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Ethiopian Institute of Architecture,
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Addis Ababa University

Landscape Based Stormwater Management Design solutions For Residential Areas: The case of two selected sub-cities in Addis Ababa, Ethiopia

A Thesis Submitted to School of Graduate Studies, Ethiopian Institute of Architecture, Building Construction and City Development (EiABC)

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This is to certify that the thesis prepared by Yewubneh Getamesay, entitled: ***Landscape Based Stormwater Management Design solutions For Residential Areas: The case of two selected sub-cities in Addis Ababa, Ethiopia*** and submitted in partial fulfillment of the requirements for the Degree of Master of Sciences (Landscape Architecture) complies with the regulations of the university and meets the accepted standards concerning originality and quality.

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Abstract

For decades, Addis Ababa has gone through several changes for its built environment, while it is having a dramatic increase in population which has given rise to extension and densification of the built-up areas of the city. Such changes of the natural landscape, lead to flooding becoming eminent. It is common to see drainage problems in old and new housing areas where residents rely on storm drains to carry a large amount of runoff generated from their compounds, where stormwater mitigation strategies are neglected on an individual plot level. Hence, on-source control of stormwater, which entails application of stormwater mitigation strategies in residential spaces (which are one of the major sources of stormwater) is essential.

Hence, to assess Landscape stormwater management (LSM) Technologies on individual plots of the residential areas of Addis Ababa, both qualitative and quantitative research methods were employed, while both primary and secondary data were collected. Moreover, the study areas selected for this study were Lebu Varnero watershed area from Nefas Silk Lafto Sub city and Dera Sefer watershed area from Arada Sub city. Different data collection methods such as field observation, questionnaires and interviews were employed in this study.

The results showed Impervious surfaces (including both built-up areas and streets) were observed to cover much of both study areas, and the study results showed that land use and size, imperviousness, soil type, precipitation (rainfall), current drainage conditions and slope were the major factors that affected stormwater runoff in residential plots and the applicability of Green Infrastructure practices. Stormwater mitigation mechanisms such as Permeable pavement, Grass Paving walkway, Rain Barrels, Lawn covers, Evergreen trees were used in the design to help control urban stormwater runoff problem in residential plots. In addition, Landscape stormwater management strategies such as a Stormwater tree, Bio retention Ponds, Road Side Vegetated Swale, Green Gutter, And Previous Driveway and Walkways were used in the design to alleviate stormwater runoff problems in the surrounding open spaces in the neighborhoods. These mechanisms proposed to handle stormwater are estimated to decrease the stormwater runoff by an amount of 0.48777246 m^3 and 0.377122032 m^3 per one hour of rainfall for the specific plots selected from Lebu Varnero apartment and Dera Sefer study areas respectively.

Keywords: Stormwater, Green Infrastructure, Landscape based stormwater management, on-source stormwater control

Yewbneh Getamesay
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List of Acronyms and Abbreviations

AABPCDA	Addis Ababa city Beautification, Parks and Cemetery Development and Administration Agency
AACRA	Addis Ababa city Road Authority
AAEPA	Addis Ababa Environmental Protection Authority
AAUPI	Addis Ababa city administration Urban Planning Institute
AAWSA	Addis Ababa Water and Sewerage Authority
BMP	Best Management Practices
BAR	Built-Up Area Ratio
CPDO	Community Participation Development Office
CSO	Combined Sewer Outflow
EDB	Extended Detention Basin
FAO	Food and Agriculture Organization of the United Nations
GI	Green Infrastructure
GIS	Geographic Information System
IUWM	Integrated Urban Water Management
KM	Kilometers
LID	Low Impact Development
LSM	Landscape Based Stormwater Management
MoWIER	Federal Ministry of Water Irrigation and Energy Resource
M	Meters
NUGIS	National Urban Green Infrastructure Standard
NMA	National Meteorology Agency
PPS	Permeable Pavement Systems
SWM	Stormwater Management
SSM	Sustainable Stormwater Management
SUDS	Sustainable Urban Drainage System
SWMP	Stormwater Management Practices
US-EPA	United States Environmental Protection Agency
UGI	Urban Green Infrastructure
UN-HABITAT	United Nations Human Settlements Programme
USDA	United States Department of Agriculture
WQCV	Water Quality Capture Volume
WSUD	Water Sensitive Urban Design

Chapter One: Introduction

1.1.Background

The high rate of urban development along with the increment of impermeable surfaces is seen as one of the major instigators of flooding in urban areas. Consequently, urban areas are predominantly covered by roads and buildings, which have less capacity to store rainfall. According to Zhang *et al.*, (2016): *"Urban development and construction led to the expansion of impervious areas, reduced rainfall infiltration and reduced groundwater recharge, increased runoff and increased peak flow in advance."*

In urban areas, existing paved streets and roads, which increase the speed of flowing water, worsen flood effects (Mukherjee, 2016). This flowing water that freely roams over the impervious areas of cities and is a significant source of flooding is termed stormwater runoff. It causes major damages to different infrastructures and the natural flora and fauna in many communities worldwide (Pazwash, 2011).

In Addis Ababa, the capital of Ethiopia, serious flooding is a common occurrence during the rainy seasons; an increased portion of the stormwater run-off is collected in the low-lying parts of the city (Muschalla & Ostrowski, 2002). According to (Birhanu et al., 2016), over time, the development of high-density urban areas with residential and commercial developments has resulted in an increase in impervious areas and a reduction in green spaces (previous areas). As a result, during the stormwater event, there is an increase in peak flows where more runoff is generated and flows faster into the conventional drains over a shorter period of time. According to (Kebede & Adugna, 2015): *"Insufficient urban stormwater drain facilities represent one of the most common sources of complaint from the citizens in many towns of Ethiopia, and this problem is getting worse and worse with the ongoing high rate of urbanization in different parts of the country, especially in Addis Ababa."*

For decades, Addis Ababa has been one of the rapidly developing cities of Africa. The city has gone through several changes for its built environment and provision of basic infrastructure services. (Muschalla & Ostrowski, 2002)

According to (Desta et al., 2011), this rapid development has culminated in the wrecking of natural vegetation, conversion of green spaces, and the development of the built environment, which has exhibited adverse effects on the environment.

On the issue regarding urban-meditated effects of climate change in Addis Ababa, the existing sealed surfaces, from each plot to the densely urbanized city level are more vulnerable to flooding due to relative increases in the intensity of rainfall and under-design of open spaces and current road networks. According to (Birhanu et al., 2016): *"Addis Ababa is vulnerable to the river as well as flash flooding due to extreme climatic events and upper catchment activities and the vulnerability to flooding is more aggravated due to a poor drainage system, rapid housing development along with river banks degradation, and using inappropriate construction materials".*

Hence, it is essential to identify the different factors that are contributing to the increased flooding starting from the individual plots which produce a considerable amount of stormwater runoff which significantly contributes to flooding. Therefore, this study tried to focus on how the city of Addis can reduce the increasing flood and stormwater problem through the landscape-based solution that can be implemented on the residential level and community/neighborhood level.

1.2.Problem Statement

As described by (European Union, 2013), *"Land take occurs particularly as a result of the expansion of cities and spread of urban areas (urban sprawl). Further land take is required to provide service for these new developments, in the form of shops, schools, wastewater treatment plants, and transport infrastructure."*

Land takes, in any areas of the world, ultimately lead to an increase of sealed-up surfaces and the significance of sealing is highlighted when coverage of most urbanized surfaces is by impervious materials such as concrete, metal, glass, tarmac, and plastic (Scalenghe & Marsan, 2009). This is seen in many cases of urban expansion where there is a creation of an abundance of sealed surface which obstruct the rainwater to infiltrate into the ground surface (Mohapatra et al., 2014).

Hence, urbanization in diverse segments of the world creates an unexpected challenge by modifying the local climate through time as a result of sealing the natural landscape surface on a large scale.

Addis Ababa, one of the fastest-growing cities in Africa is presently undergoing a city-wide rapid urban transformation. Among intensified urban expansion plans of the city, residential developments consume substantial land by changing the natural landscape into manmade structures. Addis Ababa has recently undergone housing areas densification by the formal and informal development of built structures like expanding of the built-up area of the existing buildings, paving of compounds for parking area function, access road, and other functions without considering the green space standards for the proper functioning of the urban ecology. (*Addis Ababa*, 2018)

Furthermore, Addis Ababa is having a dramatic increase in population as can be seen by the UN-HABITAT study which showed that the population of Addis Ababa increased by 1.19 million from 1994 – 2010. Currently, the city is experiencing a 3.8% annual growth rate and is estimated to reach 4.7 million inhabitants by 2030 (European Union, 2013). This has given rise to extension and densification of the built-up areas of the city to accommodate more people for housing and related facilities. This further has changed most of the land found in the city from natural and agricultural land to built-up areas (Pierrat et al., 2018).

Such intensified development changes of the natural landscape that can manage stormwater runoff naturally into the sealed surface covered with the hard impervious surface, Lead to the amount of water that infiltrates to decrease and the amount that runs off to increase (Kombe et al., 2015); where, as a result, flooding becomes eminent in the different built-up parts of the city. Hence, urbanization, impermeable structures, and improper drainage design can be considered as some of the major reasons for flooding in most developing urban areas including Addis Ababa (Adugna, 2011).

Moreover, in the design as well as the construction process of housing areas in Addis Ababa, especially in the low density and single-family housing development, some environmental aspects seem to be neglected. For example, in the emerging residential areas of the city, lack of green areas (like trees, plants, lawn, and other vegetation) and proper integration to the storm-water drainage facilities appear to be a serious problem. It is common to see drainage problems in old and new housing areas where residents rely on storm drains to carry a large amount of runoff generated from their compounds. However, the significant amount of runoff generated from roofs and the paved surface of their compounds creates significant damage on local streets and properties in the lower catchment areas of neighborhoods during the rainy seasons through flooding. This flooding, in addition to causing damage to infrastructure, can also cause health impacts on the residents and can also become a source of injuries as they try to navigate through the flooding. (Birhanu et al., 2016)

Consequently,on this kind of development, where stormwater mitigation strategies are neglected on an individual plot level, the local street and buildings may deteriorate within a short period after construction. If appropriate measures are not taken, the problem would create further damage on buildings, infrastructure and eventually lead to the entire environmental degradation. Hence, on-source control of stormwater, which entails application of stormwater mitigation strategies in residential spaces (which are one of the major sources of stormwater) is essential.

Moreover, researches, such as those done by (Adugna et al., 2019; G/wahed, 2016; McFarland et al., 2019), have tried to tackle the stormwater problem in Addis Ababa using different stormwater management techniques. Meanwhile, a study done by (Yeshitela et al., 2017) on Jemo River Catchment has recommended some LSM mechanisms that can be implemented on single family residential areas on plot and block level. However, apart from this study, there is a lack of researches done in different areas in Addis Ababa which consider the effects that individual plots have in contribution to stormwater runoff; while there is a lack of studies which also take into account the implementations of these mechanisms in the individual residential plots and their stormwater improvement potential.

Hence, the development of proper techniques to reduce stormwater runoff on the residential plot level in addition to the identification of the different factors that affect the deployment of these techniques should be given due attention. Therefore, this study will mainly focus on the integration and use of Landscape Based Stormwater Management (LSM) technologies on individual plots of residential areas of Addis Ababa and identifying the major factors that affect the applicability of these technologies.

1.3.The objective of the study

1.3.1. General objective

The general objective of this study was to identify opportunities for stormwater runoff reduction through landscape-based stormwater management design solutions within the residential areas of Addis Ababa.

1.3.2. Specific objective

- to identify trends in the incremental level of imperviousness within single-family residential neighborhood areas of Addis Ababa
- to identify and analyze the major factors that dictate the applicability of LSM technologies.
- to design potential LSM technologies and solutions for various residential plot categories and the surrounding watershed areas.
- to estimate the contribution of deisgned LSM solutions in terms of flood reduction as well as green area improvement of the entire local watershed.

1.4.Research questions

- What are the causes for the increment of imperviousness in neighborhood areas?
- What volume of stormwater is generated due to sealed surfaces?
- What volume of water can be reduced through new possible design solutions?
- How can the residential neighborhood drainage systems be improved?

1.5.Scope and delimitation of the study

1.5.1. Spatial scope

The spatial scope of this study addressed landscape-based drainage design solutions within densely developed residential areas (at plot level) of the selected site in Arada and Nefas Silk Lafto sub-cities within Addis Ababa.

1.5.2. Thematic scope

The thematic scope focused on issues related to land use/land cover change, landscape urbanism, and local hydrology of the study area. This study described general aspects and impacts of urban stormwater runoff, while investigating the residential plots' contribution to the problem and the related solutions to remedy the problem.

1.5.3. Delimitation of the study

Urban stormwater and the related stormwater management study have diverse factors, consequences, and aspects that are broad and detailed, which vary based on characteristics such as geographical locations, socio-economic contexts, urban planning and designs, environmental causes, and different other factors and effects. This study focused and limited itself on Landscape based stormwater management for single, family-owned residential plots.

1.6.Significance of the study

This research has an important significance to different stakeholders such as Policymakers, authorities concerned with environmental protection, urban planning and designing entities, governmental and non-governmental organizations working on sustainable development goals, and International organizations focusing on this area. In the future, it can instigate other professionals and academicians for further detailed researches and studies to bring solutions on the matter. Furthermore, this study can create awareness to the general public in regards to stormwater management in the case of privately-owned residential plots.

1.7.Limitation of the study

Low awareness within the general public and individual residential plot owners about stormwater management has affected the collection of data using a questionnaire. Obtaining immediate response for reliable data from government authorities has had impacts on the time schedule. Besides, not enough professionals regarding stormwater problems were available at the offices relevant to the study, and those that were contacted did not have enough knowledge regarding stormwater runoff at the residential plot level, as the primary goal of these officers was providing support after the occurrence of runoff problems such as flooding, not preventing it. Furthermore, financial limitation, such as lack of financial resources for soil tests such as soil type and infiltration, is a hindrance for this study as the authors took data from other secondary sources instead of observing it firsthand. Lastly, site observation was difficult in some of the residential plots included in the study, as residents were reluctant to allow the observation of their compounds.

1.8.Organization of the paper

This research paper is organized into five main chapters. Chapter one describes the general aspects of the study, from the topic background and problem statement of objectives, research questions, scope, and limitations. Chapter two, literature review, raises aspects that are retrieved from reliable and updated sources about the topic area to broaden the study and critically analyze the cause, effects, international trends, principles, and practices regarding stormwater management. The associated contextual study is also conducted, where urban stormwater management in Ethiopia, Addis Ababa, sub-cities, and neighborhoods is described and further literature review regarding single plot owners and responsible authorities is reviewed, while the reviews of selected similar cases both in the international and local context were presented. Chapter three introduces the research methodology and methods used for this study. Chapter four presents the results and interprets the collected data, focusing on the selected two watershed case analysis areas while also discussing the research findings, as per the research objectives. Chapter five describes the conclusions and recommendations of this research study.

Chapter Two: Literature Review

2.1.Urbanization and imperviousness

The development of urban areas has had a significant impact on urban stormwater runoff and generation (Butler & Davies, 2004). Due to this, stormwater is transported downstream at a much faster rate (since water moves faster over hard surfaces in comparison to natural surfaces).

The result will be that urban areas experience a faster-moving runoff flow (with a higher peak flow) that will enter the urban drainage system at a faster rate. But the urban runoff flow will also die away much faster (compared to natural green areas) which will result in a higher peak flow (Butler & Davies, 2004). This is due to the replacement of natural green infiltration surfaces (i.e. natural soil cover) with impervious surfaces (such as concrete roads, rooftops, and buildings) within cities (US EPA, 2003).

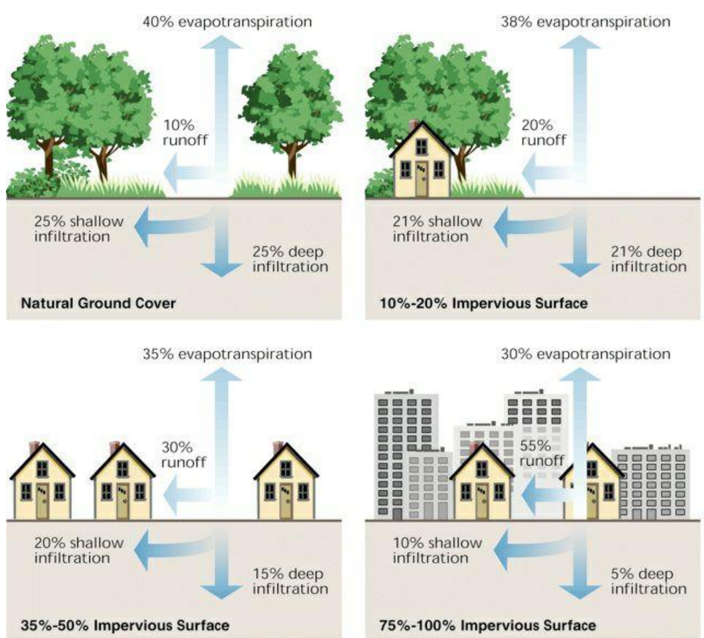


Figure 2-1: Impact of urbanization on surface infiltration, evapotranspiration, and runoff (Burian & Pomeroy, 2010)

According to (US EPA, 2003), the main impacts of urbanization on the hydrologic cycle are due to modifications on the impervious area, which changes processes as evapotranspiration, runoff, and shallow and deep infiltration. The difference in peak-flows for pre and post-urban conditions can be seen in the Figure below.

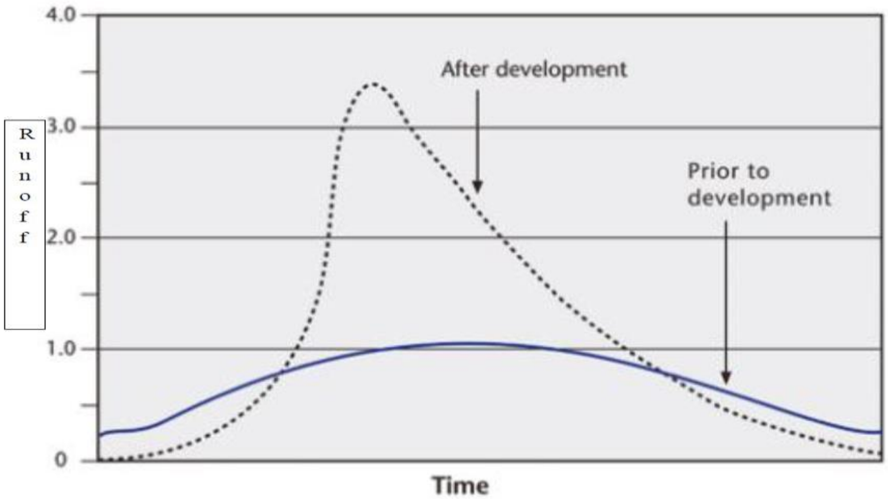


Figure 2-2: impact of urbanization on runoff quantity (US EPA, 2003)

In regards to urbanization, one of the major issues is the continual increase of the built environment and the transformation of the natural landscape into manmade structures. These structures made out of materials such as concrete and asphalt transform the natural soil into impervious surfaces blocking any surface water to infiltrate into the groundwater (Choi, 2016). Urbanization increases runoff quantity and affects stormwater quality, producing significant hydrologic changes that can potentially result in adverse impacts on streams, other receiving water bodies with their habitats (Khaniya et al., 2016).

Impervious surfaces in the landscape take form in building footprints, parking lots, infrastructure, and this plays a major role as far as problems linked with stormwater runoff. Impervious surfaces disrupt the natural hydrological cycle, as water is unable to infiltrate down to the subsurface layer (Choi, 2016).

2.2.Stormwater Runoff

Any rain or precipitation that falls on impervious surfaces such as roofs and collects on other imperviously paved areas like driveways, roads, or footpaths and drains into drainage systems is called stormwater (US EPA, 2003).

When a rainfall event occurs, some of the precipitation is either caught by a plant or infiltrates into the soil, while the remaining precipitation runs through the different surfaces and drains into the nearest outlet, whether it be a drainage system or river/water body. As urbanization has increased in many parts of the world, the amount of precipitation that becomes stormwater runoff is much more increased in urban areas than rural and other non-urban areas due to the increased impervious surfaces that prevent stormwater runoff from infiltrating into the ground and force it to move at a much faster rate to drainage systems and other outlet mechanisms. This leads to the associated flooding and erosion problems that arise as a consequence of low capacity, clogging, underdevelopment, or any other issues associated with the drainage systems (Rasmussen & Schmidt, 2009).In an urban setting, stormwater flooding is caused when runoff flow rates, which are predominantly from impervious surfaces, far exceed the capacity of the constructed sewer and storm drainage systems. This issue is fairly frequent in many parts of the world due to the different negative issues seen with various forms of drainages seen around the world (Burns et al., 2015).

Moreover, these left-over precipitations are abundant with atmospheric pollutants and various particles that are found on the impervious urban surfaces as they change into stormwater runoff. This polluted runoff then contributes to the pollution of the surface water bodies and ground waters or rivers that receive it at the end of the path (Yannopoulos et al., 2013).

When running on the land surface, stormwater runoff becomes polluted with various types of harmful pollutants and toxic materials such as sediment, harmful nutrients (from lawn fertilizers), bacteria, pesticides, harmful metals, and petroleum by-products. This polluted stormwater runoff in turn can be harmful to plants, animals, and human beings (Walsh et al., 2012).

Moreover, it is also understood that stormwater runoff, contributes to water bodies' quality degradation in addition to its effect on human beings, as well as on flora and fauna(US EPA, 2003). Hence, mitigating the source of the stormwater runoff is being considered as one of the socially, ecologically, and economically efficient and acceptable solutions to handle runoff impacts, which affect ground and surface receiving waters, ecosystems, and human health (Yannopoulos et al., 2013).

2.3.Stormwater and Drainage Systems

A storm drainage system is a collection of structures to collect and convey stormwater runoff from land areas to a discharge location in a way that efficiently rains on the roadway and diminishes the potential for flooding and other consequences to adjacent properties (Arizona Department of Transportation, 2007). Storm drainage facilities consist of curbs, gutters, storm drains, and channels. The design of storm drainage structures and conveyances including placement and hydraulic capacities shall consider damage to adjacent property and to minimize risk of traffic interruption by flooding (Ethiopian Roads Authority, 2013). The stormwater results from all kinds of precipitation (snowmelt, rainfall, etc...) and comprises the water flowing on the surface (Butler & Davies, 2004). Therefore, the characteristics of both the rainfall and the catchment area represent important factors in the stormwater properties. Indeed, part of the water of the rainfall goes to initial losses as interception, depression storage, infiltration, and evapotranspiration. The remaining water is the runoff (Durrans, 2003).

An important social aspect is to maintain public health and safety; hence efficient drainage of stormwater and wastewater is essential to avoid the impact of flooding on life and property. Also, the current environmental awareness involves the protection of the receiving waters from the pollutants that may be dragged by water flowing in the surface during heavy rain events (Viessman Jr. et al., 2014). The separated system comprises two separate pipelines for waste and stormwater protecting from flooding in the basement and floors of houses in low-lying during extreme rainfalls, as well as avoiding the release of pollutants into the environment (EPA, 1999). Stormwater is normally less polluted than sewage water so that it can be led to detention basins or watercourses saving energy and cost, whereas wastewater requires a deeper treatment. In our country the sewerage and the stormwater or drainage system is isolated. These brings the flooding of the drainage system due to the over loading of the drainage canal. The stormwater is conveyed with open channel and it joins the river near to the area without any treatment.

