tool for managing stormwater runoff from rainfall (Pazwash, 2011). Naturally, this water flows from fields to stream from stream to rivers and so on. However, development has changed some of these natural flows and has led to overflowing concerns (Pazwash, 2011). As a result, stormwater management system is required in order to deal with the overflows. Therefore, a sustainable stormwater management on the street has a potential to bring street comfort through shading and reducing peak stormwater runoff volumes. Additionally, Streets that integrate natural, landscape based features in order to infiltrate, reuse, or evapotranspire stormwater, could bring environmental sustainability (Foster et al., 2011).

3.1.2. Conventional stormwater management techniques (CSWM)

Traditionally, stormwater runoff on the streets has been managed with expensive engineering technologies (Muschalla, 2001). This type of practice is called Conventional stormwater management. CSM techniques are designed to collect and transport street stormwater runoff as quick as possible through drainage channels and pipes (conventional drainage) from urban areas (Zhou, 2014). This type of method will only transport stormwater from one section of the basin to another in order to avoid street flooding in urban areas. However, Zhou (2014) & Pazwash (2011) and other different researches showed the lack of long-term sustainability of CSWM. Because, this practice involves many structural components such as pipes, concretes, and underground basins. Additionally, when this CSWM were designed they were intended to carry both stormwater and sanitary sewage in the same pipe. These CSWM systems transport wastewater directly to the sewage treatment plant, but during heavy rainfall, the wastewater volume in a combined sewer system can exceed the capacity of the system and leads to overflowing. As a result, the street and its infrastructures are damaged and the time and cost needed for maintenance and installation of the damaged drainage system are very high. Furthermore, when there is a need for expansion of this type, drainage system, it is very hard because the system is inflexible to change and very complex to adapt to current circumstances in an area. Due to this reason, one must find sustainable and flexible systems when dealing with stormwater management.

3.1.3. Sustainable stormwater management (SSWM)

There are different terms of SSWM systems in the world that are highly recommended and applied. However, the term used to express this system is dissimilar in different regions, even if the idea is the similar Pazwash (2011). The term Sustainable Urban Drainage System (SUDS) is used in Europe; Water Sensitive Urban Design (WSUD) is a common name in Australia (Zhou, 2014). In the United States of America the term Low-Impact Development (LID) or sometimes referred to as green infrastructure (GI) which, is used to describe sustainable urban drainage systems (SUDS).

On any land development the negative impacts of urban stormwater runoff will reduce if the natural systems are implemented during street development (Pazwash, 2011). This can be accomplished by using the natural drainage system to infiltrate and divert storm-runoff into the natural landscape via landscape planters, rain gardens and swales. SSWM therefore, uses the above mentioned natural drainage systems and other methods in managing street stormwater runoff. The goal of sustainable stormwater management is to reduce stormwater runoff by treating the stormwater as close to the source as possible (on-site). "Treat" in this case does not mean to collect and discharge the stormwater to the public sewer system, as it would be treated conventionally, but to reduce runoff by using technologies for stormwater infiltration and evaporation.

Table 3. 1 Advantages and Disadvantages of Sustainable st:mwater managem)t (Source : Pazwash, 2011)

Advantages of SSWM	Disadvantages SSWM
• Avoids damages on streets and infrastructures	• Risk of clogging in most of the system caused by high sedimentation rates
• Are very flexible features so they can be applied in different types of streets	• Applicability is limited to slope, soil, and other factors
• Proper drainage of surface run-off	• Expert planning, implementation, operation and maintenance required

3.1.4. Comparison of CSWM and SSWM

Application of Conventional stormwater management (CSWM) techniques, particularly on street transports and store runoff in large centralized facilities located at the base of drainage areas. Whereas, Sustainable stormwater management (SSWM) strategies control stormwater at the source, through the use of the existing landscape relatively easily, including vegetated or landscaped area (Allerton & Pittner, 2008). In the case of installing SSWM; the cost is very low than CSWM techniques and in addition to lowering costs, the techniques will help to retain stormwater runoff on site and promotes infiltration and groundwater recharge than conventional developments (Dhalla & Zimmer, 2010). Generally, SSWM strategies provide greater benefits over conventional stormwater management systems (see table 3.2).

Table 3. 2 Comparison between conventional and Sustainable stormwater strategies (Source: Allerton & Pittner, 2008 and Dhalla & Zimmer, 2010)

Factor	Conventional strategies	Sustainable stormwater strategies
Cost	- High construction cost for stormwater management ponds, pipes, inlet structures, curb and gutter infrastructure.	- More economical than conventional approaches due to fewer pipe and below-ground infrastructure requirements. - Has also to reduce the cost of constructing urban drainage.
Drainage	- High runoff conveyance capacity and efficiency, which reduces potential for flooding, but decreases groundwater recharge and changes the natural hydrology of the site	- Retains stormwater runoff on site and promotes infiltration (therefore reduced flooding) and groundwater recharge through and natural drainage features.

Environmental	- Conventional systems could have an overflow effect specially on high precipitation event and can cause flood, erosion	- Less disturbance of the landscape and conservation of natural features, thereby enhancing the aesthetic value - Include habitat enhancement, flood control, improved recreational opportunities
Ease of implementation	- Fewer obstacles with development or building regulations since the approach already existed in many areas.	- Can be constructed in highly urbanized areas, as well as newly developing areas, with various plot sizes.

3.1.5. Green infrastructure (GI)

GI is the type of practice on the streets that provides an opportunity to control and/or treat of stormwater runoff on site where runoff is generated; accordingly it offers volume reduction and water quality improvement (Kloss & Lukes, 2008).

Green infrastructure is defined as a group of techniques that utilize natural systems, or engineered systems that "mimic" natural landscapes to capture, cleanse, and reduce stormwater runoff using plants and soils (Kloss & Lukes, 2008).

From a hydrological perspective, GI measures can be arranged into three groups in light of their effects on the stormwater management process (Zhou, 2014). The principal group suggests to source control measures for keeping and constricting excess water overflow upstream, for example, infiltration surfaces, permeable pavements and green rooftops. The second group Site control measures concentrate on lessening and diminishing the impact of flood hazards on beneficiaries, for example, individual belongings protection and modification of the topography. The final group incorporates downstream measures concerning the conveyance capacity of the system (Zhou, 2014) (see figure3. 1).

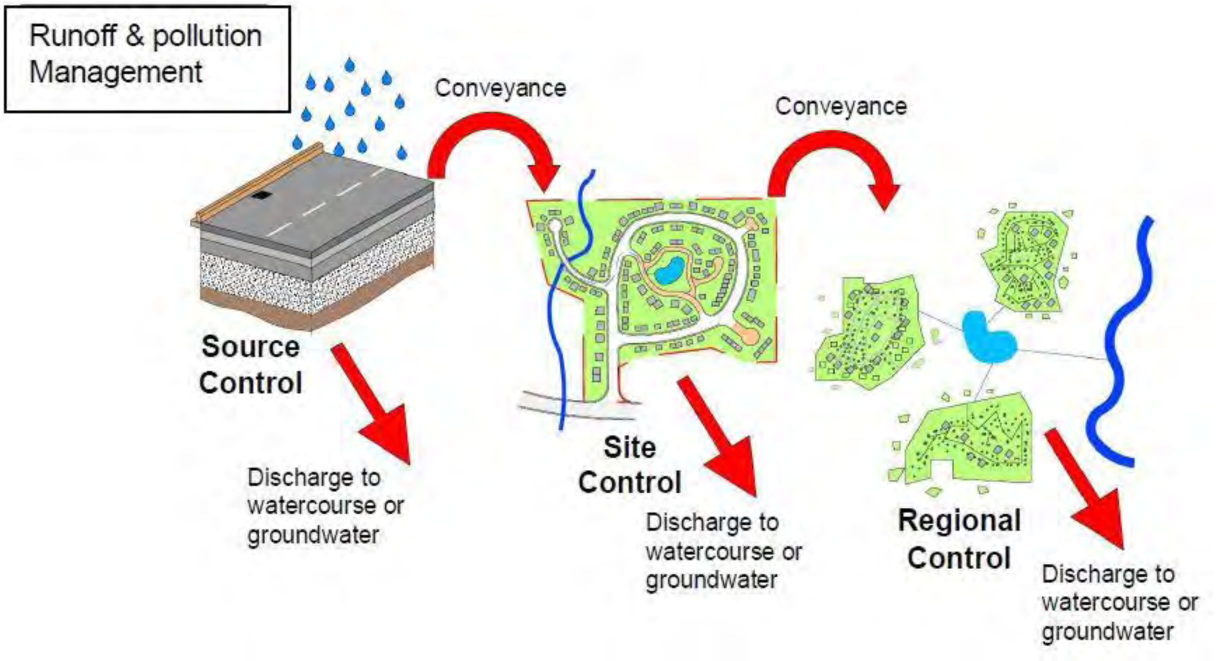


Figure 3. 1 The hierarchy of stormwater management strategy (Source: Allerton & Pittner, 2008)

GI technology solutions are often implemented with a single goal in mind, such as managing stormwater or reducing heat stress (Foster et al., 2011). However, GI developments have a wide range of multiple benefits on the same spatial area. For example, trees filter water, slow runoff, create cooling effects in the surrounding and clean air.

GI also plays an important role in reducing stormwater runoff volumes and peak flows by integrating the natural (soil, vegetation) or landscape based/ SSW management practices (Kloss & Lukes, 2008). In this way the permeable surface cover of an area will increase. This in turn will increase stormwater infiltration rates, reduce the volume of runoff entering into the combined or separate sewer systems, and finally in natural water bodies.

Summary

- Streets are designed not only to carry traffic, but also to convey stormwater from urban areas.
- When stormwater runoff in the street exceeds tolerable limits, a stormwater management system is required in order to deal with the overflows.
- There are two types of stormwater managements, these are CSWM and SSWM.
- Traditionally, stormwater runoff on the streets has been managed with CSWM systems.

- SSWM uses natural drainage systems which are economical, flexible and sustainable in managing stormwater runoff. However, CSWM practice is expensive, rigid and not sustainable.
- Sustainable stormwater management on the street has a potential to bring street comfort through shading and reducing peak stormwater runoff volumes.
- There are different terms of SSWM systems in the world that are highly recommended and applied. Green infrastructure is one of the SSWM systems that provide an opportunity to control and/or treat of stormwater runoff on site where runoff is generated.

In conclusion, integration of SSWM strategies on the streets has a greater benefit over CSWM.

3.2 Factors that dictate the applicability of GI practices

The flow of stormwater pattern and applicability of GI practices in a given watershed is dictated by different factors such as topography, imperviousness, soil type. For instance, according to Woods-Ballard et al., (2007), physiographic characteristics such as; topography and the characteristics of the soils and; geology underlying the site dictate the potential to implement GI practices and stormwater flow. Similarly, hydrogeologic characteristic; such as depth to watertable or depth to bedrock strongly influence the feasibility of applying different types of GI practices. Additionally UNEP (2003), also discussed that the land form (slope), soil (Texture, type, porosity), rainfall (intensity, duration) and other climatic factors like precipitation, have also impacts see (figure 3.2).

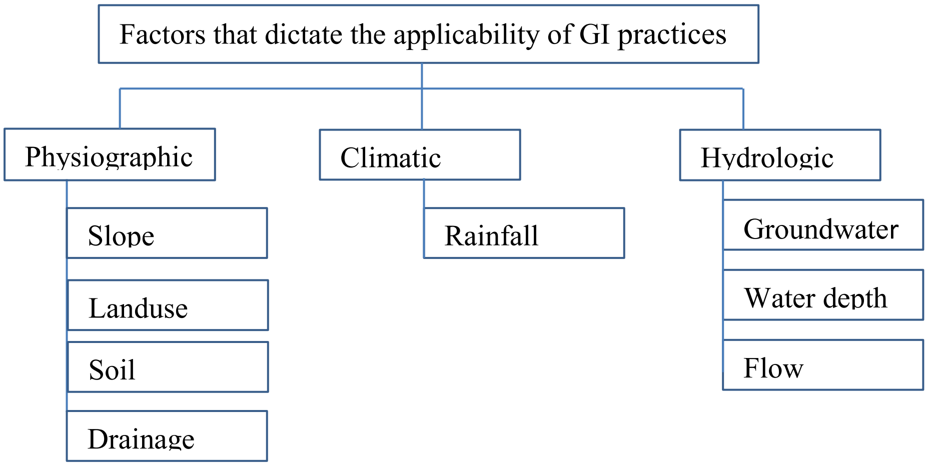


Figure 3. 2 Factors that dictate the applicability of GI design and technologies (Source: Woods-Ballard et al., 2007)

3.2.1. Physiographic factors

Topography and slope

Topography determines how fast stormwater moves from one point to another. For instance, local streets which are located on steep topography will have higher flow rates compared with runoff on a gentle slope. Topography also dictates how runoff will travel within and eventually out of the street development. Runoff will naturally travel towards lower part of the terrain because runoff water gets additional energy (velocity) due to slope and little time to infill rate (UNEP, 2003). Therefore, As a general principle; local street development plans and stormwater management practices should respect existing landform characteristics including maintaining predevelopment drainage divides and catchment area discharge point's as much as possible (UNEP, 2003).

Soil

The characteristics of soils within a site are key factors in designing stormwater management systems. The site's soil types and property should be determined to evaluate the site's ability to infiltrate stormwater and to identify suitable and unsuitable locations for siting GI practices.

Soil's which possess high permeability profile have the opportunity to apply GI practices that are infiltration based. In contrast to this, soil's which have low permeability requires other type of practices such as harvesting, evapotranspiration and detention as stormwater management strategies. (U.S. EPA, 2011).

Soil's ability to transmit water when submitted to a "hydraulic gradient" determines the ability of the soil fluid to flow through the soil under a specified "hydraulic gradient". Additionally, the soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition (U.S. EPA, 2011).

There are four hydrologic soil groups which contain sub groups of soils which have similar soil property (FAO, 2008) (see table 3.3).

Table 3. 3 Hydrologic groups of soils and their properties (Source: FAO, 2008)

Soil Group	Includes	Property
A	sand, loamy sand or sandy loam	− have low runoff potential and high infiltration rates even when thoroughly wetted(have a high rate of water transmission)
B	silt loam or loam	− have moderate infiltration rate when thoroughly wetted

	soils	− consists of chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures
C	sandy clay loam	− Low infiltration rates when thoroughly wetted and consists chiefly of soils with a layer that impedes downward movement of water and soils with a moderately fine to fine structure
D	clay loam, silty clay loam, sandy clay, silty clay, and clay	− has the highest runoff potential − have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with high swelling potential − soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface

Soil and the runoff varies with this various soil characteristics, particularly permeability and infiltration capacity (see table 3.4). Infiltration capacity is the maximum rate at which soils and rocks can absorb rainfall. The infiltration capacity tends to decrease as the soil moisture content of the surface layers increases (U.S. EPA, 2011). It also depends upon such factors as slope of the site, grain size and amount of vegetation cover.

Table 3. 4 Infiltration capacity of soils in different slope types

	Percent of slope				
Soil Texture, Type	**0-4%**	**5-8%**	**8-12%**	**12-16%**	**Over 16%**
Coarse Sand	31.8	25.4	19.1	12.7	7.9
Medium Sand	26.9	21.6	16.3	10.7	6.9
Fine Sand	23.9	19.1	14.2	9.7	6.1
Loamy Sand	22.4	17.8	13.5	8.9	5.6
Sandy Loam	19.1	15.2	11.4	7.6	4.8
Fine Sandy Loam	16.0	12.7	9.7	6.4	4.1
V. Fine Sandy Loam	15.0	11.9	8.9	6.1	3.8
Loam	13.7	10.9	8.4	5.6	3.6
Silt Loam	12.7	10.2	7.6	5.1	3.3
Silt	11.2	8.9	6.6	4.6	2.8
Sandy Clay	7.9	6.4	4.8	3.0	2.0
Clay Loam	6.4	5.1	3.8	2.5	1.5
Silty Clay	4.8	3.8	2.8	2.0	1.3
Clay	3.3	2.5	2.0	1.3	0.8

Drainage

One of the most important aspects of local street design is the provision made for protecting the road from stormwater runoff. Local street drainage is the most important aspect that determines the performance of a street. Failure of street pavement is often attributed to poor drainage.

A sustainable drainage system is the most important aspect that determines the performance of local streets (Woods-Ballard et al., 2007). GI practice is also related to the provision of appropriate and sustainable street drainage system particularly to local streets to insure longer life of pavements.

Additionally, one of the main objectives of the provision of local street drainage is to increase the efficiency of the street performance (Woods-Ballard et al., 2007). Moreover, it prevents early failures of the pavements and structures while subsequently minimizing investment loss made on the city's infrastructure development.

Landuse

The type of Landuse in a given watershed has also great effect on the runoff yield. E.g. Local Street that integrates green cover (trees or grasses) with permeable surface contributes less runoff because water is absorbed more into soil (CLUVA, 2012).

Imperviousness

One of the biggest challenges in GI design and technologies is imperviousness of the watershed which is directly associated with the level of urbanization. It is clear that the construction of more roads, parking lots, buildings and other manmade impermeable surfaces will reduce the natural landscape that absorbs water. Consequently, this impermeable surface could contribute in a creation of more stormwater runoff and flooding (Pazwash, 2011).

There are several methodologies that can be used for mapping the imperviousness of an area. For example, estimating the impervious areas in GIS form high resolution aerial photography and field observation is a common one (Johnson, 2004). Therefore, researchers can use both methods to get the exact or an approximate impervious cover of a given area.

3.2.2. Hydrologic factors

Before developing GI design to a site a full understanding of the water depth, ground water recharge rate and ground water flow patterns of that specific area is required.

Ground water is part of a stream flow that has infiltrated into the ground and has been discharged into stream channels. Site groundwater conditions should be identified prior to GI implementation. The depth to seasonal high groundwater table (normal high depth during the wet season) beneath the project may prevent infiltration Dhalla & Zimmer.

3.2.3. Climatic factors

Precipitation has great effect on the runoff. E.g. A precipitation which occurs in the form of rainfall starts immediately as surface runoff depending upon rainfall intensity. If the rainfall intensity is greater than infiltration rate of soil then runoff starts immediately after rainfall. While in case of low rainfall intensity runoff starts later. Thus high intensities of rainfall yield higher runoff.

3.2.4. Estimation of peak stormwater runoff

Estimation of peak stormwater runoff form a drainage area is often calculated with the rational method equation (Q=CIA). The calculations can be done using excel spread sheet. In this method the parameters in the equations are defined with typical units for both U.S. and S.I. units (Pazwash, 2011).

> *The Rational Method equation actually used to calculate peak stormwater runoff rate is: $Q = CiA$ (U.S. units), or $Q = 0.0028\ CiA$ (S.I. units) where:*
>
> *A = the area of the watershed (drainage area) that drains to the point for which the peak runoff rate is needed (acres for U.S. units) (ha for S.I. units)*
>
> *C = runoff coefficient for drainage area A. A physical interpretation is the faction of rainfall landing on the drainage area that becomes storm water runoff. (Dimensionless for both U.S. and S.I. units)*
>
> *i = the intensity of the design storm for peak runoff calculation (in/hr for U.S. units) (mm/hr for S.I. units)*
>
> *Q = the peak storm water runoff rate from the drainage area, A, due to the design storm of intensity, i. (cfs for U.S. units) (m^3/s for S.I. units). (Source: Pazwash, 2011)*

3.3 Green street (GS)

Application of GI tools in the detailed plan and design of streets is called Green street practices. Dill et al., (2010) defines green street (GS) as, a street that is composed of natural elements mainly soil and vegetation to convey or regulate stormwater runoff in a sustainable way. According to Kloss & Lukes (2008) applying GI approach to local streets will help to decrease stormwater runoff volume and separates runoff from sewage system by using landscape based components such as soil and vegetation instead of rigid elements (such as, concrete pipes,…). Additionally, these types of street drainage practices will also help in minimization of drainage facility construction cost. This sustainable stormwater strategy uses natural system to improve the wellbeing of watershed, improve comfort and address biodiversity as well as reduce and regulate stormwater (Kloss & Lukes, 2008). Woods Ballard et al., (2007) describes most prominent GS strategies widely used these days. These are infiltration trenches, permeable surfaces, swales, bioretention, stormwater planters, wetlands and ponds.

These devices can be structural by using mainly fixed physical constructions, such as permeable pavement, bioretention and swales. Non-structural devices involve small scale decentralized facilities for example vegetation. Additionally, delicate measures utilizing information and practice to impact the conduct and state of mind of partners, e.g., preparing and training projects, arrangements and laws Woods ballard et al., (2007). Practically speaking, GS is regularly a combination of both sorts of measures to make the best utilization of both their capacities.

Some advantages of Green Street

Green Street as it has been stated is not only a method to improve stormwater management; but also, an idea that offers different environmental and human benefits such as;

- Reduce risk of flooding in urban areas by using natural green techniques like bioretention, swale and minimizing impermeable surfaces (Grumble, 2007).
- Provide a cooling effect to the environment by increasing shade and evaporation through applying trees, vegetation, bioretention and etc. (Grumble, 2007).
- Increase in water supply by infiltrating stormwater to groundwater layer and replenish the ground water supply (Grumble, 2007).
- Using trees in the urban landscape heat stress can be reduced by breaking up continuous impervious surfaces and creating green landscape. Additionally trees have also the capacity to slow down runoff (Grumble, 2007).
- Create aesthetically attractive environment by using trees integrated with other green structures on the street. Moreover, through using vegetation, trees and soil in urban environment the biodiversity in that area will be enriched (Grumble, 2007).

- Through application of Green Street concept the cost for constructing conventional drainage system like (pipes, concrete, construction equipment and etc) as well as for the cost for maintenance will be minimized (Kloss & Lukes, 2008).

Some limitations of Green Street

- Many considerations must be taken in to account when applying green street design concept especially in cold climatic regions in order to avoid freezing and less efficiency (EPA, 2008). Using permeable pavements has also some concerns for cold climate regions that should be considered (Kloss & Lukes, 2008).
- Lack of on street parking space after the implementation of Green Street because the streets will get narrower as they get greener (Grumble, 2007).
- Risk of clogging, lack of maintenance, insect's especially in pond are some of the limitation in practices that are considered as other disadvantages of Green Street (Woods-Ballard et al., 2007).

3.4 Green street practices

The following techniques are commonly used GI technologies for GS developments. These techniques can assist in achieving reduction of stormwater runoff and brings improvement of local streets drainage system.

3.4.1. Permeable pavement

This GS practice is also called previous pavement; which is subclass of infiltration practice. This method is used to control and minimize the volume of stormwater runoff. This type of pavements allows stormwater to pass through the top layer and finally infiltrate in to the ground (Ferguson, 2005). According to Ferguson (2005) there are different types of permeable pavements which can be used to improve the quality of neighborhood. Porous concrete, porous asphalt, Porous Aggregate, Plastic Geocells and cobble stone pavements are the most used material in permeable pavement (See Figure 3.5). In very dense urban areas permeable pavement can be employed especially to reduce stormwater runoff and improve sustainability of local streets (Hoyer et al., 2011). In some areas they are also integrated with vegetation on the top layer to even increase the districts amenity. (Hoyer et al., 2011).

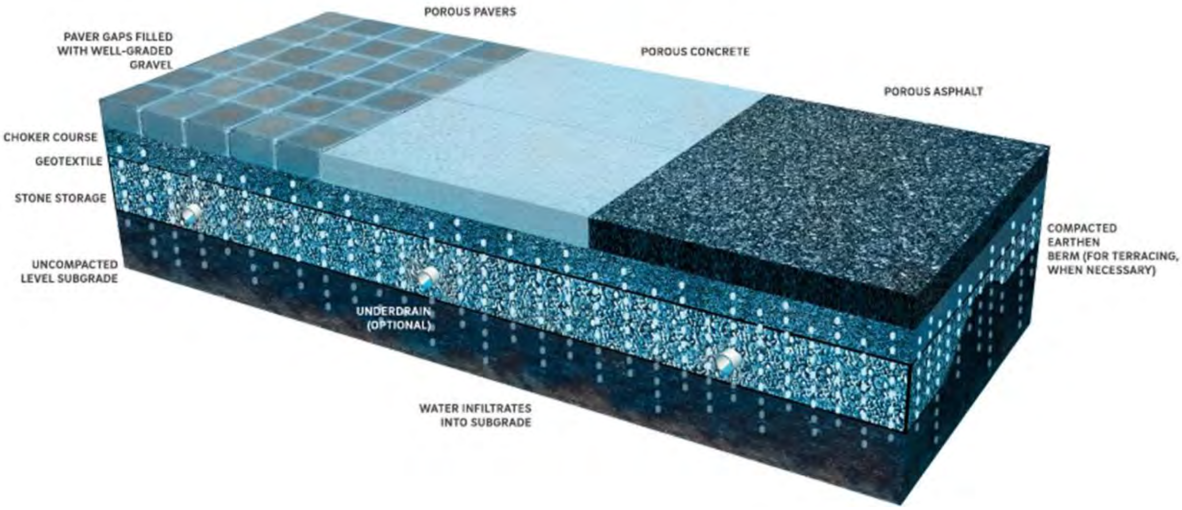


Figure 3. 5 Three-Dimensional View of permeable pavement (Source: GSDM, 2014)

There are three different types of permeable pavements based on the permeability to infiltrate stormwater to the ground

a. Fully infiltrate permeable pavement

This type of pavement is appropriate solution in an area where the soil infiltration capacity is high to allow stormwater. This kind of pavement doesn’t require drainage pipe or other mechanisms of drainage system because stormwater can easily infiltrate in to the ground. This method is best economic approach among the other pavement types (Dhalla & Zimmer, 2010).

b. Partially infiltrate permeable pavement

Partially infiltrate permeable pavement is appropriate for areas where the sub-grade doesn’t have sufficient capacity to infiltrate stormwater or in areas in a risk of excess stormwater from high precipitation events is highly noticeable. On this type of circumstances perforated pipe is needed on the top of the subgrade layer to direct the excess stormwater to another stormwater practice like vegetated swale or bioretention (Dhalla & Zimmer, 2010).

c. Partial infiltration with flow restrictor permeable pavement

This pavement type does not infiltrate storm to the ground water level. No infiltration permeable pavement could be used in area where there is high risk of ground water contamination. This method of pavement uses drainage pipe to collect and transport all the stormwater to an allocated drainage system (Dhalla & Zimmer, 2010).

Table 3. 3 Some Advantage and Disadvantage of Permeable Pavements (Source: Woods-Ballard et al., 2007)

Advantages of permeable pavement	Disadvantages of permeable pavement
Reduce stormwater volume as well as velocity of runoff.	It can be problematic when it comes to a heavy traffic road due to the heavy weight.
Cost saving method since it utilizes the urban space for multiple purposes functions (such as traffic passage and stormwater management practice).	This method cannot be applied for all conditions especially in an area where there is high rate of pollutants (due to the risk of groundwater contamination).
Cost effective method for construction as well as it is easy to integrate with natural landscape elements such as vegetation, trees	In areas where soil condition is not suitable for infiltration or where soil is not porous there will be risk of clogging
Does not need high maintenance	

Site suitability and limitations

- **Site topography**: The slope of the permeable pavement surface should be at least 1 – 5% and the contributing drainage area and surrounding land should not be greater than 20% (Dhalla & Zimmer, 2010).
- **Water table**: The base of permeable pavement reservoir should be at least one (1) metre above from the seasonally high water table (Dhalla & Zimmer, 2010).
- **Soils**: In the case of an area with low permeability soils with an infiltration rate of less than 15 mm/hr (i.e., hydraulic conductivity of less than 1x10 -6 cm/s), perforated pipe under drain must be integrated (Dhalla & Zimmer, 2010).

3.4.2. Swales

Swales are type of vegetated channels that act as open drainage line to transport stormwater and finally drain to the downstream. But, infiltration of stormwater to the ground in swales will depend on the base layer permeability. Swales are subclass for open channels and are considered as a very effective substitute for drainage pipes and gullies in urban areas (Hoyer et al., 2011).

Dry swales

Dry swales are open channels designed to convey, treat and attenuate stormwater runoff. Vegetation or aggregate material on the surface of the swale slows the runoff water to allow sedimentation, infiltration through the root zone and engineered soil bed, evapotranspiration, and infiltration into the underlying native soil. Dry swales may be planted with grasses or have more elaborated landscaping.

The main purpose of this practice is to convey stormwater runoff from one area to another. Figure 4 shows a Dry swale section.

Site suitability and limitations

- **Site topography:** Dry swales should be designed with longitudinal slopes generally ranging from 0.5 to 4%, and no greater than 6%. Check dams should be used on slopes greater than 3% (Dhalla & Zimmer, 2010).
- **Water table**: Designers should ensure that the bottom of the swale is separated from the seasonally high water table or top of bedrock elevation by at least one (1) metre (Dhalla & Zimmer, 2010).
- **Soil:** Dry swales can be located over any soil type. In areas where infiltration rates are less than 15 mm/hr (hydraulic conductivity less than 1x10-6 cm/s) an underdrain is required (,Dhalla & Zimmer, 2010).