2.4.Impacts of stormwater on the general environment

Some of the major implications of stormwater runoff include:

- Increased runoff can result in flooding,
- Characteristics of the water body which receives the collected runoff may change due to different substances in the stormwater and result in degradation of the water body,
- Chemicals in the stormwater runoff may include components toxic to organisms (Pitt, 2004)(Mallin et al., 2009)

When going through the effects of stormwater on the environment in detail, animal & human waste in the stormwater is associated with an increase in toxic waste which may be harmful to the biodiversity (US EPA, 2003). Meanwhile, dissolved solids in the stormwater change the chemical balance of waterways, which can destroy plants, while runoff also constitutes increased levels of heavy metals (e.g. copper, zinc, and lead), which are toxic for some plants and animals (Mallin et al., 2009).

Furthermore, Littering (from bottles, cigarette butts, plastic bags, and the like), in addition to oil and crease, found in the stormwater, cause visible pollution on the driveways and walkways it covers and the wet structure it drains into. This can result in an increase in toxins in the runoff and forming of film over water with reduced needed ingredient levels, thereby severely hurting aquatic animals and plants. Also, increased Sediment (soil, sand, etc.) levels and heavy metals and other pollutants attaching to the sediment particles, lead to disruption of plants and animals that live in the waterways that receive stormwater runoff (US EPA, 2003).

Furthermore, stormwater runoff, and subsequent flooding, is seen to cause damages to property, and contribute to public infrastructure destruction (bridges, roads, etc.), private property destruction and degradation (residential, commercial buildings, playgrounds, etc.), while in some severe cases leading to loss of human life (Yannopoulos et al., 2013).

On the other hand, properly managed, controlled, purified and recycled stormwater can have benefits, these include:

- For irrigation for Food crops, including all edible root crops, where the recycled water comes into contact with the crop, and food crops where the edible portion is produced above ground and not contacted by the recycled water
- For use in parks and playgrounds, schoolyards, residential landscaping
- Cooling in an industrial or commercial setting by collecting and purifying the stormwater and using it in methods that involve cooling processes.

- ➢ Structural firefighting, decorative fountains, commercial laundries, commercial car washes, where the public or individuals don't use it for purpose of personal hygiene
- ➢ Soil compaction, mixing concrete, dust control on roads and streets, cleaning roads, sidewalks, and outdoor work areas
- ➢ Flushing sanitary sewers (Talebi & Pitt, 2011).

2.5.Factors affecting stormwater runoff and its management practices

In addition to intensity, coverage, and duration of precipitation (rainfall), other factors have also been seen to influence stormwater runoff and the implementation of proper techniques to mitigate it. These include:

2.5.1. Vegetation

The type and the amount of vegetation are some of the important factors that affect stormwater runoff. Areas with proper vegetation covers have a lower amount of stormwater runoff compared to open impervious areas. Dense vegetation on a good slope reduces the surface flow of stormwater, as there is increased infiltration capacity of the soil, which enables evaporation and infiltration. Also, depending on the type of vegetation, there might be further increased stormwater retention effect, as seen in the difference between crops that have high water storage capacity and plants which do not (Demu, 2018).

2.5.2. Soil type

As soil is one of the major factors that dictate the flow of stormwater in residential or neighborhood settings, the porosity of soil affects the storage ability of an area and also influences the resistance of the flow of stormwater to the deeper layers of the soil, which affects infiltration capacity. The infiltration capacity of the soil is different for different soils, as seen in the difference between sandy soils and clay soils (Demu, 2018).

2.5.3. Slope

As stepper slopes are associated with higher velocities of the flow of stormwater from up catchment areas to lower catchment areas, runoff generally causes many problems in areas with higher slopes. The quantity of runoff decreases when there is a gentler slope where the water stays a longer duration and has space to infiltrate the soil and evaporate before reaching the lower catchment areas (Akhter et al., 2020).

2.5.4. Land (Plot) size and use

Different Plots with different sizes and uses are found in urban areas. Industrial and commercial areas are very common in addition to residential plots, leading to increased impervious surfaces. Development of these areas, in many instances, considers hydrological impacts such as stormwater runoff timing, depths, and volumes. However, increased urbanization and increased plot size and use with negligible concern given to improving pervious surfaces leads to increased stormwater runoff volume, in turn leading to negative consequences (Endreny, 2005).

2.5.5. Drainage

Waste sewers, groundwater and/or surface waste reservoirs, and other drainage mechanisms are some of the features used to remove waste from to collection site and to transport stormwater to the designated collection lake, river, or wetland. The drainage channels and networks, located on the side of roads and outside individual plots, are used to efficiently collect and route stormwater to its planned storage place and reduce the negative effects associated with it. As roads and other impervious surfaces located near the drainage networks prohibit infiltration and increase runoff magnitude and velocity, drainages play a major part in collecting runoff from these surfaces to its planned storage space; hence, an essential consideration is given to drainage mechanisms during design and construction of roads and neighborhoods (Ferronato & Torretta, 2019; Parkinson, 2003).

2.6.Stormwater Management practices

2.6.1. Best Management Practice for stormwater management sustainability

i. Reduce urban Run-off: The achievement of runoff reduction starts by recognizing that developing or redeveloping land within a watershed inherently increases the imperviousness of the areas and therefore the volume and rate of runoff and the associated pollutant load, and outlines various approaches to reduce or minimize this impact through planning and design techniques.

The extent of impervious land covering the landscape is an important marker of stormwater quantity and quality and the health of urban watersheds. Impervious land coverage is a fundamental characteristic of the urban and suburban environment -- rooftops, roadways, parking areas, and other impenetrable surfaces cover soils that, before development, allowed rainwater to infiltrate (Tafete, 2013). The techniques that are related to reducing urban run-off encompass managing watershed impervious areas, minimizing directly connected impervious areas to storm drainage systems, and considering Runoff reduction areas in planning and designing.

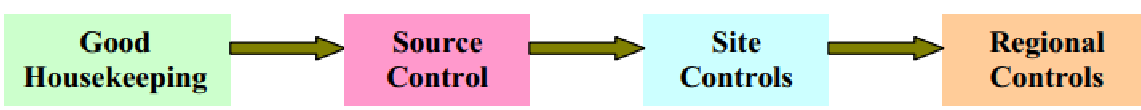


Figure 2-3: Flow chart for Urban Runoff Management (Sharma, 2008)

ii. Protect the existing best management practice: The functions that are provided by BMPs may include: volume reduction, treatment and slow release of the water quality capture volume (WQCV), and combined water quality and flood detention. If possible, site designs will include a "treatment train" which controls and treats pollutants at their sources, reduces runoff, and includes a combined variety of source control and treatment BMPs. According to (Urban Drainage Flood Control District, 2010), a few of the BMPs for stormwater management in an urban setting are:

1. Wet Retention Pond: are stormwater control structures that provide contaminated stormwater retention and treatment. Through capturing and retaining stormwater runoff, wet retention ponds control its quantity and quality, while then removing pollutants by the works of the pond's natural processes. In order to improve bank stability and aesthetic benefits, Retention ponds are expected to be surrounded by natural vegetation.

2. Extended Detention basin (EDB): are stormwater BMPs that provide general flood protection while also controlling extreme and rare occurrence floods and storm events. These basins are ideally built during the construction of new land development projects. They help manage the excess urban runoff generated by the impervious surfaces such as roads, and parking lots that are newly constructed.

3. Permeable Pavement Systems (PPS): Permeable Pavement Systems are pavements that allow movement of water into the layers below the pavement outer surface. Permeable pavements can be used to promote volume reduction, provide treatment, and slow release of the water quality capture volume (WQCV), and reduce imperviousness, depending on their design.

4. Sand Filter: is used as a step in the water treatment process of water purification. A sand filter is filtering or infiltrating BMP that consists of a "surcharge zone underlain by a sand bed with an under-drain system (when necessary)". During a storm event, accumulated runoff collects in the surcharge zone and it gradually infiltrates into the underlying sand bed, which fills the void spaces in the sand. The sand bed is then gradually dewatered by the under-drain and discharges the runoff to a nearby stormwater management mechanism such as a channel, swale, or storm sewer.

2.6.2. Sustainable Stormwater Management as Restoration

Ecological restoration is a widely interpreted term. Restoration is "a singular word offering myriad meanings and rich rhetorical resources. The term is a common language for developers, ecologists, academics, planners, environmentalists, and others. However, the term means different things to these different people in different professions and contexts (Omlid, 2009).

As seen throughout many countries, various stormwater management systems have been developed and applied to control the urban-grown stormwater problem. Some of these include Low Impact Development (LID), Water Sensitive Urban Design (WSUD), Integrated Urban Water Management (IUWM), Sustainable Urban Drainage System (SUDS), Best Management Practices (BMPs), Source control, Green Infrastructure (GI) and Landscape Based Stormwater Management (LSM).

Currently, these sustainable stormwater management systems are implemented to deal with the limitations of widely used traditional stormwater drainage systems. The traditional system often focuses on collecting and conveying stormwater runoff (Burns et al., 2012) directly to water bodies resulting in worsening pollutant concentrations and increasing hydrologic disturbance, which leads to ultimately degrading the ecosystem (Roy et al., 2008). Conversely, these sustainable stormwater management systems are implemented to retain, infiltrate, and harvest stormwater, which helps in enhancing evapotranspiration and groundwater recharge; while re-use of stormwater may lead to a more sustainable solution to stormwater.

2.7.Landscape based stormwater management

Green infrastructure and landscape-based stormwater management as flood protection

Green Infrastructure (GI), a term used for a network of different vegetation systems (for example forests and gardens) which are immensely essential in solving urban and climatic challenges. Moreover, green infrastructure is used to describe specific and bundled vegetation systems in general.

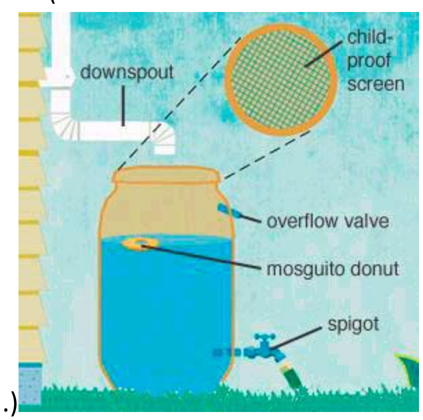
GI is an integral part of sustainable climate change resilience in many major cities throughout the world. It has been seen that blue and green infrastructure systems are an essential element for handling climate change impacts; moreover, GI has been proven to be essential for our ecosystem services.

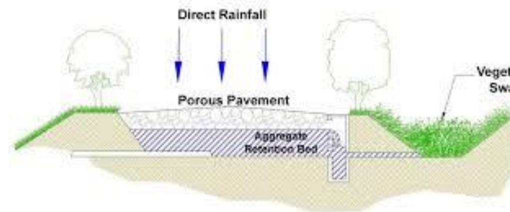
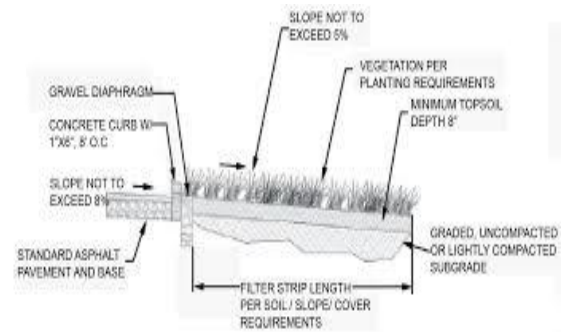
Hence, some of the GI based stormwater management techniques that can be implemented on a watershed level include:

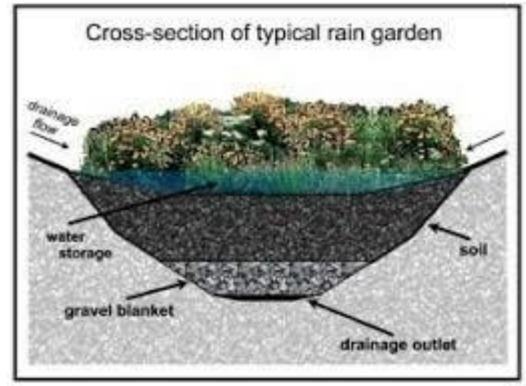
i. **Bio retention Pond:** Bio retention ponds help store and infiltrate stormwater through the use of permeable soils, vegetation, and organic matters for treating runoff from paved surfaces. They do not hold permanent water in their capacity but let the collected stormwater drain in 12 hours. They are effective as stormwater pollutant removals; they remove heavy metals as well as unnecessary oil and grease. They also increase water treatment which results in significant water quality benefits (Shafique, 2017).
ii. **Road Side Vegetated Swale:** Helping treat both quality and quantity of stormwater runoff, vegetated swales allow the infiltration and evapotranspiration of stormwater while filtering pollutants and providing tall grasses and flowers that are aesthetically pleasing. They require regular maintenance to help in mitigating and treating considerable amounts of stormwater as other invasive plant species may affect them (Penn's Corner Conservancy and Charitable Trust, n.d.).
iii. **Green Gutter:** Used for quality stormwater treatments for runoff from the bike, street, vehicle, or pedestrian lanes, green gutters help in the infiltration and filtration, soil adsorption, and plant uptake of stormwater. Green gutters are typically located along the length of the street of the required location around gutter lines. Through increased vegetation, they provide functionality and capture stormwater on roadways while also providing aesthetic attractiveness by integration with the overall streetscape (City and County of Denver, 2015).
iv. **Previous Driveways and Walkways:** Previous driveways and walkways help in improving groundwater recharge and infiltration while reducing runoff volume by allowing stormwater to soak through them and be released to the surrounding soils and other stormwater draining systems (Penn's Corner Conservancy and Charitable Trust, n.d.).

Moreover, other landscape-based green infrastructure stormwater management practices that can be applied to different residential plots are described in the following table.

Table 2-1: Landscape based stormwater runoff management methods (green stormwater infrastructure) in detail

Landscape based Stormwater mitigation methods		Benefits	Illustrative Images
Trees:	Trees are easier to plant than other options. Being one of the most effective, easy, and low-cost ways to mitigate stormwater runoff, identifying and selecting the right tree, planting it correctly, and preserving these existing trees is of utmost importance while using trees as SWM. Well, looked-after Trees can adapt to the climate and better withstand extreme weather conditions.	✓ Canopies and leaf litter of trees can cushion the impact of rainfall on the ground, which reduces soil erosion and allow more soil penetration by the water. ✓ Roots absorb water from runoff, natural drainage, and rain and help hold soil in place ✓ Help filter out some impurities before water infiltrates into the subsoil. ✓ Increase the aesthetic quality of the places they are planted in.	Tree cross-section (City of Roanoke, 2014) 
Rain collection Barrels:	This type of runoff management is associated with catching rainwater from the rooftops at the bottom of downspouts and storing it in large water collection containers for further use. Very traditional and easy to build, rain barrels are ideal for plots that are relatively small in area and do not have many green spaces, while they can also be used for households with low income and those that use much tap water to irrigate their green areas.	✓ Can replace tap water for use on green areas, vegetation, and outdoor cleaning. ✓ Provide water free of some of the chemicals found in tap water. ✓ Reduces stormwater runoff and pollution.	Rain barrels (Kalamazoo river watershed  Council, n.d.)

Grass channels (Grass Swales):	Grass channels (grass swale) are intended to direct stormwater across the vegetation landscape through a wide and shallow linear depression planted with grass. Grass channels can replace standard drainage ditches in the handling of stormwater through use in conjunction with other GI methods such as rain gardens. Grass channels work much more effectively along driveways collecting stormwater from impervious surfaces.	✓ Allow the stormwater runoff to soak into the ground which slows runoff, resulting in is less water and fewer pollutants flowing into the external environment.	Grass Channels (Bureau of Watershed Management, 2006) 
Vegetated filter strips:	Vegetated filter strips are gently sloped areas designed to receive stormwater as sheet flows from adjacent impervious surfaces to slow runoff. They are covered with grass and other vegetation and reduce the speed of stormwater through infiltration and temporary storage in the soils below the vegetation. Vegetated filter strips are commonly used in integration with the native or natural vegetation that already exists, which is maintained or enhanced, as opposed to removed and replaced	✓ Decrease velocity of stormwater runoff, ✓ Infiltrate stormwater runoff into the soil, reducing its adverse impacts, ✓ Effective removal of pollutants	Vegetated Strips Cross-section(Greater Vancouver Sewerage & Drainage District, 2005) 

Rain Garden:	Rain gardens are areas, landscaped with different types of vegetation to soak up rainwater and infiltrate it into the soil. They have the aim of capturing runoff from various impervious surfaces, such as pavements, roofs, and driveways. Rain gardens fill with a few inches of water after a storm which becomes a pool and then the runoff water is soaked into the ground, rather than running off to a drain.	✓ Reduce the amount of runoff, ✓ Filter pollutants from stormwater, protecting streams, lakes, and the natural habitat, ✓ Increase the amount of water filtering into the ground, helping recharge aquifers, ✓ Simple to implement and an aesthetically pleasing feature in the landscape	Rain garden cross-section (Harford County Government, 2013) 
Green Roofs	Green roofs could be defined as "contained" living systems on top of human-made structures. Also known as vegetated roofs or living roofs, Green roofs are specially designed roofs that accommodate different types of vegetation to capture rainfall to reduce runoff on impervious surfaces. However, in Addis Ababa, green roofs are not commonly practiced	✓ Increase the heat resistance of the roof by providing an additional thermal layer ✓ The vegetation provides layers shading the roof, blocking part of the incoming solar radiation; ✓ increases the roof thermal mass, reducing incoming heat fluxes; reducing heating, cooling costs (energy conservation) ✓ Aesthetically pleasing ✓ Stormwater runoff reduction.	Green roofs detailed (Vijayaraghavan, 2016) 

Source: (City of Roanoke, 2014; Penn’s Corner Conservancy and Charitable Trust, n.d.)

2.8.Stormwater management practices in different countries

2.8.1. USA

2.8.1.1. Northern Kentucky

The selected case is a guide prepared for Northern Kentucky communities to manage and reduce stormwater runoff while still allowing the region to grow with various developments such as residences, businesses, and jobs. The Guide includes land-use policies and strategies that are adaptable regionally and in different areas of the United States aiming to reduce stormwater runoff quantities without affecting growth. Preserving, Recycling, Reducing, and Reusing is core concepts behind the comprehensive green infrastructure approach applied to development at the regional, neighborhood, and site scales.

SWM Strategies at the Site level

The Guide addresses developers, designers, policymakers, and the general public with methodologies to be considered as a site-level design that aims to protect water quality and make the streets and development more attractive in the area of Northern Kentucky. Stormwater management as site level is addressed with two main categories. The First are techniques under Rain Absorbing Footprint Strategies and the second are techniques under Rain Garden Strategies. Rain-absorbing footprint strategies utilized include green roofs, pervious paving, and rainwater harvesting, while rain garden strategies include stormwater swales, stormwater planters, infiltration gardens, stormwater curb extensions, and residential downspout disconnection.

Figure 2-4: Previous asphalt in the parking stalls at the Sanitation District No. 1 headquarters(EPA, 2009).

Key points learned

The case study of the Northern Kentucky approach of small-scale stormwater management has pointed out those techniques to be applied shall be based on taking into consideration general integrity within the neighborhood and community level scale. The implementation of techniques shall be based on the size shape and physical conditions to obtain better results in reducing runoff velocity, quality, and volume.

2.8.1.2. Seattle, Washington	Using Natural Drainage Systems to Manage Stormwater Runoff	Key points learned
Seattle, which is located between Puget Sound and Lake Washington, is a largely urbanized area that has a strong connection to its waterways. Seattle's network of sewer and drainage systems is the responsibility of Seattle Public Utilities (SPU), whose systems include combined sewers (including combined sewer outflow (CSO) outfalls), CSO control detention tanks/ pipes, sanitary sewers, and storm drains with storm drain outfalls. During heavy rains, annual overflows are caused as a result of the combination of stormwater and sewage exceeding the drainage system's capacity (NDRC, 2013).	In addition to design manuals laying out stormwater design strategies for different kinds of projects, Seattle has demonstrated green infrastructure promotion via uses of techniques such as Green roofs, rain barrels/cisterns, permeable pavement, rain gardens, vegetated swales, street trees, green streets. To facilitate the use of resources, Seattle also provides green infrastructure incentives such as "stormwater fees", which help pay for the implementation of stormwater control strategies (NDRC, 2013). These initiatives are accompanied by regulatory green infrastructure programs, namely "Green Factors".  Figure 2-5: GI implemented under the green factor program in Seattle, Washington, USA(NDRC, 2013)	The major takeaways from this case analysis are that emphasis should be put on implementing green infrastructure mitigation strategies at the citywide level and appropriate stakeholders should be involved in this process. Moreover, the use of incentives to encourage stormwater management practices of residents should also be considered.

2.8.2. Germany	Stormwater management in Emscher and Berlin regions	Key findings learned
In Germany, applications of GI for stormwater management have been prevalent throughout the past decades. In the country, LID and LID-related technologies, such as green roofs, swales, and constructed wetlands, have been a long-standing common practice based on standards and norms. Germany is a notable experience concerning innovative policy approaches to support and promote the use of GI. Moreover, with regards to urban stormwater and wastewater management, continuous investment in maintenance and rehabilitation of the sewerage system has helped Germany avoid major problems. However, these conventional systems are challenged by issues such as changing operating and demographic conditions, and an increasing frequency and intensity of storm events (Nickel et al., 2014).	The stormwater management experiences in the Emscher Region and Berlin show the advantage of public authorities assuming leadership, as state and regional municipalities are the major stakeholders regarding stormwater in Germany. Some of the means where these authorities were successful include implementing GI projects on public grounds, raising awareness, sharing the risks and costs of introducing GI, and providing assistance with implementation and maintenance. As seen in the two areas, it is advised to have a solid data basis to assess possibilities for applying GI and to work with relevant stakeholders on the integration of GI into the existing urban structure, (Nickel et al., 2014).  Figure 2-6: GI implemented for stormwater management on the property of public housing in the Emscher region (Nickel et al., 2014)	This case has provided the important lesson of the advantages of having public authorities assume leadership and collaborate with different stakeholders in implementing stormwater management projects, in raising awareness about the projects and stormwater in general, and providing assistance and support for implementation and maintenance of GIs.

2.8.3. Sweden	Main governance factors identified in Swedish case cities	Key findings learned
In Sweden, sustainable urban drainage or sustainable stormwater management (SSM) has been reported to be in use for decades and categorized into three types: “onsite control”, which uses small-scale solutions, such as green roofs, rain gardens, and permeable pavements; “process control”, which uses swales, ditches/creeks, canals, etc. to transport stormwater slowly; and “downstream control”, which uses large-scale means, such as dry basins, large ponds, wetlands. This case study analyzed four case cities in two countries, namely Lund and Malmö in Sweden, and Xi'xian and Zhenjiang in China with regard to SSM and governance issues. Malmö mostly suffers from mainly pluvial flooding rather than flood events, while Lund is one of the Swedish cities that haven’t yet suffered from pluvial flooding, but stormwater pollution is a major issue (Qiao et al., 2019).	This study found that local governance factors influencing SSM implementation in the case cities were more or less similar to the general governance factors mentioned above. Moreover, additional governance factors that influence SSM implementation at the local level in Swedish cities were observed as local government politicians' priorities, public awareness, and trust in the performance of SSM solutions (Qiao et al., 2019).	This case study highlighted the need for identifying the different governance factors (whether it is in the governmental or private and public sense) which either positively or negatively affect stormwater management strategies before, during, and after the implementation of these strategies. Moreover, factors associated with the maintenance of these strategies should also be considered.