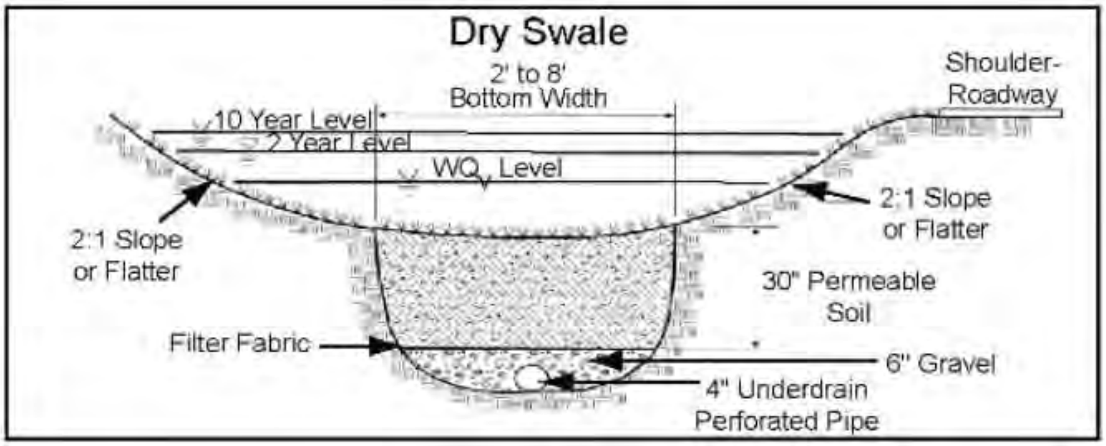


Figure 3. 4 Dry Swale section

Table 3. 6 Some Advantage and Disadvantage of Swale (Source: Woods-Ballard et al., 2007)

Some advantages of swales	**Some disadvantages of swales**
Efficient in reducing the velocity and volume of the stormwater	Difficult to apply this practice in a steep slope landscape area
Are quite flexible and can be applied in different landscape.	It is hard to plant trees in swales
Cost effective as compared to conventional approach as well as easy for maintenance.	The connection between swale and drainage pipe can be clogged so the connection between swale and pipe can work poorly.

3.4.3. Green gutter

A green gutter is a narrow and shallow landscaped strip along a street's curb line. It is designed to capture stormwater overflow by setting the highest point of the planting media in the green gutter lower than the road's canal height permitting stormwater spillover from both the road and walkway to stream specifically into the green gutter. An elevated curb can be used along the street side of the green gutter with openings along its length to allow runoff to flow into the green gutter. This system reduces stormwater flows, provides storage and, in some cases, infiltration and evapotranspiration (GSDM, 2014).

Table 3. 7 Some Advantage and Disadvantage of Green Gutter (Source: GSDM, 2014)

Some advantages of green gutter	**Some disadvantages of green gutter**
Provides a physical buffer between pedestrians and the street	Must consider existing on-street parking conditions and street width.
Does not require encroachment into sidewalk area.	Landscape materials must accommodate direct impact of gutter flow velocity.
Provides an area within the right-of-way for smaller planting	May not be appropriate in high volume pedestrian areas.

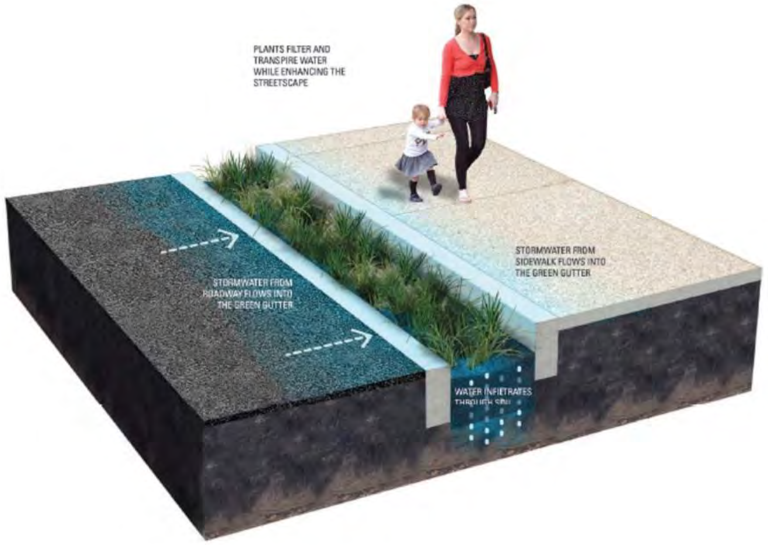


Figure 3. 5 Three-Dimensional View of Green Gutter (Source: GSDM, 2014)

Site suitability and limitations

Site topography: Green gutter slope should be no less than 1 or 2 percent slope, and no greater than 5percent. Greater slopes will encourage concentrated flow and flatter slopes may result in ponding. The recommended slope is 1 - 5% (GSDM, 2014).

well as biodiversity	management.
Are very flexible features so they can be applied in different places	Can be easily clogged if it is located in a poor

Site suitability and limitations

- **Site topography:** Bioretention is best applied when contributing slopes are between 1 to 5%. From the total size of the contributing drainage area 10 to 20% should be reserved for landscaping (Dhalla & Zimmer, 2010).
- **Water table:** Bioretention should be separated from the seasonally high water table by a minimum of one (1) metre (Dhalla & Zimmer, 2010).
- **Soil:** Bioretention can be located over any soil type. Where infiltration rates are less than 15 mm/hr (hydraulic conductivity less than 1x10-6 cm/s) an underdrain is required (Dhalla & Zimmer, 2010).

3.4.5. Stormwater tree/ Extended tree pit

Stormwater trees are also one of the GS practices to intercept precipitation from direct rainfall through using their roots and the trunk (GSDM, 2014**.** There are different types of trees that can be applied for managing stormwater such as oak however canopy tree (the outer layer of tree made by leaves) is very effective in intercepting stormwater (Kloss & Lukes, 2008). Integrating stormwater trees in the design process of local streets is highly encouraged; in order to improve aesthetic view of the environment (Hoyer et al., 2011).

Table 3. 9 Some Advantage and Disadvantage of stormwater trees (Source: GSDM, 2014).

Some advantages of stormwater trees	**Some advantages of stormwater trees**
Trees control flow with their leaves and branches and allow the rainfall to evaporate which provides cooling effect on the environment	Younger trees cannot control stormwater very effectively as older and bigger trees. This means it take some years in order to get benefit from the trees
Improve infiltration and groundwater recharge	Less effective in controlling stormwater in cold seasons because they lose their leaves
Improve the aesthetic view of streets as well as biodiversity	

Figure 3. 7 Stormwater Trees (Source: GSDM, 2014)

3.4.6. Curb extension/Stormwater bump-out

Curb extensions are, like extended tree pits and it is designed to capture, slow, and infiltrate stormwater within a planted area or subsurface stone bed. Runoff from the adjacent sidewalk can flow directly into the stormwater bump-out from the surface. Landscape plantings within the curb extension effectively take up some of the stormwater through their root systems. The remaining stormwater is temporarily stored within the curb extension until it either infiltrates or drains back to the sewer (GSDM, 2014).

Table 3. 10 Some Advantage and Disadvantage of Curb extension (Source: GSDM, 2014)

Some advantages of Curb extension	**Some disadvantages of Curb extension**
Does not take much space of the sidewalk area	May not be appropriate for high speed vehicle movement
Act as a buffer between the pedestrian and the street vehicle movement	Must consider existing on-street parking conditions and street width and vehicle turning radius.
Stormwater filters through the plant and soil, this helps to slow, and infiltrate stormwater to the ground	

Site suitability and limitation

- **Site Topography**: Facilities cannot be located on natural slopes greater than 15% type (GSDM, 2014).
- Water Table: The bottom of the facility should be vertically separated by one (1) metre from the seasonally high water table (GSDM, 2014).
- **Soils**: Soakaways and infiltration trenches can be constructed over any soil type (GSDM, 2014).

Table 3. 11 Some advantages of Soakaway and infiltration trench (Source: GSDM, 2014)

Some advantages of Soakaway and infiltration trench	**Some disadvantages of Soakaway and infiltration trench**
Infiltration can significantly reduce both runoff rates and volumes	High clogging possibility without effective pre-treatment
Can be incorporated easily into site landscaping and fits well beside roads	It is not for sites with fine particle soils (clay/silts)
Easy to construct and operate	During long wet periods the long-term performance could reduce

3.4.7. Perforated pipe systems

Perforated pipe systems are underground stormwater conveyance systems designed to reduce runoff volume (Woods-Ballard et al., 2007). The system is composed of perforated pipes installed in gently sloping coarse grain stone beds that are lined with geotextile fabric that allow infiltration of runoff into the gravel bed and underlying native soil while it is being conveyed from source areas or other green street practices to an end-of-pipe facility or receiving water-body (Woods-Ballard et al., 2007).

This system is suitable for reducing runoff from roofs, walkways, parking lots and low to medium traffic roads; with adequate pretreatment. Perforated pipe systems can be used in place of conventional storm sewer pipes, where topography; water table depth; and groundwater conditions are suitable.

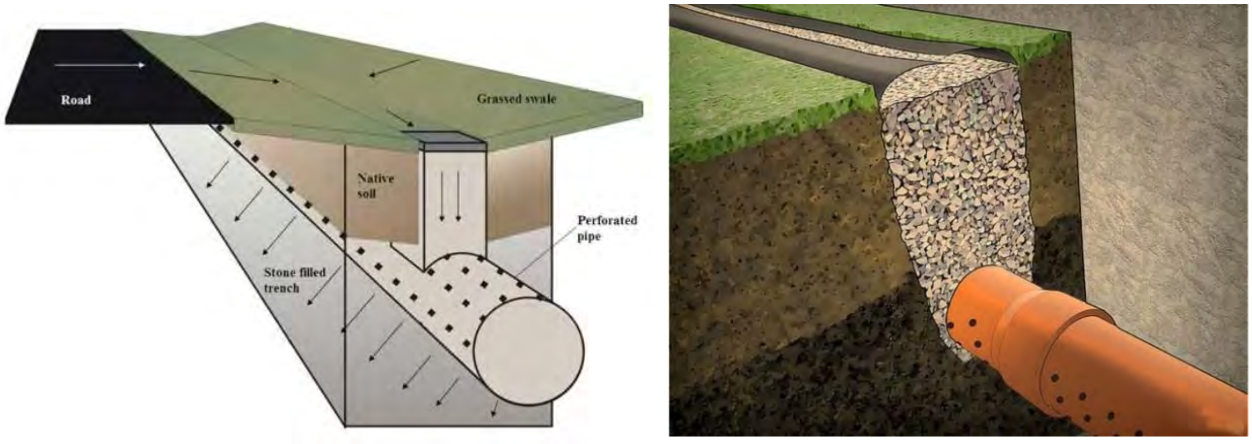


Figure 3. 10 Perforated pipe systems

Site suitability and limitation

- **Site topography:** Systems cannot be located on natural slopes greater than 15%. The gravel bed should be designed with gentle slopes between 0.5 to 1% (Woods-Ballard et al., 2007).
- **Water table**: Should be vertically separated by one (1) metre from the seasonally high water table (Woods-Ballard et al., 2007).
- **Soil:** Soil conditions do not restrain the application of perforated pipe systems but greatly influence their runoff reduction performance (Woods-Ballard et al., 2007).

Table 3. 12 Some advantages of Perforated Pipe Systems (Source: Woods-Ballard et al., 2007)

Some advantages of Perforated Pipe systems	**Some disadvantages of Perforated Pipe systems**
Good for conveyance and infiltration of stormwater runoff	Soil under the system can lead to muddy water entering the pipe, which will cause clogging.
Can be incorporated easily into in existing conventional drainage systems	Installation and maintenance of perforated pipes could be difficult

3.4.8. Steeped stormwater planter

This green street practice is best possible for sloped site. Steeped Stormwater planter consists of walled, vegetated cells that allow stormwater to pond and infiltrate over time. For every fifteen centimeter drop in elevation, a vertical check dam is placed between each level cell, allowing for overflowing water to travel downslope from cell to cell (Carlson et al., 2014).

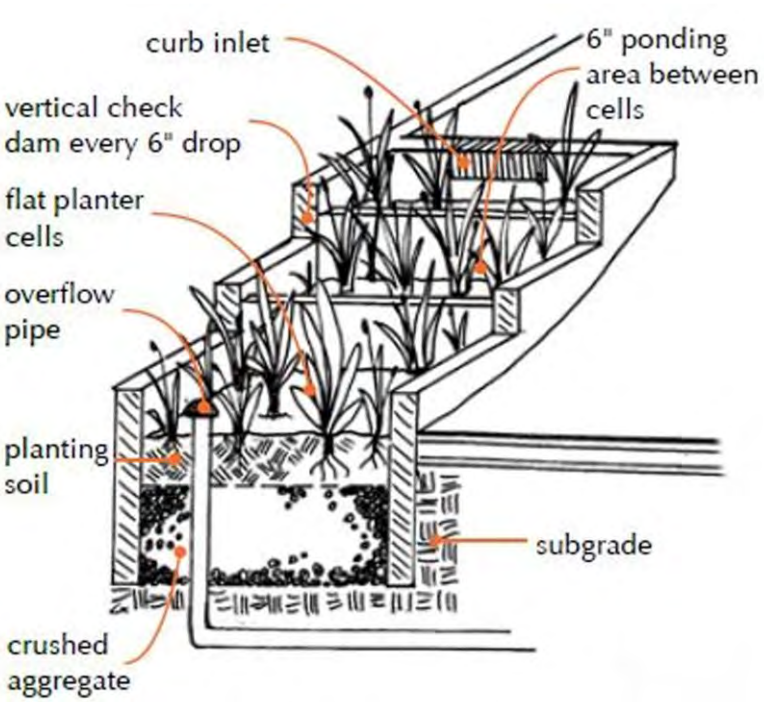


Figure 3. 11 Steeped Storm-water planter

Site suitability and limitation

- **Site topography:** This practice is applicable for slope greater than 5% (Carlson et al., 2014).
- **Water table**: Should be vertically separated by one (1.5) metre from the seasonally high water table (Carlson et al., 2014).
- **Soil:** Steeped Stormwater planter is not suitable for soils that do not drain well (Carlson et al., 2014).

Table 3. 13 Some Advantage and Disadvantage of Steeped Stormwater planter (Source: Carlson et al., 2014)

Some advantages of Steeped stormwater planter	**Some disadvantages of Steeped stormwater planter**
Works well in areas with limited spaces and can also be adapted to different slope types	Not recommended for soils that do not drain well
Have a capacity to hold stormwater during peak flows and allows infiltration over time	If planted with trees, proper examination of vertical check dam locations, additional excavation of soil, and break-outs may be necessary

Summary

Streets that are integrated with green infrastructure technologies are often called "green streets". Green streets provide a source control for a main contributor of stormwater runoff. Green streets can incorporate a wide variety of design elements including street trees, permeable pavements, bioretention, swales, etc. Successful application of these techniques will encourage soil and vegetation contact and infiltration and retention of stormwater.

Any combination of the techniques (i.e. pervious paving, filtration/infiltration devices, landscape practices) listed above can be very effective at achieving the objectives and targets for streetscape design. For maximum effectiveness, these measures need to be carefully designed as part of an overall strategy that considers local site conditions.

No single street layout will be appropriate for all development and it is largely dependent on topography, density of development and traffic volume (see table 3.15). Areas with low traffic volume (i.e. local access streets) have the greatest flexibility in design alternatives (see table 3.14).

Table 3. 14 Summary of applicability of GI practices on the different type of street

no	**Type of Green street practice**	**Functional classification of Streets**		
		Arterial	Collector	Local
1	Permeable pavement	○	●	❋
2	Swale	❋	❋	○
3	Green gutter	❋	❋	❋
4	Bioretention	❋	❋	❋
5	Stormwater tree	●	❋	❋
6	Curb extension	○	❋	●
7	Soakawy and infiltration trench	○	❋	❋
8	Perforated pipe	○	○	❋
9	Steeped stormwater planter	○	○	❋

❋ Applicable ○ Not appropriate ● Limited

Summary of applicability of GS practices on local streets with different site factors

Table 3. 15 Applicability of GS practices on the different site factors

no	Type of Green street practice	Slope	soil	Ground water depth	climate
1	Permeable pavement	Low to medium (1-5%)	Medium infiltration rate - High infiltration rate	>1meter	Adjustment is needed in Cold climate regions
2	Swale	Medium (<6%)	Medium infiltration rate - High infiltration rate	>1meter	Applicable in tropical and subtropical climate
3	Green gutter	Low to medium	Any type	>1meter	Applicable in tropical and subtropical climate
4	Bioretention	Low to medium (1-5%)	Medium infiltration rate - High infiltration rate	>1meter	Applicable in tropical and subtropical climate
5	Stormwater tree	Any slope	Any type	>1meter	Applicable in tropical and subtropical climate
6	Curb extension	Flat (1-2%)	Medium infiltration rate - High infiltration rate	>1meter	Applicable in tropical and subtropical climate
7	Soakawy and infiltration trench	Steep (<15%)	Medium infiltration rate - High infiltration rate	>1.5 meter	Adjustment is needed in Cold climate regions
8	Perforated pipe	Steep (<15%)	Medium infiltration rate - High infiltration rate	>1.5 meter	Adjustment is needed in Cold climate regions
9	Steeped stormwater planter	Steep (>5%)	Medium infiltration rate - High infiltration rate	>1.5 meter	Applicable in tropical and subtropical climate

3.5.Testing the upscale effect of GI practices

Green street (GS) practices are micro-scale control measures. The combined effects of these practices can be expected to vary spatially and temporarily at large scales. Many GI practices are evaluated at a single lot level. Even though micro-scale performance of GI practices is necessary and appropriate generalizing results from such scales is very difficult. Therefore, a software modeling tool is required in order to test the upscale effect of GI practices at different spatial (lot to watershed) and temporal (single event to long-term) (Cervantes and William, 2004). Scaling of results from lot scales to larger scales (e.g., watershed) will be a key point to identify upscale effects of GI practices so that these practices can be incorporated in watershed models to accurately represent impacts of GI practices.

3.5.1. Modeling tools

Nowadays, there are different kinds of modeling tools that can be used for measuring the impact of GI practices in terms of both water quantity and quality simulations. The Modeling tools support planning and design decisions on a range of scales from identifying GI impact for an entire watershed to measuring a GI practice effect for a particular site (Zhou, 2014). A site designer, planner, or environmental manager can create a simulation of good range of spatial scale from a site or watershed to region level and apply various environmental data to determine the possible impacts. For example, Zhou (2014) discussed about twelve different computer modeling tools such as MIKE-SWMM, MOUSE, MUSIC, GIS, etc… to test the upscale effect of GI interms of stormwater quality and quantity minimization. These modeling tools that can help to predict the large scale effect of GI approaches on water quality and water quantity management before implementation.

Among the entire reviewed computer modeling software's SWMM and Arc GIS is more commonly employed to analyze the flow volume and runoff quantity of storm drainage systems (Cervantes and William, 2004). Integrating GS models with SWMM and GIS system could reduce a huge amount of work by allowing easy interpretation of model inputs and outputs with a more user-friendly map representation (Zhou, 2014).

Limitations of the modeling tools

Even though there are diverse and complicated computer models for determining the possible effect of GI technologies there are some limitations.

- Claimed to be non-user friendly because of their technical complexity (Zhou, 2014).
- Lack of a shared interface/platform for the different models (Zhou, 2014).
- Most models have specialized use for only one or a few aspects of GI technologies. Therefore, the performed test only reveals partial effects of the GI design (Cervantes and William, 2004).
- Some models can also be poorly integrated so it is tedious and time-consuming to obtain the huge amount of input data for each sub-model (Zhou, 2014).

Summary

- Before making an investment on the GI practices, quantitative analysis of the benefit and effectiveness of the strategy is essential.
- Quantitative assessment can serve as a tool to encourage individuals, public and government to invest in GI practices.
- There are different modeling tools that support planning and design decisions on a range of scales from identifying GI impact for particular site to an entire watershed.
- SWMM and GIS-based tools can be applied as a tool to assess the effectiveness of the GI practices.
- SWMM and GIS system could reduce a huge amount of work on data formatting and process, allowing easy interpretation of model inputs and outputs with a more user-friendly map representation.

CHAPTER FOUR

CONTEXTUAL STUDY

4.1. Street network in Addis Ababa

Addis Ababa, the capital of Ethiopia, is currently undertaking citywide construction of infrastructure, buildings, parking lots; which have changed the land use from being largely un-built areas to a built-up area. The total area of Addis Ababa is approximately 518 km2 with built-up area of 169.02 km2, and road coverage constituting 15.64% of the built up area. Out of the current road networks of 4148 km in the city, about 2002 km is asphalt paved and 727 km of the street is paved with cobblestone and gravel (AACRA, 2015). The following table shows the magnitude of streets and their pavement conditions in the city.

Table 4. 1 Addis Ababa's road network length, pavement type and status (Source: AACRA, 2015)

No.	Street hierarchy	Street length in km with different width	Street length in km with 7m width	Pavement status
1	Arterial	335	1005	V.Good
2	Sub Arterial	147	411	V.Good
3	Collector	217	325	Good
4	Local	261	261	Good
Total		960	2002	
	Cobblestone	727	727	
	Gravel	1419	1419	
	Grand total	3106	4148	
	Road coverage (%)		15.64	

4.2. Introduction to cobblestone paved local streets in Addis Ababa

Local streets are type of streets which give primary access to adjoining properties, including residential properties. The street width varies from 6m to 15m (AACRA, 2014). Local Street in Addis Ababa is taking a new trend of development. Currently, almost the entire city local streets are being paved with cobblestone.

Cobblestone street construction in Addis Ababa is a new emerging practice; so, no research was conducted in relation to the design and maintenance of these streets. In the city, cobblestone street construction project has been started in 2002 G.C. This street pavement has a longer life span than asphalt roads in terms of ease of maintenance and lifespan (MUDC, 2012). That is why cities have chosen to do cobblestone street construction rather than build streets made of asphalt. Currently, government has built 727 km of cobblestone paved local streets. The following table shows the distribution of cobble stone pavement in different sub-cities.

Table 4. 2 Cobblestone paved streets in the ten sub city's of Addis Ababa (Source: AACRA, 2015)

No	Sub city	Length in meter
1	Bole	76,899.99
2	Yeka	39,739.91
3	Arada	3,018.38
4	Addis Ketema	16,610.52
5	Lideta	5,457.43
6	Kolfe Keranio	133,198.07
7	Gullele	13,365.98
8	Kirkos	11,145.82
9	Nifas selke lafto	70,922.76
10	Akaki Kality	23,048.85

4.2.1. Benefits of cobblestone pavements

The report obtained from CPCO indicates, cobblestone street construction has economic, social and environmental benefits. Economically employment opportunities will be maximized by the means of creating Micro and Small Enterprises. Socially, this street pavement construction will increase citizen's mobility. Moreover, this type of streets does not only address private, but more importantly, public and pedestrian transport. Environmentally, it encouraged the residents to dispose waste properly, which helped to keep the environment clean. Additionally, cobblestone paved streets provides safe walk way and reduction of dust and mud. Furthermore, the ease of maintenance and lifespan of cobblestone pavement is much longer than asphalt paved streets and it does not depend on imported oil as asphalt does.

4.3. Factors that dictate the applicability of GI practices in Addis Ababa

Addis Ababa is located at the geographic center of Ethiopia in the mountainous Shawa region. Topographically, the city is situated at the base of mount Entoto, with an elevation of 2987 meters. The altitude of the city varies from 1,920m to 2,987 m from north to south. Stormwater runoff at the higher elevations causes erosion as it flows with increasing velocity to the lower elevations (UNEP, 2003).

Like other large cities of the world, the landuse land cover in Addis Ababa is also dictated by the physiographic, climatic and hydrologic characteristics to apply the stormwater management practices.

4.3.1. Landform

One of the factors that make Addis Ababa streets prevalent to flooding and pavement damage is the topography. The city is characterized by steep mountains and low-lying flood plains. The center of the city lies on an "undulating" topography with some flat land areas (UNEP, 2003). The topography is "undulating" and form plateau in the northern, western and southwestern parts of the city, while gentle morphology and flat land areas characterize the southern and southeastern parts of the city (UNEP, 2003). Moreover, it is common to see sharp changes in the inclination of the slope and some flat land areas in different parts of the city. On the top of the hills and ridges streams are dense and form radial drainage pattern, whereas on the slope and most parts of the city they form tree like features (UNEP, 2003).

4.3.2. Soil

In Addis Ababa there are different types of soil groupings, which are assigned into different hydrologic soil groups based on their characteristics (Mezgebe, 2009).

Table 4.3: Addis Ababa Soil groupings based on their characteristics (Source: Mezgebe, 2009)

Soil Name	**Soil characteristics**	**Hydrologic group**
LUVISOLS	subsurface accumulation of high activity clays	D
NIT0SOLS	deep, dark red, brown or yellow clayey and sandy soils having a pronounced shiny, nut-shaped structure	C
CAMBISOLS	weakly to moderately developed soils	A
VERTISOLS	dark-colored cracking and swelling clays	D

In Addis Ababa, the groundwater movement direction is dominated by north-south and east-west flow. The flow lines converge towards the southern parts of the city. Mezgebe (2009) stated that groundwater flow from Southwest to southeast in western parts of the city and from east to west in the eastern parts of the city. In some localities, however, the groundwater flow direction changes, mostly towards the nearby streams. In general, the groundwater movement is sub parallel to the surface water flow direction and more or less controlled by the topography of the area (UNEP, 2003).

4.3.3. Precipitation

Addis Ababa is located is at a high elevation and exposed to a substantial amount of rainfall during the rainy season between the beginning of June and the end of August.

According to UNEP (2003), classification of Ethiopia's rainfall region, Addis Ababa is located in the region where the rainy months are contiguously distributed. In this region there are seven rainy months from March to September/and the small rains occur from March to May. The big rains are from June to September. High concentration of rainfall occurs in July and very high concentration in August. Thus, the city receives annual average rainfall of about 1089 mm. Moreover, the heaviest amounts of rainfall occur in the months of August.

4.3.4. Landuse

According to UNEP (2003), uphill deforestation, urban land use change and increased impervious land cover will contribute in a creation more stormwater runoff and flood risks. Addis Ababa is more or less built up with impervious materials like, asphalt, compacted gravel roads, conventional drainage system, asphalt parking and other man made impermeable structures (UNEP, 2003). These impermeable surfaces in the city will significantly increase the amount stormwater runoff. As the amount of runoff increases, it will create stress on the existing conventional stormwater management practice and cause flooding on the streets.

4.3.4. Imperviousness

Addis Ababa is located at the geographic center of Ethiopia with an approximate area of 518 km2 (as per geographic information system (GIS) delineation). The city’s land use has changed from being largely unbuilt areas (about 85% in 1984) to largely built-up areas (more than 57% of the area in 2002), with impervious areas increasing rapidly (URAdapt, 2013). The current built up area is approximately 290 km2, and the stormwater volume generated from this is estimated to be in the range of 350 million m3 per year.

4.3.5. Drainage

Addis Ababa's drainage system is under developed by any standard (Muschalla, 2001). As a result, it is common to see streets that are significantly damaged by overflowing. In addition to this considerable damage to the infrastructures occurred due to after hours of torrential rainfall in the recent past (Muschalla, 2001).

Urban drainage is a requirement in the design and construction of streets. The only official provider of urban drainage infrastructure is the Addis Ababa City Roads Authority (AACRA) (Dagnachew et al., 2014). Hence roadside ditches or underground concrete pipes are implemented along main roads. However, the larger hydrological catchment is less emphasized in the design of roadside drains. Additionally, ACCRA has no responsibility regarding maintenance, discharge rates or the quality of surface runoff (Dagnachew et al., 2014).

In Addis Ababa, street drainage lines and sewer lines and manholes are clogged with solid wastes especially, on the rainy season of the year. As a result, the street pavement will deteriorate and the life span of the road will be shortened (Atnafseged, 2011).

In the city, most of the drainage lines are old; and are built with the road as a result ,it cannot handle the existing stormwater (Muschalla, 2001). Government has a plan to build 132 km long conventional drainage lines and budgeted 4.9-64 miilon birr (Atnafseged, 2011). However, the sustainability of conventional drainage systems is questionable.

4.4. The Existing situation of cobble stone paved local streets in Addis Ababa

It is clear that Cobblestone road construction is playing a great role in bringing about social, economic and environmental benefits at the local and national level. Despite all the above social and economic benefits that the cobblestone road construction is bringing about, it is facing challenges. Cobblestone roads are not designed developed and managed well, as a result they start deteriorating. Due to these reasons the researcher identified those facts in many parts of the city empirically.

The data obtained from the cobblestone project coordination office (CPCO) indicates, when cobblestone streets were constructed the quality and sustainability of it was not considered as the main objective. Because, the main objective was to reduce the number of unemployment and to cover the entire city local street with Cobblestones. Additionally, there was no any clear design guideline that helps to implement the design. Especially in the very beginning of these street construction, drainage lines along the streets were not implemented; as it was not considered in the design.

According to the interview made with Ato Natnael, who is technical officer at CPCO, “recently drainage system is included in the street designs”. However, the drainage proposal doesn’t consider the stormwater generated from entire watershed in a given area. The only consideration is the runoff generated from the street surfaces.

According to the interview with Ato Alemayehu, who is a cobblestone project coordinator at AACRA, cobblestone streets are constructed with the collaboration between government (ERA) and the residents of Addis Ababa. The community will contribute money for the construction of the sub base. After the sub base construction is completed by the community ERA will receive and pave the streets with cobblestones. In receiving these streets AACRA will check the quality of the sub base and the provided drainages. But, what is interesting is that the quality of the sub base material and appropriateness of the drainage is checked only through visual inspection (refer appendix 5).

Most of the local streets that are paved with cobblestones are deteriorating in a very short time after construction. Seeing this problem the CPCO officials tried to identify the gaps in the street design and implementations. According to their finding, in the report; fragmentation of cobblestones from the road part, destruction of curve stone from the edge of the roads, accumulation of water on the streets, submerged cobblestone due to heavy vehicle movement on the road are identified to be the main problems. Generally, because of this and other causes it is a fact that cobblestone street are deteriorating in a very short time after construction. If this continues, the whole local streets in the city could totally be destroyed. So, it is essential to take measures as quickly as possible by studying the main causes of the problem in detail.

Summary

- Currently, most part of the local streets in the city is being paved by cobblestone pavement. Paving local streets with cobblestone has started in 2002 GC.
- Construction of local streets with cobblestone pavements brings economic, social and environmental benefits. However, the main focus was only the socio-economic benefits out of the construction activities.
- In the city cobblestone streets are constructed with the collaboration between government (ERA) and the public community. The community will contribute money for the sub base construction and ERA will pave the streets with cobblestones.

- In receiving local street in which the sub base and drainage construction is completed, ERA will check the quality of the sub base material and appropriateness of the drainage is checked only through looking in eye.
- The constructed local cobblestone Street is deteriorating from time to time. This is because of lack of sustainable drainage and the larger hydrological catchment is not considered in the design of roadside drains.
- There are various factors that affect the applicability of GI practices in the city. The physiographic and hydrologic factors are the major ones.
- The city's mountainous and undulating type of topography and location on high elevation level makes it more exposed to a substantial amount of rainfall during the rainy season between the beginning of June and the end of August.
- The city receives annual average rainfall of about 1089 mm and the heaviest amounts of rainfall occur in the months of August.
- The city is undergoing city wide transformation which changes the urban land use from being largely unbuilt areas to a built-up area that increased impervious land cover of the city.
- The current built up area of the city is approximately 290 km^2, and the stormwater volume generated from this is estimated to be in the range of 350 million m^3 per year.
- In the city most of the drainage lines are old and under developed by any standard. As a result, it cannot handle the existing stormwater. That's why it is common to see streets that are significantly damaged by overflowing.
- When drainage is proposed along the local streets the proposal doesn't take into account the topographic, soil and watertable of the watershed area drainage.

CHAPTER FIVE

CASE STUDY

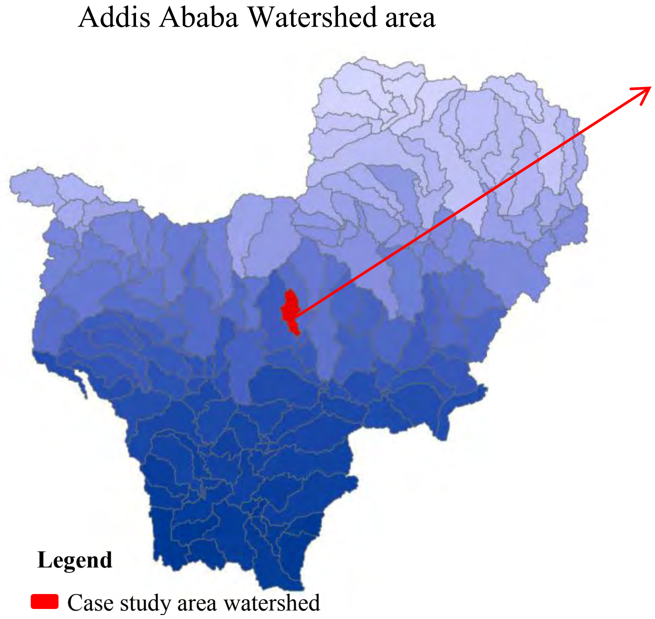
5.1. Watershed level analysis

In this part the research, existing situation of local streets in the planning area especially related to the major factors that dictate the applicability of green street practices and influence the flow of stormwater runoff will be discussed. This section also presents the results from the analysis of the land use, imperviousness, soil type, flow accumulation, water depth, and slope of the watershed area. In addition to this, the data obtained from different offices, interviews and site inventory are presented with maps, pictures, tables and charts.

5.1.1. Introduction to the watershed

Currently, Addis Ababa has Ten-Sub-Cities. “Yeka” and “Bole” is two of the ten Sub-Cities under the structure of Addis Ababa City Government.

The case study areas are located within the same watershed see fgure5.1.



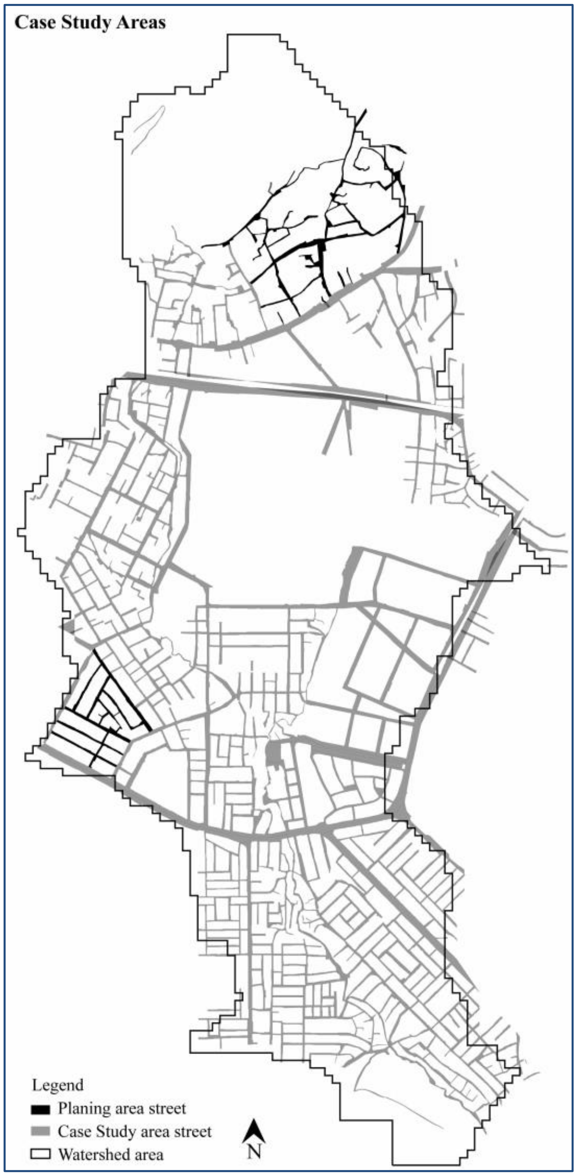


Figure 5. 1 Location Map of the case study’s watershed (Source: Author, 2016)

Yeka

Yeka is one of the ten sub-cities in Addis Ababa city administration. It is located in the north east of the city. The sub-city is bounded from the south by Bole, from west by Lideta and from north and east by oromia region. The total area of the sub-city is 8213.10 hectare and the altitude ranges from 2314 to 3025 meter above sea level. At present, the sub-city is divided into 13 woredas. In woreda 9 a local neighborhood called "Lamberet Abunaregawi sefer" is selected as a case study area. The area is selected based on the data obtained from Yeka Subcity Community Participation Development Office (CPDO) (See table 5.1). As it is reported to be one of the local neighborhoods in woreda 9 in which the local street face deterioration and are identified for purpose of maintenance.

Table 5. 1 Cobble stone paved local streets that need maintenance in the sub city (Source: CPDO)

Woreda	Local Streets that needs maintenance in meter	Maintenance cost needed
1	35	9,000
8	121	106,582
9	**616**	**511,667.15**
10	376	151,200
11	170	28,295
12	90	127,826
Total	1408	934,570

Bole

Bole is one of the ten subcities in Addis Ababa City Administration. It is situated in the Easten Part of Addis Ababa, bounded from South by Akaki, from West by Kirkos and Nifas Silk, from North Yeka and from East by Oromia region. The total area of the sub-city is 11,849.49 hectare and the altitude ranges 2408 to 2120 m, which has a range of 288 meters with relatively gentle grounds exist in the western part of the sub city. At present, the sub city is divided in to 14 woredas. In woreda 6 a local neighborhood called "Mekerbetoch sefer" is selected as a case study area. The area is selected based on the interview made with the officials that work in bole sub-city Community Participation Development Office (CPDO). As it is explained to the researcher, this area is one of the local neighborhoods in the woreda in which the local street face water logging problem and cause different impacts on the society living within that vicinity.

5.2. Factors that dictate the applicability of GI practices

5.2.1. Land-use

There are different types of landuse practices in the watershed area such as residential, commercial, recreational green spaces, administrative etc. From the total area of the site more than 52% of it is dominated by residential type of uses followed by manufacturing and storage which occupies 16.69%.

Table 5. 2 Landuse of the watershed area (Source: Author, 2016)

Landuse	Area (m^2)	Percent (%)
Administration	548087.34	10.64
Commercial	66450.44	1.29
Green area	596508.59	11.58
Manufacture and storage	859734.74	16.69
Mixed use	38633.98	0.75
Recreational open spaces	261680.80	5.08
Residential	2711589.99	52.64
social services	68510.92	1.33
Total	**5151196.785**	**100**

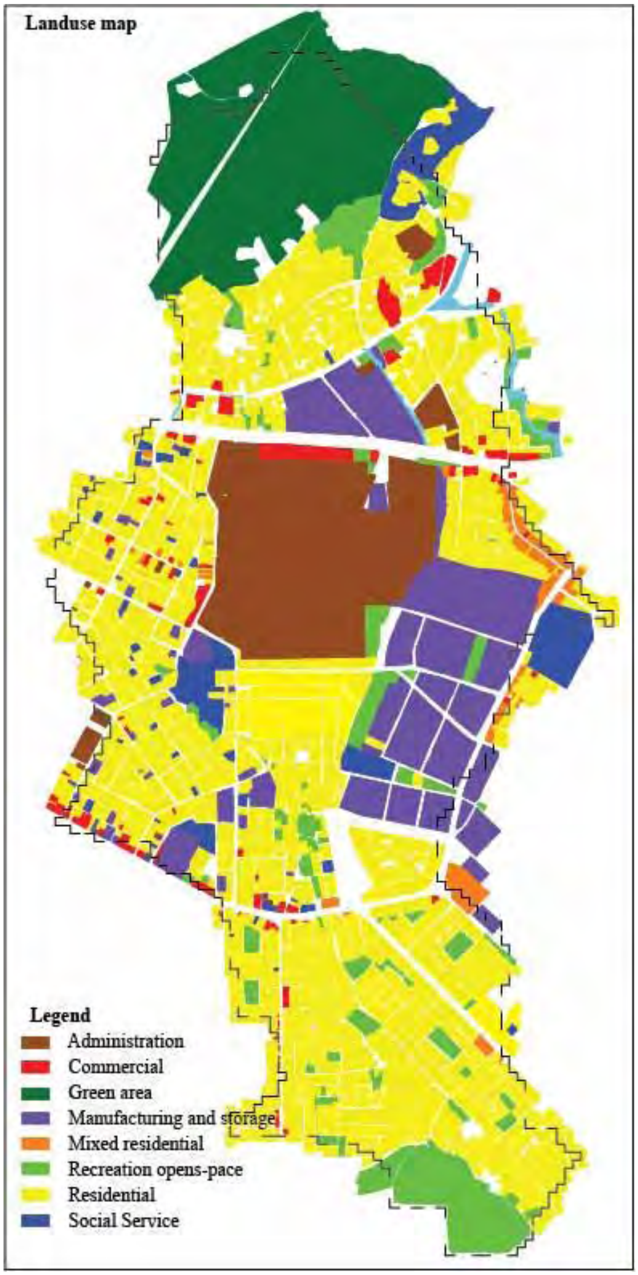


Figure 5. 2 Landuse map of the watershed area (Source: Author, 2016)

Implication

As shown in table 5.2 residential and manufacturing and storage uses covers more than 68% of the watershed.

Replacement of the natural landscape with such type of uses will strongly influences hydrological processes.

5.2.2. Imperviousness

According to the site observation, the landuse land cover of this area is completely sealed with impervious materials like asphalt and concrete. Impervious surfaces are mainly artificial structures such as pavements (roads, sidewalks, driveways and parking lots) that are covered by impenetrable materials such as asphalt, concrete, brick, stone and rooftops. Compacted soils by urban development are also considered highly impervious. The conducted imperviousness analysis allowed the evaluation of land-use development impacts on the stream network, and identification of suitable areas for stormwater management practices.

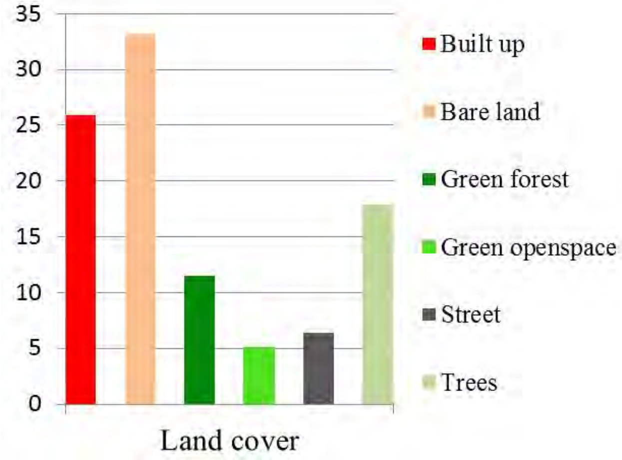


Figure 5. 3 Impervious surfaces in the watershed area in percent, (Source: Author, 2016)

Implication

As shown in the figure 5.3 the built up area and the streets are considered to be impervious surfaces. This impervious surface covers 34.32% of the watershed area. This amount of imperviousness in a given watershed strongly influences hydrological processes in the watershed areas. It is considered to be the main source of high stormwater runoff.

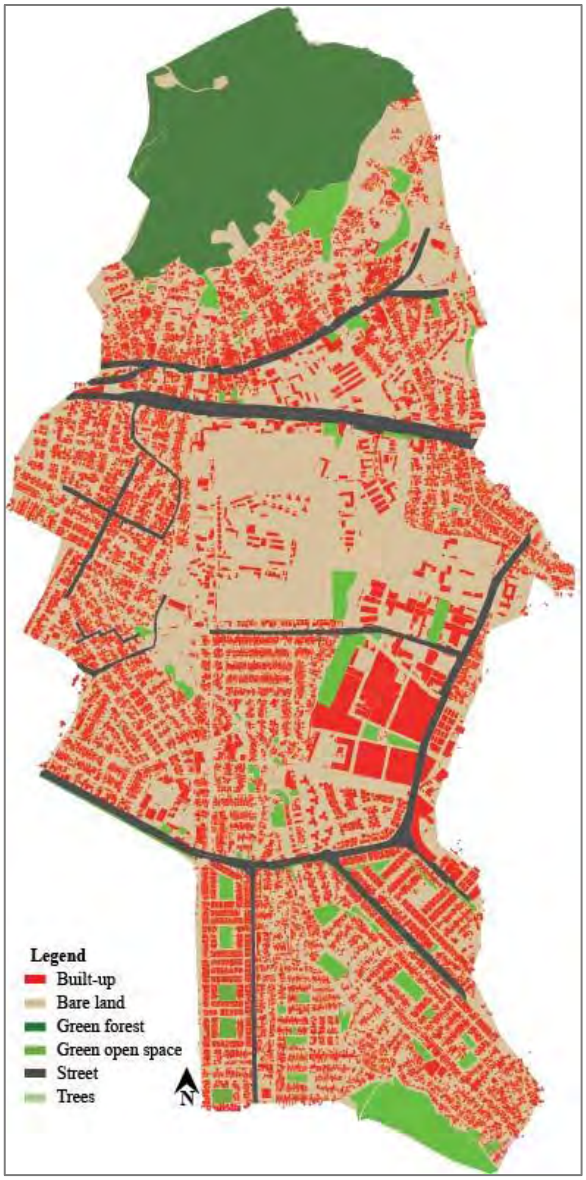


Figure 5. 4 Landcover map showing the impervious surfaces of the watershed area (Source: Author, 2016)

5.2.4. Soil and water depth

As mentioned earlier in the literature review, runoff varies with soil characteristics, particularly permeability and infiltration capacity. In this watershed there are different types of soil namely eutric nitsols, chromic vertisols and calcic xerosols. Eutric nitisols / clay loam type of soil which is found in the middle part of the watershed. These types of soils have a high runoff potential due to very slow infiltration rates. Clay soil that is composed of flat particles has a low permeability and water holding capacity, because water and air cannot move through clay easily. Calcic xerosols type of soils which belongs to hydrologic group B this type of soil has moderate infiltration rate when thoroughly wetted. The water table map shows the shallowest distance to the top of a wet soil layer within a given watershed. Therefore, the water depth in this watershed started from 2m to 73m. So, the area has potential to apply GI technologies depending on the water table depth.

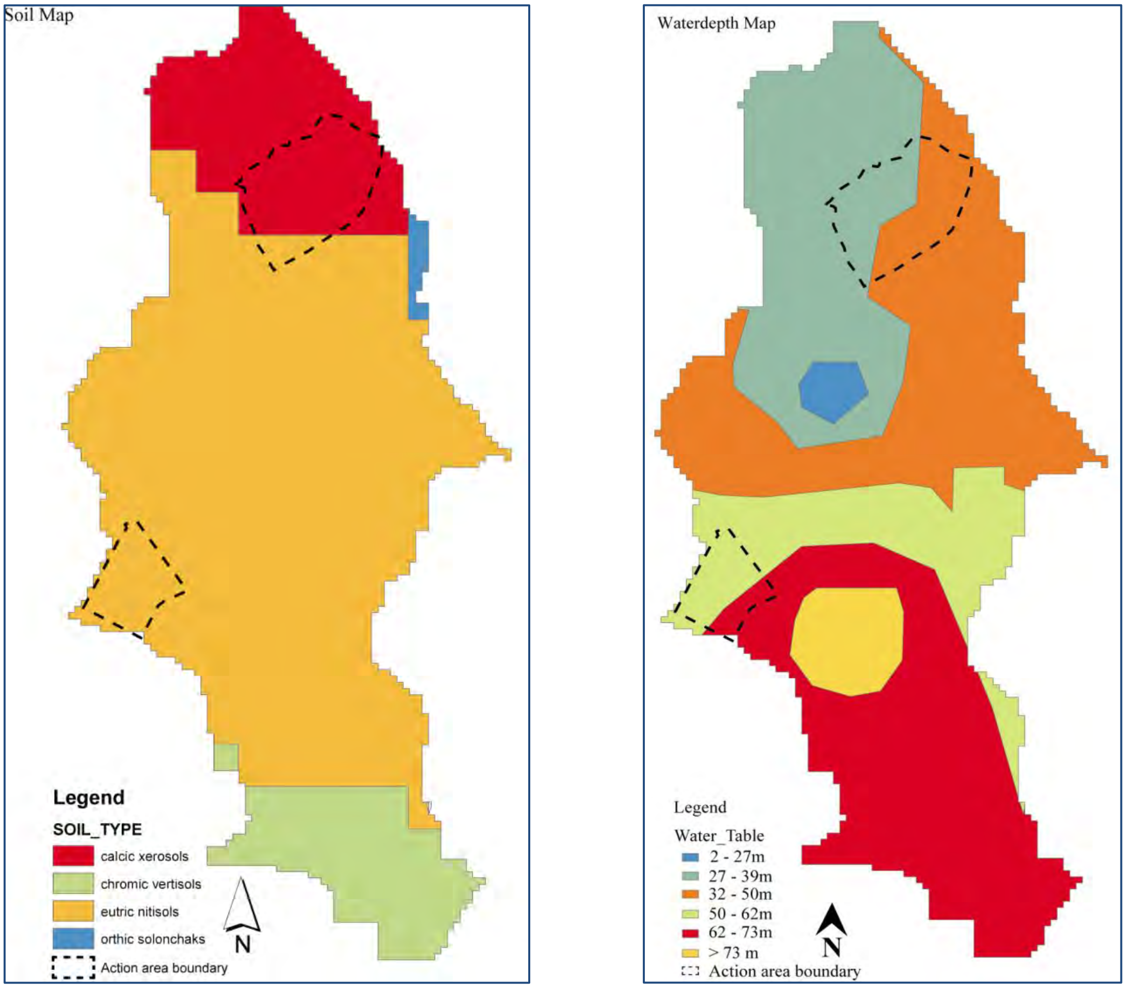


Figure 5. 6 Soil and water table map of the watershed area (Source: Author, 2016)

5.3. Existing situation of Local Street in the watershed

The finding from the data collected and the field observation indicated that majority of the cobblestone paved local streets in this watershed faced some defects like becoming deteriorated or losing their quality. The respondents to the researcher's interview also supported this fact. But, the type and degree of the problem is different in all parts of the area largely depending on the physical location of the areas where the street is located.

5.3.1. Causes of deterioration or destruction of the streets

Basically, the sustainability of cobblestone paved local streets depends largely on the type of design provided. Because, according to the interviews made with the technical staffs and professionals explanation, the design provided doesn't take into account the local site condition of a given area. Even though, analyzing the site factors is the basic requirement of any design work. Also, equal attention should be given to the implementation process of the design.

As explained earlier, the type of drainage systems provided along the street also have a major impact on the sustainability of local streets. Drainage systems should be built in a way that fit the purpose and in line with the streets. However as explained by Ato Natnael, who is the main officer in Community Participation Development Agency (CPDA) office, in this watershed the constructed drainage systems are not in line with the purpose and design of the street. Moreover, heavy vehicle movement and digging of the streets for other infrastructure developments like water and electric provision are also the main causes for the deterioration of these streets. Therefore, all these reasons and other factors have contributed for the deterioration of the local streets in this watershed.

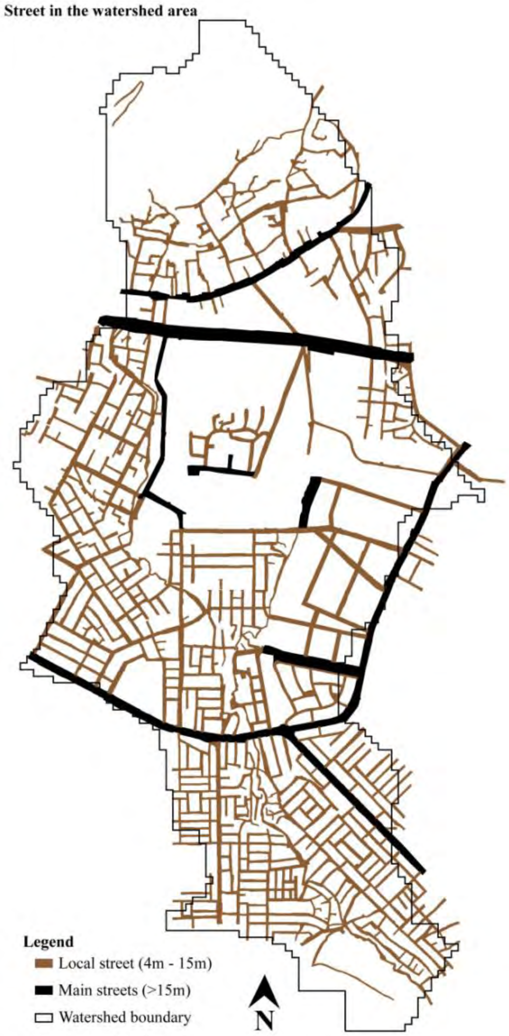


Figure 5. 7 Main and local Streets in the watershed area (Source: Author, 2016)

CHAPTER SIX

DATA INTERPRTATION AND CASE STUDY

6.1. Introduction to Local Street in Lamberet Abunaregawi area

The first case study area is located around the new "Lamberet" bus station area; to the North of the road that goes from "Megenagna" to "Kotebe" (See figure 6.1). The neighborhood is locally known as "Lamberet Abunaregawi sefer". The local street in this area is represented by organic kind of street pattern. The width of the streets varies from 4m to 12m. The streets are found in bad condition. The researcher site observation indicates there seems to be a lack of proper stormwater drainage. Additionally, the design made by the local authorities seems not to consider the existing physical condition of this area specially the slope. There are also other factors that may have contributed for the deterioration of the street like imperviousness of the site, rainfall intensity, soil permeability etc. This and other factors are discussed further in detail below.

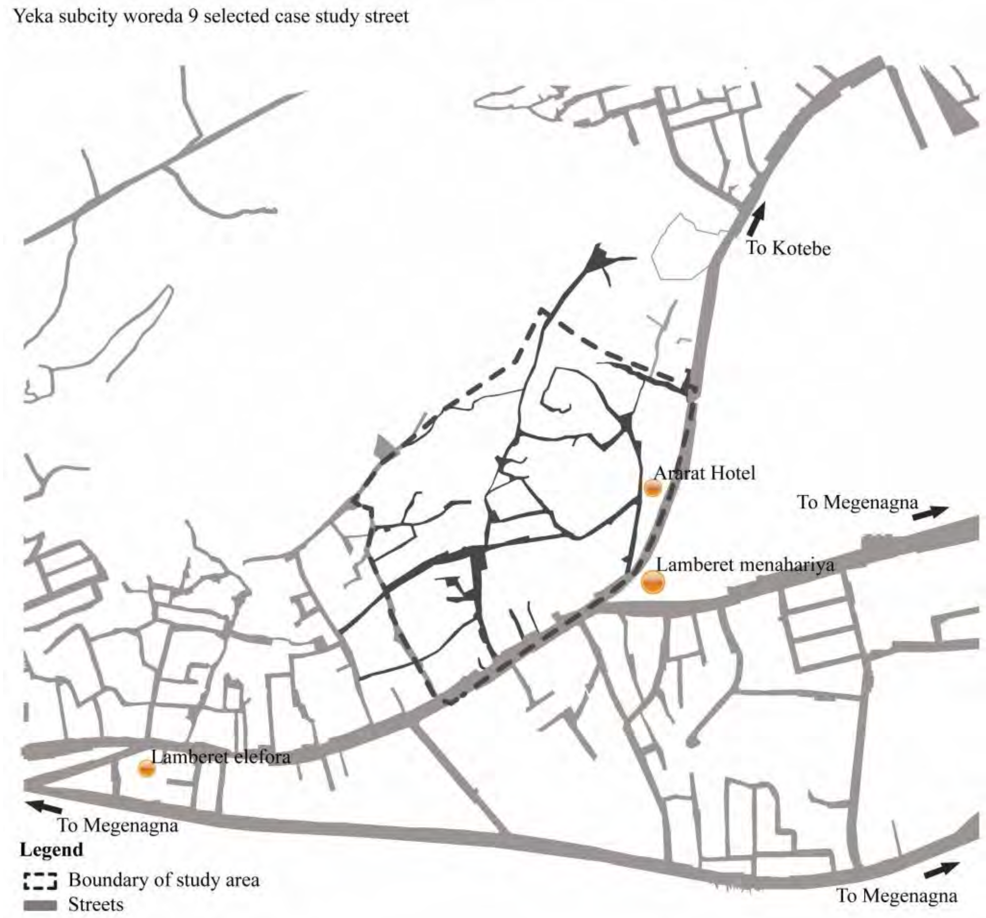


Figure 6. 1 Location map of local streets in Lamberet Abunaregawi area (Source: Author, 2016)

6.2. Introduction to Local Street in Mekerbetoch area

The second case study area selected for this study is located along the road that goes from "Megenagna" to "Yerer" see figure (6.2). This neighborhood is locally known as "Mekerbetoch sefer". The street in this area is represented by regular grid kind of street pattern. The width of the street varies from 4m to 15m. Most of the street in this area seems to be in a bad condition. For instance, the streets are completely water logged specially during high rain event even though conventional drainage systems are integrated along the streets. This probably could come from lack of proper stormwater drainage that fits in the existing condition of this area. In addition to this imperviousness of the site, soil permeability, slope, etc… could have their own contribution to this problem. This and other things related to the street are discussed in detail below.

Figure 6. 2 Location map of local streets in Mekerbetoch area (Source: Author, 2016)

6.3. Factors that dictate the applicability of GI practices

As explained in the literature review, the provision of GI technologies is very much site sensitive. Therefore, analyzing the physiographic and hydrologic characteristics of the given area will help to identify the major constraints and potentials for application of GI practices. Furthermore, it will help to analyze the existing situation local streets by the framework developed from the literature review.

6.3.1. Landuse

6.3.1.1. Lamberet Abunaregawi area

In this area, land use is categorized in to different uses like Administrative, residential, commercial etc. Out of this more than sixty percent (60%) is residential followed by green open spaces which cover around 23% of the area. The local street in in this area covers around 17% of the total area.