2.8.4. South Africa	Self-help stormwater management strategies	Key points learned
This case study was done on community-based initiatives on stormwater management in informal settlements, in the case of Slovo park settlement in Johannesburg, South Africa. This case sheds light on self-help stormwater mitigation strategies and community-led initiatives in the settlement, as well as assistance and engagement from non-state agencies in managing stormwater (Adegun, 2014).	The management measures by which Slovo park residents self-manage stormwater runoffs were: ➢ Building-related practices ➢ Water channels ➢ Rainwater harvesting ➢ Vegetation/ green infrastructure (Adegun, 2014). Moreover, through community-initiated developmental drives, an urban design framework (which includes stormwater mitigation strategies) for development of the settlement has been developed; which includes a proposed commercial urban farm and a chicken farm.  Figure 2-7: Cultivated gardens to handle stormwater in Slovo park settlement, Johannesburg, South Africa (Adegun, 2014)	The case study points out that while individual self-help strategies are effective techniques, community-based initiatives are essential to cope with and manage stormwater, although there are significant hurdles associated with the implementation of these community-based initiatives.

2.8.5. Egypt	Stormwater and flooding mitigation strategies	Key points learned
This case study analyzed the 2015 flooding which occurred in Alexandria and the neighboring areas in Egypt. According to this study, one of the three institutions responsible for flood risk management in Alexandria is the Holding Company for Water and Waste Water (HCWW). Hence, two main challenges of HCWW are to manage Egypt's shortage of water and to maintain adequate sanitation. With this regard, enough work has not been conducted on water sanitation. In addition, flooding during storm events have been caused by insufficient capacity of the current stormwater management systems of the city, including conveyance systems of Alexandria, which has been identified through rainfall analysis, remote sensing analysis, and fieldwork. (Zevenbergen et al., 2017).	To handle any stormwater problem and flooding event that might occur, the authors proposed an effective and flexible general strategy that should consist of a mixture of measures addressing flood preparedness, flood protection, and flood prevention. These potential measures include short-term flood mitigation actions, such as the installation of extra pump capacity and drains at some low-lying sections in the city (some of these plans have been implemented). Additional actions include cleaning urban drainage and irrigation systems and protecting critical infrastructure. Moreover, anticipatory water management which involves effective flood forecasting and warning systems and "designed for exceedance" to manage the excess rainfall, which the drainage system cannot cope with, should be given emphasis, according to the authors. These approaches help to manage extreme water flows and reduce their impact on the city and mitigate any adverse effects that occur, such as flooding (Zevenbergen et al., 2017).	This case shows that a flexible approach should be taken to handling stormwater (considering anticipatory stormwater prevention techniques) and subsequent flooding. The approaches undertaken should consider both short-term and long-term stormwater management mitigation and should involve discussions with all relevant stakeholders before implementation.

2.9.Contextual review

2.9.1. The practice of stormwater management in Ethiopia

Ethiopia, located in the so-called horn Africa, is the second-most populous country in Africa. The country has an estimated population of close to 90 million inhabitants; where the majority of Ethiopians reside in rural areas. However, the urban population has increased from 4.87 to 11.86 million between 1984 and 2007. According to (World Bank, 2015) report, urbanization is growing at a rate of 3.8% annually and is expected to triple by 2037 (UN-Habitat, 2017).

The country with a total area of approximately 1.13 million kilometer square is characterized by a topography consisting of massive highlands, rugged terrain, and low plains. The geographical aspect of the terrain has also extreme aspects regarding elevation differences with heights that range from the lowest of 125m below mean sea level in Dankali Depression to the highest of Ras Dejen (Dashen) peak which measures 4,620m above mean sea level. Ethiopia is characterized by complex topographical, climate conditions, and abundant water resources. The variability of the water resources is also characterized by diverse weather and rainfall conditions. Rivers become full and flood their surrounding areas especially the three main rainy months which are June, July, and august (Berhanu et al., 2014).

The mean annual rainfall of the country ranges from 141mm in the arid area of the eastern and northeastern borders of the country to 2,275mm in the southeastern highlands (Berhanu et al., 2013). Rainfall in Ethiopia is the product of multi-weather systems that are characterized by seasonal and inter-annual variability. Besides, Ethiopia's rainfall system is significantly more complex as it is associated with topographical variability which is greatly affected by the spatial distribution of rainfall (Berhanu et al., 2014).

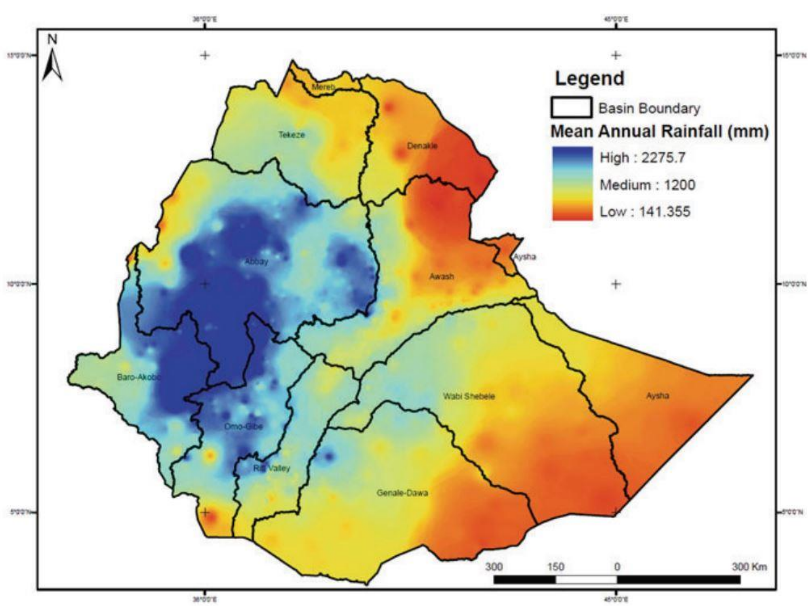


Figure 2-8: Spatial variability of the mean annual rainfall in Ethiopia(Berhanu et al., 2014).

Ethiopia, similar to many developing countries, has low coverage and development of urban stormwater management systems characterized by the absence of on-site management and lack of safe discharge to natural receiving environments (Adugna, Lemma, Jensen, et al., 2019). The Urban drainage cover for the conventional method of the stormwater management system is limited and does not sufficiently cover urban areas. Due to the topographical contexts, the rugged terrain conditions and the characteristics of the flow of rivers make the development of water-related infrastructure including hydraulic structure to be expensive and need much investment (Berhanu et al., 2014).

In Addis Ababa, with increased population, the amount of land needed to sustain the population is increasing and forest areas are being cleared to provide living spaces which leads to increased urbanization.

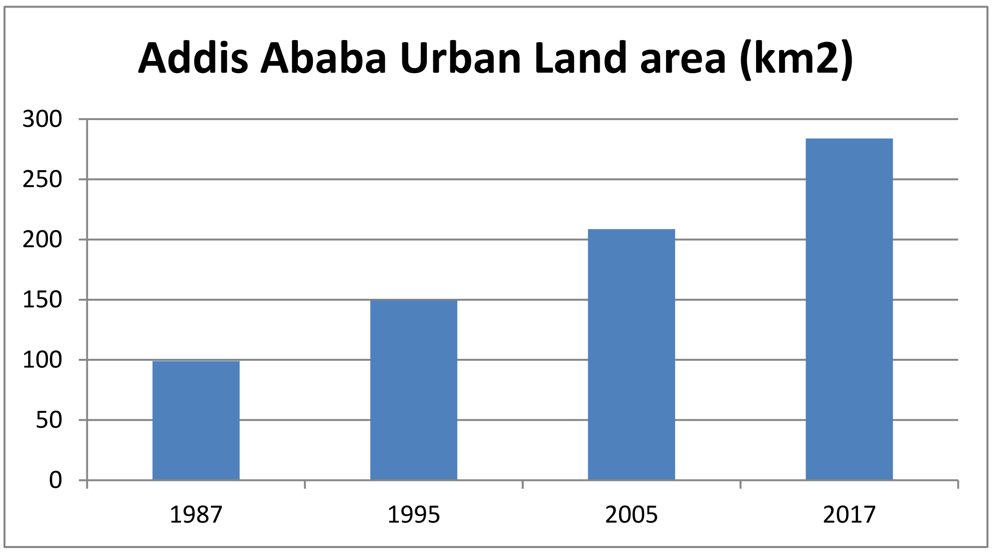


Figure 2-9: Total urban area (km^2) increase of Addis Ababa from 1987 to 2017 G.C. (Terfa et al., 2019)

The city experiences huge amounts of rainfall during the winter months which is the rainy season and the city's underdeveloped drainage system exacerbates stormwater runoff problems. The topography of the city exacerbates flooding within the city as Addis Ababa has very steep slopes within the elevation of 3000 m in the north to 2100 m in the south, which leads to runoff flows at higher and faster volumes. Also, some of the soil types found in the city have high clay content and are not well-drained. Furthermore, the development of impervious surfaces, which increases the amount of stormwater, is more than the capacity of the existing drainage system can handle, which leads to erosion and flooding in addition to water pollution (McFarland et al., 2019; Mezgebe, 2009).

Stormwater management in Addis Ababa is generally limited to underground concrete pipes which are constructed near primary arterial and local streets in addition to roadside ditches. The stormwater in these sewers is discharged into local streams and rivers with the waste it contains. To exacerbate the stormwater runoff problem, as the drainage system is poorly developed, only a fraction of the city's households have access to the city's drainage system. In most cases, the highly populated and crowded inner part of the city is the most susceptible to the effect of stormwater runoff (McFarland et al., 2019; Mezgebe, 2009).

All in all, in Addis Ababa, the use of such sustainable stormwater management systems are generally lacking. Moreover, although the city administration of Addis Ababa is working towards improving these management practices, the existing stormwater management system is hampered by impervious structures, poor waste management, increasing frequency and intensity of rainfall, and poor coordination with other stakeholders (Adugna et al., 2019).

Among the important regulations set to address the stormwater management problem is the National Urban Green Infrastructure Standard. The NUGIS place responsibility on national, regional, and local public authorities to improve different green infrastructure issues among which to provide better stormwater management and enhance stormwater quality through the regulation of river flow and protection of river banks (MUDHo, 2015). Nevertheless, public awareness of the matter, coordination between concerned authorities is still a large problem in the country.

2.9.2. The practice of Stormwater management in Addis Ababa

Addis Ababa, the capital of Ethiopia, is one of the fastest-growing cities in Africa based on the 2014 Ethiopian Central Statistical Agency report. The city, in 2013, had an estimated population of 3.2 million. The total surface area of the city is 540 kilometers square with mixed land uses and composed of formal and informal/unplanned settlements (McFarland et al., 2019). Addis Ababa is undergoing rapid urbanization with a very high rate of road and building constructions, which increases sealed surfaces, and generates significant amounts of stormwater (Adugna et al., 2019).

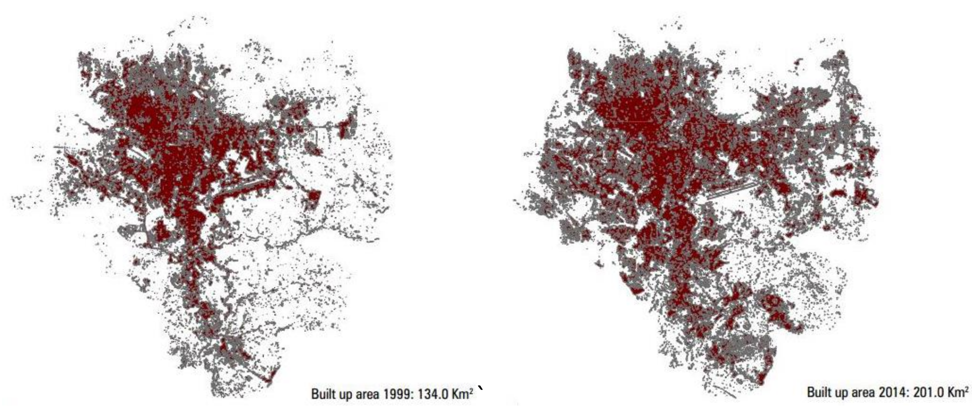


Figure 2-10: Increase of Addis Ababa Built-up area in 1999 & 2014(UN-Habitat, 2017)

The problem of poor stormwater drainage management and facilities is worsening by the fast rate of urbanization and the inability of related authorities to develop and manage the physical infrastructure to keep pace with the increase of population and increase of basic needs. The lack of financial and human resources increases the problem, especially in the development of stormwater drainage systems which have been viewed as a solution for urban stormwater (Fryd et al., 2016). Stormwater management has not been given much attention when compared with other urban development activities, resulting in flash flooding, and degradation of urban infrastructure. Apart from few data collected in small neighborhoods of the oldest part of the city, the coverage of the traditional piped drainage systems and their respective hydraulic capacity in Addis Ababa is largely unknown (Adugna et al., 2019).

2.9.3. Watershed Level Analysis (On sub-city level)

Some of the simplest strategies to manage stormwater runoff in residential areas are to preserve and protect the site's existing natural resources, such as trees, plants, or any other vegetation. Another method would be to convert excess impervious area, both inside and outside the plot compound, to landscape space with abundant vegetation. Transforming this impervious "gray space" into "green space" not only helps reduce stormwater runoff volume but can also provide room for the planting of additional trees and plants, furthering the stormwater runoff management property while beautifying the community (Greater Vancouver Sewerage & Drainage District, 2005).

Landscape-based stormwater runoff management practices such as green infrastructure are considered to address causes of stormwater issues through reduction of stormwater from impervious surfaces and through acting as a natural hydrologic system. Besides, this provides an opportunity to reduce stormwater runoff in the forms of natural landscaping and vegetation. Other than mitigation of stormwater runoff, several environmental issues can also be addressed through green infrastructures, such as urban heat island effects, degraded air quality, and energy consumption in buildings (Tian, 2011).

The watershed analysis is a key element in the development of a framework for decision-making regarding how to design an appropriate stormwater management method for a particular area. Watershed analysis provides a practical framework that provides information that guides essential decisions and provides a more complete understanding of landscape-scale processes. It is intended to provide the information required to assess and develop appropriate management plans for implementing stormwater runoff (Montgomery et al., 1995).

Addis Ababa is divided into ten sub-cities to have an efficient, effective management system and better serve the inhabitants. As drainage is used as the primary method through which urban storm runoff is managed, there are limited data in regards to the housing units connected to drainage lines. The main aspect of sub-cities is that drainage systems are underdeveloped by any standard. Within this matter, things are even in critical conditions whereas improperly disposed of solid wastes blocks existing drainage channels mainly in and around the inner-city slums. Within this context, it is common to see streets that are becoming significantly damaged by overflowing runoff. Torrential rainfalls that last for hours leading to floods have inflicted damages to humans and property (Kloosterboer, 2019).

Hence, to tackle this problem, according to the Ethiopian Urban Green Infrastructure Standard, section 7, competent authorities shall combine structural and non-structural stormwater management practices (SWMPs) and related strategies to create an integrated stormwater management system. Authorities shall also check and verify that surface water drainages are laid out functionally and implemented based on detailed plans, including assessment of potential disposing of surface water utilizing a sustainable drainage system. Within this regard, related urban planning and design bodies are advised to follow the Urban Planning preparation and Implementation Strategy, which allocates 30% of the land for roads and infrastructure, 30% for green areas and shared public use, and 40% for building construction in their urban land management plan (MUDHo, 2015).

As for single-family private domestic gardens, the standard states that every plot area up to 150m^2 should be provided with at least one tree and at least one additional tree should be provided for every additional 50m^2 of the plot area. 12% of a plot area is expected to be unsealed, making it green open space, allowing rainwater to infiltrate into ground soil reducing runoff. Private gardens design and management are left to the Owners jurisdiction; while pavements within green open spaces are expected to be made out of permeable materials to improve runoff infiltration (MUDHo, 2015).

The major factors related to the applicability of landscape-based stormwater management practices for the watershed areas were analyzed and discussed throughout this research. The watershed analysis locations were found in the two sub-cities selected for the study, namely: Arada sub-city and Nefas Silk Lafto sub-city, as will be explained in the methodology section of the study.

2.9.3.1. Soil characteristics of watershed areas

According to (Mezgebe, 2009), even though there isn't enough data to accurately pinpoint the soil characteristics of the city, a classification using the FAO soil characteristics and USDA soil hydrology groupings can be made. Hence, the following types of soils were generally seen to be found in Addis Ababa.

- CAMBISOLS (CM): Soils with characteristics of weakly to moderately developed soils and assigned for this study into soil hydrologic group A. Soil Group A includes sand, loamy sand, or sandy loam types of soils. These soils have low runoff potential and high infiltration rates. They consist chiefly of deep, drained sands or gravels and have a high rate of water transmission.
- NITOSOLS (NT): Soils with characteristics of deep, dark red, brown, or yellow clayey and sandy soils having a pronounced shiny, nut-shaped structure and assigned for this study into soil hydrologic group C. Soil Group C contains sandy clay loam. This soil has low infiltration rates when thoroughly wetted and consists mainly of soils with a layer that restricts the downward movement of water and soils.
- VERTISOLS (VR): Soils with characteristics of dark-colored cracking and swelling clays and assigned for this study into soil hydrologic group D.
- LUVISOLS (LV): Soils with characteristics of subsurface accumulation of high activity clays and high base saturation assigned to soil hydrologic group D. Soil Group D contains clay loam, silty clay loam, sandy clay, silty clay, and clay. This group has the highest runoff potential. These soils have very low infiltration rates and consist mainly of clay soils with high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface. These types of soils are found around Mekanisa and its surrounding areas(Akalu, 2017).

2.10. Stormwater management practices in Ethiopia

2.10.1. Jemo river catchment, Addis Ababa

The study chosen as a local case study relies on a study made for Landscape based stormwater management for the Jemo river catchment in Ethiopia. Based on the increasing urbanization rates impacts, such as an increase of urban stormwater runoff, are leading to the increased amount of floods in cities, where it creates a danger to people and settlements in cities. Within this context, by analyzing the flood-prone of residential areas, the most vulnerable are residences made of mud and straw which amounts to 51%, the second is villas and single-story houses which take 34% of the share and at last condominium buildings which are 15% of the total share. The study objective was to identify specific LSM elements that could be integrated into the landscape to enhance stormwater using retention, infiltration, evapotranspiration, and reuse and accordingly improve the visual amenity, aid local temperature regulation, and enhance public space quality.

Proposed LSM strategies

a) **Jemo Mountain:** field crop farming, afforestation of steep slopes, terracing, and alley cropping.
b) **Condominium residential:** rainwater harvesting, detention pond, vegetable farm development, and grass space developments.
c) **Single-family residential (planned and unplanned):** roof rainwater harvesting, detention pond in neighborhood green space, rain garden, and adapting cobblestone roads for internal roads.

Figure 2-11: Detention pond in neighborhood green space (Yeshitela et al., 2017)

d) **Primary Arterial street and cobblestone street:** paving the walkway with the previous concrete pour, green gutter application, and vegetated swale application.
e) **Repi Hill:** rain garden, infiltration trench, retention pond, permeable inner road surface, and multifunctional spaces.

Key points learned

The main aspect drawn from the case study is that the approach to defining the techniques in Landscape based stormwater management shall be deducted from analyzing the site's geographical, functional, physical characteristics. Such recommendations can lead to a better result in reducing the runoff amount as well as increasing the quality of water by screening pollutant particles from urban stormwater runoff.

2.10.2. Mekelle City, Tigray Regional State	The existing drainage system of Mekelle city	Key points learned
Stormwater runoff and flood generation is a common incident in Mekelle, because of low vegetation cover and the vastly spreading land cover with impervious surfaces, which translates to less water infiltrating into the ground. Moreover, the increasingly impervious structures facilitate stormwater severity and subsequent flooding, overloading the conventional system of drainage in the city. Hence, this case tried to analyze and study the existing flooding impacts on the conventional system with the help of geographical information system (GIS) application (Abraha, 2018).	**Natural Drainage** As Mekelle city is part of the Tekeze basin where the tributaries join Geba River and subsequently Tekeze River, the catchment is characterized by flow from areas with high elevation to areas with flat topography. Elala and Aynalem Rivers are the perennial streams and major tributaries of the Giba River; Elala River drains the central plain, while Aynalem River drains the south of the potential zone. The two rivers facilitate the surface drainage system of the city that contributes to small-scale irrigation, while their tributaries feed both rivers with a substantial amount of discharge during rainy seasons (Abraha, 2018). **Stormwater Drainage System** The trend of stormwater drainage lines development in Mekelle city and Concrete pipe drain is the dominant type of infrastructure showing a constant increment of use while other categories of conveyances are applicable in subways. Hence, to propose stormwater management strategies, the case also presented diverse stormwater management techniques and evaluated their sustainability using Analytical Hierarchy Process (AHP) decision support tool. The result showed that the best sustainable stormwater management solutions are Rain gardens, infiltration trenches, Bio-cells, Vegetation swales, and Permeable pavements(Abraha, 2018).	All relevant data should be gathered before the implementation of SWM mechanisms and all relevant stakeholders should be involved in the decision-making process. The use of specific SWM practices should be decided based on scientific analysis of data gathered; for example, the policy of prioritizing source control solutions should be given deliberate consideration.

2.10.3. Kemise Town, Amhara Regional State

Kemise, one of the towns located in Amhara regional state in Ethiopia, has faced stormwater problems for a long time, hence this specific case studied and assessed the stormwater drainage system in Kemise town. To analyze the existing conditions and system and to analyze the peak discharge for the town, statistical analysis was applied. Based on primary and secondary data collected, the problems in the areas were categorized and explained (Asfaw, 2016).

Existing Stormwater management conditions

Closed drainage lines were found in areas especially along main roads while open drainage channels were found along sub-mains and local roads. Within the two broad classifications, three types of storm drainage facilities were seen in the city, namely; access roads which serve as open drainage channels (gravel earth surfaces and stone-paved surfaces), concrete pipe conduits, and stone-lined open ditches. However, drainage service was seen to be inadequate in quality and coverage and the stormwater drainage management was not efficient. (Asfaw, 2016).

Figure 2-12: Open drainage system with no outlet(Asfaw, 2016)

In addition to specific engineering-related recommendations, the authors recommended periodic cleaning and adjustment of the slope for drainages, workmanship for drainage operations, and creating community awareness towards the effects of disposing of solid materials into drainage facilities.

Key points learned

After the implementation of appropriate stormwater management techniques to handle any associated problems that may arise, appropriate emphasis should be given to the maintenance of these practices. In many parts of Addis Ababa and other cities around the country, drainages and other stormwater BMPs are neglected after installation and construction. Hence, all relevant bodies should put paramount emphasis on protecting and maintaining these SWM mechanisms.

2.11. Research gaps

The major research gap identified from the review and analysis of literature was the lack of detailed researches into applications of stormwater management techniques in residential plots level in the Ethiopian setting. Although many types of research are quoted in this research regarding stormwater management in a general setting and roadside manner, there is a lack of information regarding SWM practices at individual residential homes, which are one of the major sources of stormwater runoff that comes out of compounds and contributes to street stormwater. Having considerable impervious surfaces such as roofs and parking areas, rain is usually not handled appropriately in residential spaces as it increases runoff into drainages or any other channels which empty into sewer systems which cause pollution along with pollutants picked up along the path.

Another research gap that was observed the lack of data regarding the contribution of Green Infrastructure practices in the reduction of stormwater runoff at residential plots in Addis Ababa. As can be seen in extensive researches, LSM practices have been found to contribute significantly in decreasing stormwater-related problems such as flooding and erosion, can moderate the local climate and mitigate urban heat island effect, preserve natural ecosystems and provide a natural habitat for different types of plants and animals; however, researches regarding quantifying the effects GI and other LSM mechanisms have on stormwater runoff in residential settings are scarce. Some studies such as (G/wahed, 2016) have tried to analyze and quantify stormwater runoff estimates and the subsequent decrease due to implementation of LSM on streets surrounding residential neighborhoods; however, there is an evident gap in the literature regarding the quantification of stormwater being generated by residential plots and the effects of LSM on alleviating stormwater-related problems.