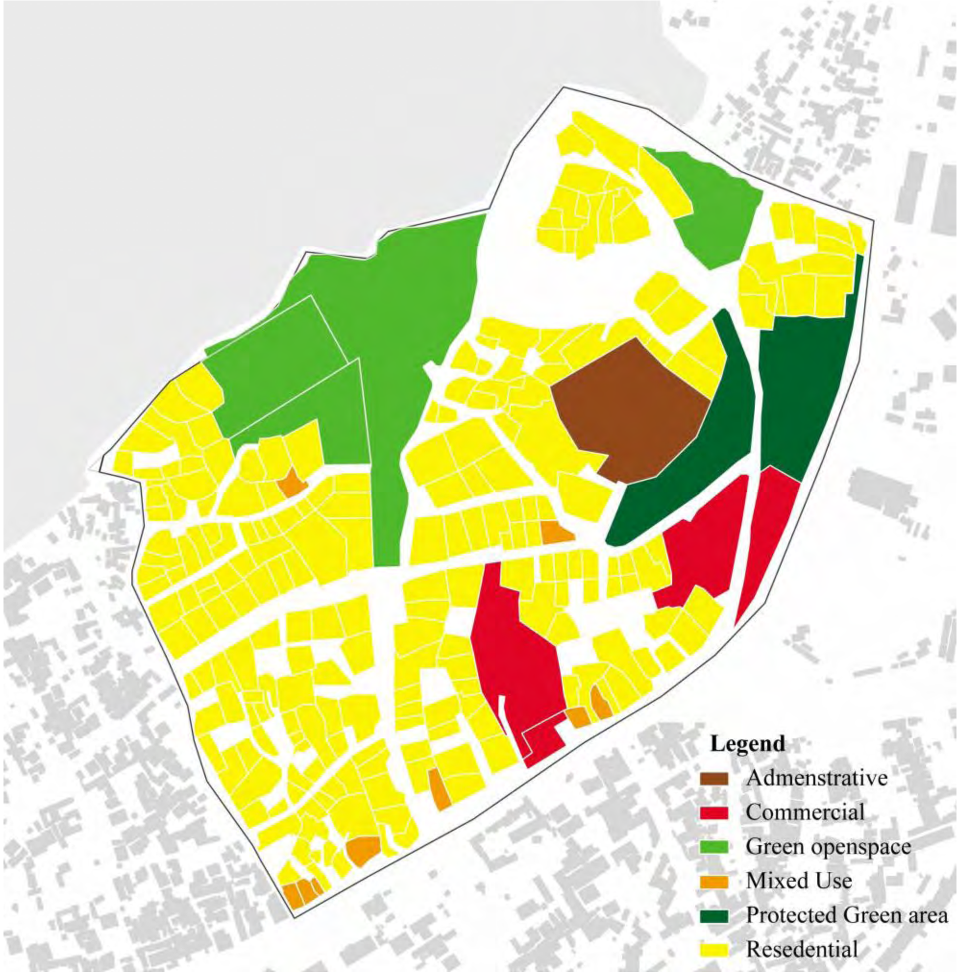


Figure 6. 3 Landuse map of Lamberet Abunaregawi area (Source: Author, 2016)

Table 6. 1 Landuse area and percentage cover (Source: Author, 2016)

Land use Type	Area (m^2)	Percent
Administrative	11439.55	5.34
Commercial	17883.86	8.35
Green open spaces	50915.67	23.79
Mixed use	3553.46	1.66
Residential	130265.98	60.86
	214058.52	**100**

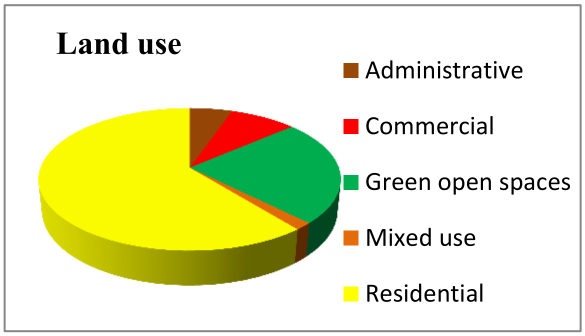


Figure 6. 4 Landuse percentage cover

6.3.1.2. Mekerbetoch area

As shown in the figure 6.5 below, there are different types of land uses in this area like commercial, social Services, manufacturing & storage, etc. Among the land uses of this area 60.86% of the space is occupied by pure residential uses and green open spaces cover 23.8 % of the total area.

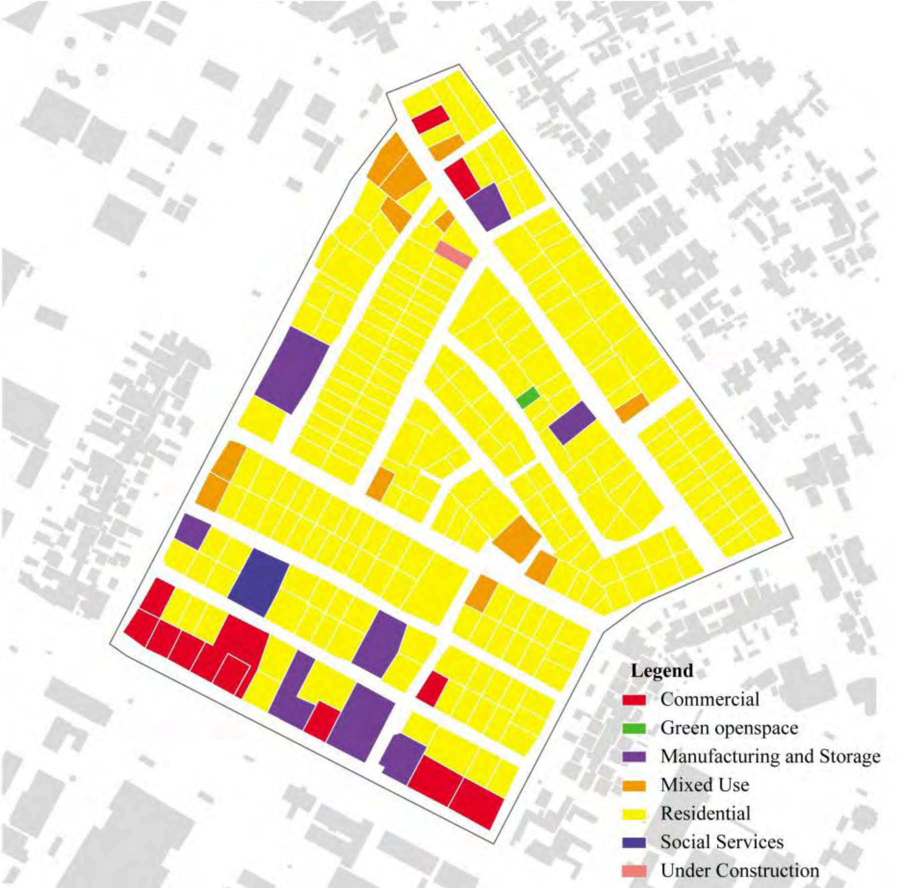


Figure 6. 5 Land use map of Mekerebetoch area (Source: Author, 2016)

6.3.2.1. Selected samples from Lamberet Abunaregawi area

Residence one (G+2)

Total Plot Area =743.79 m^2 Built up Area = 266.75 m^2

Paved area = 419.67 m^2 Green area = 57.37 m^2

Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.75 *27 mm * 266.75 m^2 = 5401.69 liters/day

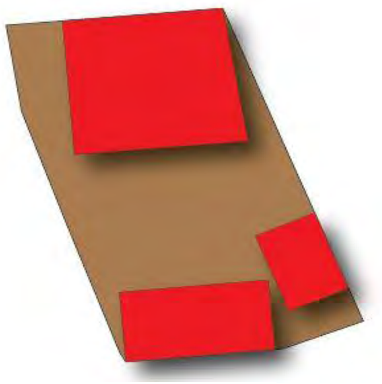
Paved area = 0.8 * 27mm * 419.67 m^2 = 9064.87 liters/ day

Green area = 0.25 * 27mm * 57.37 m^2 = 387.25 liters/ day

Therefore total runoff volume of this compound is **14853.81** liter per day.

Sample Plot A

Residence Two (G+0)



Total Plot Area =275.22 m^2 Built up Area = 128.1 m^2

Paved area = 147.12 m^2 Green area = 0 m^2

Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.75 *27 mm * 128.1 m^2 = 2594.03 liters/ day

Paved area= 0.8 * 27mm * 147.12 m^2 = 3177.79 liters/ day

Therefore total runoff volume of this compound is **5771.82** liter per day.

Sample Plot B

Commercial (Hotel)

Sample Plot C

Total Plot Area =5533.14 m^2 Built up Area = 2126.45 m^2

Paved area = 3406.69 m^2 Green area = 0 m^2

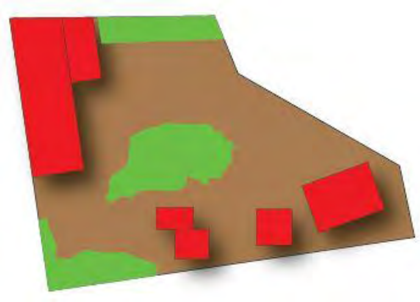
Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.9 *27 mm * 2126.45m^2 = 51672.74 liters/ day

Paved area = 0.8 * 27mm * 3406.69m^2 = 73584.50 liters/ day

Therefore total runoff volume of this compound is **125257.24** liter/ average per day.

Mixed use (G+0)



Sample Plot D

Total Plot Area =5533.14 m^2 Built up Area = 2126.45 m^2

Paved area = 3317.05 m^2 Green area = 89.64 m^2

Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up= 0.8 *27 mm * 2126.45 m^2 = 45931.32 liters/ day

Paved area= 0.8 * 27mm * 3317.05 m^2 = 71648.28 liters/ day

Green area= 0.25 * 27mm * 89.64 m^2 = 605.07 liters/average/ day

Therefore total runoff volume of this compound is **118184.67** liter per day.

Open space (grass cover)

Sample plot E

Total Plot Area =5769.82 m^2

Runoff volume=Coefficient x daily maximum rainfall intensity x green area

Runoff= 0.7 * 27mm * 5769.82 m^2 = 109049.59 liters/ day

Therefore total runoff volume of this open space is **109049.59** liter per day.

Table 6. 3 Total Runoff generated from Lamberet Abunaregawi area landuse (Source: Author, 2016)

Land use type	Runoff Generated in liter per day
Administrative	227790.17
Commercial	323921.51
Mixed Use	67959.99
Green Open space	549889.23
Residential	2249529.17
Total Runoff volume in liter/day	**3419090.1**

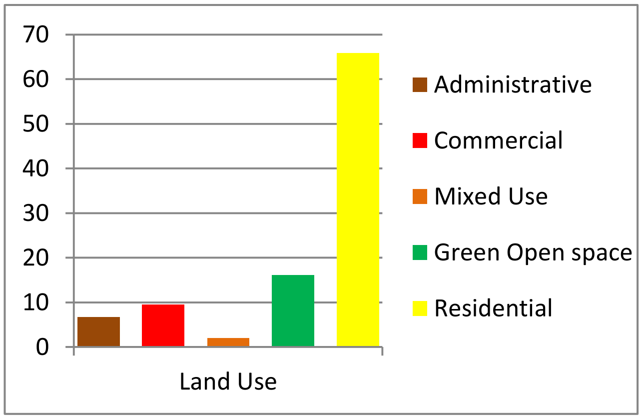


Figure 6. 7 Figure 4.15 Runoff generated from each landuse in percent (Source: Author, 2016)

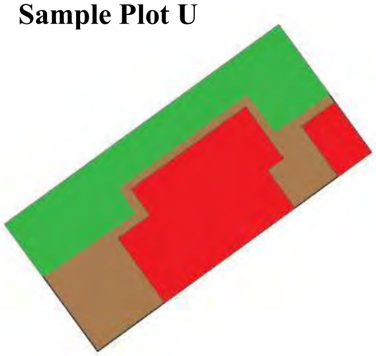
Implication

According to the result obtained from the runoff calculation, more than sixty five percent (65%) of the runoff is generated from the residential type of uses. This is because most of the residential plot doesn't have any infiltration or detention mechanisms. Therefore, the runoff generated from this land use has its own contribution for the deterioration of the streets. Especially, during the rainy season of the year, overflow and flooding is a common in this area. Since, in the design of the local streets drainage system, the runoff generated from each land use is not considered as a contributing factor.

6.3.2.2. Selected samples from Mekerbetoch area

Residence one (G+0)

Sample Plot U



Total Plot Area =256.9 m^2 Built up Area = 98.33 m^2

Paved area = 78.51 m^2 Green area = 80.06 m^2

Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.75 *27 mm * 98.33 m^2 = 1991.18 liters/average/day

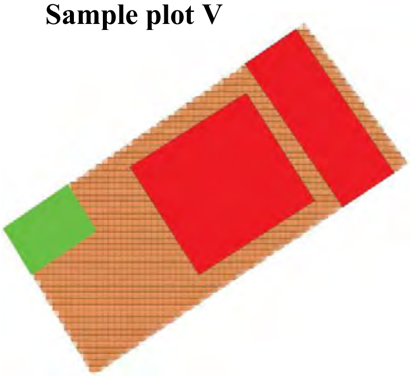
Paved area= 0.8 * 27mm * 78.51 m^2 = 1695.82 liters/ day

Green area= 0.25 * 27mm * 80.06 m^2 = 540.41 liters/ day

Therefore total runoff volume of this residence is **4227.40** liter per day

Residence two (G+1)

Sample plot V



Total Plot Area =291.11 m^2 Built up Area = 127.83 m^2

Paved area = 139.52 m^2 Green area = 23.76 m2

Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.75 *27 mm * 127.83 m^2 = 2588.56 liters/ day

Paved area= 0.8 * 27mm * 139.52 m^2 = 3013.63 liters/ day

Green area= 0.25 * 27mm * 23.76 m^2 = 160.38 liters/ day

Therefore total runoff volume of this residence is **5762.57** liter per day

Social service (school)

Sample Plot W

Total Plot Area =1259.93 m^2 Built up Area = 474.41 m^2

Paved area = 785.52 m^2 Green area = 0 m2

Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.75 *27 mm * 474.41 m^2 = 11528.16 liters/ day

Paved area= 0.3 * 27mm * 785.52 m^2 = 6362.71 liters/ day

Therefore, total runoff volume of this compound is **17890.88** liter per day

Commercial

Sample Plot X

Total Plot Area =425.83 m^2 Built up Area = 60.6 m^2

Paved area = 365.23 m^2 Green area = 0 m2

Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.75 *27 mm * 60.6 m^2 = 1472.58 liters/ day

Paved area= 0.8 * 27mm * 365.23 m^2 = 7888.97 liters/ day

Therefore, total runoff volume of this compound is **9361.55** liter per day

Manufacturing and storage

Sample plot Y

Total Plot Area =1089 m^2 Built up Area = 459.18 m^2

Paved area = 630.65 m^2 Green area = 0 m2

Runoff volume=Coefficient x daily maximum rainfall intensity x Built-up/Paved/green area

Built up = 0.75 *27 mm * 459.18 m^2 = 11158.07 liters/ day

Paved area= 0.7 * 27mm * 630.65 m^2= 11919.29 liters/ day

Therefore, total runoff volume of this compound is **23077.36** liter per day

Table 6. 4 Total Runoff generated from Mekerbetoch area landuse (Source: Author, 2016)

Land use type	**Runoff Generated in liter per day**
Commercial	125392.21
Social Services	25796.81
Manufacturing & Storage	154385.68
Mixed Use	96498.15
Green Open space	1665.79
Residential	1514576.21
Total Runoff volume in liter/day	**1918314.9**

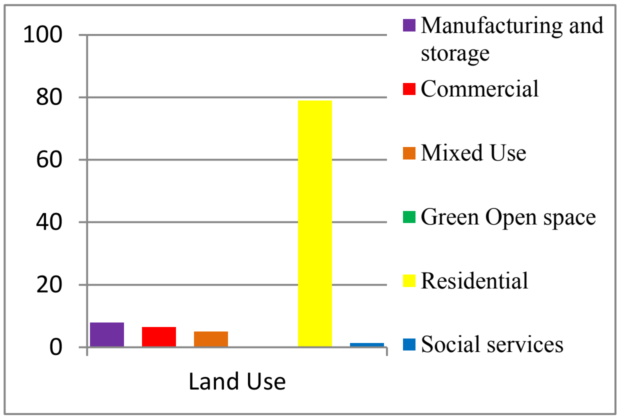


Figure 6. 8 Runoff generated from each landuse in percent (Source: Author, 2016)

Implication

According to the result obtained from the runoff calculation indicated, residential type of land use generates more than seventy five percent (78%) of the runoff per month. The residential plots pavement is dominated by impermeable type of surfaces. As a result, almost all of the rain that touches these surfaces is changed to stormwater runoff. Therefore, this will create stress on the existing drainage infrastructure as it flows through these systems resulting overflow and waterlogging.

6.4. Slope

6.4.1. Lamberet Abunaregawi area

As shown in figure 6.10, more than 60% of the area is categorized as steep slope. The steeply character of the topography has influenced the stormwater to increase its velocity and decrease amount of infiltration. As runoff speed generally increases with steepness of slope. According to site observation, the drainage system provided along the local streets of this area doesn't consider this slope character of the area. Therefore, stormwater in this area flows with high velocity in the provided drainage systems. When the velocity of stormwater increases it creates different impacts like erosion and flooding on the houses which reside along the local streets. The local streets which are perpendicular to the slope are also affected by the velocity of the stormwater. For example; fragmentation of cobblestone as observed in the site.

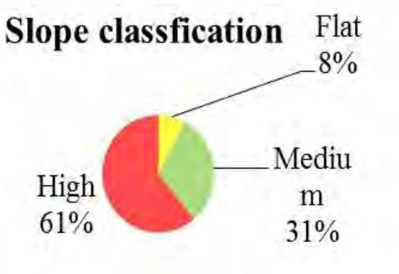


Figure 6. 9 Slope Cover age in percent (Source: Author, 2016)

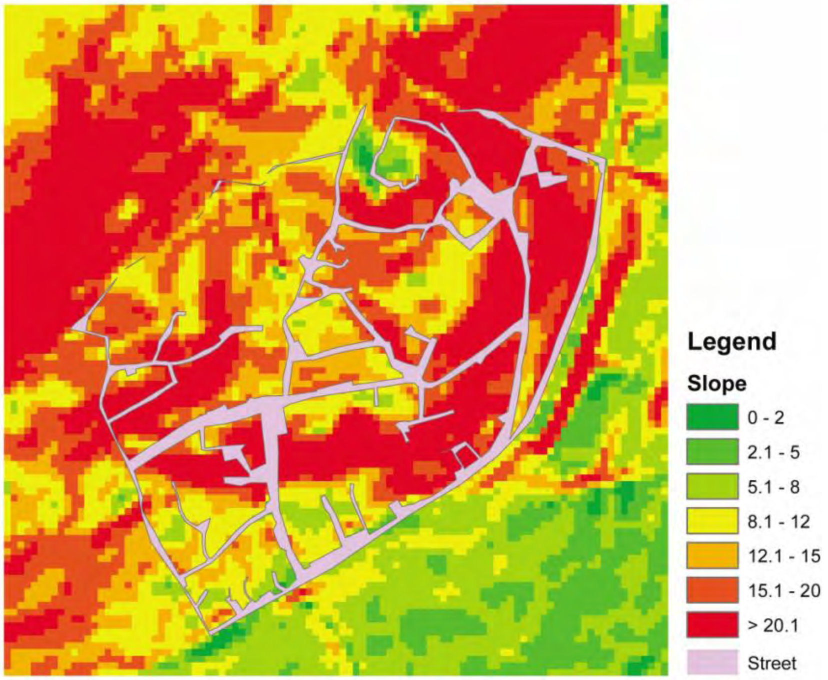


Figure 6. 10 Slope analysis of Lamberet abunaregawi area (Source: Author, 2016)

6.4.2. Mekerbetoch area

As illustrated in the figure 6.12 the landform in this area is characterized by flat type of terrain. Even if this kind of topography is suitable for street construction there are some gaps in the street design of this area; that are not taken into account. For example, the drainage system that is provided along the local streets is not based on the slope character of this area. As a result, when there is high rain event; stormwater accumulated on the surface of local streets and in the drainage systems. Consequently, the area will be flooded with the over flow.

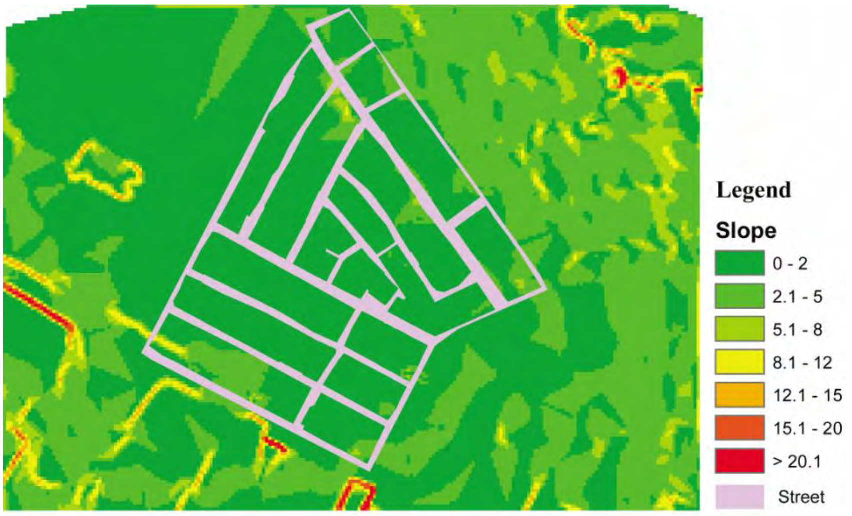


Figure 6. 11 Slope Cover age in percent (Source: Author, 2016)

Figure 6. 12 Slope analysis of Mekerbetoch area (Source: Author, 2016)

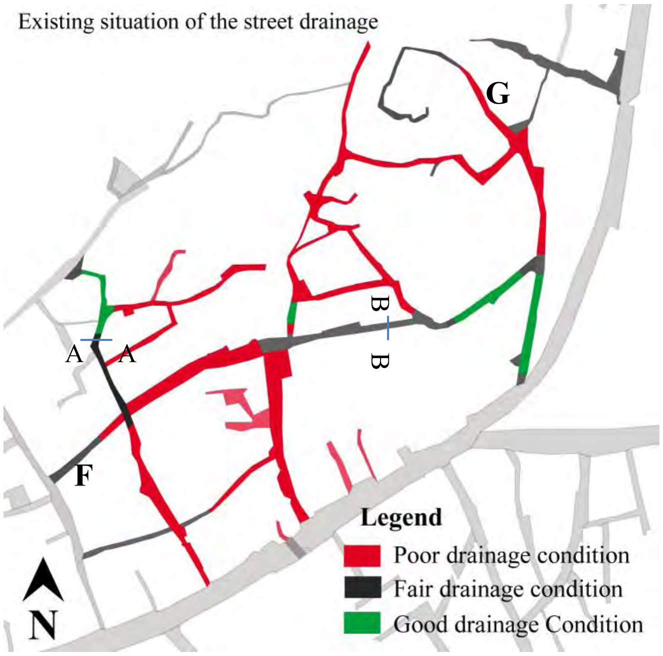


Figure 6. 15 Drainage condition map (Source: Author, 2016)

Fair condition

Poor condition

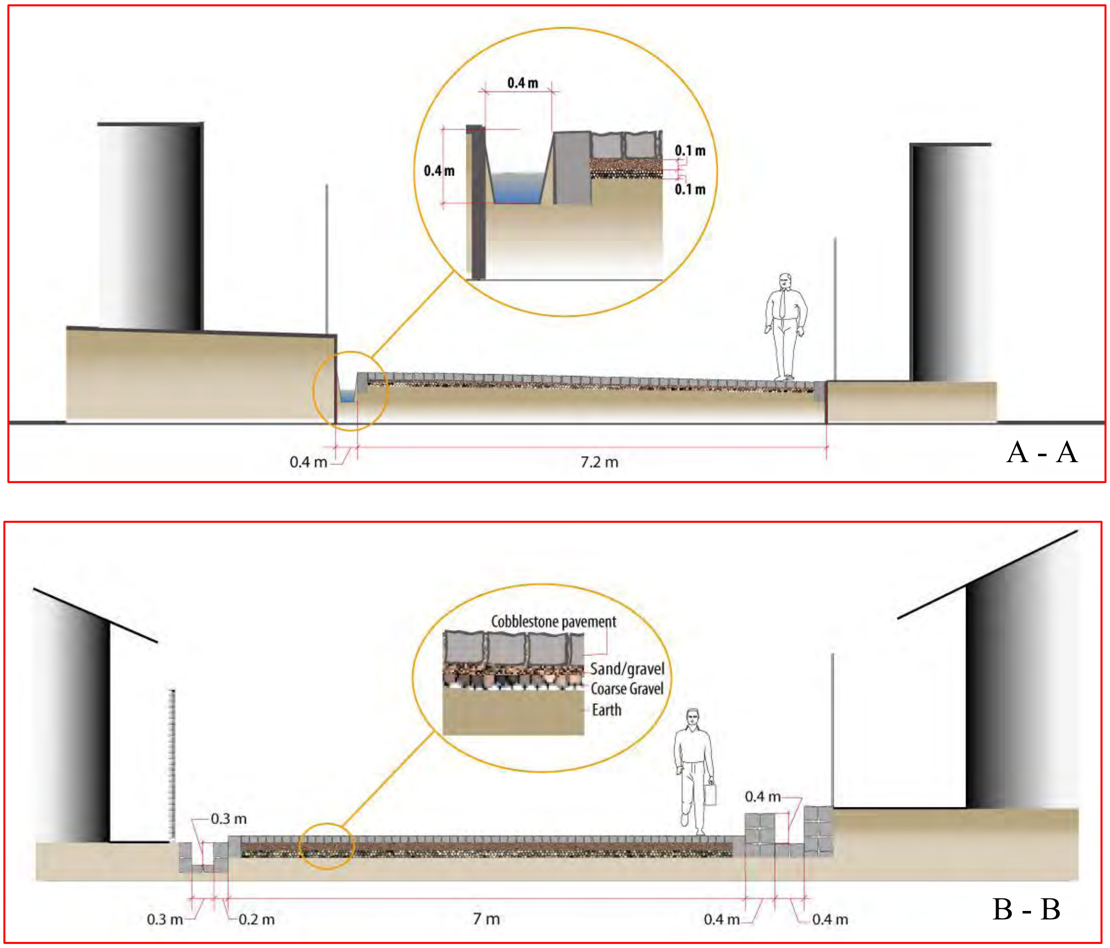


Figure 6. 16 Local street section A – A and B – B (Source: Fieldwork, 2016)

6.6. Street pavement

6.6.1. Lambret Abunaregawi area

There are four types of street pavements in this area. These are cobblestone (52%), asphalt (7.29%) stone (9.01%) and earth (30.81 %). Currently, these streets and their pavement material are being affected by stormwater runoff. Especially, the cobblestone paved streets are in a bad condition because of flooding and erosion of the sub base material. The researcher asked respondents to identify the problems that they have observed on the cobblestone streets. Accordingly, the respondents indicated that fragmentation of cobblestone is the major problem in this area. The respondents also identified the root cause of this problem is the lack of proper and interconnected drainage systems along the street. Additionally, heavy vehicle movement is also the other problem that destroyed the cobblestone pavements in this area.

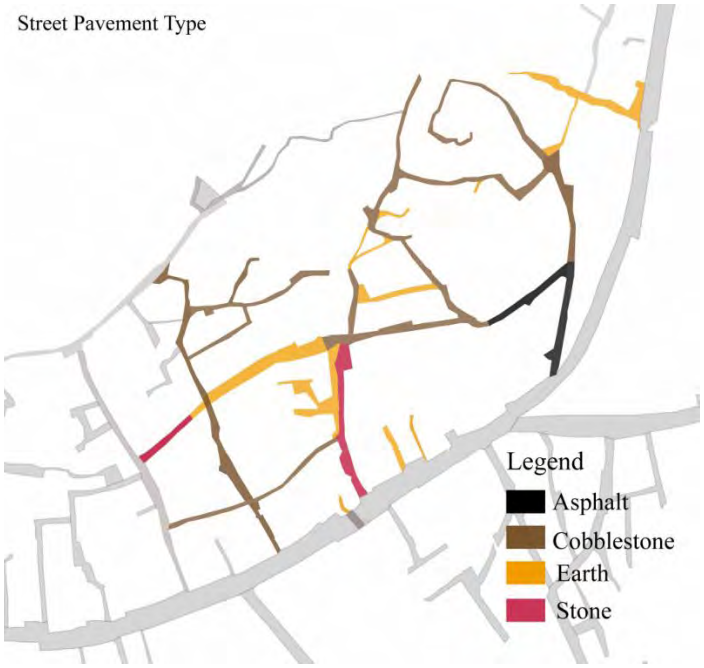


Figure 6. 21 Street pavement type (Source: Author, 2016)

Table 6. 5 Street pavement type in area and percentage cover

Pavement type	Area in m^2	Percent (%)
Asphalt	2891.17	7.29
Cobble stone	20984.39	52.89
Earth	12221.31	30.81
Stone	3575.24	9.01
Total	39672.11	100

Table 6. 6 Runoff generated from Streets

Pavement type	Runoff in litter/day
Asphalt	70255.43
Cobblestone	283289.26
Earth	164987.68
Stone	67572.03
Total	**586104.41**

Figure 6. 22 Street pavement types (Stone, Asphalt and cobblestone) Source: Fieldwork (2016)

6.6.1.1. Existing situation of local street pavement in Lamberet Abunaregawi area

As identified by the residents living in this area, fragmentation of the street pavement is the major problem. These have resulted due to lack of proper and interconnected drainage system as the most of the respondents indicated. In addition to this, as observed by the researcher the existing drainage system doesn't fit the slope character of the site. As a result, the cobblestone pavement in this area becomes fragmented from the overflow of stormwater that was not managed with the provided conventional drainage system. The researcher tried to map the fragmented cobblestone spots in this area as shown in figure 6.2 below.