More over researches such as those done by (Muschalla & Ostrowski, 2002), examined the state of the storm water drainage system in the central part of Addis Ababa, and identified existing and resulting problems of this storm water drainage system. In addition, (Adugna, 2011) tired to assess the existing condition of road and urban storm water drainage infrastructure and to identify the extent of integration of urban storm water drainage infrastructure with essential infrastructures of the city, and to examine the impacts of Urban storm water drainage infrastructure on related environment issues. However, both of these researches did not give much emphasis to stormwater being generated from one of the major contibutors of urban stormwater runoff, residential plots.

Hence, this research aimed at providing solutions and answers to some of these identified research gaps related to a stormwater runoff on a residential level by analyzing data collected from the study areas and providing designs and recommendations based on the results obtained.

Chapter Three: Research Methodology

3.1. Research Design

This research, which aimed to assess Landscape stormwater management (LSM) Technologies on individual plots of the densely developed residential areas of Addis Ababa, employed the triangulation research method, which enables the use of a combination of different approaches for measuring and describing the same characteristic (variable) in research (whether it is methods, theories or sources of data) (Ashour, 2018).

In this particular research, triangulation research methods, which utilize both qualitative and quantitative research approaches, were used to collect both primary and secondary data regarding stormwater management in residential plots (which include both qualitative and quantitative data) through the implementation of data collection methods such as case study analysis, interviews, questionnaires, review of the literature and relevant documents, and observations.

3.2. Research Methodological Framework

After the choice of the research design to conduct the study, a research methodological framework was developed to use as a methodological tool to identify the factors that affect the applicability of green infrastructure (GI) practices and to perform contextually and case study analysis, to meet the research objectives and answer the research questions. 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.

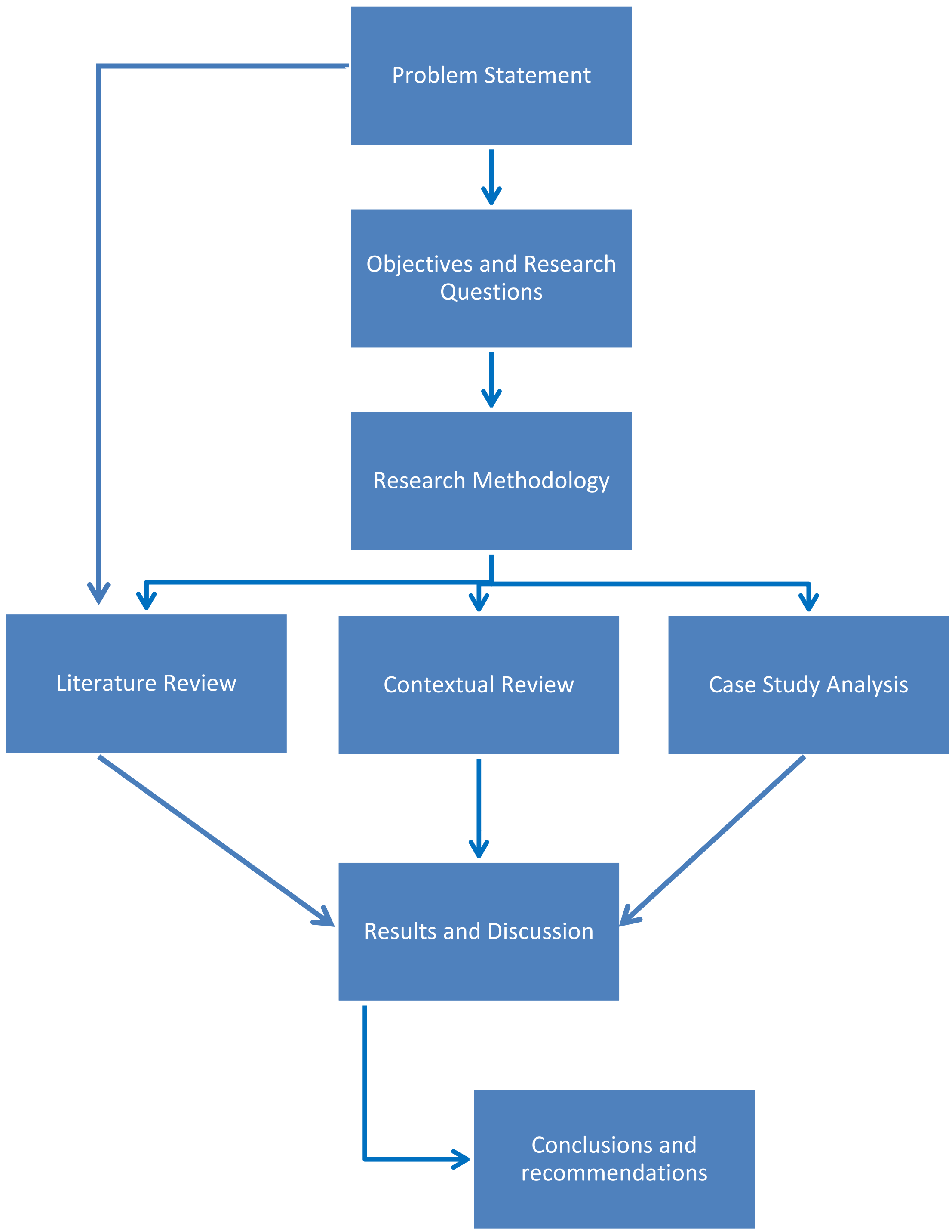


Figure 3-1: Research methodological framework (Author, 2020)

3.3.Data type and sources

In this study, both primary and secondary data were collected. Primary data were used to bring first-hand experiences on stormwater management, while secondary data were collected to enable the researcher to have information about cases of stormwater management practices.

3.3.1. Primary Data

The primary data used in this study are, measurements of built and green structures in the residential spaces, and opinions of residents and officials concerned with the study area, and all necessary maps. To collect primary data, questionnaires were conducted with the plot owners, physical measurements of built structure and non-built areas using maps and personal observations with regards to issues associated with stormwater management were conducted, in addition to interviews with officials in the selected different local authority's offices like Beautification, Parks and Cemetery Development and Administration Agency of Addis Ababa (BPCDAA), and Arada and Nefas Silk lafto sub-cities' administrations. Furthermore, a land-use map was collected from the Addis Ababa city administration construction permit and control authority and additional data regarding annual rainfall was collected from National Meteorology Agency (NMA).

In addition to conducting interviews and questionnaires with the officials and residents, the on-site observation was made on the existing major problems related to sealed surfaces, existing drainages, vegetation, soil type, and slope characteristics of the case site plots.

3.3.2. Secondary Data

The secondary data collected for this study were information regarding relevant experiences in the Ethiopian and international setting in the handling of stormwater runoff; in addition data regarding factors affecting stormwater management and commonly used stormwater management practices was also conducted. The secondary data was obtined from books, journals, documents, reports, and other relevant sources. The published journals were obtained from reliable sources such as universities and peer-reviewed open-access journal publication websites such as "Elsevier journals" and "Science Direct", while relevant documents and reports were collected from associated governmental offices in the Addis Ababa city administration and selected sub-city administrations. The experiences of other countries were also reviewed through the internet.

3.4.Study Areas

Arada and Nifas-Silk Lafto Sub cities were chosen as case sites for this study based on the criteria:

- Arada Sub City and Nifas-Silk Lafto Sub-city being sub-cities with small and large area coverage respectively that can represent the rest of the sub-cities
- According to development character: Nefas-Silk lafto sub-city represents newly developed areas of the city and Arada sub-city represents older developments.

- According to the topography type character; that is Nefas-Silk Lafto represents more of flat topography with Arada sub-city as a representative of areas with steep topography.
- Furthermore, the Arada sub-city is chosen as it is one of the sub-cities which have the highest climate change vulnerability, while the Nefas-Silk Lafto sub-city is chosen as one of the sub-cities with lower to moderate climate change vulnerability(Feyissa et al., 2018).

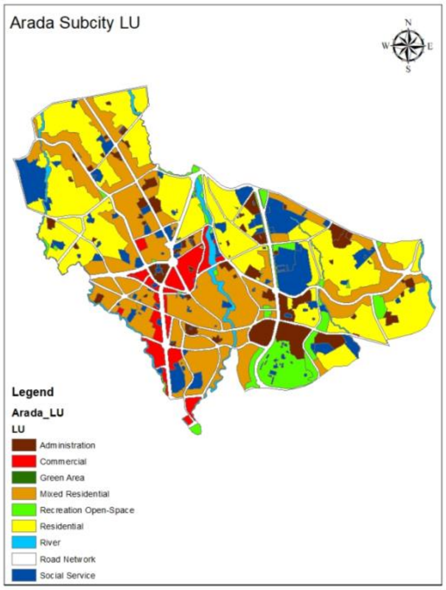
Arada sub-city, one of the ten sub-cities under the jurisdiction of the Addis Ababa Administration, is located in the area which is one of the oldest and most known places in Addis Ababa. Some of the most iconic landmarks of the city, including the National Museum of Ethiopia, Hager Fikir Theatre, Sheraton Addis hotel, and Kidus Giyorgis Church are found in this sub-city. It is located in the upper part of the city and it is surrounded by Lideta, Kirkos, Yeka, Gulele, and Addis Ketema sub-cities. The sub-city is home to 225,999 residents and lies in an area of 990 hectares. There are 10 woredas in the sub-city and the population density per square meter (m^2) is recorded as 22,805.1 (Addis Ababa City Government, n.d.).

The other sub-city selected for watershed analysis is Nefas Silk Lafto Sub-city. This sub-city is home to Prominent Institutions such as Addis Mojo Cooking oil Complex and Bunana Shay Quality Control Center. Nefas Silk Lafto sub-city is surrounded by Kolfe Keranio, Lideta, Kirkos, Bole, and Akaki Kaliti sub-cities in addition to Oromia regional state. It has a total area coverage of 68.3 km^2 (6830 hectares) while it has a population size of 335,740 people. The subsidy has 12 woredas under its jurisdiction. Also, the population density per square meter (m^2) of the sub-city was found to be 4,912.7 (Addis Ababa City Government, n.d.).

3.4.1. Characteristics of the study areas

Land-use and size

The study areas comprised of different types of plots with different sizes and different uses, such as residential, commercial, manufacturing, storage, and green spaces among other types. From these, most were seen to be residential and some were found to be for commercial purposes in both Arada Sub-city and Nefas Silk Lafto as can be observed from the map below.



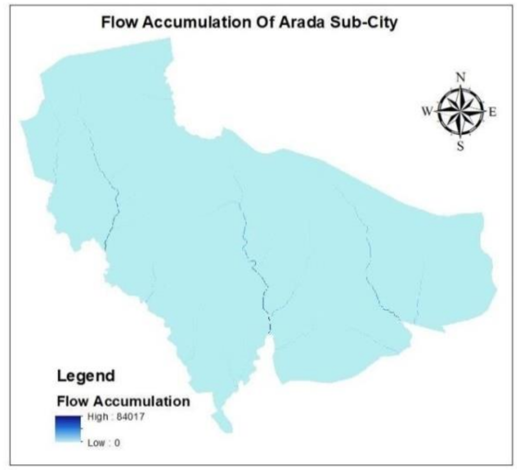
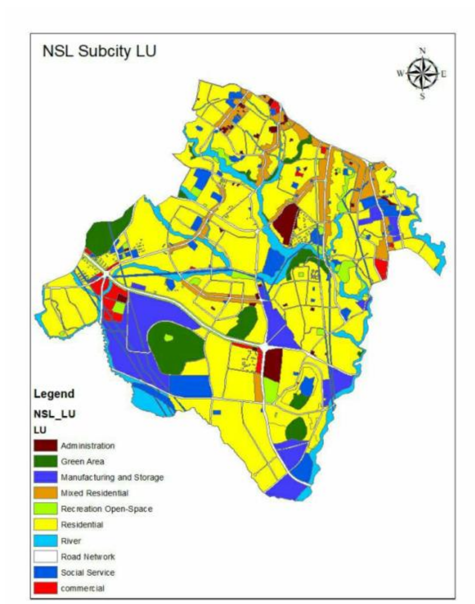


Figure 3-2: Land use map of Arada Sub-city (Author, 2020)

Figure 3-3: Flow Accumulation map of Arada Sub-city (Author, 2020)



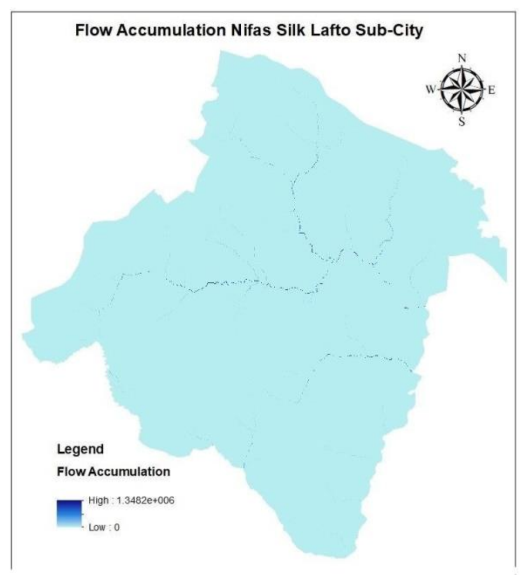


Figure 3-4: Land use map of Nifas Silk Lafto sub-city (Author, 2020)

Figure 3-5: Flow Accumulation map of Nefas Silk Lafto sub-city (Author, 2020)

Imperviousness

The imperviousness analysis of the sub-cities, focusing on residential plots, evaluated the level of imperviousness in the two areas with regards to different land layers such as built-up areas, streets, forests, and green open spaces.

From the total watershed area, the impervious surface (including both built-up areas and streets) was seen to cover much of both Arada and Nefas Silk Lafto sub-cities.

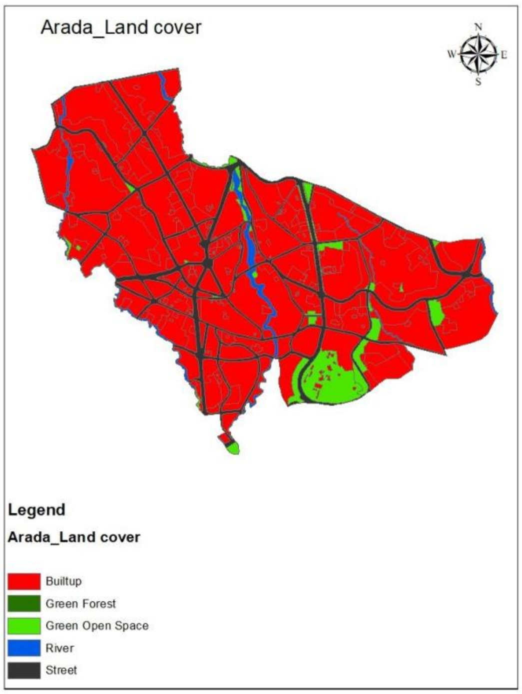


Figure 3-6: Arada Sub-city land cover (Author, 2020)

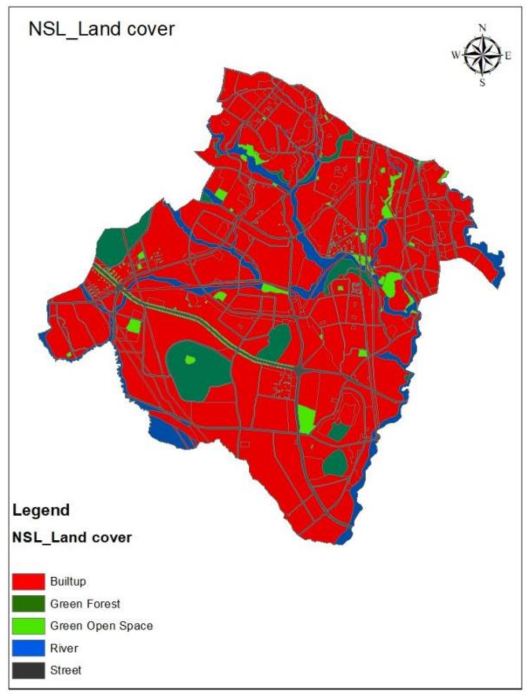


Figure 3-7: Nefas Silk Lafto Sub-city land cover (Author, 2020)

Slope and hydrology of the watershed

According to (Feyissa et al., 2018), Arada sub-city's topography more similar to the undulating and form plateau found in the northern parts of the city. Meanwhile, the topography in Nefas Silk Lafto sub-city is more characterized by gentle morphology and flat land areas. The slope layers of the plots in the watershed areas were classified per a modified scale based on FAO criteria (categories of 0–4%, 4–8%, 8–12%, 12–15%, and greater than 15%) and analysis was carried out accordingly.

As shown in the map, most of the watershed area in the two sub-cities is categorized be a more moderately flat area with slopes of 0-4% and 4-8%elevations. Meanwhile, smaller portions of each of the two sub-cities were observed to have the more steep type of slope with elevations of, 12-15% and above 30%. Plots of land around these steep areas are observed to be more vulnerable to stormwater runoff problems.

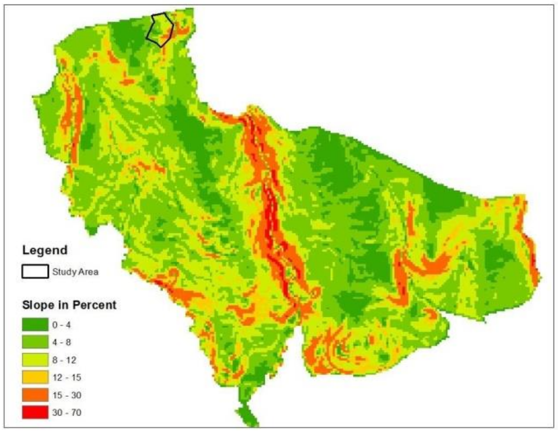


Figure 3-8: Slope Diagram of Arada Sub-city (Author, 2020)

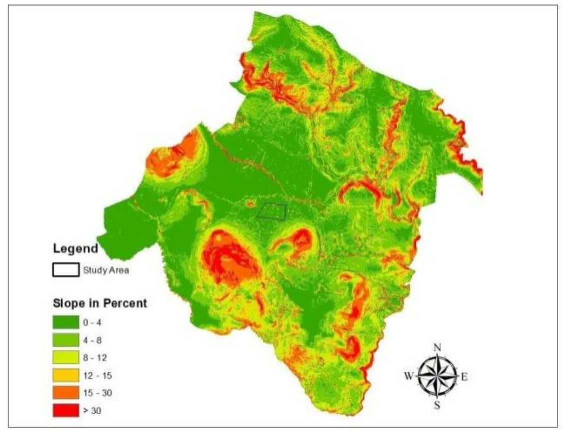


Figure 3-9: Slope diagram of Nifas Silk-Lafto sub-city (Author, 2020)

3.4.2. Selection of watershed areas

The watershed areas from both sub-cities were selected as prototypes for other sub-cities and watershed areas for being areas where there are consistent stormwater problems. The two selected watershed areas from each sub-cities were Dera Sefer study area from Arada Sub-city and Lebu Varnero Apartments Study area from Nefas Silk Lafto sub-city.

Dera Sefer Study Area

The first case study area selected is located around Dera Sefer in Arada sub-city, which is one of the oldest and most familiar places in the city. This area and has residential plots with different area sizes. Some of the residential plots located in this area are seen to be in poor conditions, while it was noticed there seemed to be a lack of proper stormwater drainage mechanisms both on the alleys and in the residential compounds. In addition, the slope of Dera Sefer is seen to be steep. This situation, coupled with other factors including imperviousness of the area, intensity of rainfall, and lack of proper drainage mechanisms that are suitable to the area, increase the susceptibility of the area for severe damages such as flooding associated with stormwater runoff.

Lebu Varnero Study Area

The other case study location selected, which is in the Nefas Silk Lafto Sub-city, is the Lebu-Varnero Apartments area around Jemo neighborhood. The population density in this area is relatively scattered compared to other dense areas around the city while the plots of land constructed in this area are properly developed following the master plan of the city. Meanwhile, in this area, the terrain is less steep; also, although the drainage system around the neighborhood of the different plots located in this area is much underdeveloped and needs improvement, the main roads' drainage system is better constructed and there are fewer waterlogged streets as results of stormwater runoff. Hence, the risk of severe stormwater runoff-related flooding is low in this area. But, this doesn't mean it doesn't affect the surrounding more rural areas located in the sub-city.

3.4.2.1. Precipitation in watershed areas

The average precipitation (rainfall) of the city was observed to be a peak in the winter months of Addis Ababa. For this study, the researcher has taken the maximum average daily precipitation recorded in June 2018, which was observed to be one of the months with the highest intensity of rainfall. The selected recording was taken as 34.7mm. Maximum daily rainfall intensity is selected as runoff generation is increasing with the increase in the intensity of rainfall; hence, stormwater runoff management mechanisms will and should be designed considering this factor (National Meteorology Agency, 2018).

3.4.2.2. Increase in imperviousness in watershed areas

In Addis Ababa, the level of imperviousness has been increasing throughout the past few years and decades. The increasing level of imperviousness is more evident in how the Lebu Varnero Apartments watershed area transformed through decades. Vast areas of land that were covered by green areas are now replaced by impervious structures that contribute heavily to stormwater runoff problems observed in the area.

Figure 3-10: Aerial view of Lebu Varnero Apartments watershed area in 2002 G.C.(Google LLC, 2020)

Figure 3-11: Aerial view of Lebu Varnero Apartments watershed area in 2002 G.C.(Google LLC, 2020)

In the Dera Sefer watershed area, although most of the built structures have been around for many years and have covered most of the watershed area for decades, the green areas that existed in compounds and in between streets and homes have been minimized and are being replaced by impervious surfaces.

Figure 3-12: Aerial view of Dera Sefer watershed area in 2002 G.C.(Google LLC, 2020)

Figure 3-13: Aerial view of Dera Sefer watershed area in 2020 G.C.(Google LLC, 2020)

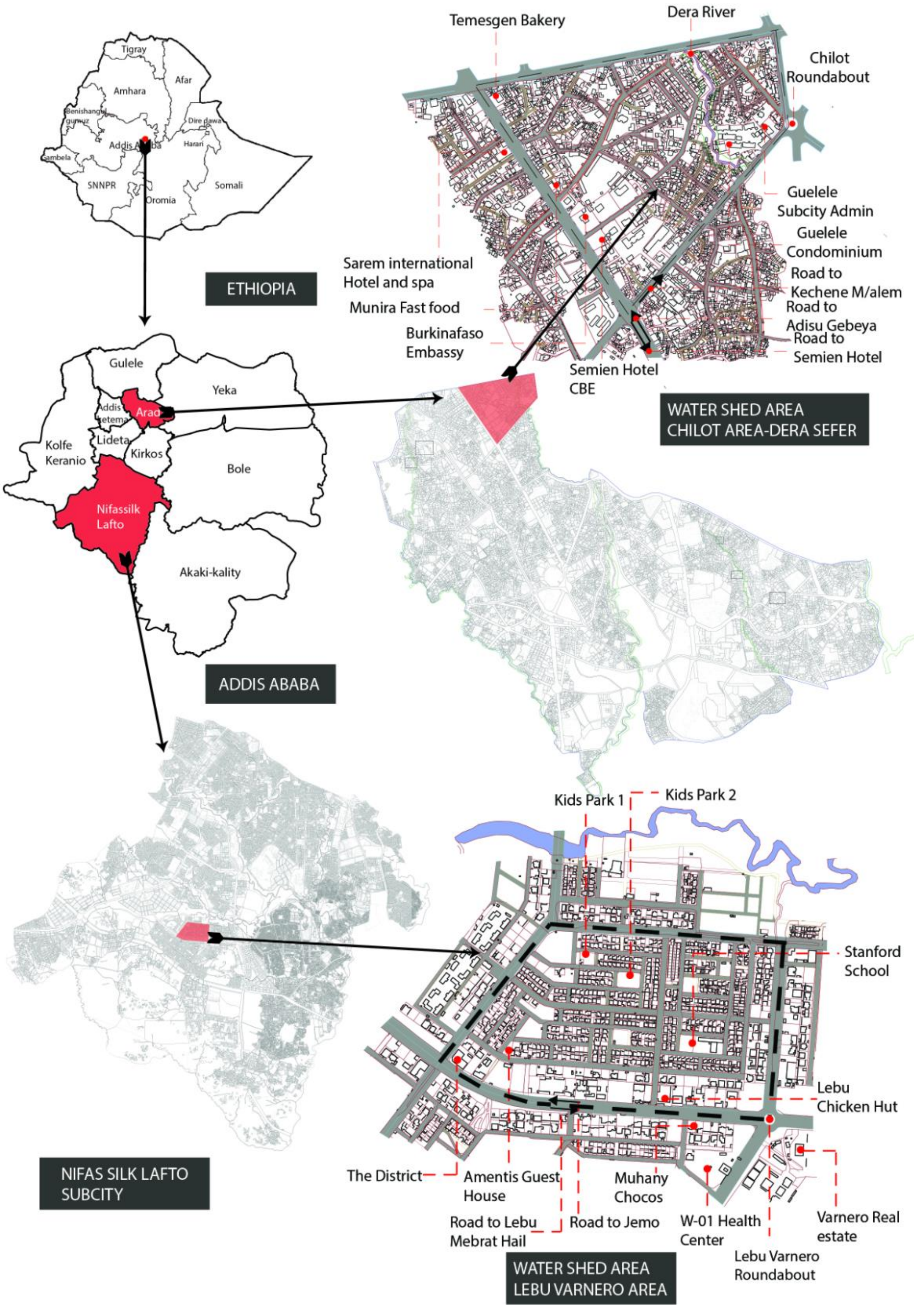


Figure 3-14: Location Map of the study areas (Author, 2020)

3.5. Selection of case studies for site analysis and follow up design

After the study areas to be included in the study have been identified, the specific case studies for site analysis and design provision were selected as representative from each watershed area as per the following selection criteria:

A. Residential plots of land with different areas, shapes, and sealed surfaces whose building, green and paved layouts are representative of the other residential plots.