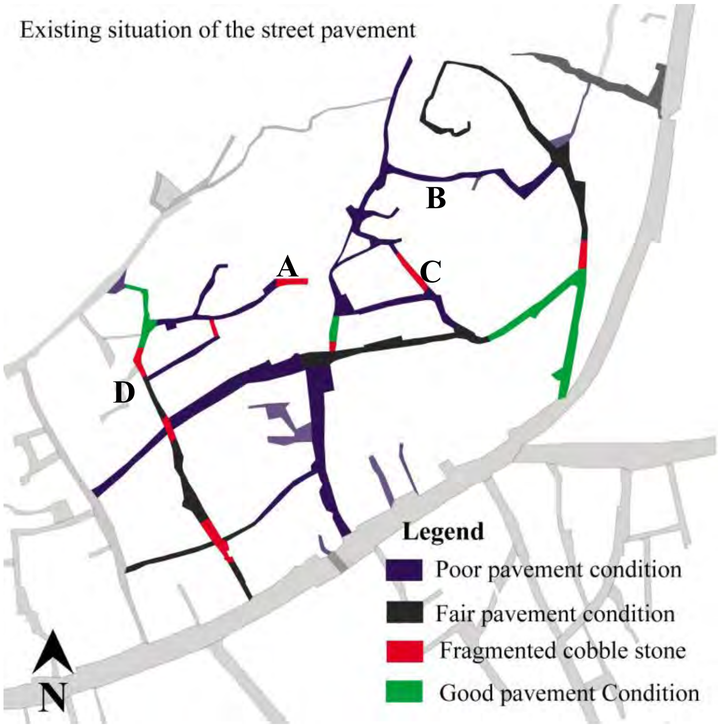


Figure 6. 23 Street pavement condition
(Source: Author, 2016)

Figure 6. 24 Fragmented cobblestone pavement Source: Fieldwork (2016)

6.6.2. Meker Betoch area

More than 83% of the street in this area is paved with cobblestone. There is also Asphalt paved street (8.21%) and unpaved streets which covers (7.84%). According to the respondents survey result indicates 97% of them observed waterlogging on the streets. The researcher also asked the residents to identify the main cause for the water logging of this area. Accordingly, most of the respondents identified the problem to be lack of proper drainage on both side of the street.

As observed by the researcher, the existing drainage system doesn't respect the topography of the area. As a result, when there is heavy rain it is common to see waterlogged streets and overflow of stormwater from the drainage systems. Furthermore, the street in this area remains water logged for more than two days.

Table 6. 7 Street pavement in area and percentage cover

Pavement type	**Area in m^2**	**Percent**
Asphalt	2197.27	8.21
Cobble stone	22462.29	83.95
Earth	2098	7.84
Total	26757.56	100

Table 6. 8 Runoff generated from Streets

Pavement type	**Runoff in litter/day**
Asphalt	5393.61
Cobblestone	303241.05
Earth	28323
Total	**384957.71**

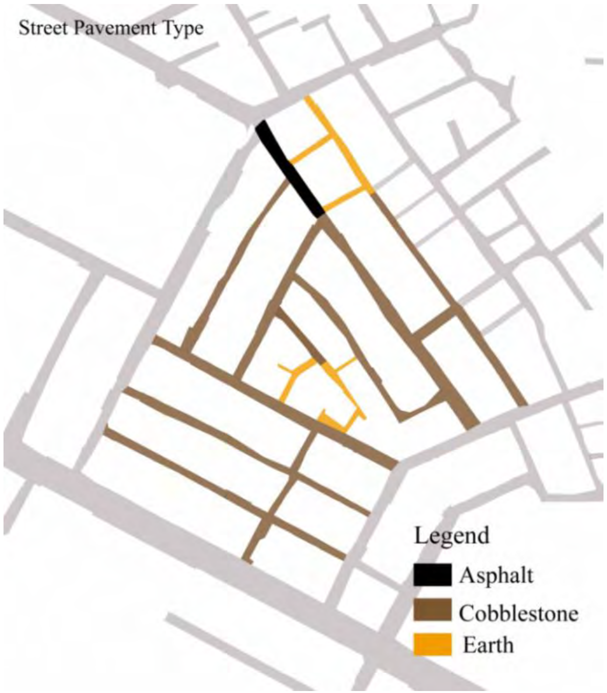


Figure 6. 25 Street pavement type (Source: Author, 2016)

Figure 6. 26 Street pavement types (Earth, Asphalt and cobblestone) Source: Fieldwork (2016)

6.6.2.1. Existing situation of local street pavement in Mekerbetoch area

As discussed earlier, there are several problems that are observed in the local streets of this area. Lack of sustainable drainage system is one of the major problems. As observed in the site, when a heavy rain hits the ground, the street will become flooded quickly. Eventually, this water becomes stagnant for more three days without infiltrating to the ground due to waterlogging nature of the surface. As a result, the stormwater on the streets will erode the street sub base material. Consequently, when a heavy load vehicle pass on these streets the cobblestones become submerged and easily fragmented.

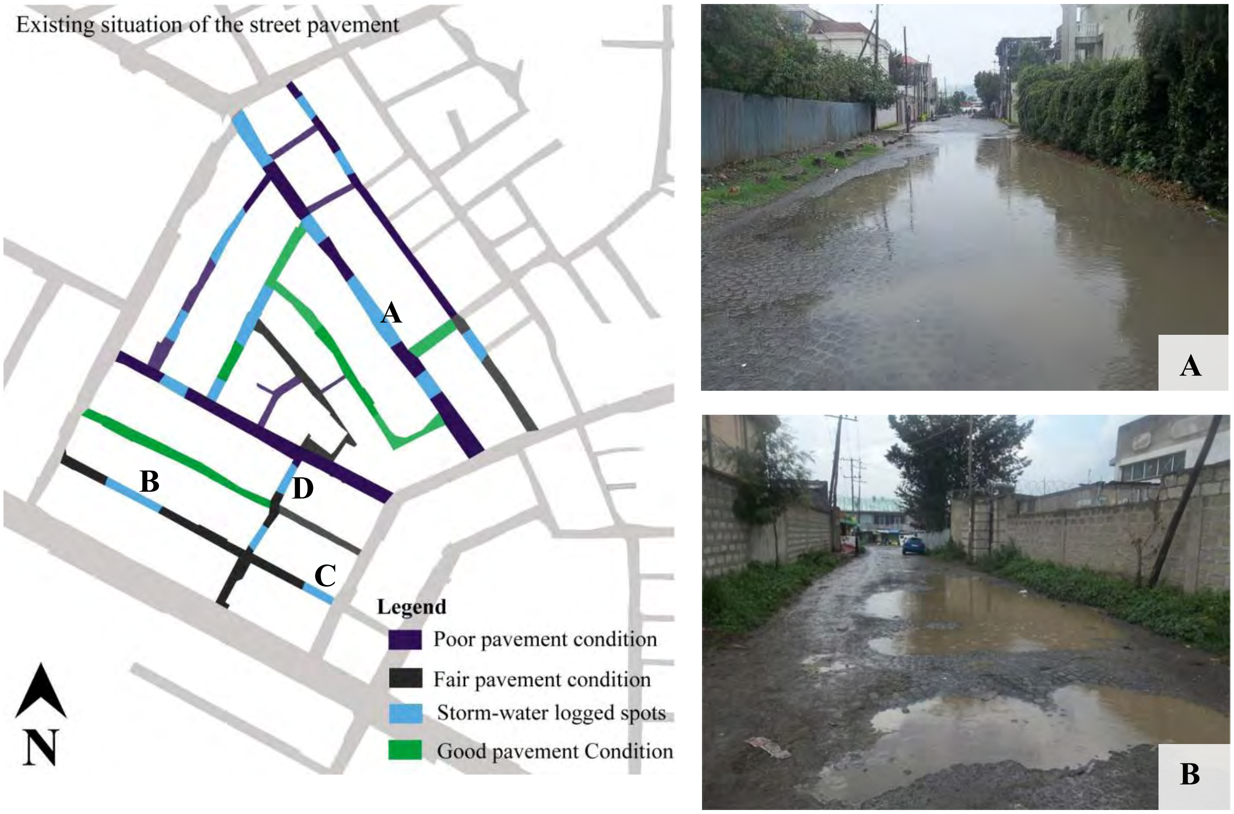


Figure 6. 27 Street pavement condition Source: (Source: Author, 2016)

Figure 6. 28 Waterlogged local streets in Mekerbetoch area Source: Fieldwork (2016)

6.7. Vegetation covers along the local streets

In both of the case study areas there are no any trees that are planted intentionally along the streets. But, the researcher observed some vegetation like grass and shrubs planted along the resident's compound fences. However, the resident's response during the interview indicated this planting of vegetation is done only for the sake of aesthetics. The researcher also observed that, there are some practices which looks like green infrastructure technologies like bioretention and vegetated swale (See figure 6.29). But, as understood from the interview these practices are not provided for stormwater management. Additionally, the provided curbstone along this practice doesn't have any break at all, that can allow stormwater from the street to get into the system. However, with some modifications on the structures they can be used as a potential to intercept the runoff from the streets.

Figure 6. 29 Form of bioretention with curbstone around it with no break in between Source: Fieldwork (2016)

Figure 6. 30 Vegetation planted along the compounds fence Source: Fieldwork (2016)

6.8. Impact of stormwater runoff in the study areas

As discussed earlier in both case study areas, the local streets lack sustainable type of drainage systems that can infiltrate the stormwater to the ground. Additionally, the individual plots also don't have any detention and infiltration practices. As a result, the residents living within these areas are facing different challenges. For example, in the rainy season their compounds are flooded due to stormwater overflow, coming from the streets and its drainage (See figure 6.31, 6.32 and 6.33) and in the dry seasons the residents are exposed to harsh sunlight when walking on the streets. Beside, as the residents explained during the interview, they feel disappointed because the road they had put up their money on took only few years to be destroyed. Moreover, the cost for lessening the impact of stormwater runoff through providing new drainage lines or other methods is very high.

Figure 6. 31 Flooded compounds with stormwater that overflows from the streets Source: Fieldwork (2016)

Figure 6. 33 Overflow from the drainage to the streets Source: Fieldwork (2016)

Figure 6. 32 Flooded business area with storwater that flows from the streets Source: Fieldwork (2016)

6.9. Measures taken to reduce this impact

6.9.1. Lambret Abunaregawi area

Different measures have been taken to lessen the negative impacts of stormwater runoff in this area. The residents have tried to divert the stormwater runoff from the local street by digging a natural drainage along the street (See figure 6.35). Additionally, using drain grating cover in front of compounds gate is a common practice observed in the site (See figure 6.36). However, the taken measures didn't work for long time or it is not sustainable.

As explained by the residents during the interview, in collaboration with the resident's public participation officials of woreda 9, the residents have tried to divert the runoff by making drainage diagonally on the sloppy area of the streets (See figure 6.34 and 6.37). However, as explained by the dwellers this measure was not effective solution because on high rain event the stormwater overflows and flooded the area. Since, the only purpose of the drainage is to divert the runoff, not infiltration.

Figure 6. 35 Diagonal street drainage construction Source: Fieldwork (2016)

Figure 6. 34 Natural drainage line created by the resident Source: Fieldwork (2016)

Figure 6. 37 Diagonal street drainage Source: Fieldwork (2016)

Figure 6. 36 Drain grating cover Source: Fieldwork (2016)

6.9.2. Meker Betoch area

In this area waterlogging on the local streets and flooding of the compounds that live along the streets is the major problem. In order to reduce this problem, the residents have tried different kinds of measures. For instance, some of the residents in this area creates bumper like structure to stop stormwater getting in to their compounds (See figure 6.38). Accordingly, some of them uses drain grating covers in front of their compound gates (See figure 6.40). But, most of the residents do nothing to reduce these impacts. The interview made with the residents indicated these types of methods are applied in order to disconnect the flow of stormwater that is entering in to their compound.

Figure 6. 38 Bumper like barrier Source: Fieldwork (2016)

Figure 6. 39 Form of bioretention along the fence Source: Fieldwork (2016)

Figure 6. 40 Drain grating cover Source: Fieldwork (2016)

Figure 6. 41 Street drainage construction Source: Fieldwork (2016)

CHAPTER SEVEN

FINDING, CONCLUSION AND RECOMMENDATIONS

The following section presents summary of the research findings from the data collected and the field observation analysis by linking them with the findings from the literature review.

7.1. Discussion of findings

As mentioned earlier the local street in these areas is deteriorating from time to time mainly because of the imperviousness of the land use and due to lack of sustainable drainage systems. Additionally, lack of compatibility of the street design with the soil and slope character of the area is observed. This is resulted from lack of assessment of the factors that dictate the applicability of GI practices in a specific area.

The major factors that dictate the applicability of GI practices:-

- **Land form:** The slope analysis of the case study areas showed that the flow of stormwater is dictated by the slope type of the area. For example, in Lamberet abunaregawi area stormwater flows with high velocity because slope is dominated by steep kind of topography. This in turn has contributed to the fragmentation of cobblestone. Whereas in Mekerbetoch area, water is logged on the local streets because of the flat topographic character of the site.
- **Drainage:** The finding form site observation of both case study areas indicated conventional drainage systems are used as a primary means for conveyance of stormwater runoff. These drainage systems cannot handle the amount of stormwater passing through especially on high rain events. This has contributed to the waterlogging and fragmentation of the local streets from the overflow and flooding.
- **Soil:** According to the literature review soil are key factors in designing stormwater management systems. For instance, the soil type that is found in Lamberet abunaregawi area is called calcic xerosols which has moderate infiltration rate. And the soil type in Mekerbetoch area is called Eutric nitisols / clay loam which have high runoff potential due to very slow infiltration rate.
- **Imperviousness of landuses:** The landuse and lancover analysis of both case study areas indicated that residential types of uses generate 65% in Lamberet Abunaregawi

area and 78% in Mekerbetoch area. This is because the residential plots don’t have any detention or infiltration mechanisms.

- **Water table:** According to literatures reviewed in order to apply GS practice a given area should be vertically separated by one (1) metre from the seasonally high water table. Accordingly the water depth of both case study areas is greater than 2m. Therefore, the case areas are suitable to exercise GS practices.

The existing situation of local streets and impact of stormwater runoff with in the study areas

- **Existing situation of local street surfaces:** Local streets in both case study areas are in bad condition. However, the degree and type of deterioration depends on the physical location of the area. For example, in Lamberet abunaregawi area the problem is mainly fragmentation and in Mekerebetoch area the main problem is water logging.
- **Existing situation of drainage:** The drainage system in both case study areas is composed of closed and open ditch which are a conventional type of drainage system. Moreover, in Lamberet abunaregawi area 68% of the drainage system is found in a poor condition and in Mekerbetich area 52% of the drainage system is in a poor condition. Therefore, the cost for maintenance or constructing new drainage infrastructures is highly unlikely.
- **Vegetation:** As mentioned in the literature review plants intercept precipitation from direct rainfall through using their roots and the trunk and also gives shade to pedestrians. However, in both case study areas there is no any kind of vegetation cover like tree along the local streets. This has exposed the streets to flooding since there is no detention and infiltration.
- **Flooding in resident’s compound:** stormwater runoff flowing from the local streets is directly flowing in their compounds. This rises from lack of sustainable drainage and lack of infiltration and detention mechanisms along the streets.
- **Loss of money:** As discussed in the contextual review the society and government is contributing for the construction of the sub base and drainage. So, when these streets are affected by the stormwater; indirectly they are losing their money. Additionally, the money they spend for mitigating these problems is also another loss.

7.2. Summary of findings

Table 7. 1 Summary of findings from the case study areas

Major factors that dictates the applicability of GI practices		
	Lamberet abunadregawi area	**Mekerebetoch area**
Slope	61% steep and 31 % moderately steep	91% flat
Landuse	Dominantly residential	Dominantly residential
Runoff generated	65% generated from the residential uses and 16% is from the open spaces	78% generated from the residential uses
Drainage	CSWM, Dominantly open ditch	CSWM, Closed and open ditch
Vegetation	No tree along the local street	No tree along the local street
Soil	Moderate infiltration rate and moderate runoff potential	High runoff potential and low infiltration rate
Water table	2m -73m	2m -73m
Existing situation of local streets and impact of stormwater on the study area		
	Lamberet abunadregawi area	**Mekerebetoch area**
Problem observed on the streets	Fragmentation of cobblestone pavements, lack of vegetation like tree Wreckage of drainage systems	Waterlogging on the streets, submerged cobblestone pavement, lack of vegetation
Cause of the problem	Lack of proper drainage, Lack of suitable street design that fits the area, imperviousness of the residential landuses	Lack of appropriate drainage, Lack of suitable street design that fits the area, imperviousness of the residential landuses
Consequences/ Impact of stormwater runoff	Flooding of compounds, loss of asset and loss money, loss of infrastructure	Flooding of compounds, loss of asset and loss money and loss of infrastructure

7.3. Conclusion

According to the findings from the contextual study, local street construction with cobblestone; is currently one of the infrastructure developments in Addis Ababa. However, these local streets are being affected by stormwater runoff during the rainy season of the year. Most of the time, this problem occurs because of defects in the proposed street and its drainage design. Furthermore, the provided drainage systems along the local street are found in a poor condition. The drainage systems are mostly overloaded, causing flooding in the neighborhood and damage to the streets. The research finding also indicated that, some local streets are developed without any drainage system.

By using two case studies, the study tried to demonstrate that lack of site specific local street design and lack of sustainable drainage systems along the street are the main cause of street deterioration. The case study sites were analyzed in the framework of GI practice and the factors that dictate the applicability of GI practices and influence the flow of stormwater runoff. The results from the analysis demonstrated that imperviousness of the watershed, slope, soil type, ground water table depth and type of drainage dictates the applicability of GI practices and the flow of stormwater runoff. Additionally, on the case study analysis it is found that fragmentation of cobblestones on steeped slope areas and water logging on flat slope areas are the major problems associated with stormwater runoff.

One of the solutions observed for mitigating these problems was providing new conventional drainage system along the local streets. Another solution was maintaining the existing drainage system. But these solutions are not sustainable and effective in minimizing the destructive impact of stormwater runoff. Additionally, they require a lot of money and time.

Finally, the research showed how GI design and technologies can be useful tools for sustainable stormwater management through retrofitting of the existing urban local street systems. It also demonstrated how the amount of runoff is reduced through the application of GI technologies, particularly related to sustainable drainage systems. Applying these technologies as a sustainable stormwater management tool will also increase, the vegetation cover in a given area. Therefore, when there is more green space, the amount of runoff decreases. Therefore, by developing more green street designs, local street drainage systems can be enhanced more effectively. But, this can be achieved through detail analysis of the major factors that dictate the applicability of GI practices in specific areas before proposing any GS design.

7.4. General recommendations

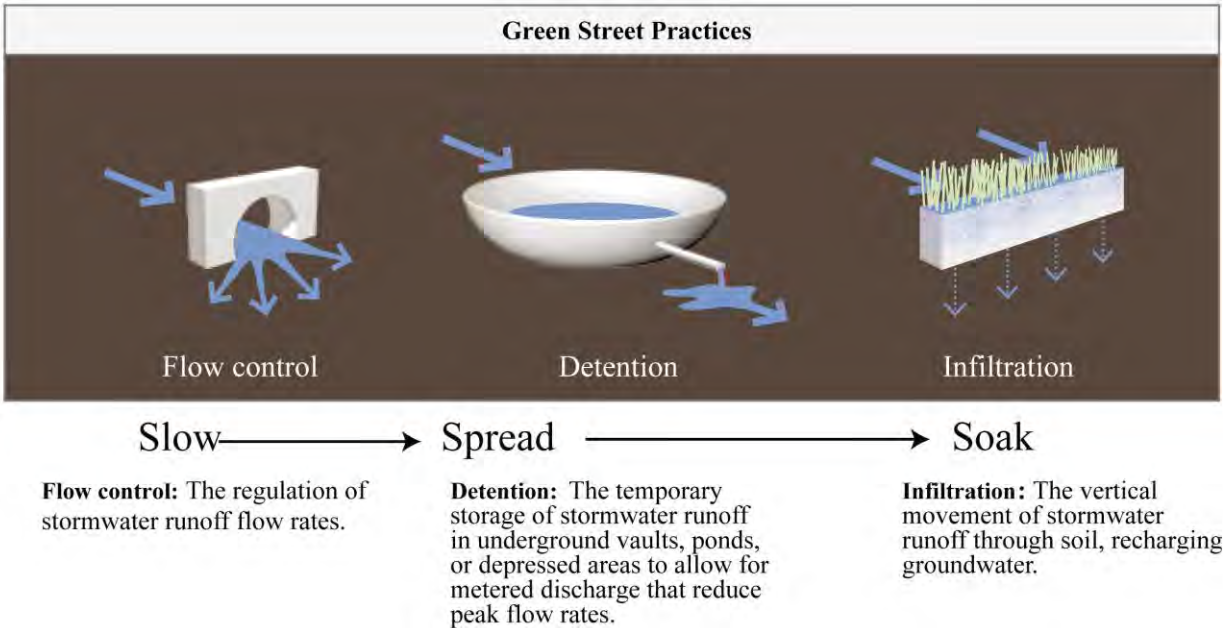
According to the research finding local streets in Addis Ababa are facing many problems and are deteriorating from time to time. So, in order to minimize these challenges the researcher forwarded the following recommendations:-

- When Local Street is designed for some specific area in the city; detail analysis of the contributing drainage area (the watershed) should be conducted.
- When Local Street is designed for some specific area in the city; detail analysis of the major factors that dictate the applicability of GI practices in the watershed area should be conducted.
- There should be local street design standard and guidelines that are based on the specific site condition of an area. Because, as shown in the study every site has its own character in terms of slope, land use, soil infiltration rate, etc.
- There should be proper follow up, monitoring and evaluation mechanisms after the development of sustainable drainage systems are constructed.
- Responsible government organs, designers and other concerned stakeolders should create awareness to the society about GI practices and benefits. Additionally, government should encourage the people to apply green infrastructure starting from their individual plot.

7.5. Site specific recommendations and designs

As the research finding indicates both case study areas have their own physical characteristics that can dictate the design and applicability of green street practices. Therefore, based on the research findings on the specific areas; the researcher proposes the following recommendations and design solutions.

The provided design solutions incorporate detention, infiltration and flow control mechanisms through retrofitting of drainage systems (See figure 7.1).



Flow control: The regulation of stormwater runoff flow rates.

Detention: The temporary storage of stormwater runoff in underground vaults, ponds, or depressed areas to allow for metered discharge that reduce peak flow rates.

Infiltration: The vertical movement of stormwater runoff through soil, recharging groundwater.

Figure 7. 1 Conceptual diagram of the proposed elements

7.5.1. Lamberet Abunaregawi area

In this area the identified green street practices that can be integrated along the cobblestone streets are the following

- Stormwater tree (Extended tree pit)
- Steeped stormwater planter
- Bioretention
- Perforated pipe
- Soakaway and infiltration trench

These green street practices are specifically selected for this area because of the following main physical characteristics of the area.

- Slope character: - More than 60% of the area is dominated by high slope (≥15.1%).
- Infiltration rate: - The soil infiltration rate for this area is between 3.3mm/hr to 10.2mm/hr.
- Street width and longitudinal slope of each local street

Figure 7. 2 Proposed GI practices neighborhood level (Lamberet Abunaregawi area)

Proposed green local street

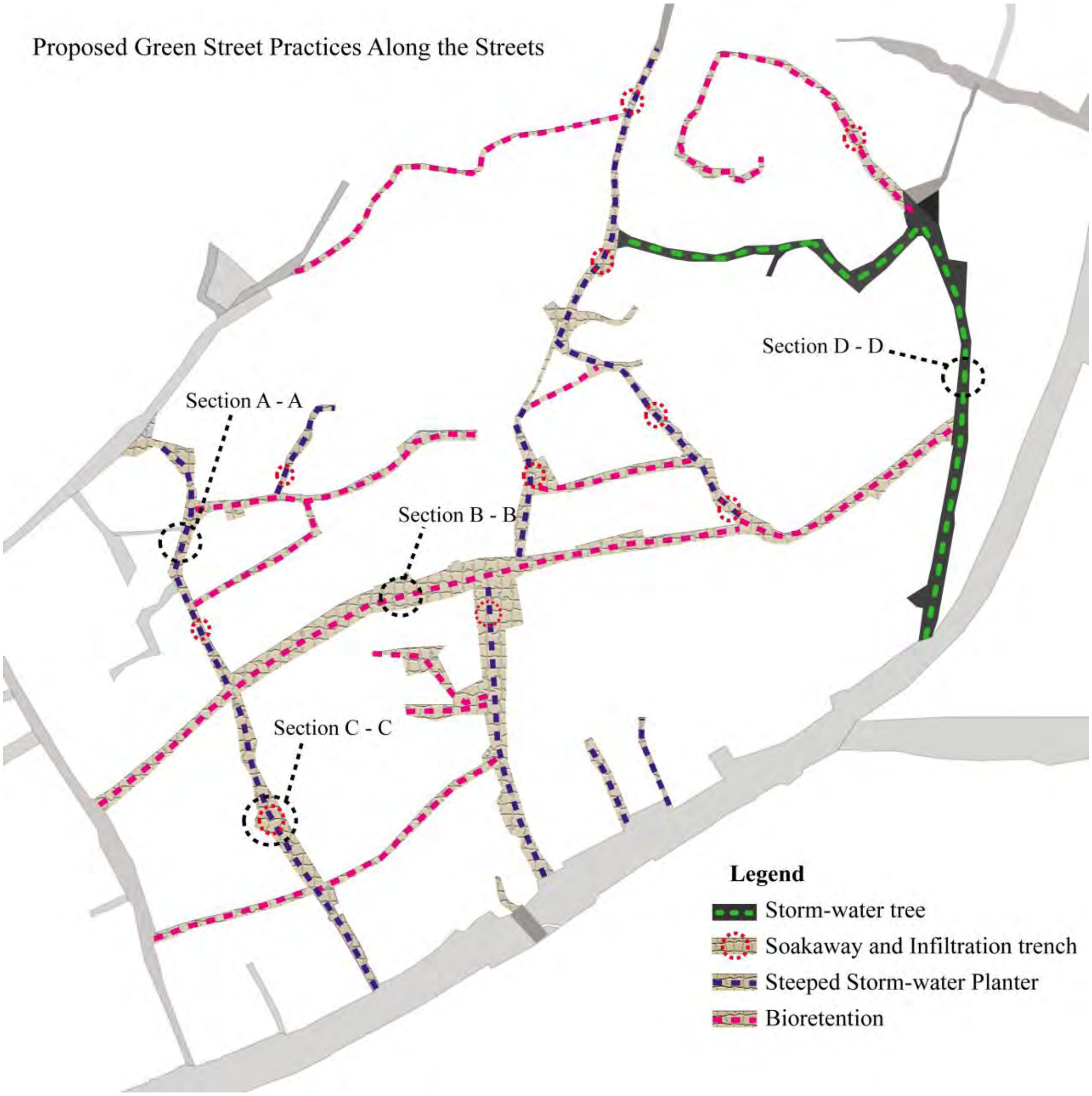


Figure 7. 3 Proposed GS practice along the local streets of Lamberet Abunaregawi area

Providing drainage systems on steep sloped areas is challenging. However, among the green street practices detention and flow control mechanisms can be used together in order to minimize the speed of stormwater runoff. Steeped stormwater planter, stormwater tree (Extended tree pit) Soakaway and infiltration trench are among the recommended practices that suits the physical profile of this area. For example, bioretention is suggested to be used on the narrow streets that are running parallel to the slope. Whereas on the streets running perpendicular to the slope steeped stormwater planter is recommended to match the slope character of the site. Perforated pipe should also be used together with this practice since the soil infiltration rate of this area is less than 15mm/hr. When implementing these practices it is advisable to apply them on the top of the watershed rather than on the bottom parts.

Steeped stormwater planter

This GS practice is suitable for this area since majority of the area is characterized with steep and moderate kind of topography. This planter is made of walled vegetated cells that allowed stormwater to be detained and infiltrate over time. The size (width) can vary from 0.76m (without tree) to 1.52 meter (if tree is integrated). For every 15cm drop in elevation a vertical check dam is placed between each level cell allowing for overflowing water to travel downslope from cell to cell.