The classification was made based on the area size, categorized according to a scale developed by authors and adapted from work done by (Anderson et al., 1976, edited in 2007), but modified to meet and reconcile with the contrasting existing land size situations in the two different watershed areas. The categories are listed as:

- Residential units on areas that are less than 110m^2.
- Residential units on 110-199 m^2 areas.
- Residential units on 200-299 m^2 lots.
- Residential units with greater than 300-499 m^2.
- Residential units with greater than or equal to 500 m^2.

N.B.: In Addis Ababa, it is not allowed for a single person to own a residential plot with a size of more than 500m^2. (Addis Ababa city administration Land Development and Management bureau) However, during the conducting of the study, it was observed there were some situations and scenarios where this was not found to be entirely correct.

B. Residential areas that fall on different slope classifications

For this research, the land slope classification system proposed by the Food and Agriculture Organization of the United Nations (FAO) and adapted in the research done by (Feyissa et al., 2018), was adopted and modified to meet the existing situation at the watershed level of both study sites. Hence, the slopes of the residential plots selected for this study were categorized in ranges of 0-4%, 4-8%, 8-12%, 12-15%, and >15%.

Hence, a total of 4 plots from the Arada sub-city (there were no plots with areas below 110m^2 at this watershed) and 5 plots from the Nefas Silk Lafto sub-city were selected.

3.6. Data Collection Techniques

3.6.1. Field Observation

Using maps that were obtained from the study area administrations and digital maps such as Google maps, the individual plot areas selected for on-site analysis and their surrounding watershed areas were located and surveyed. The area was physically measured in length, width, and shape of the plot (rectangular, trapezoidal); while other related dimensions and materials used in the stormwater management practices of the residential plots were also observed and analyzed.

3.6.2. Questionnaires

To gather data regarding LSM in the selected residential neighborhoods, data were collected through open-ended questionnaires, which were administered to selected participants from the residential neighborhoods. Hence, to find the total number of participants of the questionnaires, the above-mentioned size-based classification was used to categorize the different plots and the contact people from each plot. Then, the number of plots to be included in the questionnaire deployment per each category was calculated by using the sample size calculation formula that was developed by (Yamane, 1967). This formula was used for each category separately and it is illustrated as follows:

$n = N / [1 + N*(e)^2]$

Where n is the sample size (selected number of plots),

N is population size (total number of plots within a category)

e is the level of precision required (sampling error margin) at a 10% margin of error (e=0.1).

Table 3-1: Sample sizes for each watershed area

Nefas Silk Lafto, Lebu Varnero Apartments watershed area Total number of plots = 627	**Arada Sub-city, Dera Sefer watershed area** Total number of plots = 490
Plots with areas of <110 m^2 Total number of plots – 96 n= $96/[1+96*(0.1)^2]$ = 49 plots	-----
Plots with areas of 110-199 m^2 Total number of plots – 280 n= $280/[1+280*(0.1)^2]$ = 74 plots	**Plots with areas of 110-199 m^2** Total number of plots – 190 n= $190/[1+190*(0.1)^2]$ = 66 plots
Plots with areas of 200-299 m^2 Total number of plots – 154 n= $154/[1+154*(0.1)^2]$ = 60 plots	**Plots with areas of 200-299 m^2** Total number of plots – 150 n= $150/[1+150*(0.1)^2]$ = 60 plots
Plots with areas of 300-499 m^2 Total number of plots – 47 n= $47/[1+47*(0.1)^2]$ = 32 plots	**Plots with areas of 300-499 m^2** Total number of plots – 90 n= $90/[1+90*(0.1)^2]$ = 47 plots
Plots with areas of >= 500 m^2 Total number of plots – 50 n= $50/[1+50*(0.1)^2]$ = 33 plots	**Plots with areas of >= 500 m^2** Total number of plots – 60 n= $60/[1+60*(0.1)^2]$ = 37 plots
Total selected plots = 248	**Total selected plots = 210**

Source: (Author, 2020)

The data were collected by the researcher and all data was encoded to data collection sheets and transferred to spreadsheets and word documents on computers. To ensure the validity and accuracy of the data, a pilot study was conducted by taking 5% of the total selected plots from each watershed area.

3.6.3. Interviews

In addition to questionnaires administered to residents (participants representing the selected residential plots), interviews were also conducted with selected individuals from different stakeholder organizations that are involved with stormwater management in Addis Ababa and more specifically, in the watershed areas. These stakeholders were selected on the basis that they are the primary organizations that are concerned with the development and maintenance of stormwater managing roadside ditches and other stormwater management methods in the study areas. The selected interviewees from each organization are listed below:

Table 3-2: Description of respondents

Organization	Position in the organization	Number
Addis Ababa city administration, roads authority	Senior engineer	1
Addis Ababa city administration water and sewerage service authority	Case team leader (Senior Engineer)	1
	Sewerage line design and control Officer (Engineer)	2
	Sewerage information and GIS center Officer (Engineer)	1
Arada Sub-city administration Office	Officer (Engineer)	1
Nefas Silk lafto sub-city administration office	Officer (Engineer)	1
Arada Sub-city beautification, Parks and cemetery bureau	Case team leader (Engineer)	1
	Plant expert	2
Nefas Silk lafto beautification, parks and cemetery bureau	Case team leader (Engineer)	1
	Plant Expert	2

Source: (Author, 2020)

3.7.Calculation of stormwater runoff

To calculate the amount of stormwater generated from each specific residential plot, the rational method of runoff calculation proposed by (Spellman & Whiting, 2014) was used, which is described as:

Q = C*i*A (As this formula uses the US measurement system instead of the SI measurement system, the formula has to be adjusted to Q = 0.0028*C*i*A to use the SI measurement units)(Bengtson, n.d.)

Where,

Q = Runoff rate (m^3/sec)

A = Area of Plot (presented in m^2, but changed to hectares to do the calculations) (classified per the built-up, unbuilt, and green spaces)

C = Runoff Coefficient (runoff coefficients differ based on the land-use and landcover type).

i = Rainfall intensity (mm/hr) (Intensity of rainfall differs from day to day and from month to month. However, for this study, a recording of 34.7mm which was the average daily maximum rainfall amount of June 2018 was used; hence, changing this to mm/hr, it gives us approximately 1.45 mm/hr) (National Meteorology Agency, 2018).

Hence, after calculating the runoff rate for each selected sample plot area of the study area, the volume of runoff generated was identified by, multiplying the runoff rate for each land cover type with the duration of rainfall considered for this study (1 hour (3600s) was used as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014)). Then, the total of the runoff amount was calculated for the plot category and each watershed area and is presented in m^3.

3.8.Methods of data collection and analysis for each objective

A. To identify trends in the incremental level of imperviousness within single-family residential neighborhood areas of Addis Ababa

Data Collection

Primary and secondary data were gathered from selected residential plots using site observations, interviews with residents, and through data gathering from different reports, researches, and studies conducted on the imperviousness of residential neighborhoods in Addis Ababa.

Data Analysis

The collected data were analyzed qualitatively as one of the factors that dictate the suitability and applicability of Stormwater management practices in selected residential plots in Addis Ababa, hence by analyzing the trends of imperviousness of the surfaces located in the study areas.

B. To identify and analyze the major factors that dictate the applicability of LSM technologies

Data collection

Quantitative and qualitative data were collected from interviews with representatives from selected governmental offices in addition to information gathered from different books, journals, researches, and other related articles.

Data analysis

The data was analyzed using GIS software and presented using tables, charts, and diagrams to identify factors that affect the use of Landscape based stormwater management (LSM) and the level to which these factors affected the cases under study was presented through diagrams and pictures.

C. To develop and design potential LSM technologies and solutions for various residential plot categories and the surrounding watershed areas.

Data collection

Data regarding different LSM technologies and green infrastructures (GI) concepts such as pervious pavements, green roofs, rain gardens, etc. were assessed and referred from different books and manuals to identify and design potential LSM methods that can be used to alleviate stormwater runoff problem in the different residential plot categories, while additional data such as rainfall data, soil map, water depth map, land use map and urban cadastral index map, and land administrative domain (LAD) were also collected.

Data analysis

Through analysis of the collected data using software such as GIS, the resulting output was displayed and appropriate and applicable LSM methods that can be applied for each watershed area plot categories were selected, designed, and presented based on the findings.

D. To estimate and describe the contribution of LSM in terms of flood reduction as well as green area improvement of the entire local watershed.

Data collection

The different landscape-based stormwater management designs that were put forward as a solution were used as data. Data from on-site observation and GIS software were also used, while other quantitative data such as rainfall data and land use data were obtained from relevant authorities such as Ethiopian National Meteorology Agency (NMA) to estimate the amount of stormwater runoff.

Data analysis

The contribution of these LSM designs towards flood reduction and green area improvement was analyzed at the watershed level using data obtained from GIS, such as slope. The collected data were utilized and estimation of stormwater runoff was analyzed by using the rational stormwater runoff calculation methods; results were presented in charts, maps, and tables.

Chapter Four: Results and Discussion

4.1.Socioeconomic description of respondents

From the selected samples, respondents from 176 (70.97%) plots from lebu varnero watershed area and 168 (80%) plots from Dera sefer watershed area were seen to be willing to participate in the study, and a representative was present during the collection of data. Hence, the overall response rate of the study was found to be 75.11%. The rest of the respondents were either not willing to be included in the study or representative/owner of the plot were not present during data collection.

Based on data collected from the representatives of the residences included in the study for conducting questionnaires, it was determined that most of them have been living in the neighborhoods in the study areas for more than 5 years, and the majority of the plot was found to be in the 110 - 199m^2 area size ranges. Moreover, the majority of the respondents from each study area indicated that they were owners of the land they were living in, while a few expressed they were renting the plots or were property guardians looking after the plots for the owners.

Table 4-1: Demographic Characteristics of Respondents (Residents)

Study Area	Respondents' years of living in the neighborhood			Respondents' ownership of the plot	
	<1 year	2-5 years	>5 years	Yes	No
Lebu Varnero Apartments	23	68	85	139	37
Dera Sefer	7	32	129	147	21

Source: (Author, 2020)

Concerning the demographic background of the officials from different stakeholder organizations interviewed, it has been explained in the "methodology" section of this study.

4.2.Incremental level of imperviousness within residential neighborhood areas of Addis Ababa

Seen through observation of individual plots for the level of imperviousness, the impervious surface (including both built-up areas and streets) was seen to cover much of both Arada and Nefas Silk Lafto sub-cities and the subsequent watershed areas, which hints at the replacement of green landscape through the built-up neighborhoods, which influences the stormwater runoff and its management. As explained in the literature review part of this study, the watershed areas have experienced a rapid expansion of impervious surfaces in the past decades, which contribute heavily to the runoff problems seen in these places.

The watershed areas were seen to be comprised of different types of plots with different sizes and different uses, such as residential, mixed residential and administration, and commercial buildings in both Arada Sub-city and Nefas Silk Lafto sub-city, which are all a part of impervious surfaces.

As observed through physical inspections and questionnaires with the residents, most of the residential houses included in the study were seen to have both green and open spaces in the compounds, while some plots had filled their whole compounds with impervious surfaces without any provision for green area coverage. Moreover, the level of imperviousness was seen to be more predominant with most of the plots observed in the study having a greater ratio of their compound surface covered by concrete pavement and concrete tiles (with some having no green or open spaces and filled with impervious tiles), while relatively few compounds were seen to have a majority of grass cover their compound surfaces in addition to their built-up impervious surfaces.

According to respondents from both watershed areas, stormwater runoff was caused as a result of heavy rain that occurs during the rainy season, coupled with the high level of imperviousness of the compounds and ineffective drainage mechanisms constructed within the compound and throughout the neighborhood. The type of materials used for the surfaces in the compounds was also another major reason as most of the plots contained highly impervious surfaces.

Due to these reasons, effects of stormwater runoff in the selected plots and selected watershed areas were observed, as both study areas selected for this study are not exempt from this hindrance. In both Lebu varnero apartment area and Dera Sefer area, there are problems of lack of adequate sustainable stormwater management techniques in the individual plot areas which causes flooding and property damage in the plots, in some cases with runoff coming inside to the residential plots from the neighborhood streets and adjacent plots. Also, the local street drainages are underdeveloped in both case study areas which creates a problem for residents to transfer water runoff to the local street drainage system. These situations coupled with negligence from some residents (according to other respondents) have made sure both areas cannot be risked-free of the effects of stormwater runoff without the implementation of appropriate mitigation strategies.

Besides, in some of the neighborhoods within the watershed areas, stormwater drained from the plots in upper catchment areas will travel down to lower catchment areas as it is not properly managed through GI mechanisms. This stormwater will collect around these lower catchment areas and clog the surrounding streets and drainage systems, which creates flooding through these areas.

Figure 4-1: Street of Dera Sefer area with a steep slope (Author, 2020)

Figure 4-2: Street of Dera Sefer area during rainy seasons (Author, 2020)

The findings of this study are supported by the study done by (Dissanayake et al., 2019), which looked in-depth about the increased level of impervious surfaces in Addis Ababa over the past 30 years (1986-2016 G.C.) through the use of Landsat data. The findings showed that imperviousness has steadily increased in the city over the mentioned period, which is contributing to the increased stormwater runoff problems seen throughout the city. The level of imperviousness in terms of built-up area was observed to be 6,262.3 hectares in 1986 G.C. which was 7% of the total area of Addis Ababa. This amount increased to 14,033 hectares in 2001, which amounted to 15.6% of the total area. In 2016, the level of imperviousness reached 30,700 hectares (equal to 34.1% of the total area of Addis Ababa), which shows the alarming rate by which the city is being covered by impervious surfaces that contribute to stormwater problems.

Moreover, a study was done by (Moges et al., 2013) also observed Addis Ababa was experiencing a rapid level of expansion of the built environment and impervious surfaces, which found that the amount of roads and areas covered by Asphalt in Addis has increased from 4.72 km^2 to 27.7 km^2 in the period 1984 - 2002 G.C. Meanwhile, the built-up area was observed to have increased from 60.1 km^2 to 212.7 km^2throughout the study period, while the paved areas had also increased by five-fold from the originally observed amount of 11.1 km^2. All in all, this amount of urbanization and expansion was observed to increase the runoff generation potential in the city from 28% to 45% starting from 1984 up to 2002 G.C. This uncontrolled expansion was observed to be causing and adding to flooding problems which are exacerbated by stormwater runoff.

4.3. Major factors that dictate the applicability of LSM technologies

As stormwater runoff increases with an increase in impervious surfaces, these surfaces, which do not infiltrate water to the deep layers of surfaces, contribute to adverse effects arising from uncontrolled stormwater. Factors such as precipitation, vegetation, soil type, slope, land (plot) size, and use and drainage were seen to affect the amount and intensity of stormwater runoff and its subsequent management, while the major adverse effects of stormwater were associated with increased runoff and associated flooding, water body degradation and inclusion of toxic elements in the stormwater.

The issues of stormwater were evident in the responses gathered from residents that answered questionnaires, who explained that most of the plots of land in both watershed areas had experienced some kind of stormwater runoff in their compounds with differing levels of severity and flooding, owing to the level of imperviousness in the plots observed in this study. Problems of stormwater were observed in residential neighborhoods in both watershed areas as mentioned by the respondents, while most of them also explained they have experienced varying side effects of stormwater in their compounds. Almost all respondents indicated water logging in their compounds was a recurring situation in the rainy seasons of each year, while some compounds had eroded watershed away surfaces that created small ponds of rainwater.

Table 4-2: Effects of stormwater observed in the single-family plot compound

Study Area	Effect of stormwater observed in the single-family plot compound		
	Waterlogging	Dissected fragmented surface	Eroded washed away the surface
Lebu Varnero Apartments	160	44	58
Dera Sefer	143	77	53

Source: (Author, 2020)

Figure 4-3: Lebu Varnero study area street stormwater runoff (Author, 2020)

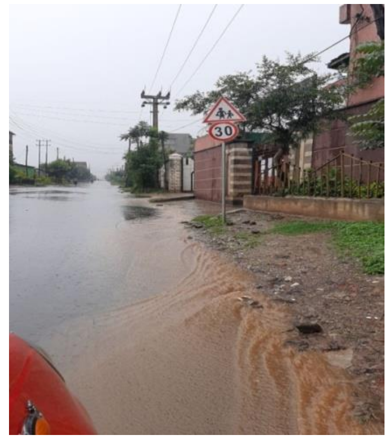


Figure 4-4: Stormwater Runoff in the streets of Dera Sefer with no drainage ditches road-side (Author, 2020)

Moreover, this study analyzed the current situation of two watershed areas in Arada and Nefas silk Lafto sub-cities as per the factors influencing landscape-based stormwater management methods' applicability. With regards to land use and size, urbanization of the watershed areas was evident as there was the replacement of green landscape through built-up neighborhoods. As with the associated imperviousness, the impervious surface (including both built-up areas and streets) was found to be covering much of both Arada and Nefas Silk Lafto sub-cities. Besides, most watershed areas in the two sub-cities have flat areas with moderately gentle slopes while also having smaller portions with relatively steeper slopes. Also, through extensive research of associated literature and other secondary resources, soil types such as vertisols (VR) and luvisols (LV) were seen to be available in the areas, which have their own infiltration capacity. Based on the results, the most amount of stormwater runoff is generated from built-up spaces in both watershed areas. Most plots in the watershed areas have predominantly impervious surfaces through built-up areas and paved surfaces, which contributes significantly to the amount of stormwater runoff that is generated at each plot. The slope of residential plots in the Dera sefer watershed area was relatively steep while Lebu Varnero apartment's study area had a relatively flat slope, while the maximum average daily precipitation recorded in June 2018, which was observed to be 34.7mm was used.

4.3.1. Characteristics of watershed areas with regards to factors that dictate applicability of GI

To properly design and recommend appropriate GI practices for each study area, analysis of the physical factors that affect the suitableness and applicability of these practices in addition to the current state of the different plots of land being examined was deemed essential. This enabled us to identify areas of strength and weakness for the application of these GI practices.

4.3.1.1. Land use

In this section, we categorized the different plots of land in this area according to their different uses such as residential and social services.

Dera sefer area

Most of the plots selected in this area were found to be giving residential services (57.30%), in addition to mixed residential houses (34.55%), and administration buildings (1.85%).

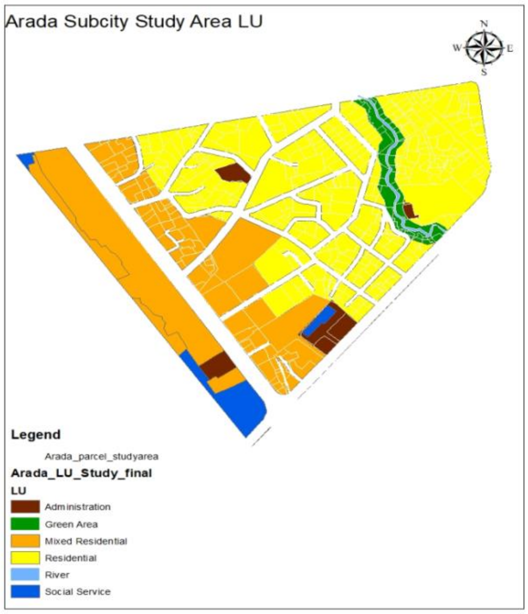
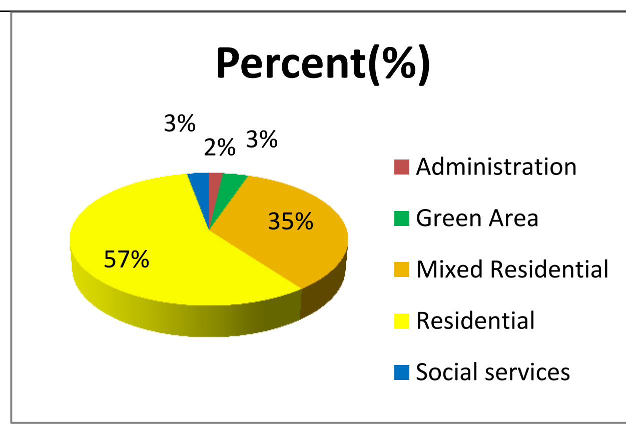


Figure 4-5: Dera Sefer Area Land Use map (Author, 2020)

Table 4-3: Dera Sefer Land use, area, and percentage

Land use	Area (m^2)
Administration	13,321.01
Green Area	24,472.63
Mixed Residential	248,995.93
Residential	412,925.65
Social services	20,946.22
Total Area	720,661.45



Source: (Author, 2020)

Lebu Varnero Apartments area

As described in the following table, areas with residential plots (75.96%), followed by mixed residential plots (22.3%) and green spaces (1.73%) were found to be the major plot sizes located in the area. Furthermore, lands with uses for commercial services (1.34%) were also observed.