If this practice is properly applied Stormwater could be able to infiltrate into the soil within 48 hours of a storm event. If planted with trees, proper examination of vertical check dam locations, additional excavation of soil, and break-outs may be necessary; use wetland-tolerant plants

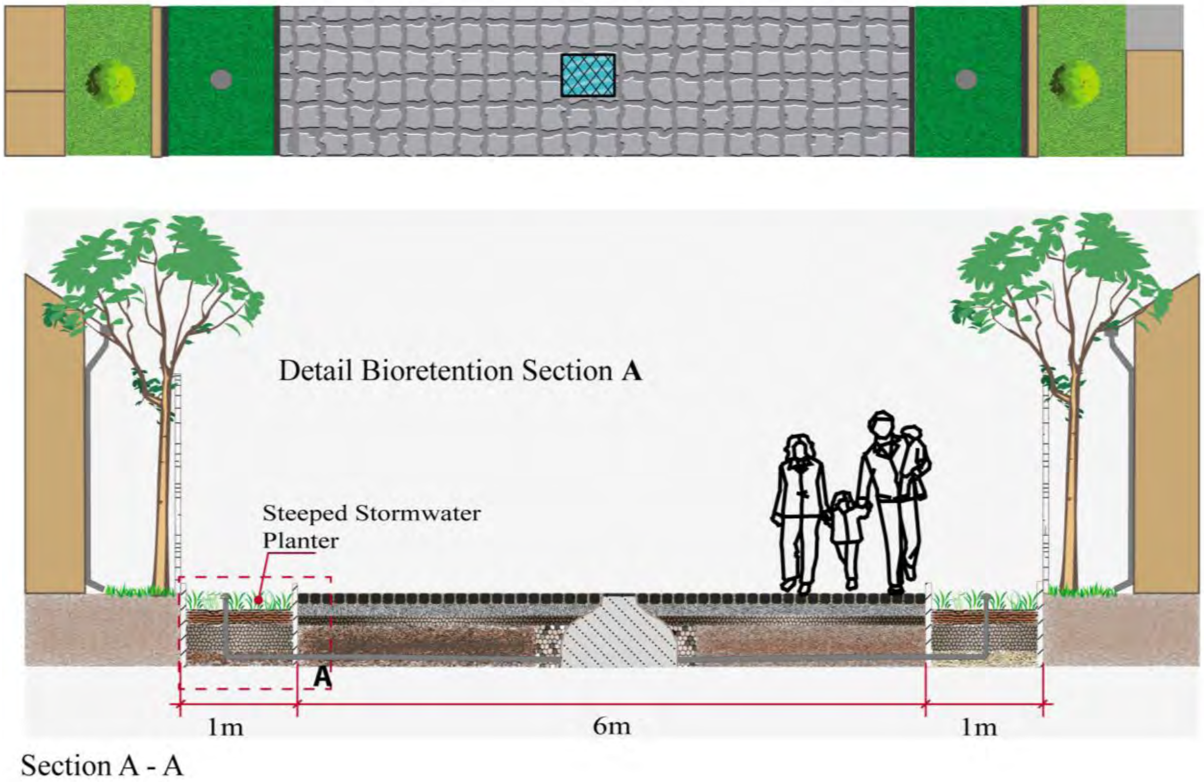


Figure 7. 4 Street level section for steeped stormwater planter

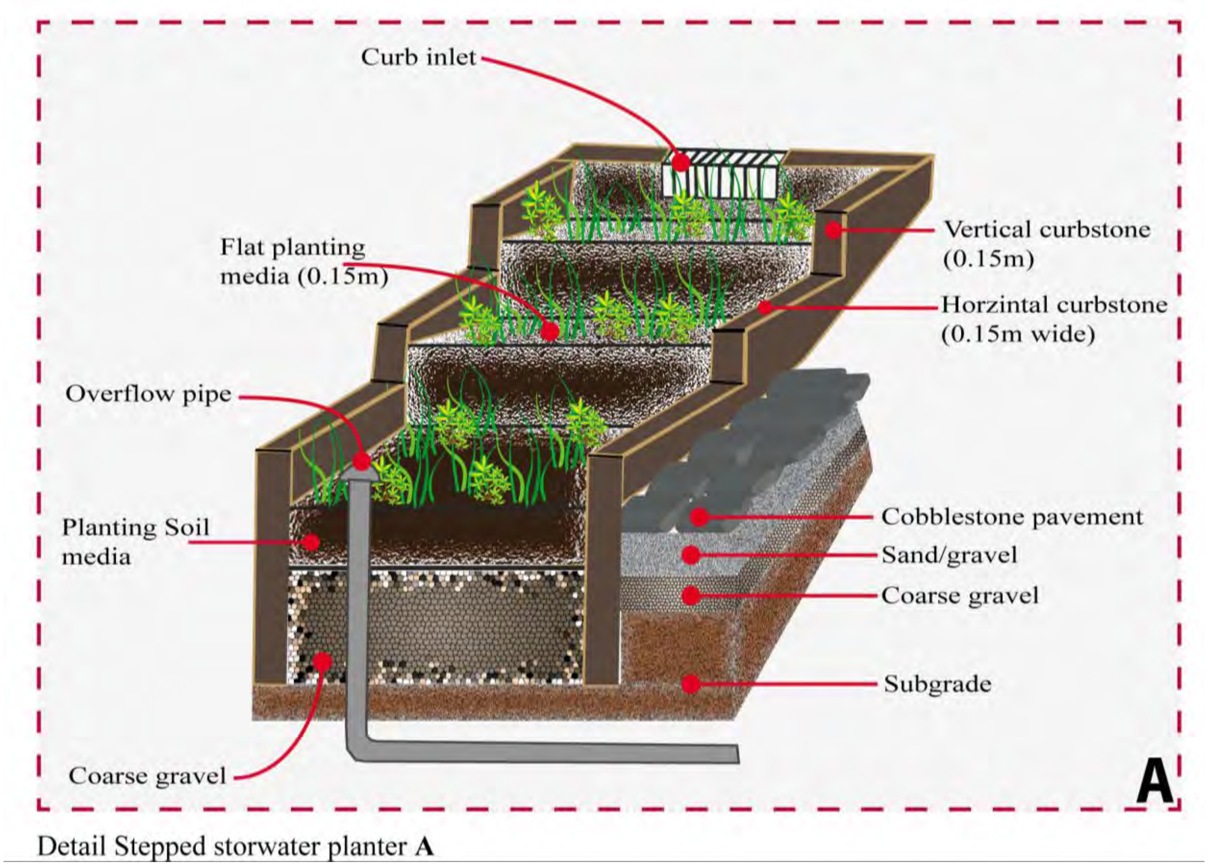


Figure 7. 5 Detail section of stepped stormwater planter

Soakaway and infiltration trench

This are type of underground stormwater infiltration practices could be integrated with other GS practices. However, Soakaway and Infiltration trenches could also be used in the local streets where available space for other types of green street practice is limited.

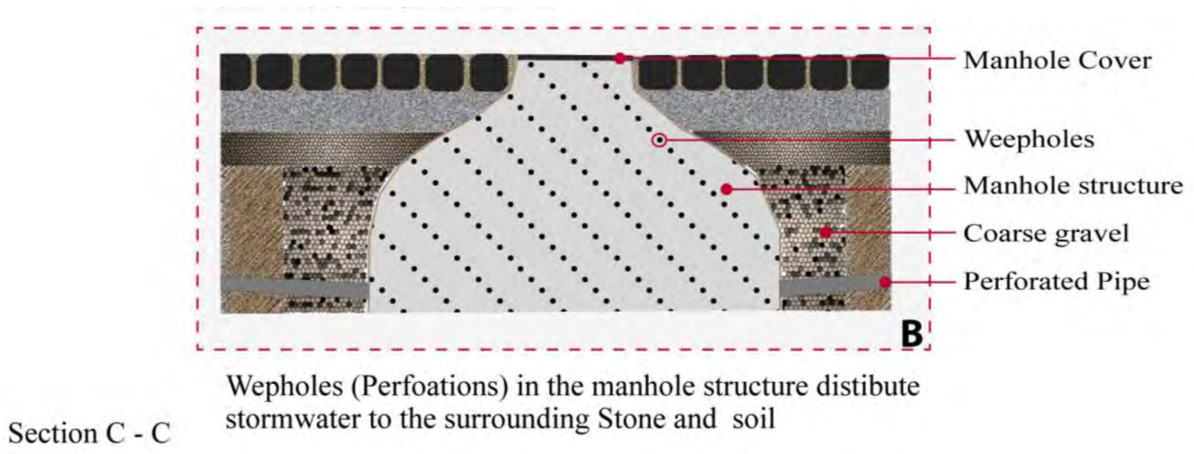


Figure 7. 6 Detail section of Soakaway

Bioretention

Bioretention is proposed in this area along the local streets that are parallel to the slope and on streets that have moderate longitudinal slope. Usually, this GS practice is rectangular and has 0.30m depth that could hold stormwater and be able to infiltrate stormwater within 48 hours. Additionally and overflow pipe should be integrated because of the low soil infiltration rate.

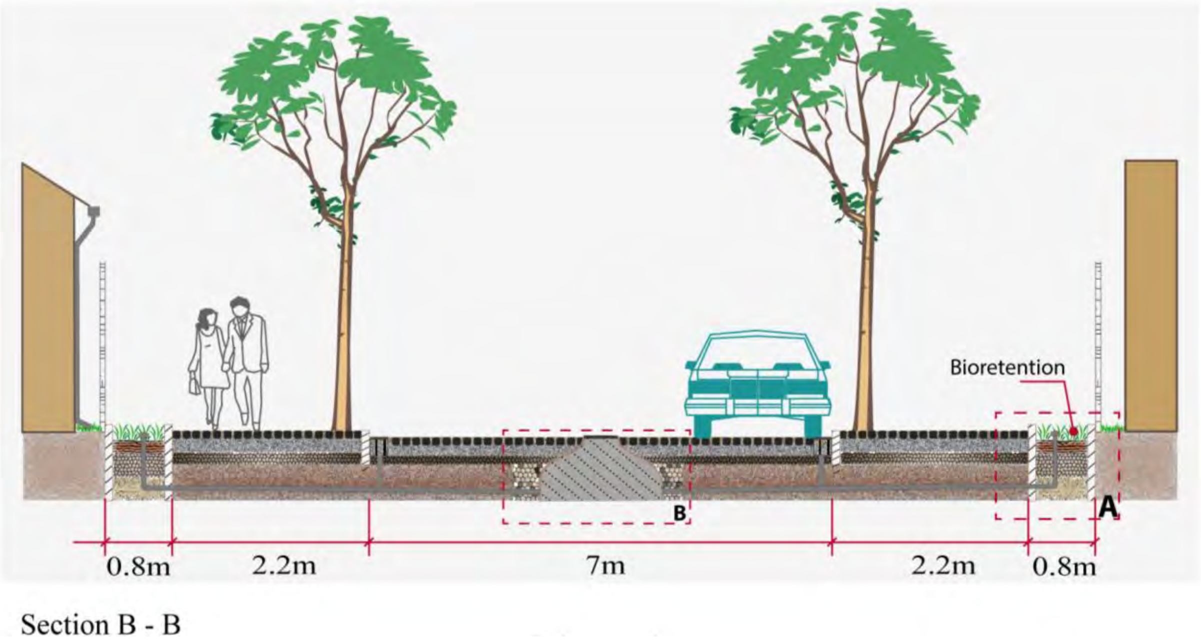


Figure 7. 7 Street level section for bioretention

To make the permeable pavements infiltration capacity more effective providing this kind of sustainable drainage system along the street is advisable.

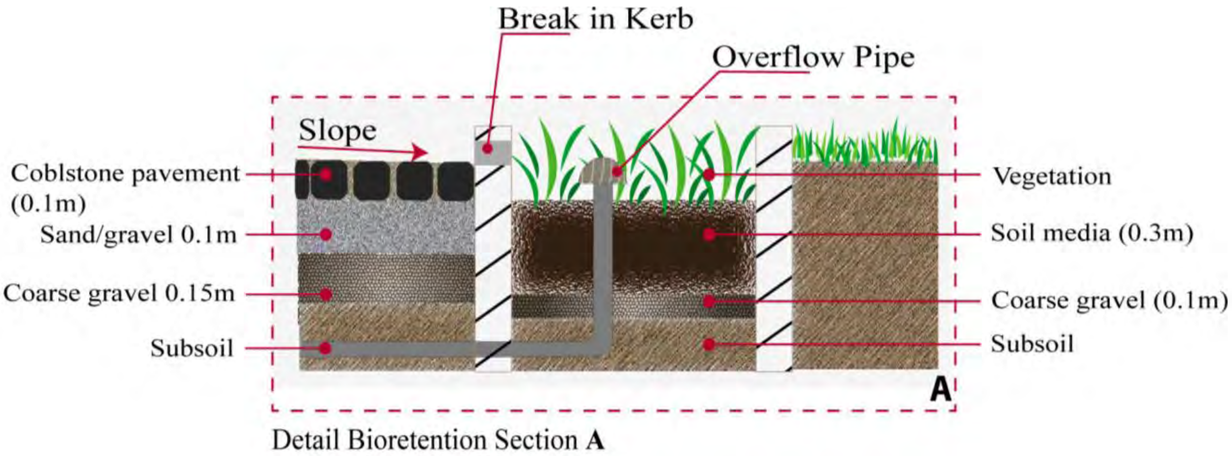
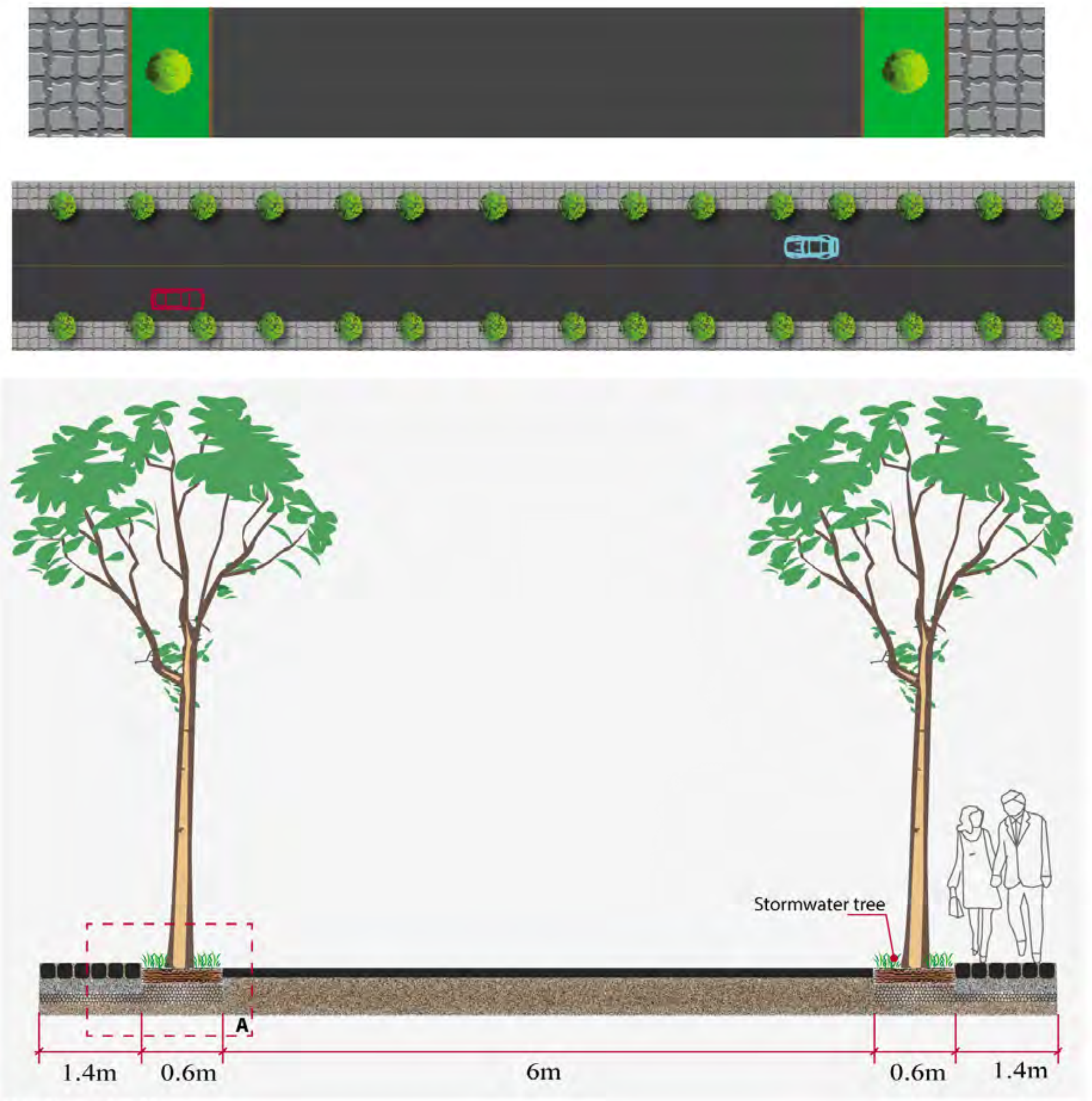
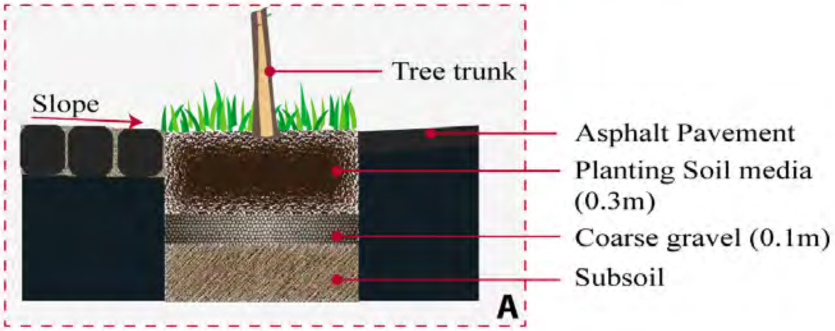


Figure 7. 8 Detail section of Bioretention

Stormwater planter



Section D - D



Detail storwater planter **A**

Figure 7. 9 Street level and detail section for extended treepit/ stormwater planter

7.5.2. Mekerbetoch area

In order to reduce the waterlogging problem in this area, it is recommended to use the following retrofitting drainage practice along the permeable cobblestone pavement.

- Vegetated swale
- Green Gutter
- Bioretention
- Perforated pipe

This green street practices are specifically selected because of the following main physical characteristics of the area.

- Slope character: - More than 92% of the area is dominated by flat slope 0.2% - 5%).
- Infiltration rate: - The soil infiltration rate for this area is between 5mm/hr to 6.4mm/hr.
- Street width and longitudinal slope of each local street

Figure 7. 10 Proposed GI practices neighborhood level (Mekerbetoch area)

Proposed green local street

Figure 7. 11 Proposed GS practice along the local streets of Mekerbetoch area

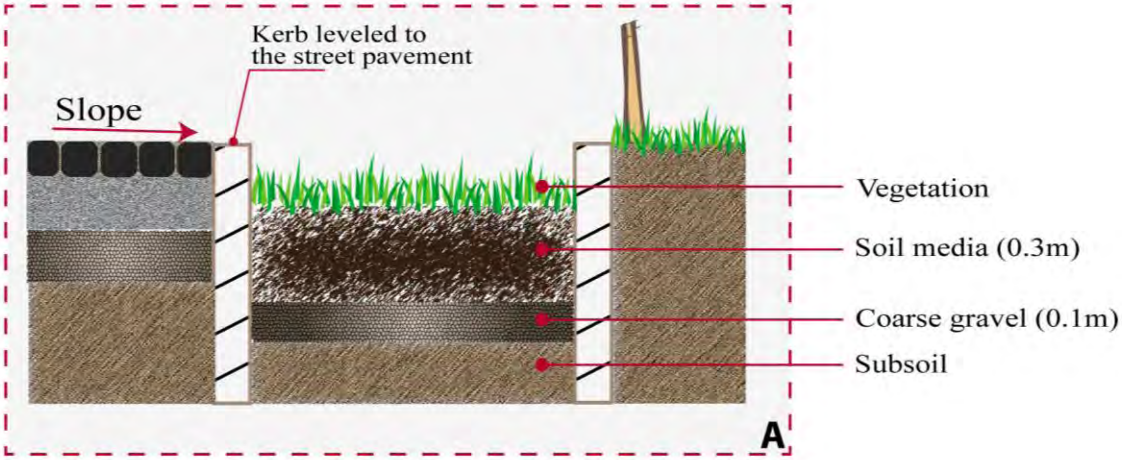
The recommended GS practices suits the physical profile of this area. For example, Green gutter is suggested on the local streets that have small space for application of GS practices. Whereas, on the streets that have large spaces for implementing GS practices, vegetated swale is recommended.

Green gutter

As discussed above green gutter is a narrow and shallow landscaped sustainable drainage system provided along a street's curb line. This GS practice requires space between 0.5m to 0.8m. This practice is a linear drainage system that is filled with vegetation which provides storage and, in some cases, infiltration and evapotranspiration.

Section A - A

Figure 7. 12 Street level section for Greeen Gutter



Detail Green Gutter Section **A**

Figure 7. 13 Detail section of Green Gutter

A leveled curb or an elevated curb can be used along the street side of the green gutter with openings along its length to allow runoff to flow into the green gutter.

Vegetated swale

This GS practice is proposed on the local streets that have large space for implementation. The proposed vegetated swale is designed to allow stormwater to travel and infiltrate within 72 hours. The plants that are integrated in this system must be wetland tolerant. The size could vary based on the available space for landscaping and the vegetation type. For example when a tree is integrated with this system the width can be extended up to 2meter and without a tree 1meter.

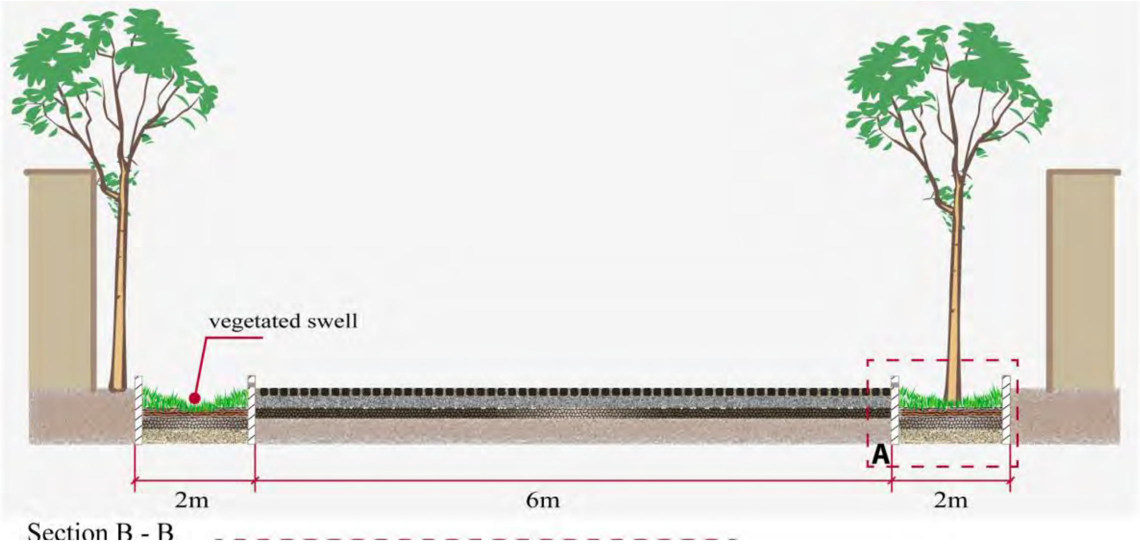


Figure 7. 14 Street level section for section Vegetated swale

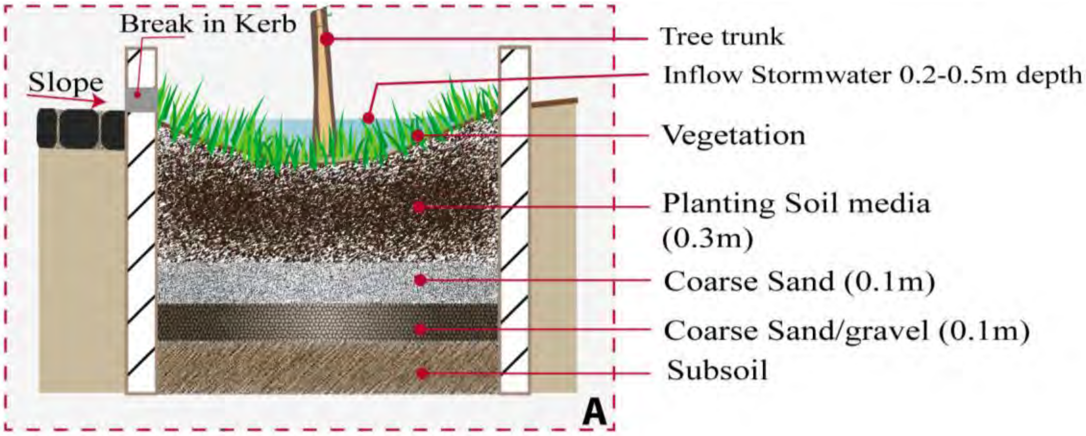


Figure 7. 15 Detail section of Vegetated swale

7.5.3. Landuse landcover proposal

In both case study areas, by analyzing the available space in the compound and the site factors; it is possible to design astormwater sensitive home. Therefore, each individual plot could integrate detention and infiltration practices; in order to allow the stormwater into the ground. This will contribute in the minimization of impervious surfaces in the watershed area. Furthermore, the stormwater runoff generated from the landuses will also be minimized before reaching the local streets.

Within the individual plots or compounds except for the roof, other surfaces in the compound have been replaced with infiltration and detention practices. But, the runoff coming from the roof can be directed into the permeable surfaces and garden areas in the compound. Therefore, these recommended practices will reduce any excess runoff from reaching the local streets on a daily basis as illustrated in the designs below. Moreover, the individual plots in the study area will have an aesthetically pleasing compound.

The following design illustration shows the possible design solutions for different kind of landuses in the case study areas

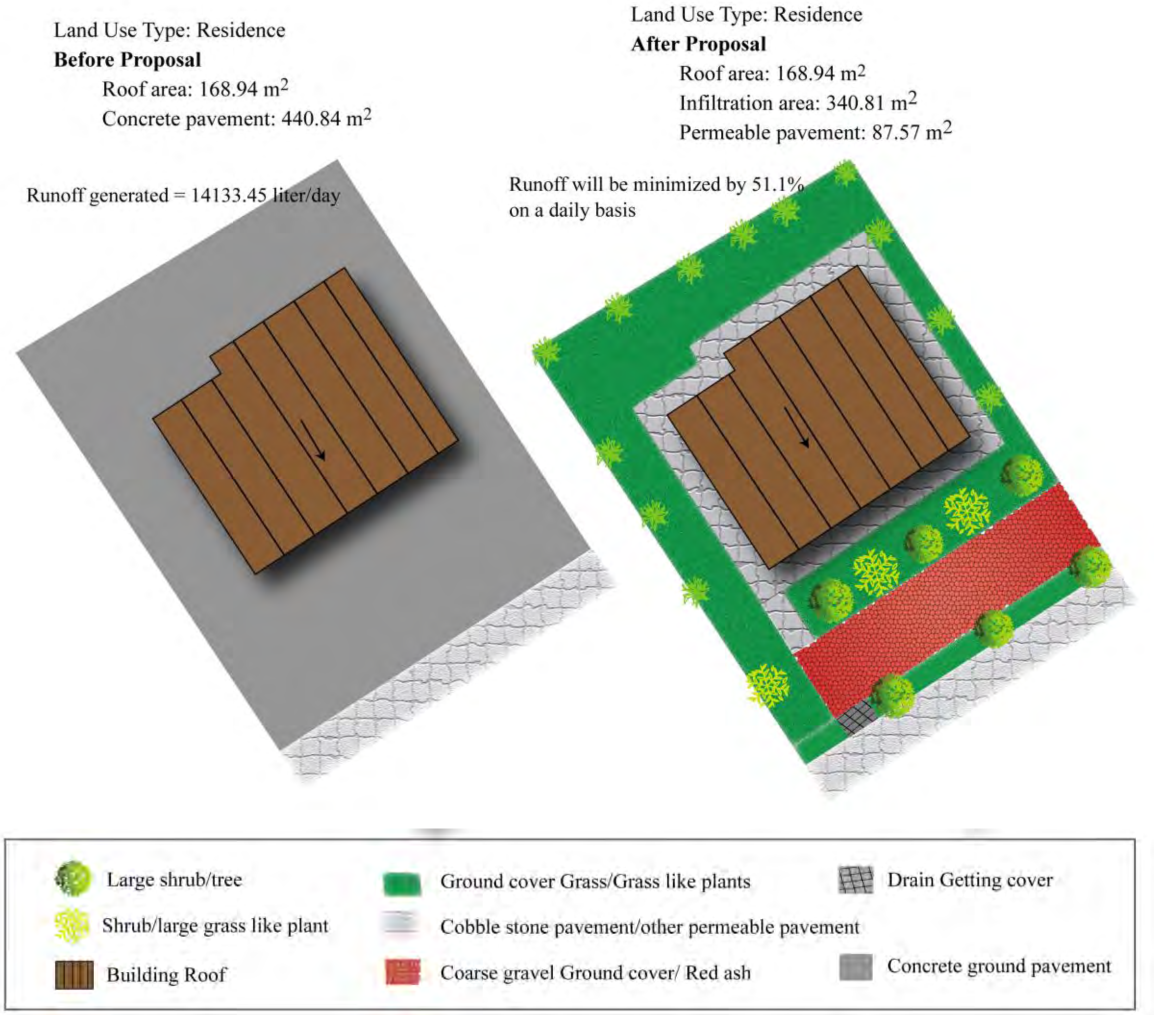


Figure 7. 16 Sample plot level GI poposal for resedential compound

Figure 7. 17 Sample plot level GI proposal for school compound

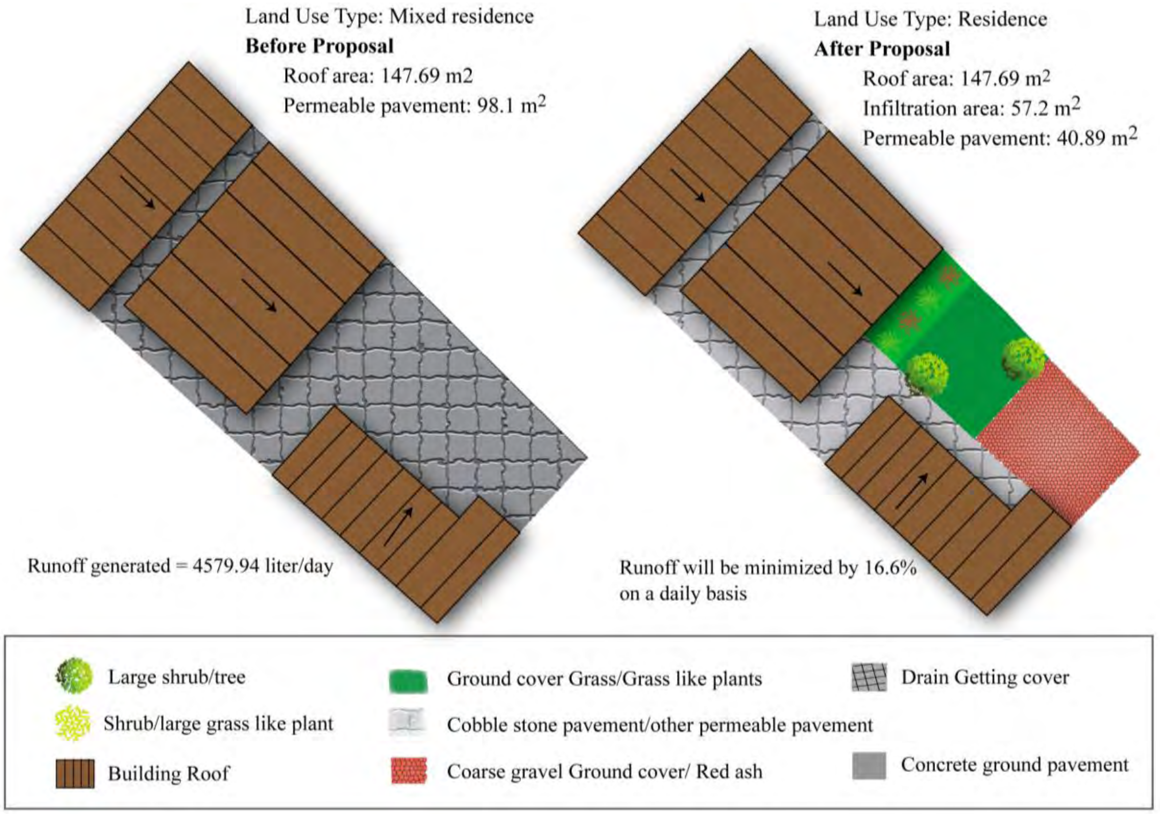


Figure 7. 18 Sample plot 1 level GI proposal for mixed use compound

Figure 7. 19 Sample plot 2 level GI proposal for mixed use compound

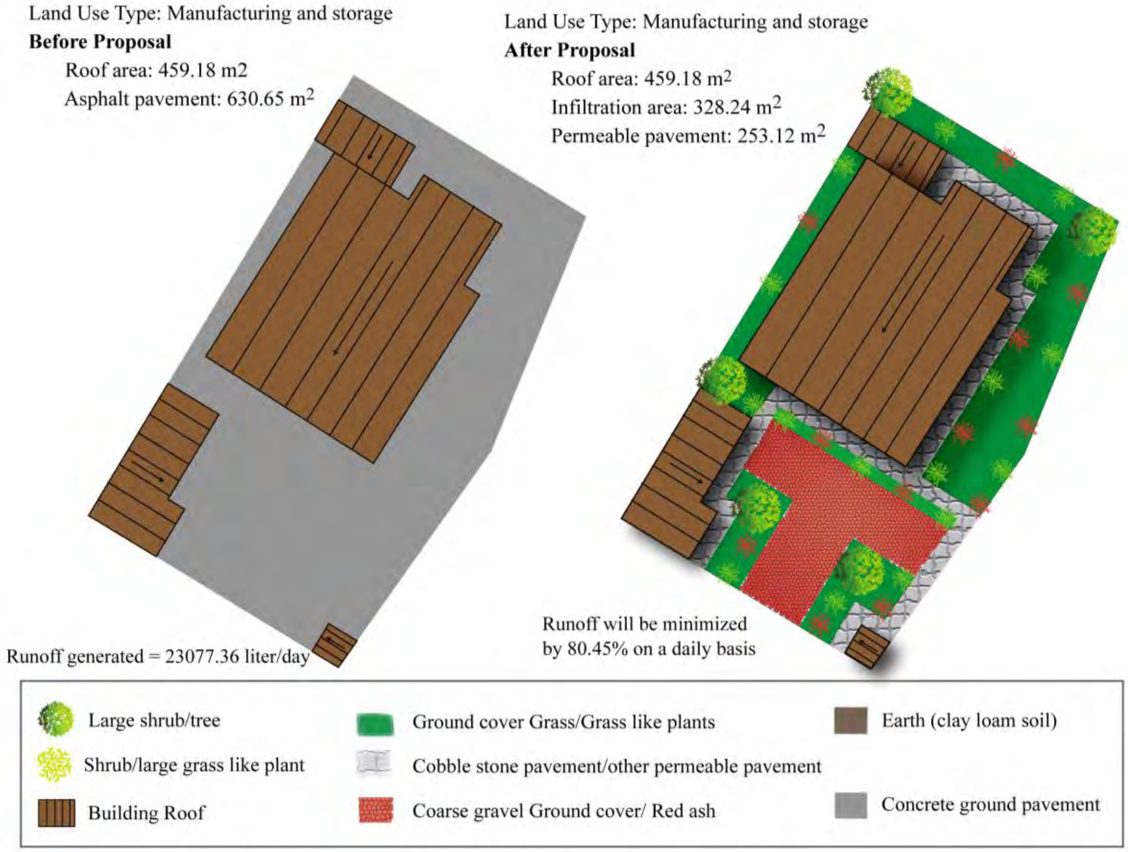


Figure 7. 20 Sample plot level GI proposal for Manufaturing and strorage compound

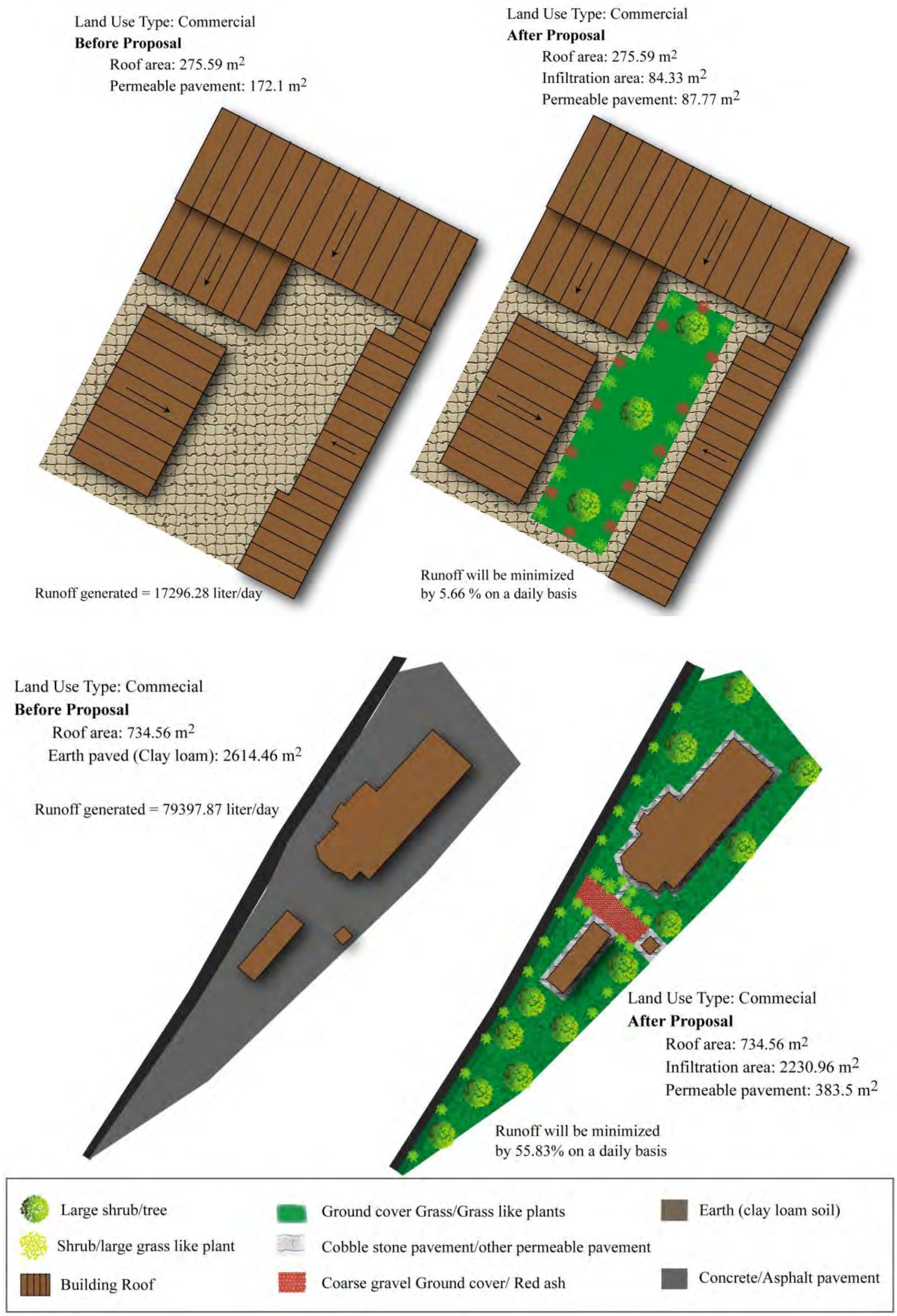


Figure 7. 21 Sample plot level GI proposal for commercial use compound

7.5.4. Open spaces

As discussed in the findings in lamberet abunaregawi area, open spaces cover more than 23% of the study area. This landuse contribute 16% of the runoff on a daily basis. Therefore, in order to reduce amount of runoff generated the researcher recommends detention and evapotranspiration practices by integrating both different hard landscape features like pours paver for walkwasys and soft landscape such as grass, tree, flower and shrubs.

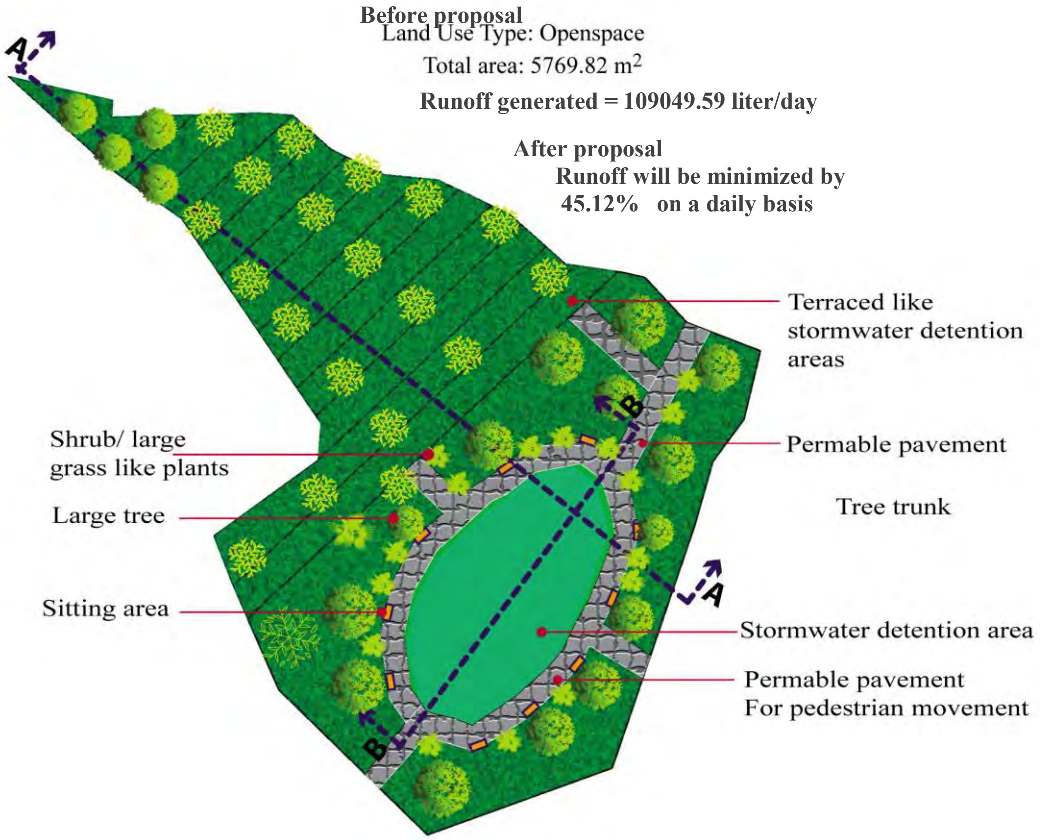


Figure 7. 22 Proposed GI practice on the open space (Lamberet Abunaregawi area)

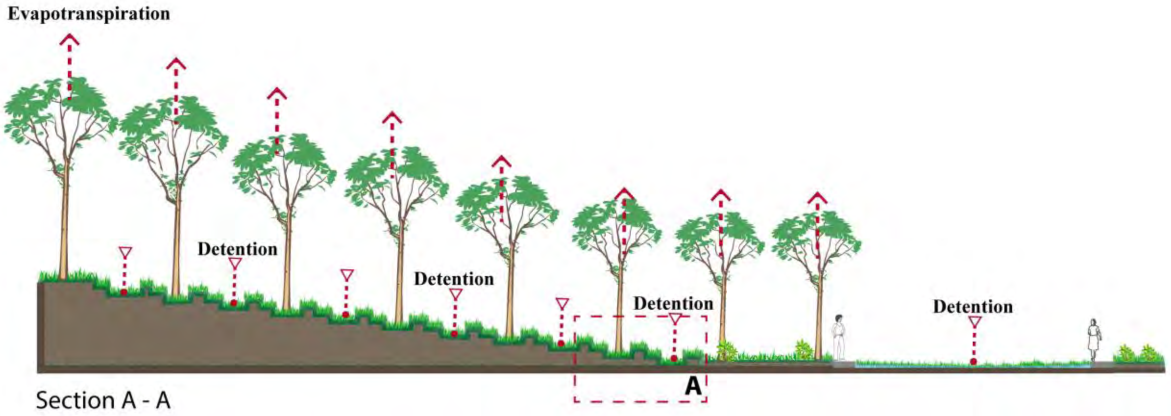


Figure 7. 23 Open space level section

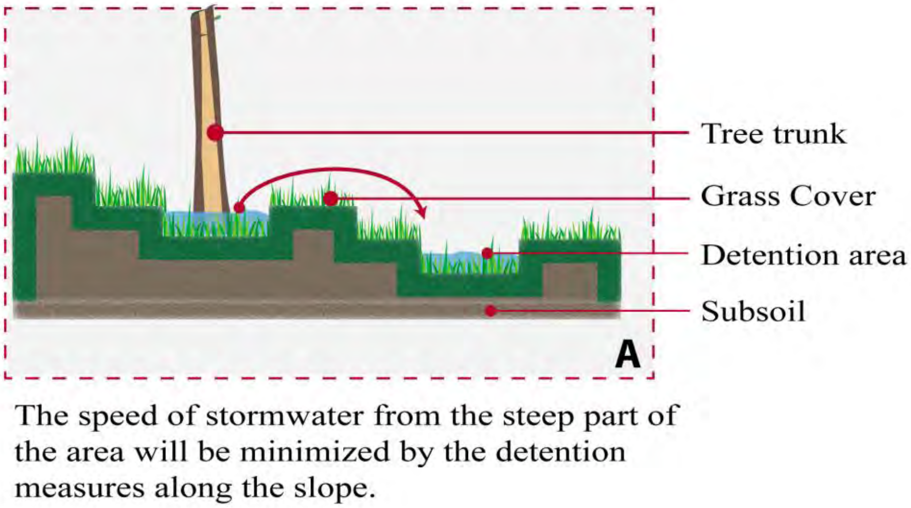


Figure 7. 24 Detail Section

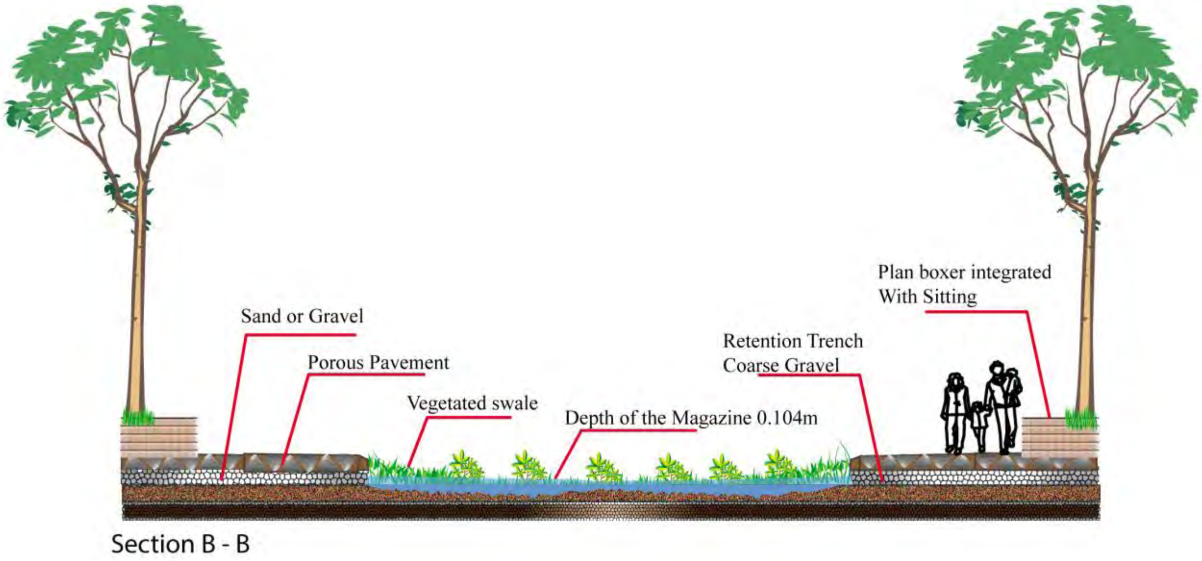


Figure 7. 25 Detail Section

7.5.5. Modification of existing local measures

As discussed in the findings in both case study areas the residents plant trees and vegetation along their fence. Even though they do these things only for aesthetic reasons with some modifications they can be turned into opportunities for lessening stormwater impacts along the local streets. The following design illustrations shows how the existing street side vegetation, speed bumpers and natural grass cover could be modified for stormwater management.

Speed bumpers

The existing speed breakers could be used as an advantage to the car movement as well as to direct stormwater to the adjoining GS facilities.

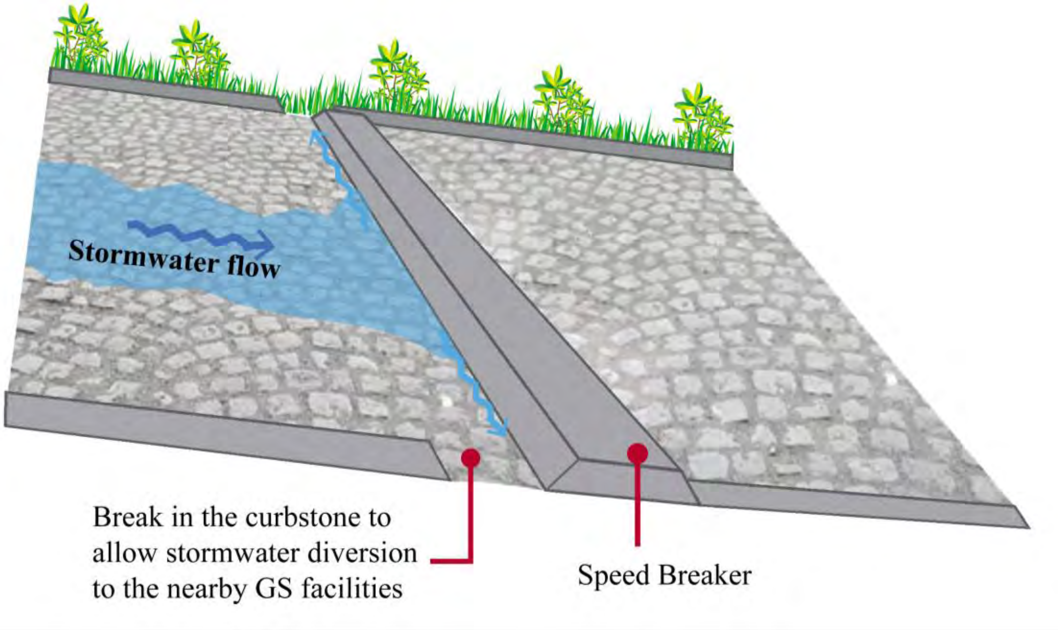


Figure 7. 26 Poposed modifiction on the existing speed bumpers

Leveling the curb to the street pavements

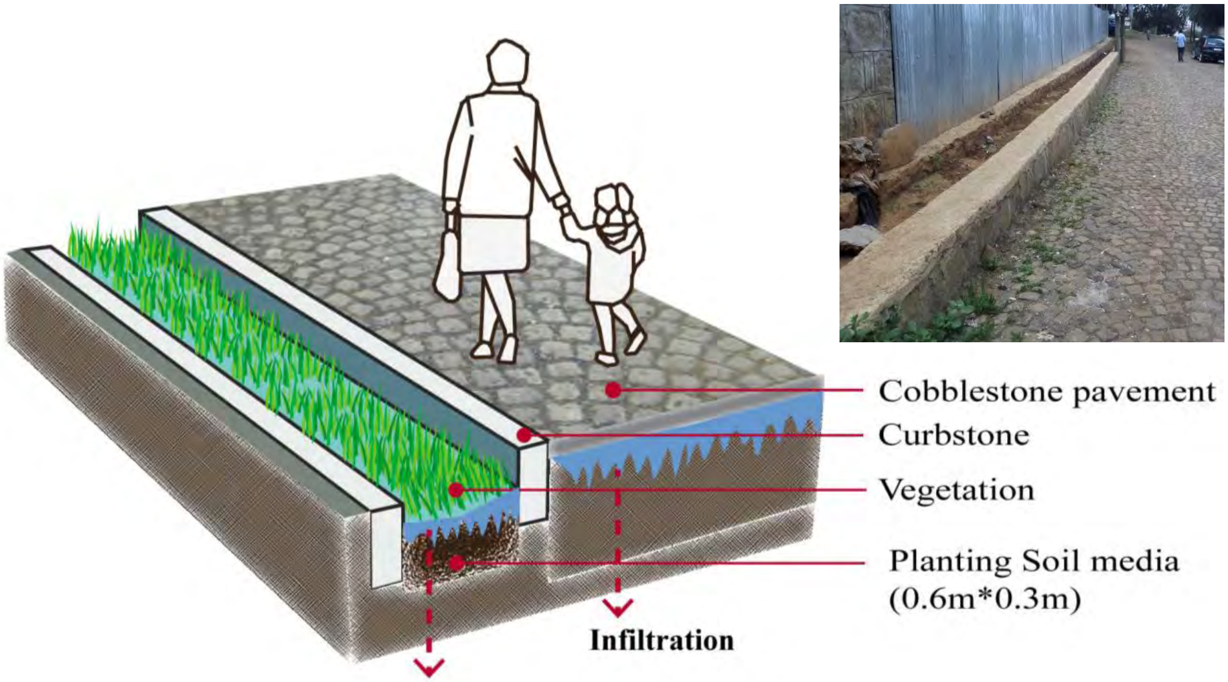


Figure 7. 27 Proposed modification on the existing drainage and its curbstone

Cutting hole through the existing curb stones

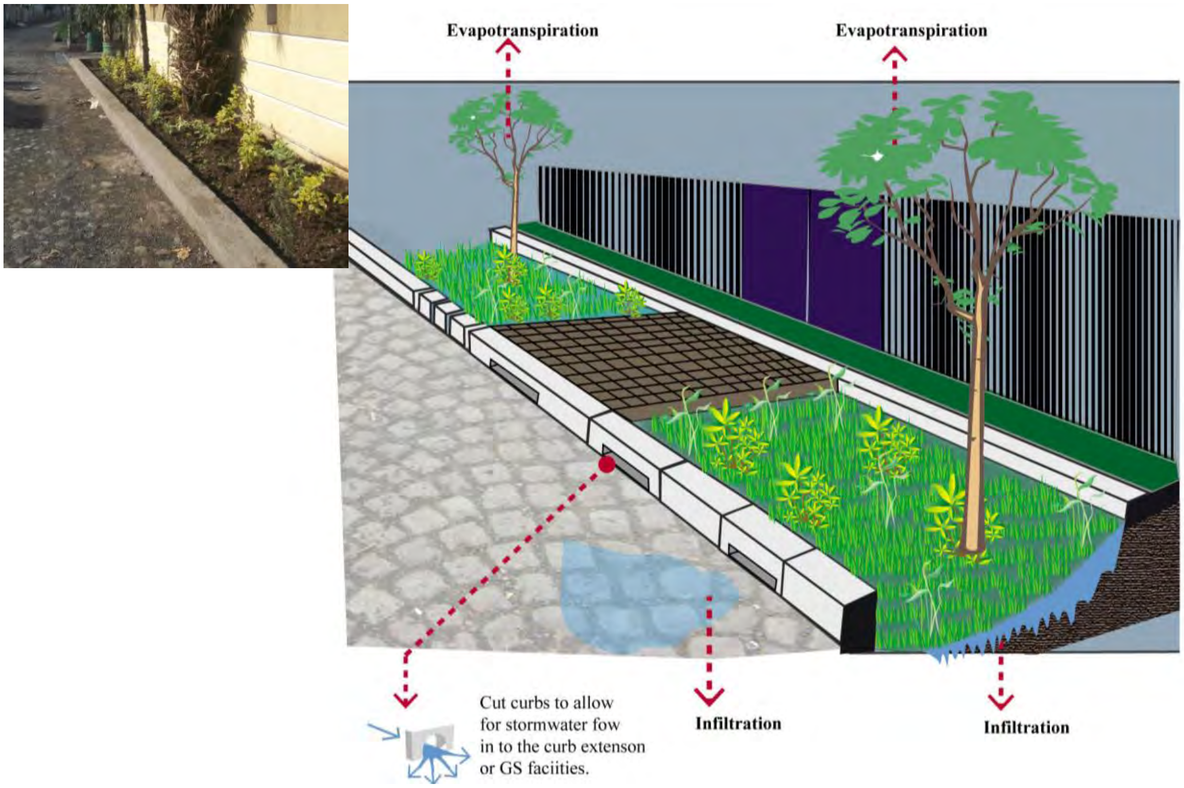


Figure 7. 28 Proposed modification of curbstone along the drainage systems

Creating break in between the curbstone

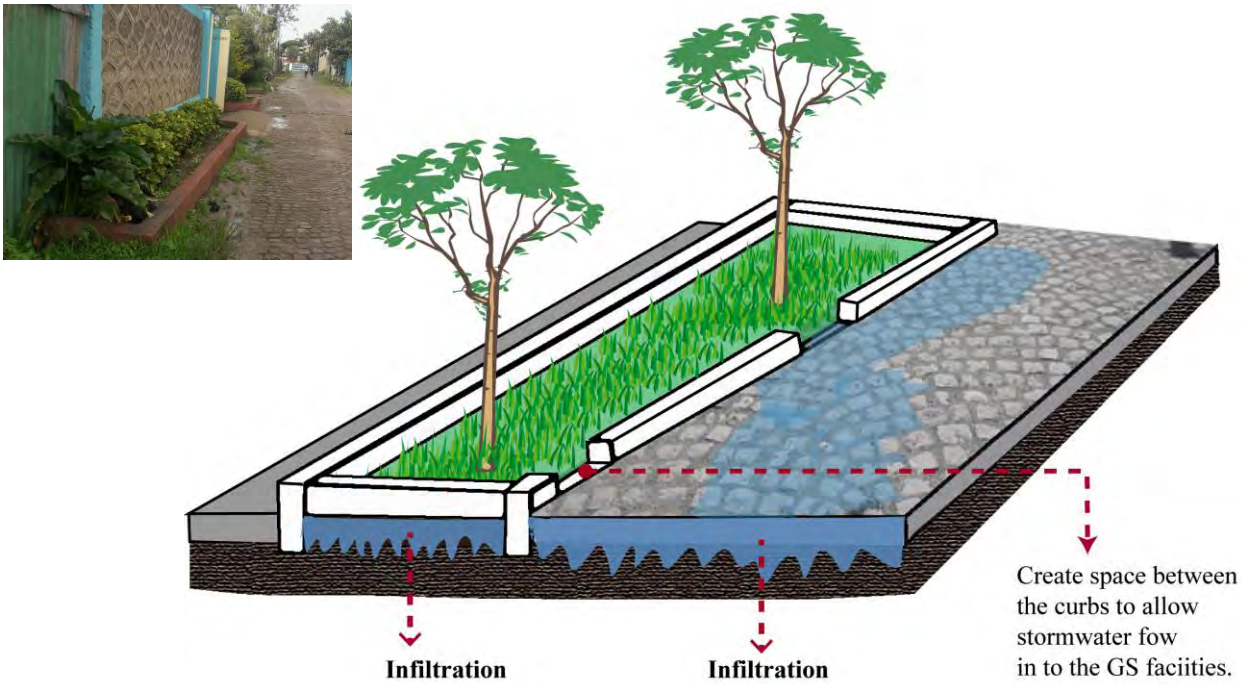


Figure 7. 29 Proposed modification of curbstone along the exsiting bioretention practice

7.6. The Upscale effect of the designed green infrastructure technologies on watershed level

Figure 7. 30 Proposed GI practice watershed level

The recommended green street practices along the local streets of the watershed areas and in the individual plots will help to protect the local streets from the destructive impacts of stormwater runoff. Moreover, the GI technologies will contribute to the improvement of local street drainage. Additionally, environmental comfort of the area will be improved through the shed from harsh sunlight as well as humidity from the evapotranspiration of plants. Therefore, if this all green street practices are applied from the steep to the flat parts of the entire watershed the impacts of stormwater runoff could be minimized.