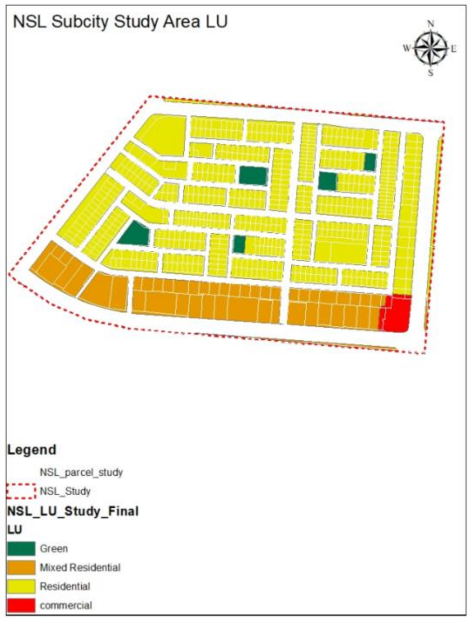
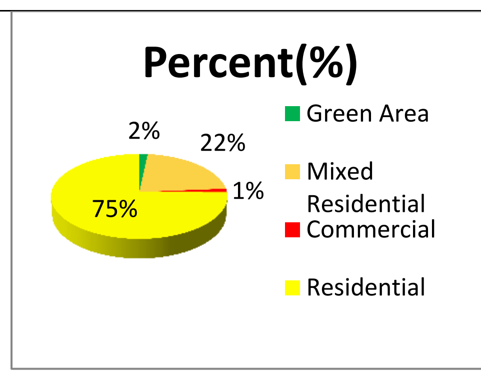


Figure 4-6: Lebu Varnero Apartments study area Land use map (Author, 2020)

Table 4-4: Lebu Varnero apartment's area Land use, area, and percentage

Land use	Area (m^2)
Green Area	10,319.81
Mixed Residential	132,654.49
Commercial	8,000.00
Residential	451,837.74
Total Area	594,812.03



Source: (Author, 2020)

4.3.1.2. Slope

Here, the slope of the residential plots in each study area was analyzed, and results are described below

Dera Sefer area

As illustrated in the figure below, some of the residential plots in this study area were seen to be in the slope range of 8–15%, which shows that this area has a relatively steeper slope. This daunting topography, together with the underdeveloped and poorly connected local street drainage system and inadequate runoff mitigation practices (such as green roofs and infiltration) have contributed to damages to the built-up spaces within the residential plots and erosion and degradation of the local streets located adjacent to these plots.

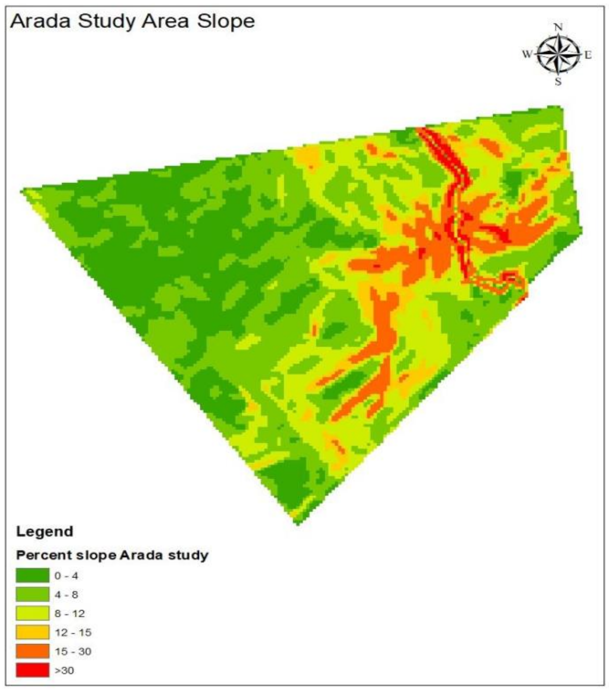


Figure 4-7: Slope of Dera Sefer watershed Area(Author, 2020)

Lebu Varnero Apartments Area

As per the modified FAO slope classification system used by the researcher to identify the slope of the watershed area, the residential plots' slopes in the Lebu Varnero Apartments area were analyzed. The study results showed that the majority of the residences in this watershed area had a relatively flat slope of 2-8%. This showed that these plots were not mostly affected by runoff as a result of the steep slope, but were affected by runoff due to the bad conditions and poor construction and misuse of the drainage systems of the local streets which leads to overflow in the middle of the neighborhoods and flooding in particular residential plots. The slope of the area is demonstrated in the figure presented as follows.

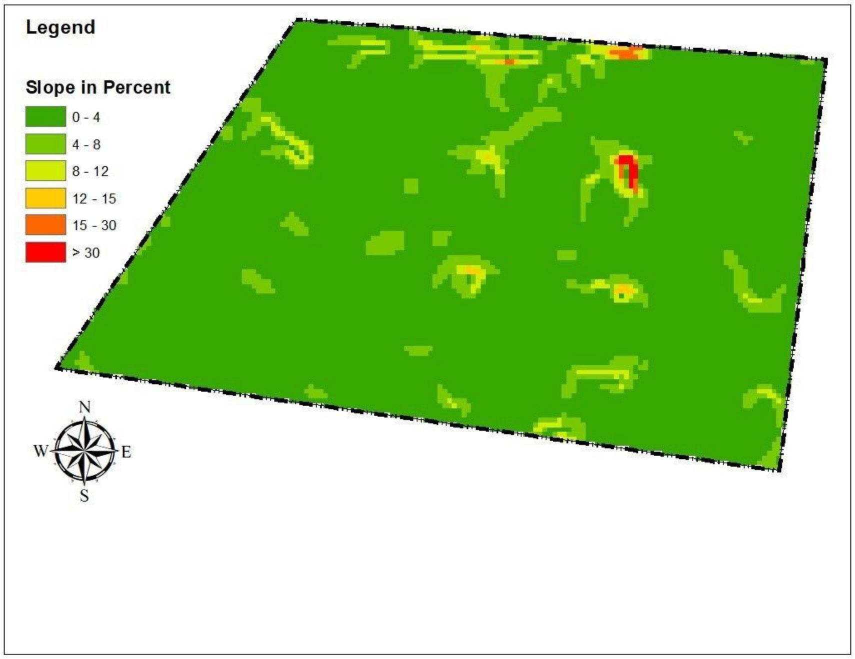


Figure 4-8: Slope diagram of Lebu varnero apartments watershed area(Author, 2020)

4.3.1.3. Drainage

Dera Sefer Study area

In this area, most of the residential plots use surface drainage systems to remove excess water from the area by using parallel ditches on the ground and pipes on the built-up house at a slope. Infiltration drainage systems such as subsurface drainages which enable removal and reuse of water beneath the soil level are not utilized. As the drainage systems of the individual plots are mostly not properly connected to the local street drainage systems, and in some cases, the local street drainages are in a bad condition, there is a frequent risk of waterlogging and flooding in the selected area during the rainy season.


Figure 4-9: Dera Sefer Area residential plot drainages (Author, 2020)

Lebu Varnero Apartments area

As observed, most of the houses built in this area are relatively more recent. Hence, the most predominantly used type of drainage system is the downspout and gutter drainage system which collects water from gutters on the roof and diverts it to the ground. The downspouts carry the water from the roofs and drain either into the sewers that are shared by the sewage system of the house or onto the paved surfaces to drain using the surface drainage system to remove any water floods at the base of the downspout. But, in some instances, due to poorly installed drainage mechanisms in the plots and underdeveloped local street drainage systems connected to these individual drainage systems, some instances of flooding and runoff problems may arise.

Also, it was observed that the drainage systems of the plots in this area are mainly focused on removing the stormwater out of the compound, while little consideration is given to reusing this excess stormwater and installing GI mechanisms. This is evident in the fact that most of the houses in this area have a sealed (impervious) residential compound with a minimal amount of green cover.

All in all, the identification and use of these factors was supported by research done by (Woods-Ballard et al., 2007), which identified topography and the characteristics of the soils as factors that influence the type of SuDs (sustainable drainage systems, which include GI) that will be implemented to tackle stormwater. Moreover (Lei et al., 2020) also described how rainfall, soil properties, and slope gradient influence stormwater runoff, explaining that different soil types have a different level of runoff absorption. Also, rainfall intensity, slope, land use, and soil moisture content were considered to affect the runoff intensity and subsequent erosion(Ziadat & Taimeh, 2013).

4.4.Potential LSM technologies and solutions for various residential plot categories and the surrounding watershed areas

Before proposed LSM technologies and solutions can be put forward, it is importance to understand the current practices to handle stormwater runoff in the study areas.

In both study areas, Dera sefer and Lebu varnero apartment areas, residents in collaboration with the local officials have undertaken measures to combat stormwater runoff problems that arise during heavy rainfall. However, most of the activities carried out involved tackling stormwater runoff on street level, not in the residential plots, which are one of the major sources of the runoff.

One of the measures is digging of natural drainage ditches adjacent to main and feeder roads. In Dera Sefer area, as the streets were steeper, this method was effective in addressing the runoff issue. However, the poor handling of these drainage systems has led to instances where the ditches are clogged and give rise to flooding and water clogging. Besides, the residents have resorted to increased vegetation cultivating within the compound and drain grating cover system. The results of these techniques were varied as some residents explained they experienced flooding problems even with these mechanisms in place.

Also, the residential plots in the Dera Sefer area have experienced built-up area expansion on the compounds themselves by the residents through the years which has contributed to the imperviousness and increased stormwater runoff problems. This may be attributed to an increased number of residents within each compound and the economic situation of the residents which makes it harder to implement GI technologies, according to the respondents. Furthermore, it was observed that there were many households within single residential plot compounds, which minimizes spaces for the implementation of GI mechanisms and further exacerbates the stormwater runoff problem.

In Lebu varnero Apartments area, these drainage ditches are built around the residential plots which are effective in handling the stormwater runoff. However, according to the residents, one of the main problems observed was the inner streets were not fully developed and do not enable the flow of this stormwater and the ditches do not connect in some instances which give rise to water overflows. Besides, most of the houses in this area use the downspout and gutter drainage system to collect water from rooftops which are usually collected in the sewage collection hole built underground.

Moreover, when interviews were conducted with officers from government offices, they explained that some of the causes of stormwater problems in Addis Ababa were attributed to:

- the mishandling of neighborhood drainages and drainages of arterial streets by the residents,
- clogging and underdevelopment of main roads and streets and,
- an excessive amount of stormwater being drained out from residences, factories, buildings, and other built-up structures.

With some of the officials explaining their belief individual residential plots contribute to stormwater runoff problem, almost all respondents from the organizations further described the absence of rainfall retention mechanisms. The preference of residents was to drain rainwater from the compound to the outside neighborhood. The underdevelopment and misuse of neighborhood drainages were seen to be the main causes of stormwater runoff in single-family residential plots as per the officers' perspectives. Inside the compounds, respondents believed that residents do not use effective retention mechanisms to deal with rainfall and subsequent flooding. They also mentioned, the type of surface material used in the compounds such as the use of stone pavement instead of grass pavements contributing to the problem as well as some residents disconnecting their gutter and downspout systems for sewages and letting this sewage drain with the rainwater to the outside neighborhood. Moreover, according to the respondents, stormwater runoff problem coming from residential plots has led to clogging of drainages and other stormwater collecting street ditches which in turn contribute to flooding. This further contributes to the degradation of the drainage mechanisms in place, the structures in and around the compounds, and the neighborhood and environment as a whole.

Hence the officials put forward suggestions that more should be done to ensure residential plots do their part in collecting rainwater and properly handling the drainage method by which the rainfall goes out of the compound.

On the other side, according to residents in Plots of land in both study areas, they tried to tackle the stormwater runoff problem through mechanisms such as increased vegetation cultivating within the compound and drain grating cover system at the gates, in addition to the use of the downspout and gutter drainage system, that is common in most houses of the city, to collect water from rooftops. According to the residents, the measures taken were effective in some instances and non-effective in other instances. One of the reasons for the non-effectiveness of these mechanisms was the drainage systems of some residences are not properly developed and other reasons was that the stormwater generated in the compound doesn't properly go to the outside drainage systems which have their problems also.

The residents also explained that to tackle stormwater runoff in individual compounds, more stormwater tackling measures like rain barrels (that collect rainwater for further use) should be implemented and increased use of green spaces and vegetation should be encouraged. Furthermore, they indicated that solutions that encompass the whole neighborhood as a whole such as consulting the residents of the community on the construction of street drainages that collect the rainwater from the individual plots should be implemented by the relevant local authorities.

Hence, taking the responses of both the officials and residents into account, for the selected plots of land in both Lebu Varnero apartments and Dera Sefer study areas, a host of GI measures which includes, Rain Barrels, Rain gardens, permeable pavements, Lawn covers, Evergreen trees, and Shrubs were used in the design of effective stormwater management mechanisms as explained in detail below.

Moreover, for upscale watershed effect, Landscape based stormwater management methods such as planting trees, Bio retention Ponds, Road Side Vegetated Swales, Green Gutters, and previous Driveways and Walkways were also proposed. The use of these methods was proposed for a communal green space located at Lebu Varnero watershed area and its adjacent roads to further reduce stormwater runoff outside the residential plots.

The use of these stormwater mitigation strategies was derived from and is supported by researches, such as the guideline produced by (Penn's Corner Conservancy and Charitable Trust, n.d.), which aimed at explaining how stormwater flows across and leaves residential properties; and identifying best management practices on how to reduce the amount of stormwater runoff residential plots. The strategies proposed include GI techniques such as rain gardens and vegetated swales among other mitigation strategies. Moreover, these findings that were presented are similar to a study done by (Esmail & Suleiman, 2020) which separated and used sustainable urban water management (SUWM) methods into green (wet ponds, rain gardens, and green roofs) and gray (rain barrels and porous pavements) measures.

Moreover, the use of GI and LSM mechanisms in residential plots is encouraged by different articles including the stormwater guidebook presented by (City of Roanoke, 2014), which highlighted and analyzed the use of GI practices such as rain barrels, vegetated filter strips, grass channels, roof drain disconnections, trees, pervious pavements, rain gardens, green roofs, and other infiltration techniques.

4.4.1. Potential LSM technologies

4.4.1.1. Proposed stormwater mitigation GI mechanisms for selected residential plots

Both in Lebu Varnero apartments and Dera Sefer study areas, a host of GI measures which includes, Rain Barrels, Rain gardens, permeable pavements, Lawn covers, Evergreen Trees, and Shrubs. Based on the factors that affect their applicability, the use of these strategies is recommended and has been estimated to be effective in alleviating stormwater problems in individual residential plots. (See Appendix)

Based on the results from the study, GI mechanisms were applied to both watershed areas to help mitigate stormwater runoff by reducing it to the lowest amount it can be produced at the residential level. For this purpose, GI mechanisms such as permeable pavements, rain gardens, and rain barrels are used.

Dera Sefer study area

From the plot areas selected for design and implementation recommendation for GI mechanisms, the $643m^2$ plot from Dera Sefer watershed area was used to provide a further in-depth demonstration.

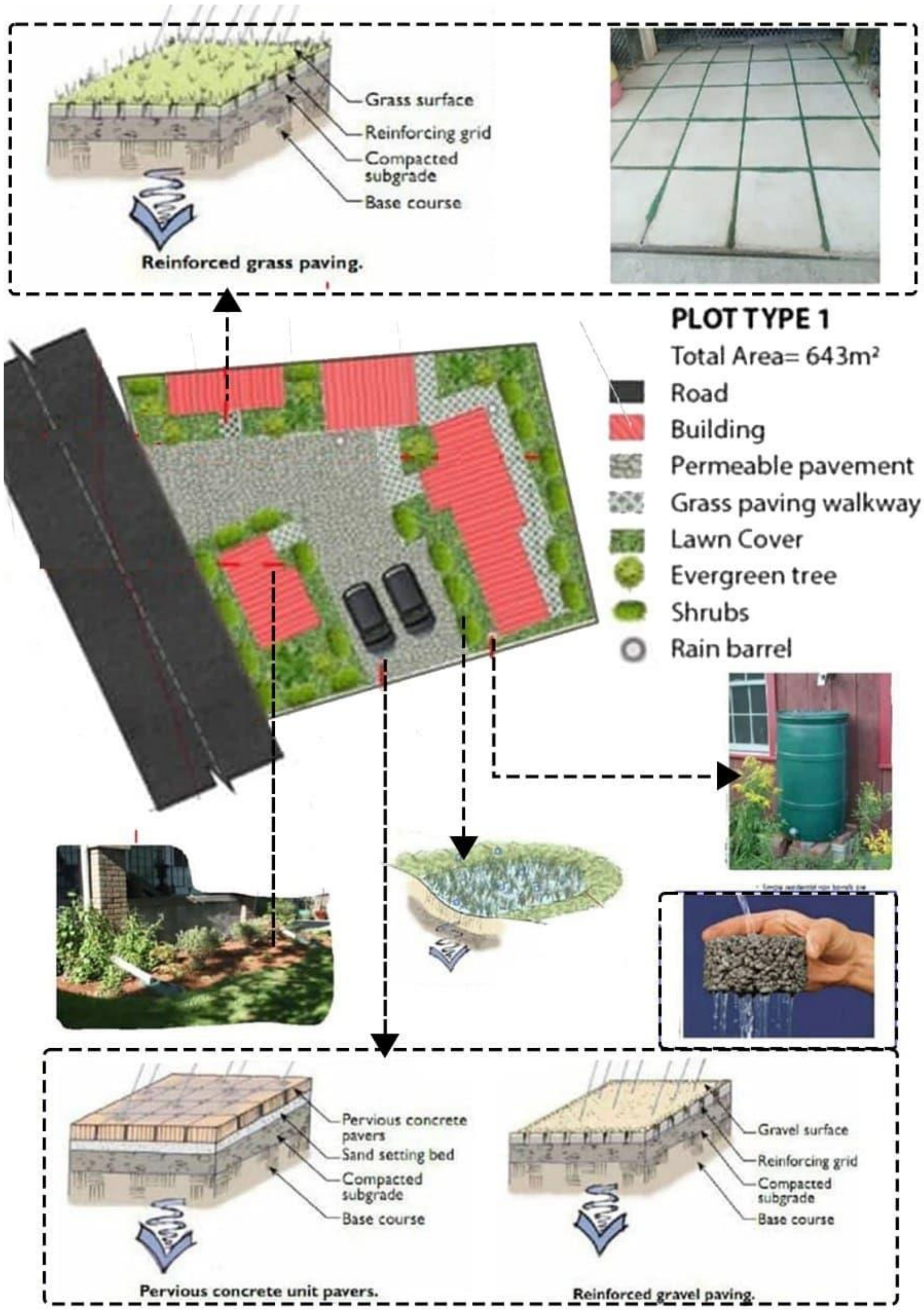


Figure 4-10: Dera Sefer 643m^2 plot detailed GI measures (Author, 2020)

By using a slope of 10%, the stormwater runoff from this residential plot was handled by using indigenous trees, permeable pavements, a rain garden, and rain barrels as shown in the figure above.

Figure 4-11: Dera Sefer 643m^3 sample plot GI measures cross-section plan (Author, 2020)

Also, other residential plots in the area use the aforementioned mechanisms to handle stormwater runoff with detailed specific implementation requirements as described in the next figure.

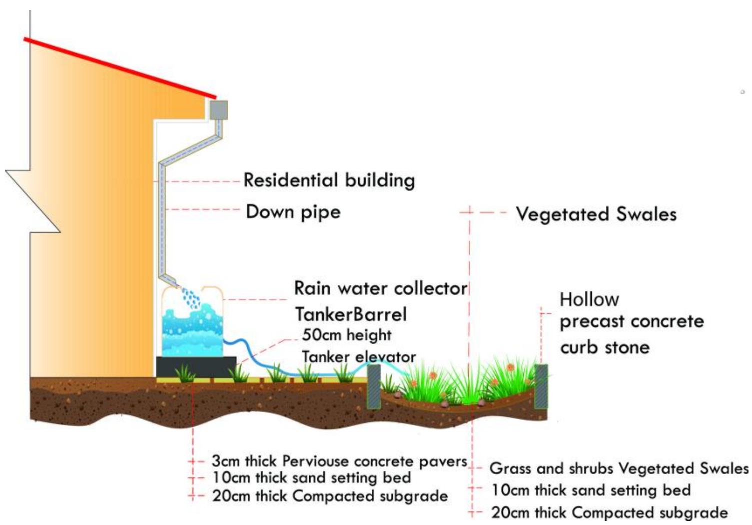


Figure 4-12: Dera Sefer other residential plots GI measures detail (Author, 2020)

Lebu Varnero Apartments study area

Here, the 500m^2 plot area from Lebu varnero watershed area was redesigned with different GI mechanisms to handle the stormwater runoff that will occur throughout the year.

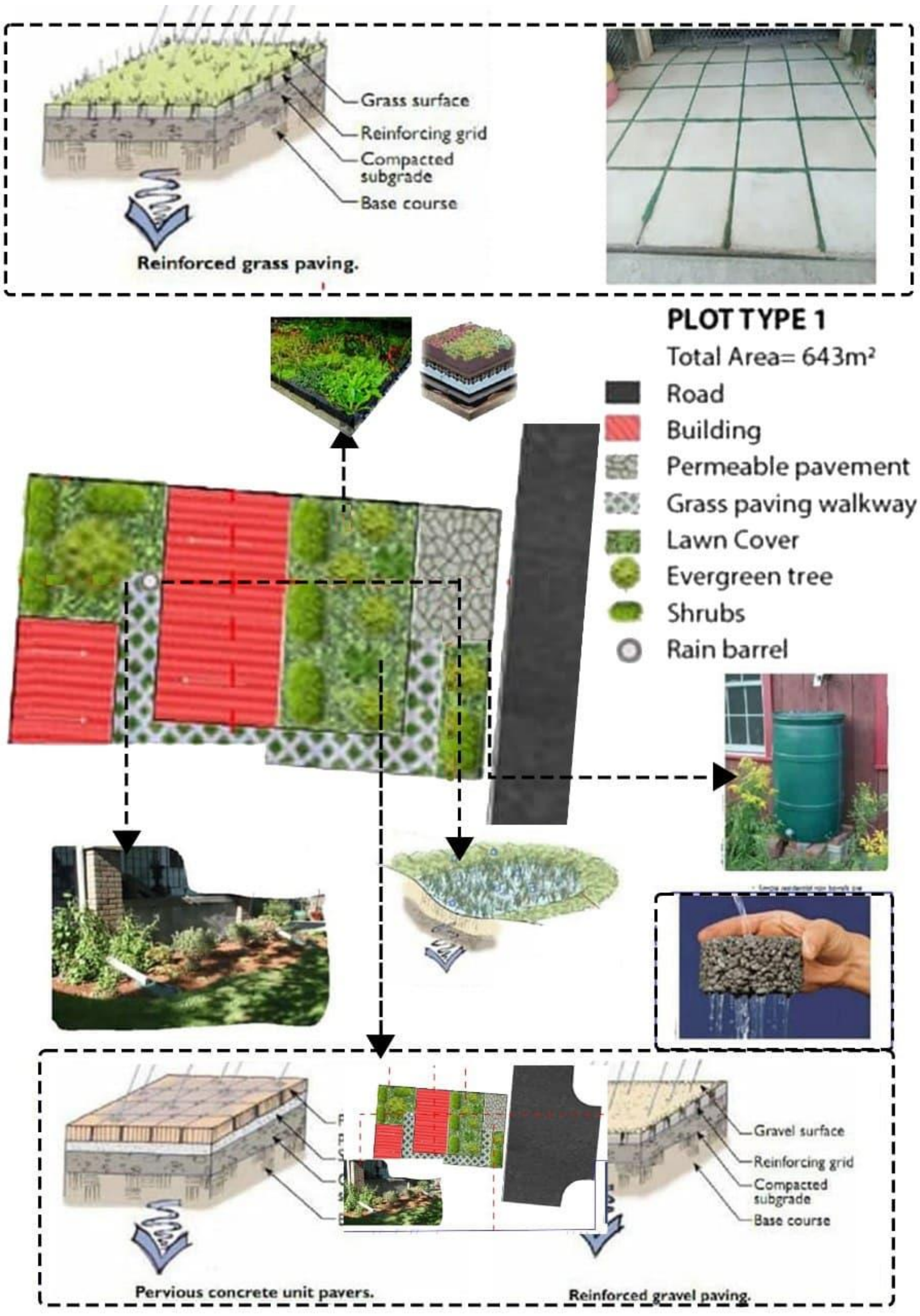


Figure 4-13: Lebu Varnero Apartments 500m^2 plot detailed GI measures (Author, 2020)

By using the slope of the compound as 3%, the LSM mechanisms put in place, including green roofs and disconnected downspout pipes that drain into rain gardens, enable the effective decrease of stormwater runoff from the compound; which in turn contributes to a decrease in runoff from the neighborhood and helps in prevention of runoff related problems.

Figure 4-14: Lebu Varnero apartments 500m^2 sample plot GI measures cross-section plan (Author, 2020)

Furthermore, other residential plots in the area, especially smaller plots, are proposed to use roof gardens (green roofs) and rain gardens to make use of the available space left within the compound where the majority of the plot is covered by built-up space as observed in many houses in the area. This is demonstrated in the following figure.

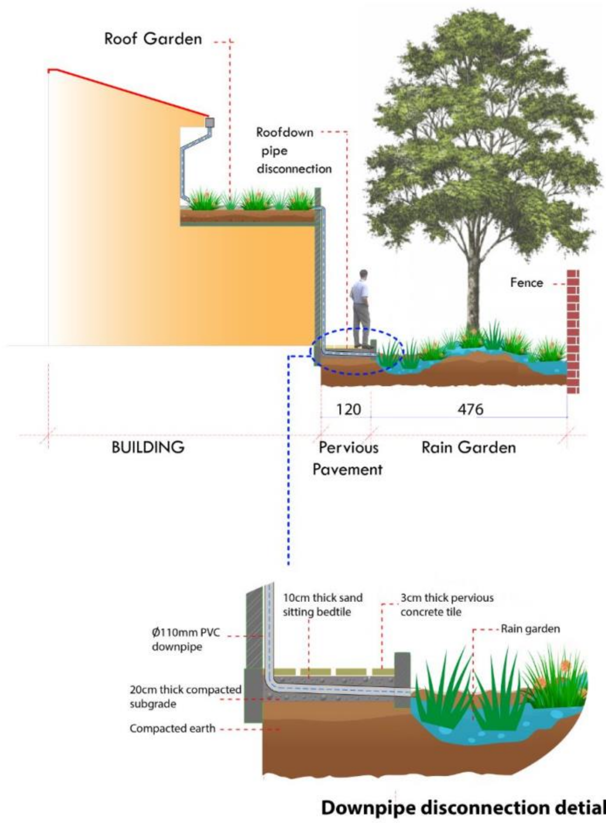


Figure 4-15: Lebu Varnero apartments other residential plots GI measures with downpipe disconnection detail (Author, 2020)

After stormwater runoff come out of individual residential plots, it is also necessary to handle the excessive runoff on driveways, walkways, and general open areas of the watershed areas to ensure the continuous reduction of the risk of flooding within the area. The GI mechanisms applied in both study areas, including 3%-sloped green gutters near the pedestrian walkways and pervious pavements for both driveways and walkways, will play a part in enhancing the sustainability of the walkways and driveways and functionality of the open spaces while also being aesthetically pleasing.

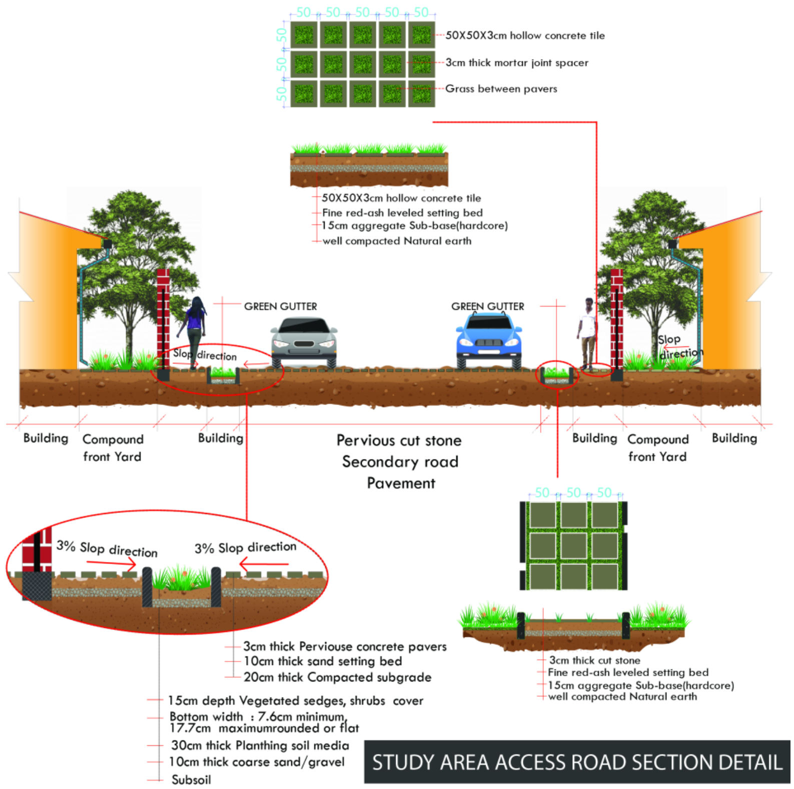


Figure 4-16: Cross-sectional view of proposed driveways and walkways at both watershed areas (Author, 2020)

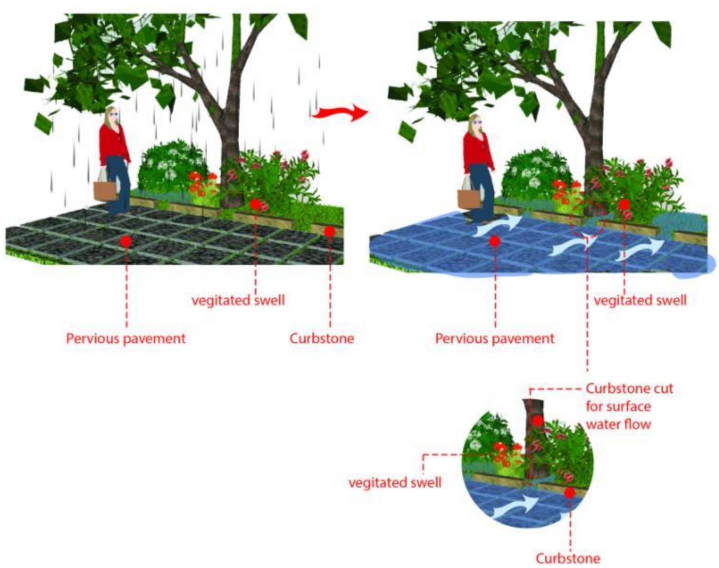


Figure 4-17: Movement of stormwater from pervious pavements to vegetated swales at roadside walkways (Author, 2020)

4.4.1.2. Watershed area upscale green cover improvement

After controlling the stormwater at the specific residential sites of the two study areas, the excessive stormwater runoff for each plot site will be handled together with the street in the overall watershed area. So based on the study area, observation, and the existing physical characteristics problems, LSM green street practices such as stormwater trees, bio-retention ponds, roadside vegetated swales, green gutters, and previous driveway and walkways are recommended.

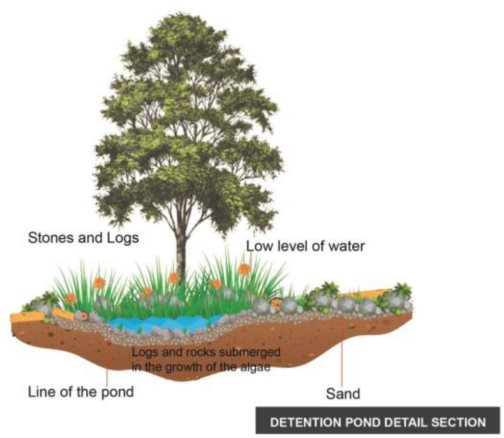


Figure 4-18: Detention pond section(Author, 2020)

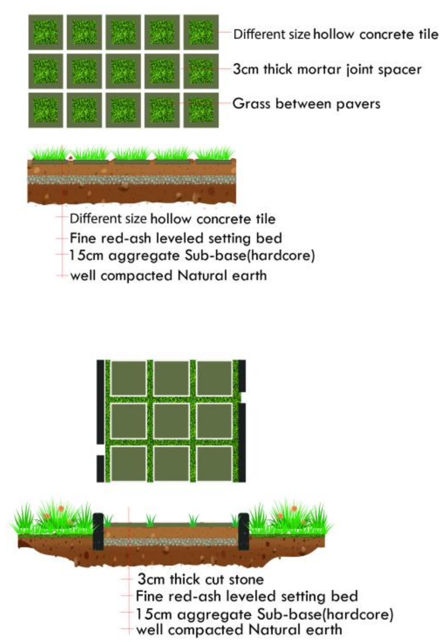


Figure 4-19: Pervious Pavement detail(Author, 2020)

At Lebu Varnero apartments study area, the presence of communal green space enabled the design of a much-developed space that handles runoff efficiently while providing biodiversity and an aesthetically pleasing place useful for any activity. The design was done using GI mechanisms which were described above.

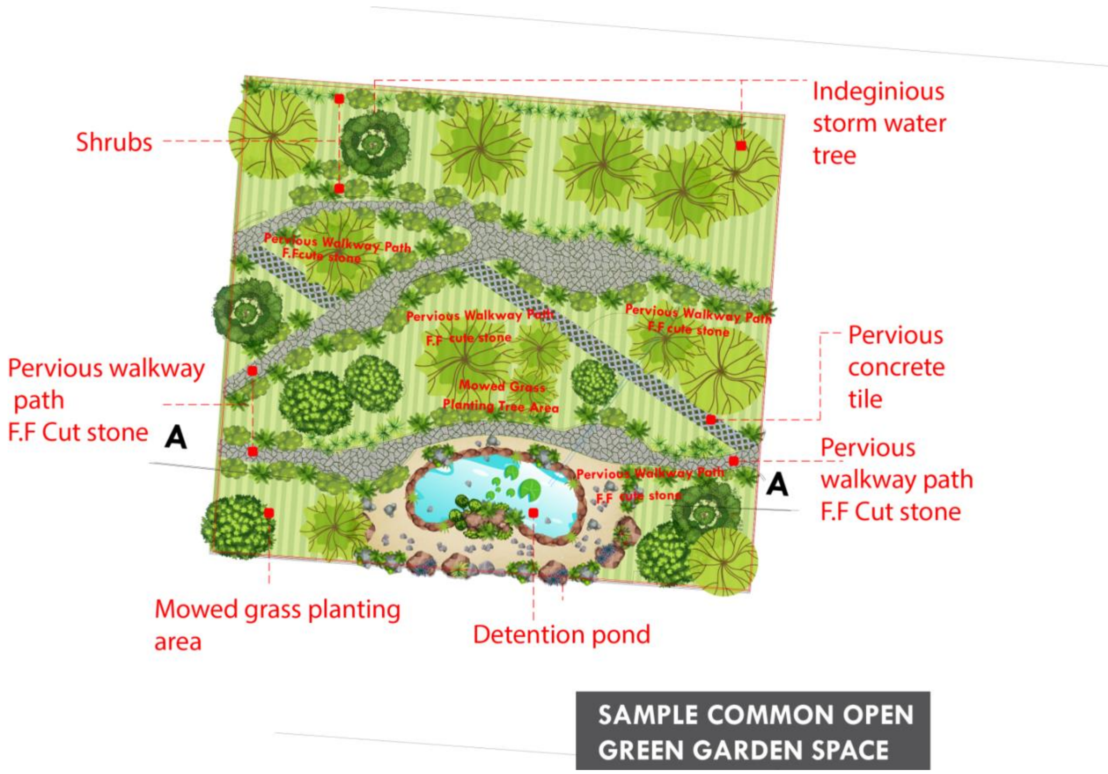


Figure 4-20: Sample common open green garden space with GI measures (Author, 2020)

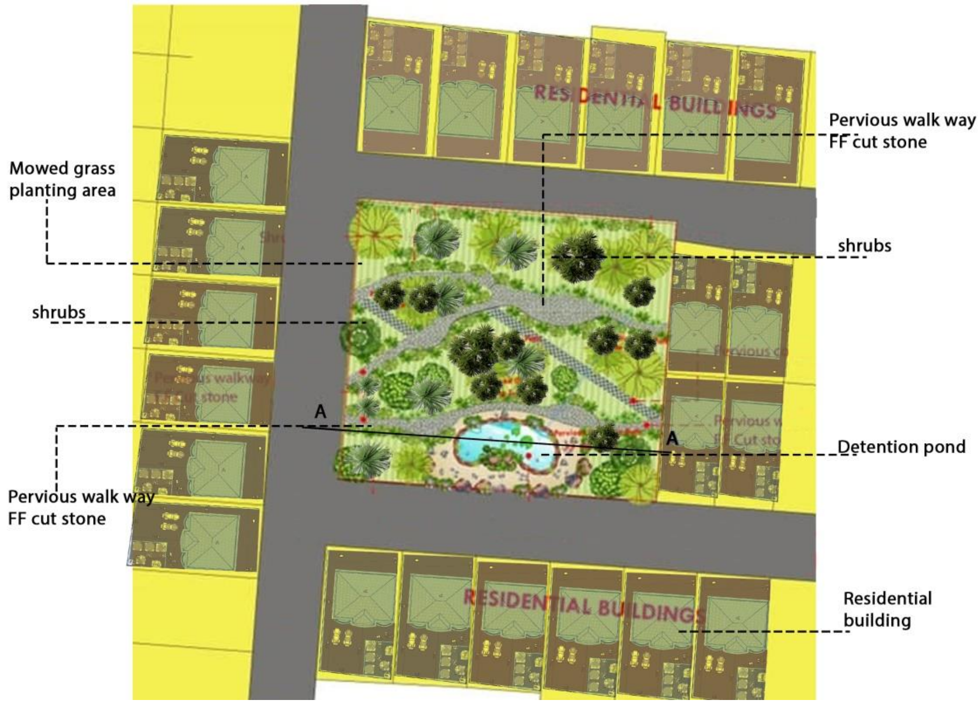


Figure 4-21: Communal Open space in relation with the surrounding plots (Author, 2020)

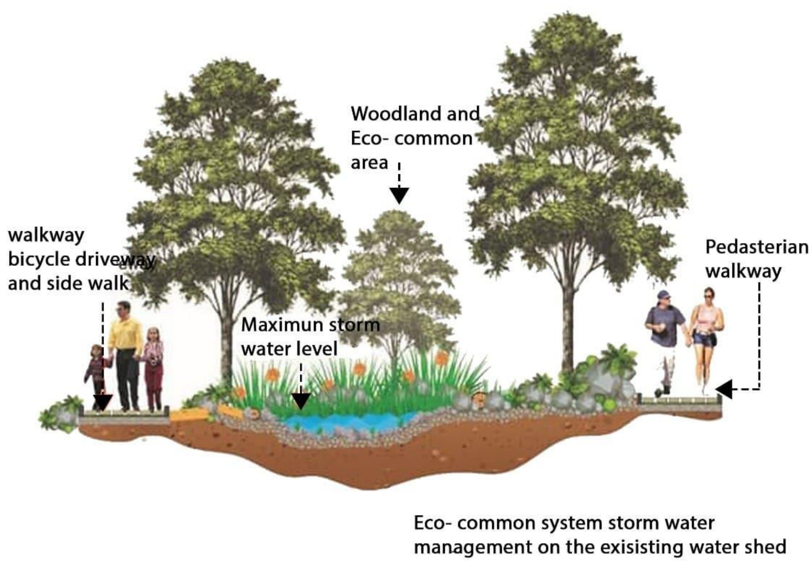


Figure 4-22: Cross-section view of the communal open space (Author, 2020)

The open communal space in conjunction with the access roads near it, the adjacent houses, and the walkways were designed in this study to work simultaneously to handle as much amount of stormwater runoff as possible while providing a healthier and comforting space to live in. This is demonstrated in the following figure, where shows a cross-sectional view of how stormwater is handled after leaving the residential plots.

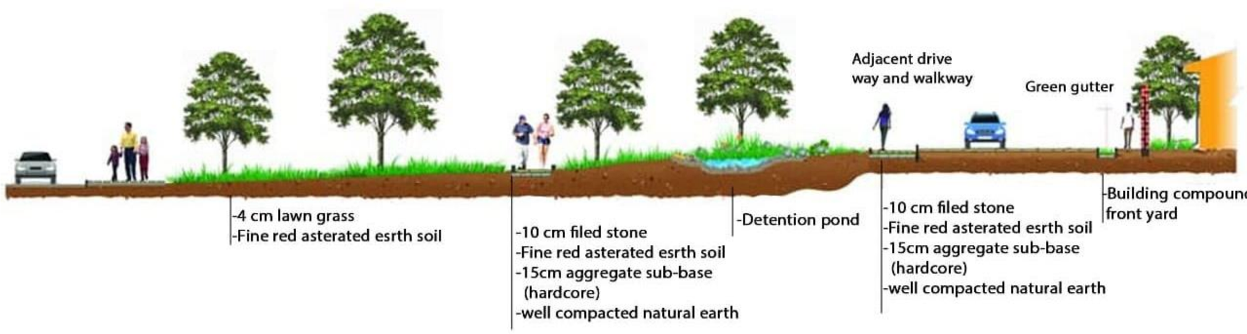


Figure 4-23: Cross-sectional view of walkways, driveways, and open spaces of the Lebu Varnero Apartments study area (Author, 2020)

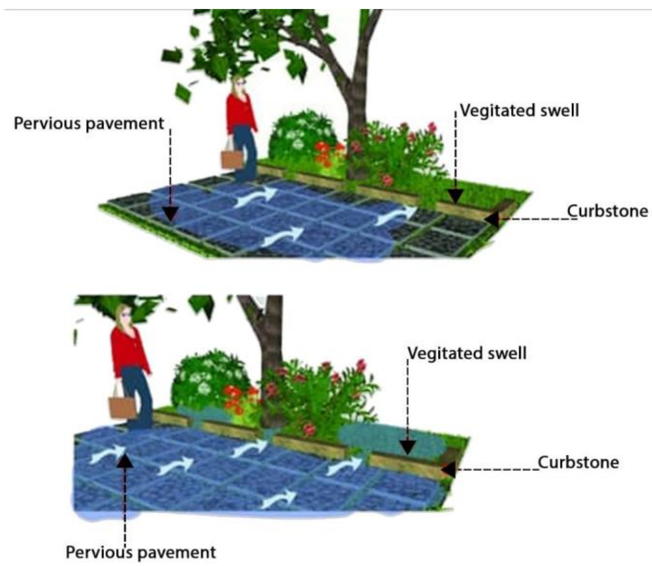


Figure 4-24: Communal open space pervious pavement and vegetated swale design at Lebu Varnero Apartments study area (Author, 2020)

The implementation of the GI mechanisms proposed in this study is expected to reduce stormwater runoff by more than half as explicitly shown above, as well as providing residents with an environment filled with an abundance of biodiversity and green structures. The spaces will be both aesthetically pleasing and highly effective at tackling stormwater runoff simultaneously.

Moreover, in Dera Sefer study area, several GI mechanisms are proposed to be implemented in the available open spaces, walkways, and pathways which will provide stern protection against any severe stormwater problems that may arise, in tandem with source control at the residential levels. The GIs are presented in the following figure.

Figure 4-25: Views of the communal open space and adjacent streets after implementation of GI mechanisms at Dera Sefer study area (Author, 2020)

4.5.Contribution of LSM as flood reduction and green area improvement of the entire local watershed

Before estimating the amount of stormwater runoff that can be reduced by the above-mentioned mitigation strategies, it is first paramount to calculate the amount of runoff that is generated by the existing conditions of the selected case sites of the study.

4.5.1. Stormwater Runoff generated from the existing conditions in selected plots in watershed areas

Here, the calculation for each selected sample plot of the study area was calculated to identify the amount of runoff generated in both study areas. Hence, using the total runoff amount calculated for each plot, the stormwater runoff generated per day was calculated for both watershed areas.

To do this calculation, the rational method of runoff calculation was used, which is described as Q=(C* I*A)*0.0028 (which has been explained in detail in the methodology section).

Hence, the total amount of stormwater runoff generated from the selected plots in the Dera Sefer and Lebu Varnero apartment watershed areas is presented as follows. (Calculation of runoff from each specific residential plots selected is presented in the Appendices section)

Table 4-5: Total runoff of the Dera Sefer study area

Types of plots	Total stormwater runoff per one hour of rainfall for each plot size (m^3)	Percentage (%)
110 m^2-199 m^2	0.16399152	10.5
200 m^2-299 m^2	0.21766878	14
300 m^2-499 m^2	0.45733464	29.4
>=500 m^2	0.71647632	46.1
Total estimated runoff from selected residential plots	1.55547126	100

Source: (Author, 2020)

As seen from the results described above, of the different plot areas used in this study, the most amount of stormwater runoff was generated from plots with large area sizes where most of the area of these residential plots was covered in non-permeable, impervious surfaces which contributed to increased runoff. This shows that runoff management mechanisms are not properly implemented in these types of residential plots. Coupled with the underdeveloped street runoff drainage system located in the study area, the risk of severe stormwater runoff and flooding is fairly high.

Table 4-6: Total runoff of the Lebu varnero study area as per each type of plots

Types of plots	Total stormwater runoff per one hour of rainfall for each plot size (m^3)	Percentage (%)
<110 m^2	0.083281968	6.1
110 m^2-199 m^2	0.2199708	16.2
200 m^2-299 m^2	0.24379488	18
300 m^2-499 m^2	0.27711936	20.4
>=500 m^2	0.53319168	39.3
Total estimated runoff from selected residential plots	1.357358688	100

Source: (Author, 2020)

In the Lebu Varnero apartments area, plots with area sizes of >=500m2 were seen to generate the most amount of runoff water. Most of the plots studied in this area have mostly impermeable paved surfaces and contribute immensely to the total runoff generated in the watershed area. This watershed area was also found relatively affected by the risk of flooding and runoff water flow due to the underuse of effective runoff mitigation techniques and the underdeveloped street drainage systems that are not connected with the individual plot runoff drainage.

4.5.1.1. Vegetation covers

From the calculations done above, the amount of runoff for each type of part of the plot, such as built-up area, vegetation covers, and impervious surfaces (paved areas) was calculated. Hence, the below table describes the amount of runoff generated from the vegetation covers in the study areas:

Table 4-7: Residential Plots vegetation cover stormwater runoff

Watershed area	Estimated total vegetation cover stormwater runoff per one hour of rainfall
Dera Sefer area	0.0332514 m^3
Lebu varnero apartments area	0.084597408 m^3

Source: (Author, 2020)

As the results show, the amount of runoff volume obtained from vegetative covers is small compared to the built-up and paved surface runoff volumes in both study areas. This might be because, in most of the samples taken for the study, green infrastructure is given little concern and most house owners focus on maximizing paved and built-up surfaces by sacrificing vegetation covers. In some cases, although there will be trees and flowers planted around the compounds, there was no area allocated for vegetation in the inside of the compounds of some plots and some of the respondents of the study even consider the GI infrastructure as unnecessary and time-consuming. Hence, considering these circumstances and to ensure the proper mitigation of stormwater runoff problems that may arise, properly designed sustainable stormwater management practices as detailed above should be implemented.

4.5.2. Stormwater Runoff could be generated after implementation of GI in selected plots in watershed areas

With regards to stormwater runoff reduction, the GI mechanisms proposed in this study are estimated to reduce the amount of runoff by an amount of 0.48777246 m^3 and 0.377122032 m^3 per one hour of rainfall for the selected plots from Lebu Varnero apartment and Dera Sefer study areas respectively. Coupled with the upscale watershed level recommendation put forward, the proposed GI mechanisms will improve the green area coverage of the study areas greatly. This will be impactful in ensuring the effectiveness of the implementations and reduction of stormwater runoff.