Summary

Addis Ababa is currently undergoing city wide transformation with respect to its built environment and provision of basic infrastructure services. Local street construction with cobblestone pavement is one of the infrastructure development implemented in every part of the city. However, the constructed local streets in many parts of the city are deteriorating within a short time after construction. The main cause of such structural failure on the street might be the result of poor drainage design and lack of appropriate green structural elements to reduce the stormwater generated from the cobblestone street surfaces and the surrounding area.

Therefore, during the rainy season of the year, the negative impact of stormwater runoff on the streets as well as on the surrounding environment is clearly observed. Because, the existing conventional drainage systems are not managing the stormwater runoff passing through, resulting overflows. Associated with stormwater runoff, defragmentation of pavements on steeped slope areas and waterlogging on flat areas are some of the problems observed on the local streets. Therefore, the main objective of the study was; to device green infrastructure design and technologies for the local streets of Addis Ababa in order to reduce the impact of stormwater runoff and at the same time to environmental quality of the city neighborhood.

In order to accomplish the objective, research methods were developed for each specific objective. Case study method is then used in the research, by selecting two areas in Addis Ababa that are found in the same local watershed, based on appropriate criteria. Consequently, the existing situation of local streets and impact of stormwater runoff in the study areas was analyzed; through, the methodological framework developed from theoretical reviews. The developed methodological framework helped to understand the research problem in a holistic manner on the city level (macro scale); watershed level (meso scale) and on the case study areas (micro scale level).

The findings from this study show that, the imperviousness of residential uses, slope type, soil type, and type of drainage are the major factors that dictate the applicability of green infrastructure practice and influence the flow of stormwater runoff. Moreover, the local streets that are found in both case study areas are found in poor condition. Furthermore, the impacts of stormwater runoff in the study areas are flooding in the individual houses/plots, loss of infrastructure and loss of money. The main reason for these problems is lack of site specific street design and appropriate drainage system.

Based on the research findings, the research proposes site specific green street design and technologies for the local streets of the study area. Moreover, the research tested the upscale effect of green infrastructure practices on watershed level and found that the application of this practice could reduce stormwater runoff by 75.41% on a watershed level. Finally, the research concluded that, the application of site specific green infrastructure practice along the local street is the possible way to improve/enhance stormwater management capacity both at Local Street and watershed level

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APPENDICES

Appendix 1: Interview questions

Office interview

1. What is your name and position in this organization? ________________________________
2. Are there any site specific local street guidelines? ___________________________________
3. What are the physical factors considered during the design of cobblestone paved local streets?
   ____
4. What is the current status of cobble stone streets in Addis Ababa generally?
   ____
5. What problems have been encountered/ have you observed so far?
   ____
6. What do you think are the reasons for the deterioration of cobblestone paved local streets?
   ____
7. In which areas and site condition is the problem high? _________________________________
8. What could be the consequences if the deterioration continues? _________________________
9. In order to reduce this problems what is your office currently doing? ___________________
10. What problems do you observe to be corrected in the cobblestone local streets? ___________
11. What are the possible solutions suggested for improving the quality of cobblestone paved local streets? ____

Informant interview

1. For how many years did you live in this area?

   ☐ < 1 year ☐ 2 – 5years ☐ > 5years

2. Which of the following; have you observed in the street?

   ☐ Waterlogging ☐ Fragmented cobbles ☐ Washed away ☐ Submerged cobble

   Other____

3. Are there any problems so far in the local streets in this area?

   ☐ Yes ☐ No

   3.1. In which spots or location on the map? __________________________________

4. What do you think is the possible cause of the street deterioration?

   ☐ Heavy Rain ☐ Heavy load ☐ Lack of drainage
   other____

5. How is this problems minimized and what measures are taken so far?

   ____

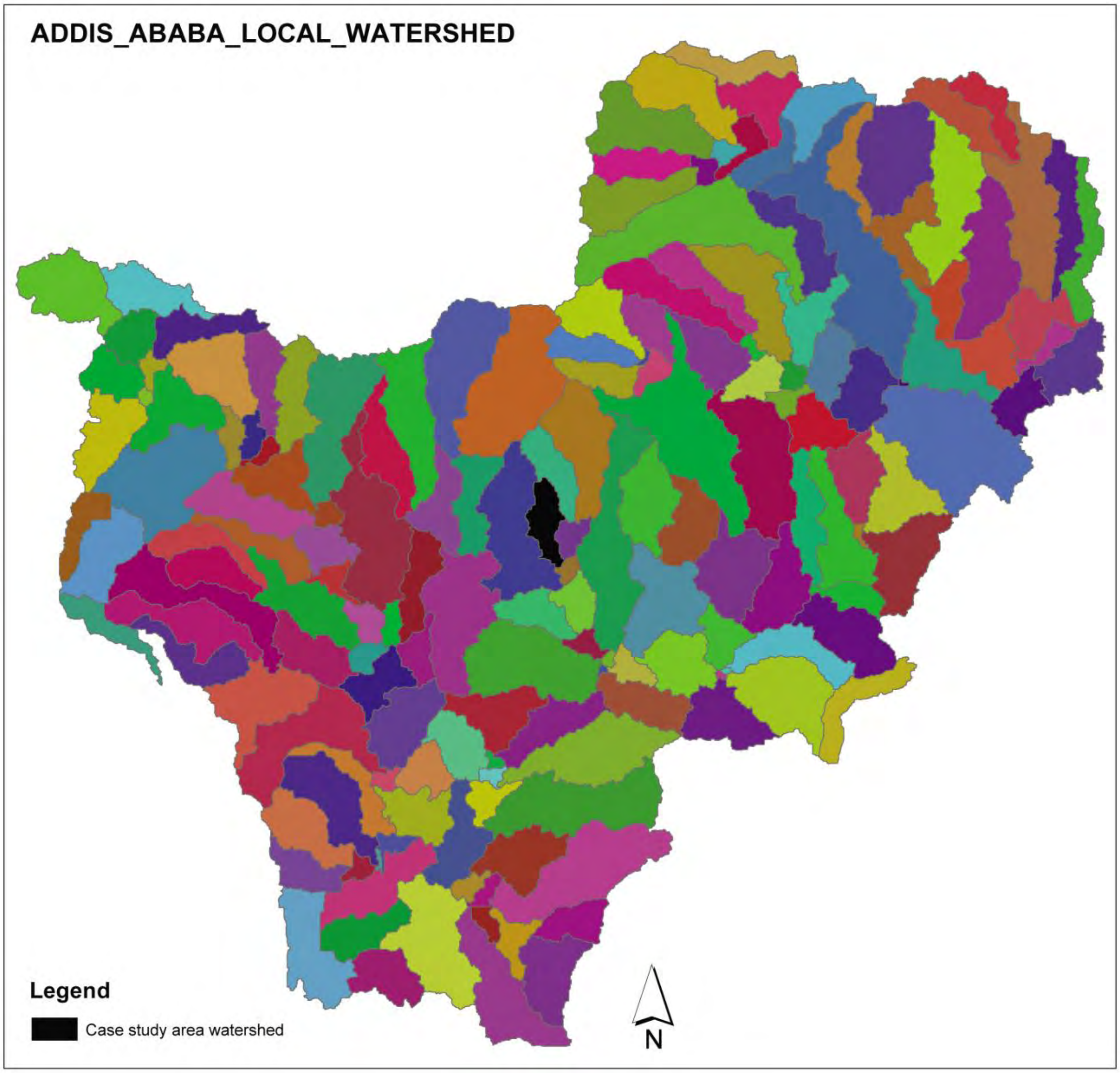
   5.1 Does the taken measure work?

   ☐ Yes ☐ No

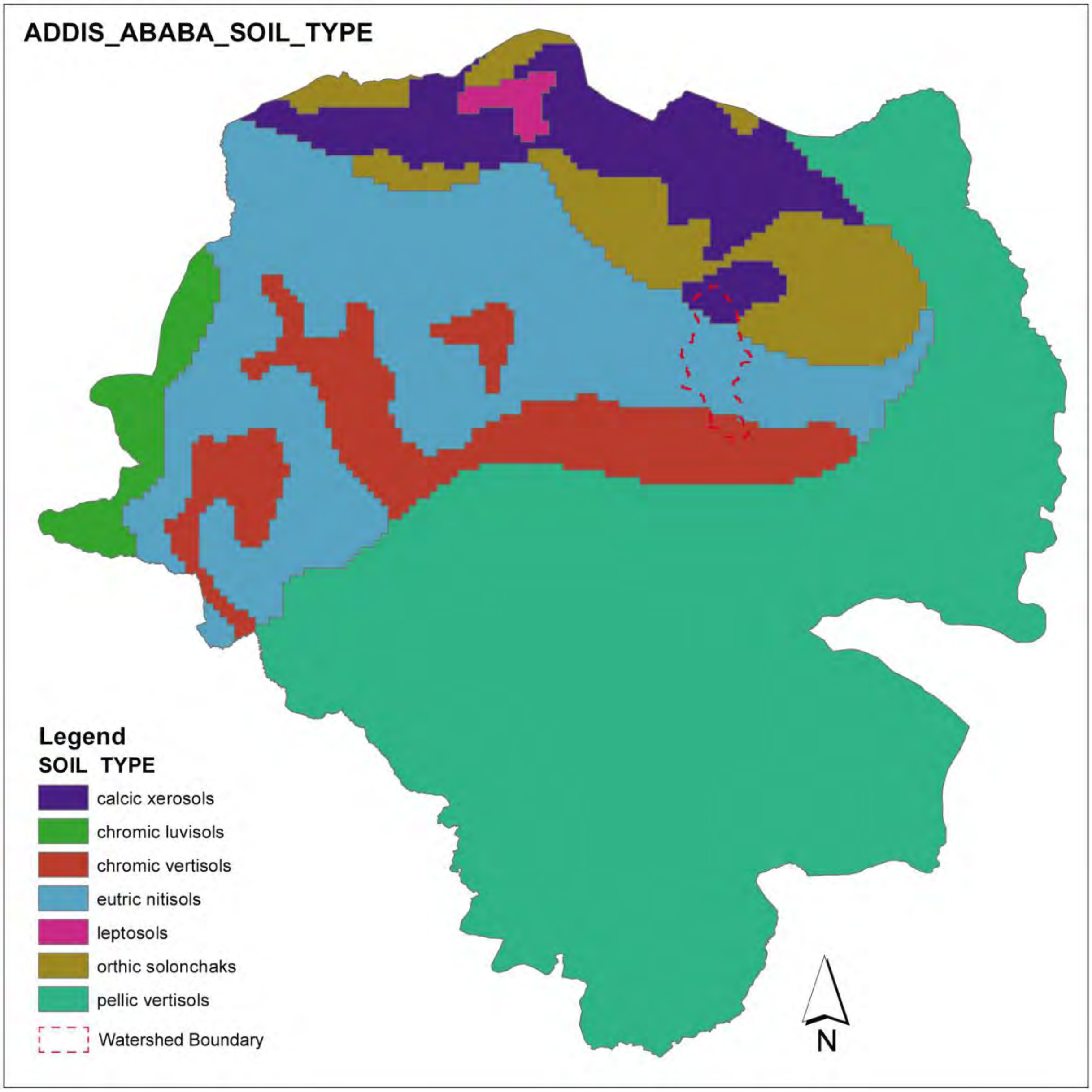
6. **6.** What do you think should be done to have Street quality for the future?

   ____

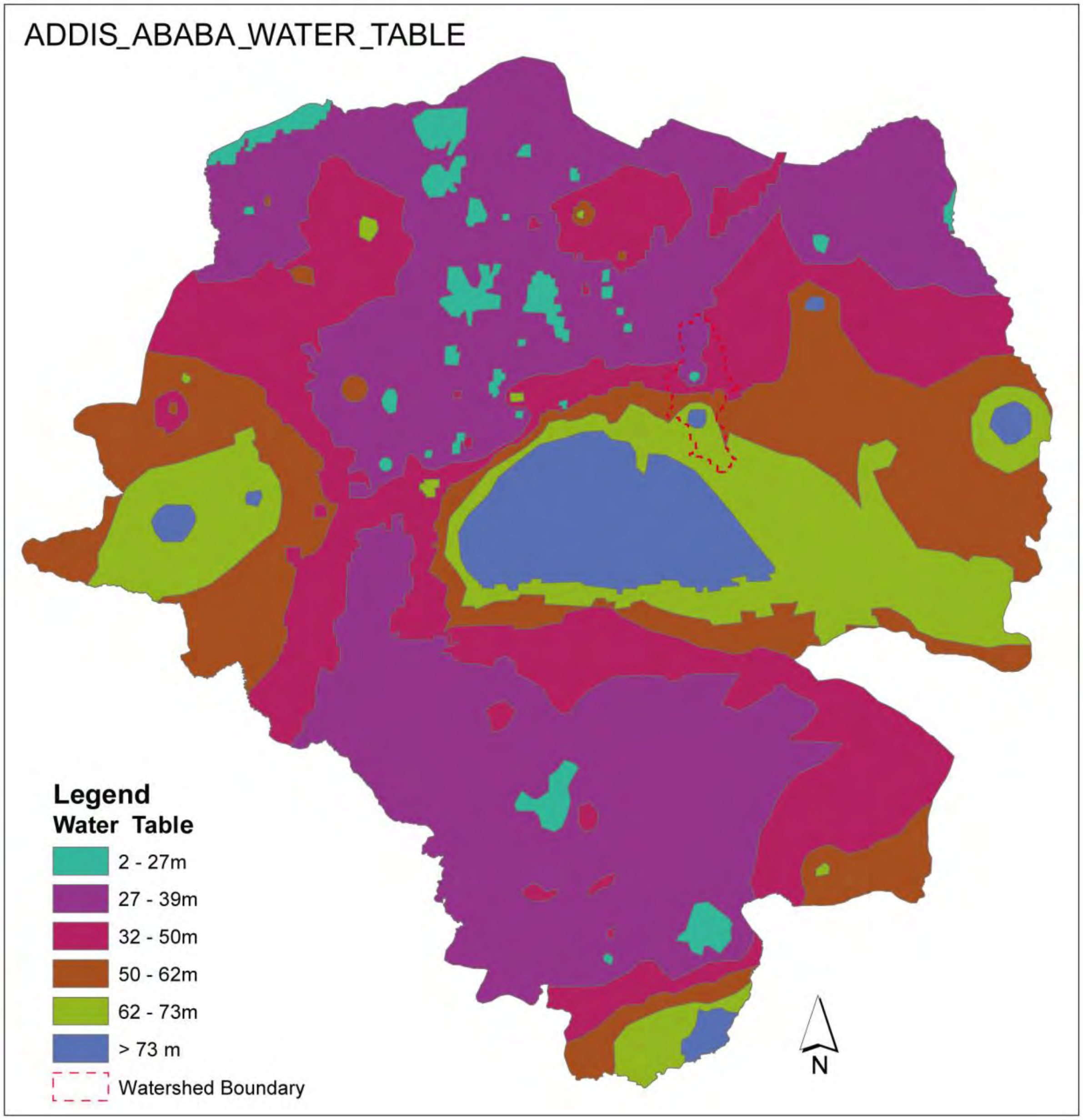
Appendix 2: Addis Ababa local watershed



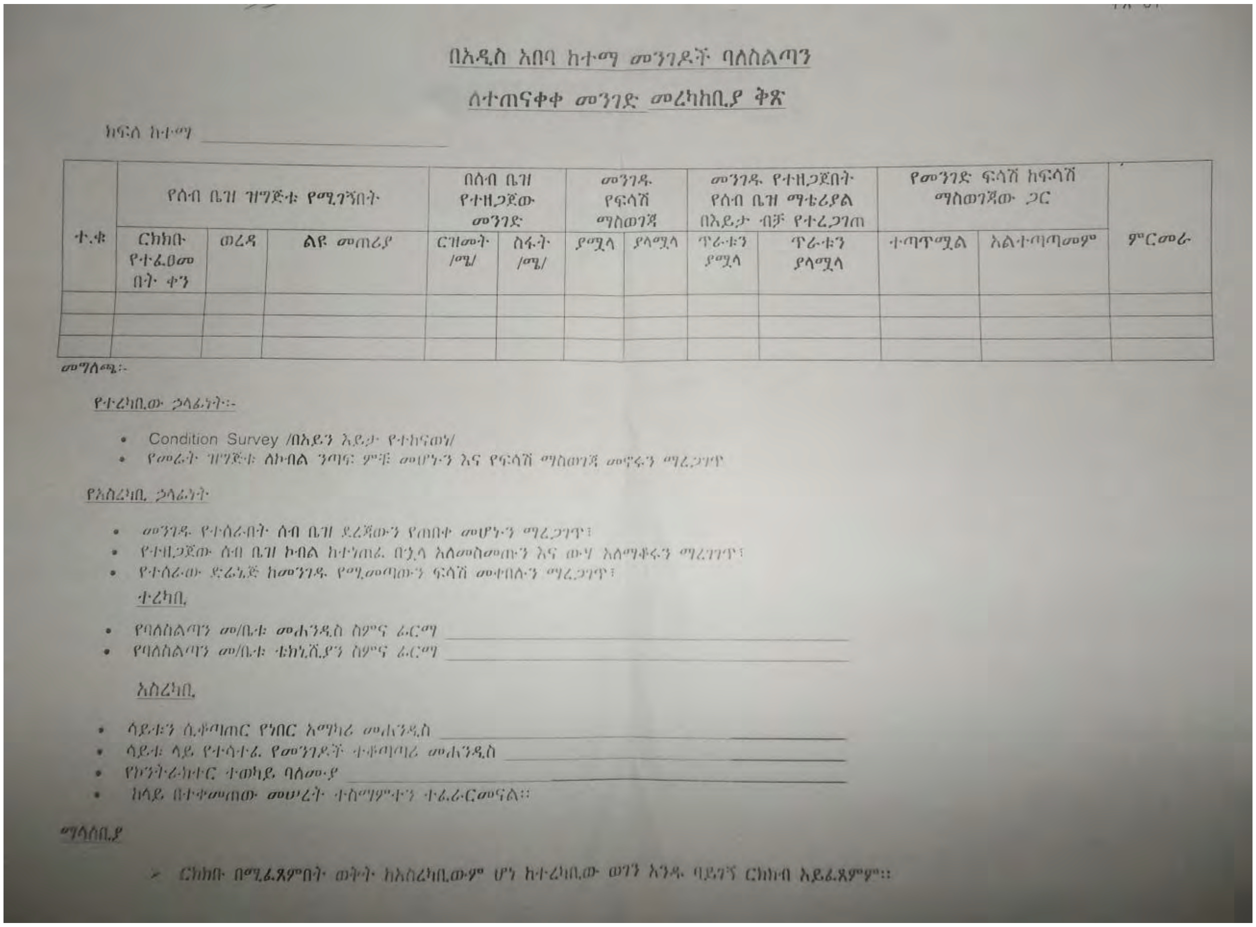
Appendix 3: Addis Ababa soil type



Appendix 4: Addis Ababa water table



Appendix 5: AACRA completed local street receiving form



በአዲስ አበባ ከተማ መንገዶች ባለስልጣን

ለተጠናቀቀ መንገድ መረካከቢያ ቅጽ

ክፍለ ከተማ ____________________

	የሰብ ቤዝ ዝግጅቱ የሚገኝበት			በሰብ ቤዝ የተዘጋጀው መንገድ		መንገዱ የፍሳሽ ማስወገጃ		መንገዱ የተዘጋጀበት የሰብ ቤዝ ማቴሪያል በእይታ ብቻ የተረጋገጠ		የመንገድ ፍሳሽ ከፍሳሽ ማስወገጃው ጋር		
ተ.ቁ	ርክክቡ የተፈፀመበት ቀን	ወረዳ	ልዩ መጠሪያ	ርዝመት /ሜ/	ስፋት /ሜ/	ያሟላ	ያላሟላ	ጥራቱን ያሟላ	ጥራቱን ያላሟላ	ተጣጥሟል	አልተጣጣመም	ምርመራ

መግለጫ፡-

የተረካቢው ኃላፊነት፡-

- Condition Survey /በአይን እይታ የተከናወነ/
- የመሬት ዝግጅቱ ለኮብል ንጣፍ ምቹ መሆኑን እና የፍሳሽ ማስወገጃ መኖሩን ማረጋገጥ

የአስረካቢ ኃላፊነት

- መንገዱ የተሰራበት ሰብ ቤዝ ደረጃውን የጠበቀ መሆኑን ማረጋገጥ፣
- የተዘጋጀው ሰብ ቤዝ ኮብል ከተነጠፈ በኋላ አለመስመጡን እና ውሃ አለማቆሩን ማረጋገጥ፣
- የተሰራው ድሬኔጅ ከመንገዱ የሚመጣውን ፍሳሽ መቀበሉን ማረጋገጥ፣

ተረካቢ

- የባለስልጣን መ/ቤቱ መሐንዲስ ስምና ፊርማ ____________________
- የባለስልጣን መ/ቤቱ ቴክኒሺያን ስምና ፊርማ ____________________

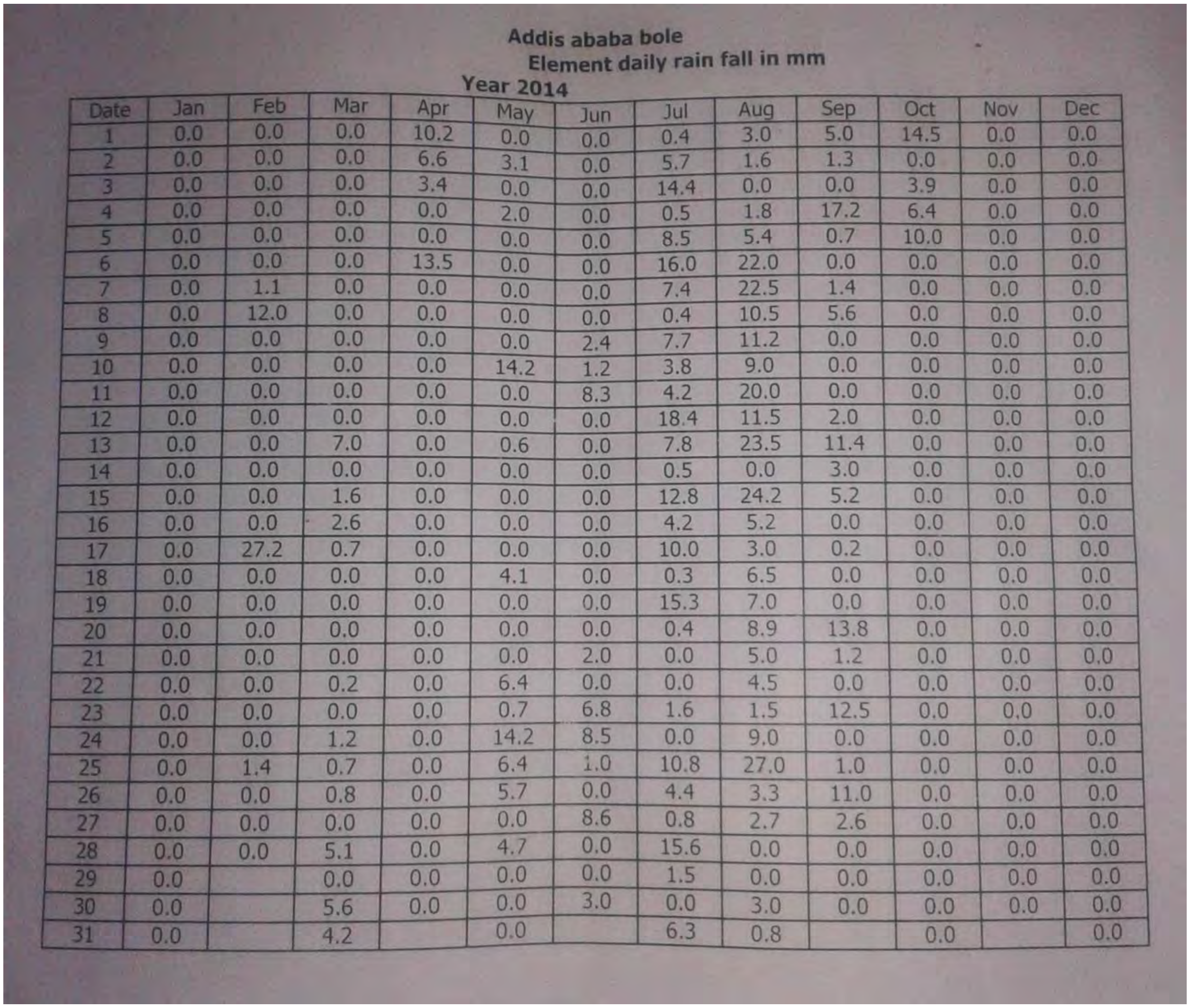
አስረካቢ

- ሳይቱን ሲቆጣጠር የነበር አማካሪ መሐንዲስ ____________________
- ሳይቱ ላይ የተሳተፈ የመንገዶች ተቆጣጣሪ መሐንዲስ ____________________
- የኮንትራክተር ተወካይ ባለሙያ ____________________
- ከላይ በተቀመጠው መሠረት ተስማምተን ተፈራርመናል፡፡

ማሳሰቢያ

➢ ርክክቡ በሚፈጸምበት ወቅት ከአስረካቢውም ሆነ ከተረካቢው ወገን አንዱ ባይገኝ ርክክብ አይፈጸምም፡፡

Appendix 6: Rainfall data of august 2014, Addis Ababa



Addis ababa bole
Element daily rain fall in mm
Year 2014

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	10.2	0.0	0.0	0.4	3.0	5.0	14.5	0.0	0.0
2	0.0	0.0	0.0	6.6	3.1	0.0	5.7	1.6	1.3	0.0	0.0	0.0
3	0.0	0.0	0.0	3.4	0.0	0.0	14.4	0.0	0.0	3.9	0.0	0.0
4	0.0	0.0	0.0	0.0	2.0	0.0	0.5	1.8	17.2	6.4	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	8.5	5.4	0.7	10.0	0.0	0.0
6	0.0	0.0	0.0	13.5	0.0	0.0	16.0	22.0	0.0	0.0	0.0	0.0
7	0.0	1.1	0.0	0.0	0.0	0.0	7.4	22.5	1.4	0.0	0.0	0.0
8	0.0	12.0	0.0	0.0	0.0	0.0	0.4	10.5	5.6	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	2.4	7.7	11.2	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	14.2	1.2	3.8	9.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	8.3	4.2	20.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	18.4	11.5	2.0	0.0	0.0	0.0
13	0.0	0.0	7.0	0.0	0.6	0.0	7.8	23.5	11.4	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	3.0	0.0	0.0	0.0
15	0.0	0.0	1.6	0.0	0.0	0.0	12.8	24.2	5.2	0.0	0.0	0.0
16	0.0	0.0	2.6	0.0	0.0	0.0	4.2	5.2	0.0	0.0	0.0	0.0
17	0.0	27.2	0.7	0.0	0.0	0.0	10.0	3.0	0.2	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	4.1	0.0	0.3	6.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	15.3	7.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.4	8.9	13.8	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	2.0	0.0	5.0	1.2	0.0	0.0	0.0
22	0.0	0.0	0.2	0.0	6.4	0.0	0.0	4.5	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.7	6.8	1.6	1.5	12.5	0.0	0.0	0.0
24	0.0	0.0	1.2	0.0	14.2	8.5	0.0	9.0	0.0	0.0	0.0	0.0
25	0.0	1.4	0.7	0.0	6.4	1.0	10.8	27.0	1.0	0.0	0.0	0.0
26	0.0	0.0	0.8	0.0	5.7	0.0	4.4	3.3	11.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	8.6	0.8	2.7	2.6	0.0	0.0	0.0
28	0.0	0.0	5.1	0.0	4.7	0.0	15.6	0.0	0.0	0.0	0.0	0.0
29	0.0		0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0
30	0.0		5.6	0.0	0.0	3.0	0.0	3.0	0.0	0.0	0.0	0.0
31	0.0		4.2		0.0		6.3	0.8		0.0		0.0

Appendix 7: Recommended runoff coefficients (C) for urban watersheds in Addis Ababa

Run Off Coefficients for Urban Watersheds	
Type of Drainage Area	**Runoff Coefficient**
Business:	
· Down town/ city center areas	0.70-0.95
· Neighborhood area	0.30-0.70
Residential:	
· Single-family areas	0.30-0.30
· Multi-units, detached	0.40-0.60
· Multi-units, attached	0.60-0.75
· Suburban	0.35-0.40
· Apartment dwelling areas	0.30-0.70
Industrial:	
· Light areas	0.30-0.80
· Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
· Sand or sandy loam soil, 0-3%	0.15-0.20
· Sand or sandy loam soil, 3-5%	0.20-0.25
· Black or fine-grained soil, 0-3%	0.18-0.25
· Black or fine-grained soil, 3-5%	0.25-0.30
· Black or fine-grained soil, >5%	0.70-0.80
· Deep sand area	0.05-0.15
· Steep grassed slopes	0.70
Lawns:	
· Sandy soil, flat 2%	0.05-0.10
· Sandy soil, average 2-7%	0.10-0.15
· Sandy soil, steep 7%	0.15-0.20
· Heavy soil, flat 2-7%	0.13-0.17
· Heavy soil, average2-7%	0.18-0.22
· Heavy soil, steep 7%	0.25-0.35
Streets:	
· Asphalt	0.85-0.95
· Concrete	0.90-0.95
· Brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95