The total amount of stormwater runoff generated in the selected plots from the Dera sefer and Lebu Varnero apartment watershed area after implementation of GI mechanisms is presented as follows. (Calculation for runoff from each specific residential plots selected after implementation of GI mechanisms is presented in Appendices section)

Table 4-8: Estimated runoff from selected residential plots in both watershed areas after implementation of GI

Types of plots	Dera sefer study area		Lebu Varnero apartment study area	
	Stormwater runoff per one hour of rainfall for each plot size (m^3)	Percentage (%)	Stormwater runoff per one hour of rainfall for each plot size (m^3)	Percentage (%)
<110 m^2	-	-	0.067438224	6.9
110 m^2-199 m^2	0.08089956	7.6	0.134145648	13.7
200 m^2-299 m^2	0.16435692	15.4	0.146481552	14.9
300 m^2-499 m^2	0.36196524	33.9	0.198017568	20.2
>=500 m^2	0.46047708	43.1	0.434153664	44.3
Total estimated runoff from selected residential plots	1.0676988	100	0.980236656	100

Source: (Author, 2020)

According to (Zhang et al., 2015), which tried to investigate the changes of urban green spaces in Beijing, China, and estimate their effects on rainwater runoff reduction, showed that runoff reduction rate continuously decreased in conjunction with decrease and composition changes in green spaces throughout the study period. It showed that working on and improving the urban green spaces and infrastructure through recommendation and use of optimal landscape-based solutions improves the stormwater management capacity of the study area and reduces urban stormwater runoff. Moreover, at source control of stormwater using stormwater control measures and low impact development are effective in mitigating flooding in urban catchments, while also mitigating overland flow intensity on roads and reducing building damages (Burns et al., 2015).

Chapter Five: Conclusions and Recommendations

5.1.Conclusions

The rapid covering of land with impervious surfaces, sacrificing of the natural landscape to give way for towering structures, also, to poorly designed, constructed, and used structures, including drainage systems of the city, has been contributing a lot to the Stormwater runoff problems observed in the city. This has given rise to severe flooding in certain parts of the city which has been a recurring scenario every year and creates damage to infrastructure and which can potentially lead to entire environmental degradation. Residential plots of land in the city are one of the sources that contribute significantly to the stormwater runoff.

Hence, by taking specific cases from Arada and Nefas Silk Lafto sub-cities, this study tried to identify opportunities for stormwater runoff reduction through landscape-based stormwater management within individual plots of residential areas of Addis Ababa, while also trying to shed light on the main factors that contribute to stormwater runoff and its mitigation.

Impervious surfaces (including both built-up areas and streets) were observed to cover much of both study areas, due to ever-increasing built-up neighborhoods, which have their impact on stormwater runoff and its management.

Through analysis of the cases, and with the support of relevant literature, the study found that land use and size, imperviousness, soil type, and slope were the major factors that affected stormwater runoff in residential plots and the applicability of GI practices. Furthermore, it was also found that precipitation (rainfall) and current drainage conditions were also seen to affect the GI measure's applicability.

As the main focus of the study was to assess and identify efficient and sustainable landscape-based stormwater management strategies, mitigation mechanisms such as Permeable pavement, Grass Paving walkway, Rain Barrels, Lawn covers, Evergreen trees, and Shrubs were identified, recommended, and designed to help control urban stormwater runoff problem from one of its most significant and contributing sources. Besides, LSM strategies such as a Stormwater tree, Bio retention Ponds, Road Side Vegetated Swale, Green Gutter, And Previous Driveway and Walkways were recommended to alleviate stormwater runoff problems in the surrounding open spaces in the neighborhoods in both watershed areas. Moreover, these mechanisms will increase the green footprint of the area and tackle the observed imperviousness in the residences and the surrounding neighborhoods.

The LSM mechanisms that are proposed in this study are estimated to have a significant contribution to flood reduction through curbing stormwater runoff. The GI mechanisms proposed to handle stormwater is estimated to decrease the stormwater runoff by an amount of 0.48777246 m^3 and 0.377122032 m^3 per one hour of rainfall for the specific plots selected from Lebu Varnero apartment and Dera Sefer study areas respectively.

5.2.Recommendations

To handle stormwater runoff effectively, due consideration should be given to successfully managing all forms of stormwater runoff. As individual residential plots being one of the major sources of stormwater runoff, the government, policymakers, and other relevant stakeholders should consider the following general recommendations, in addition to the GI mechanisms recommended in this study:

- ✓ Residents near the streams and rivers in the low catchment area, which receive the stormwater runoff generated from sealed surfaces in upper catchment areas, are being increasingly affected by overflowing and subsequent flooding. Hence, developing a sustainable solution to alleviate this problem for the residents is an important task.
- ✓ As this study only focused on only two specific study areas and could not assess the effect of stormwater runoff from individual residential spaces on either sub-city or city scale, a study to assess this topic on a large scale should be conducted by relevant authorities to assist in drafting future policies and regulations on stormwater mitigation in individual residential plots.

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Appendices

Appendix 1: Calculation of existing stormwater runoff for selected samples from each study area

The calculation was done using the formula (as explained in the methodology):

Q = C*i*A (As this formula uses the US measurement system instead of the SI measurement system, the formula has to be adjusted to Q = 0.0028*C*i*A to use the SI measurement units)

Where,

Q = Runoff (m^3/sec)

A = Area of Plot (presented in m^2, but changed to hectares to do the calculations) (classified per the built-up, unbuilt, and green spaces)

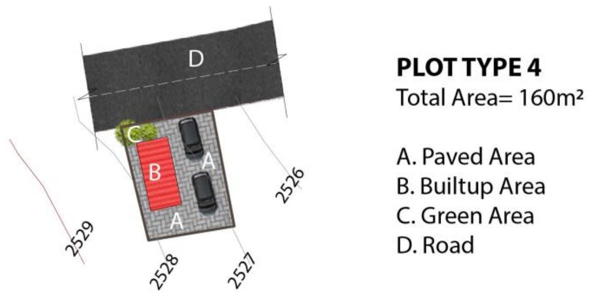
C = Runoff Coefficient (runoff coefficients differ based on the land-use and landcover type).

i = Rainfall intensity (mm/hr) (Intensity of rainfall differs from day to day and from month to month. However, for this study, a recording of 34.7mm which was the average daily maximum rainfall amount of June 2018 was used; hence, changing this to mm/hr, it gives us approximately 1.45 mm/hr) (National Meteorology Agency, 2018).

- The duration of rainfall was taken to be 1 hour for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014).

Selected samples from the Dera Sefer area

Plot 1: 110-199m^2



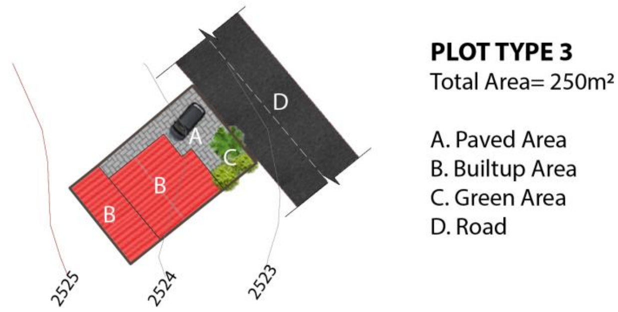
Total Plot Area = 160m^2		Paved area = 48m^2
Built up Area = 102m^2		Green area = 10m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(10 m^2=0.001 ha*0.15*1.45)* 0.0028	0.000000609
Paved Area	(102 m^2=0.0102 ha *0.85*1.45)* 0.0028	0.0000352002
Built Up Area	(48 m^2=0.0048 ha *0.50*1.45)* 0.0028	0.000009744
Total		

Figure 7-1: Dera Sefer study area 160 m^2 plot map and runoff calculation (Author, 2020)

A runoff coefficient of 0.15 was used for the green area as it is expected there was sandy soil with slope of 2 - 7% in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.5 was used as runoff coefficient for the built-up area as it is a single family area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.000000609*3600)+(0.0000352002*3600)+(0.000009744*3600)= 0.16399152 m^3 is generated in one hour of rainfall.

Plot 2: 200-299m^2



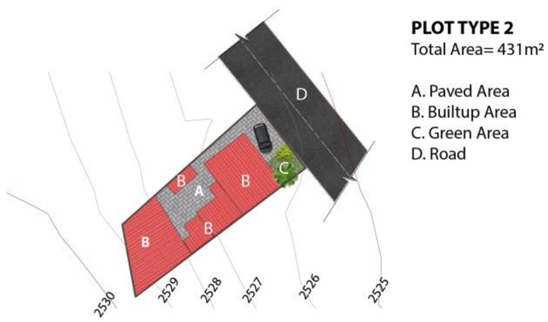
Total Plot Area = 250m^2		Paved area = 58.7m^2
Built up Area = 156.3m^2		Green area = 35m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(35 m^2=0.0035 ha *0.15*1.45)* 0.0028	0.0000021315
Paved Area	(58.7 m^2=0.00587 ha *0.85*1.45)* 0.0028	0.00002025737
Built Up Area	(156.3 m^2=0.01563 ha *0.60*1.45)* 0.0028	0.00003807468
Total		

Figure 7-2: Dera Sefer study area 250 m^2 plot map and runoff calculation(Author, 2020)

A runoff coefficient of 0.15 was used for the green area as it is expected there was sandy soil with slope of 2 - 7% in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.6 was used as runoff coefficient for the built-up area as there are multiple units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.0000021315*3600)+(0.00002025737*3600)+(0.00003807468*3600)= 0.21766878 m^3 is generated in one hour of rainfall.

Plot 3: 300-499m^2



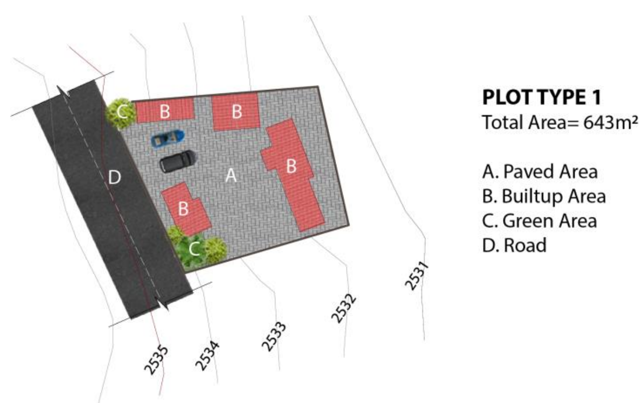
Total Plot Area = 431m^2		Paved area = 111m^2
Built up Area = 281m^2		Green area = 39m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(39=0.0039 ha*0.20*1.45)* 0.0028	0.0000031668
Paved Area	(111 m^2=0.0111 ha *0.85*1.45)* 0.0028	0.0000383061
Built Up Area	(281 m^2=0.0281 ha *0.75*1.45)* 0.0028	0.0000855645
Total		

Figure 7-3: Dera Sefer study area 431 m^2 plot map and runoff calculation(Author, 2020)

A runoff coefficient of 0.2 was used for the green area as it is expected there was sandy soil with slope of 7% and above in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units within the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.0000031668*3600)+(0.0000383061*3600)+(0.0000855645*3600)= 0.45733464 m^3 is generated in one hour of rainfall.

Plot 4: >=500m^2



Total Plot Area = 643m^2		Paved area = 305m^2
Built up Area = 41m^2		Green area = 297m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(41 m^2=0.0041 ha*0.20*1.45) * 0.0028	0.0000033292
Paved Area	(305 m^2=0.0305 ha *0.85*1.45) * 0.0028	0.0001052555
Built Up Area	(297 m^2=0.0297 ha *0.75*1.45)* 0.0028	0.0000904365
Total		

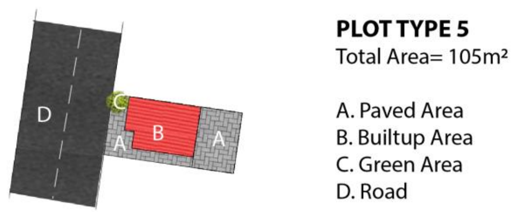
Figure 7-4: Dera Sefer study area 643 m^2 plot map and runoff calculation(Author, 2020)

A runoff coefficient of 0.2 was used for the green area as it is expected there was sandy soil with slope of 7% and above in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units within the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.0000033292*3600)+(0.0001052555*3600)+(0.0000904365*3600)= 0.71647632 m^3 is generated in one hour of rainfall.

Selected samples from Lebu varnero apartment area

Plot 1: <110m²



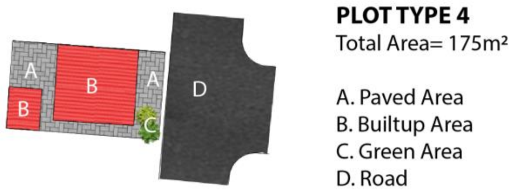
Total Plot Area = 105m^2		Paved area = 16m^2
Built up Area = 85m^2		Green area = 4 m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(4 m^2=0.0004 ha*0.22*1.45)* 0.0028	0.00000035728
Paved Area	(16 m^2=0.0016 ha*0.85*1.45) * 0.0028	0.0000055216
Built Up Area	(85 m^2=0.0085 ha*0.50*1.45) * 0.0028	0.000017255
Total		

Figure 7-5: Lebu Varnero Apartments study area 105 m^2 plot map and runoff calculation(Author, 2020)

A runoff coefficient of 0.22 was used for the green area as it is expected there was heavy soil with slope of 2-7% and above in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.5 was used as runoff coefficient for the built-up area as it is a single family area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.00000035728*3600)+(0.0000055216*3600)+(0.000017255*3600)= 0.083281968 m^3 is generated in one hour of rainfall.

Plot 2: 110-199m^2



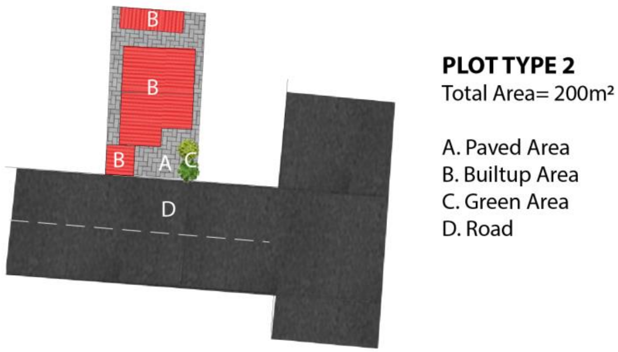
Total Plot Area = 175m^2		Paved area = 50m^2
Built up Area = 110m^2		Green area = 15m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(15 m^2=0.015 ha*0.17*1.45)* 0.0028	0.000010353
Paved Area	(50 m^2=0.005 ha*0.85*1.45)* 0.0028	0.000017255
Built Up Area	(110 m^2=0.011 ha*0.75*1.45) * 0.0028	0.000033495
Total		

Figure 7-6: Lebu Varnero Apartments study area 175 m^2 plot map and runoff calculation(Author, 2020)

A runoff coefficient of 0.17 was used for the green area as it is expected there was heavy soil with slope of 2% in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.000010353*3600)+(0.000017255*3600)+(0.000033495*3600)= 0.2199708 m^3 is generated in one hour of rainfall.

Plot 3: 200-299m^2



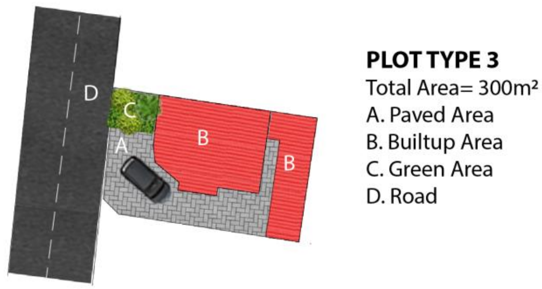
Total Plot Area = 200m^2		Paved area = 52m^2
Built up Area = 140m^2		Green area = 8m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(8 m^2=0.008 ha*0.22*1.45)* 0.0028	0.0000071456
Paved Area	(52 m^2=0.0052 ha*0.85*1.45) * 0.0028	0.0000179452
Built Up Area	(140 m^2=0.014 ha*0.75*1.45) * 0.0028	0.00004263
Total		

Figure 7-7: Lebu Varnero Apartments study area 200 m^2 plot map and runoff calculation(Author, 2020)

A runoff coefficient of 0.22 was used for the green area as it is expected there was heavy soil with slope of 2-7% in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.0000071456*3600)+(0.0000179452*3600)+(0.00004263*3600)= 0.24379488 m^3 is generated in one hour of rainfall.

Plot 4: 300-499m^2



Total Plot Area = 300m^2		Paved area = 90m^2
Built up Area = 180m^2		Green area = 30m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(30 m^2=0.003 ha*0.17*1.45)* 0.0028	0.0000020706
Paved Area	(90 m^2=0.009 ha*0.85*1.45)* 0.0028	0.000031059
Built Up Area	(180 m^2=0.018 ha*0.6*1.45)* 0.0028	0.000043848
Total		

Figure 7-8: Lebu Varnero Apartments study area 300 m^2 plot map and runoff calculation(Author, 2020)

A runoff coefficient of 0.17 was used for the green area as it is expected there was heavy soil with slope of 2% in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.6 was used as runoff coefficient for the built-up area as there are multiple units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.0000020706*3600)+(0.000031059*3600)+(0.000043848*3600)= 0.27711936 m^3 is generated in one hour of rainfall.

Plot 5: >=500m^2

Total Plot Area = 500m^2		Paved area = 110m^2
Built up Area = 350m^2		Green area = 40m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(40 m^2=0.004 ha*0.22*1.45)* 0.0028	0.0000035728
Paved Area	(110 m^2=0.011 ha*0.85*1.45) * 0.0028	0.000037961
Built Up Area	(350 m^2=0.035 ha*0.75*1.45) * 0.0028	0.000106575
Total		

Figure 7-9: Lebu Varnero Apartments study area 500 m^2 plot map and runoff calculation(Author, 2020)

A runoff coefficient of 0.22 was used for the green area as it is expected there was heavy soil with slope of 2-7% in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.0000035728*3600)+(0.000037961*3600)+(0.000106575*3600)= 0.53319168 m^3 is generated in one hour of rainfall.

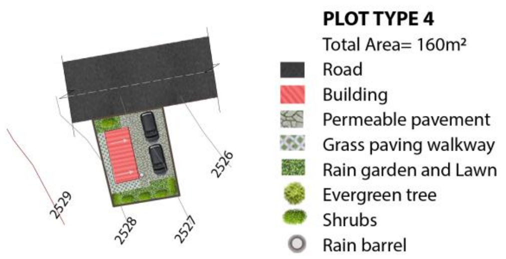
Appendix 2: Calculation of stormwater runoff for selected plots after proposed implementation of GI measures

Points:

- ✓ As the runoff coefficient standard for pervious pavements was not present in studies carried out by USDA or other organizations, a value of 0.35 observed by (Smith, 1984) was used for the runoff calculation of pervious pavements.
- ✓ The area of a rain garden is reduced from the total estimated green area coverage of the proposed designs during the calculation of runoff to find the runoff effects of the rest of the Green mechanisms implemented (Evergreen Trees, Shrubs, and Lawn covers).
- ✓ A standard 55-gallon storage barrel was used for the GI measure “rain barrels” in this study.

Selected samples from Dera Sefer area

Plot 1: 110-199 m^2



Total Plot Area = 160m^2	Paved area = 78m^2
Built up Area = 48m^2	Green area = 37m^2

Runoff volume for each part of the area is calculated as:

Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	((37-10=27 m^2=0.0027 ha) *0.15*1.45)* 0.0028	0.0000016443
Paved Area	(78 m^2=0.0078 ha*0.35*1.45)* 0.0028	0.0000110838
Built-Up Area	(48 m^2=0.0048 ha*0.50*1.45)* 0.0028	0.000009744
Total		

Figure 7-10: Plot map and estimated runoff for Dera Sefer watershed area 160m^2 plot after implementation of GI(Author, 2020)

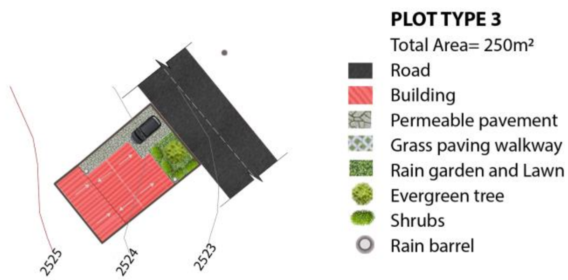
A runoff coefficient of 0.15 was used for the green area as it is expected there was sandy soil with slope of 2 - 7% and above in the area. A runoff coefficient of 0.85 was used for the paved area, while 0.5 was used as runoff coefficient for the built-up area as it is a single family area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as: (0.0000016443*3600)+(0.0000110838*3600)+(0.000009744*3600)= 0.08089956 m^3 is generated in one hour of rainfall.

Rain Garden = 10m^2, ponding depth = 0.15m; Volume that can be held at rain garden: The ponding depth * surface area = 0.15m*10m^2 = 1.5m^3

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there is one barrel; hence 208.198 liters (0.208198 m^3) are saved.

Plot 2: 200-299m^2



Total Plot Area = 250m^2		Paved area = 47m^2
Built up Area = 155m^2		Green area = 48m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	((48-20=20 m^2=0.002 ha) *0.15*1.45)* 0.0028	0.000001218
Paved Area	(47 m^2=0.0047 ha*0.35*1.45)* 0.0028	0.0000066787
Built-Up Area	(155 m^2=0.0155 ha*0.60*1.45)* 0.0028	0.000037758
Total		

Figure 7-11: Plot map and estimated runoff for Dera Sefer watershed area 250m^2 plot after implementation of GI(Author, 2020)

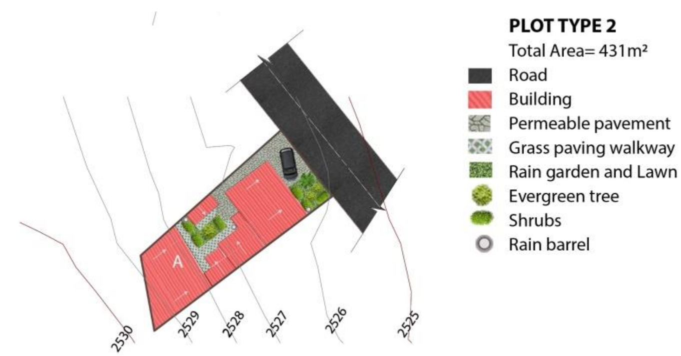
A runoff coefficient of 0.15 was used for the green area as it is expected there was sandy soil with slope of 2-7% and above in the area. A runoff coefficient of 0.85 was used for the pervious pavement area, while 0.6 was used as runoff coefficient for the built-up area as there are multiple units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.000001218*3600)+(0.0000066787*3600)+(0.000037758*3600)= 0.16435692 m^3 is generated in one hour of rainfall.

Rain Garden = 20m^2, pounding depth = 0.15m; Volume that can be held at rain garden: The pounding depth * surface area = 20*0.15 = 3m^3

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there are two barrels, hence 416.396 liters (0.416396 m^3) are saved.

Plot 3: 300-499m^2



Total Plot Area = 431m^2		Paved area = 82m^2
Built up Area = 281m^2		Green area = 68m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	((68-27=41 m^2=0.0041 ha) *0.20*1.45)* 0.0028	0.0000033292
Paved Area	(82 m^2=0.0082 ha*0.35*1.45)* 0.0028	0.0000116522
Built-Up Area	(281 m^2=0.0281 ha*0.75*1.45)* 0.0028	0.0000855645
Total		

Figure 7-12: Plot map and estimated runoff for Dera Sefer watershed area 431m^2 plot after implementation of GI (Author, 2020)

A runoff coefficient of 0.2 was used for the green area as it is expected there was sandy soil with slope of 7% and above in the area. A runoff coefficient of 0.35 was used for the pervious pavement area, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units within the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.0000033292*3600)+(0.0000116522*3600)+(0.0000855645*3600)= 0.36196524 m^3 is generated in one hour of rainfall.

Rain Garden = 27m^2, ponding depth = 0.15m; Volume that can be held at rain garden: The ponding depth * surface area = 27*0.15 = 4.05m^3

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there are three barrels; hence 624.594 liters (0.624594 m^3) are saved.

Plot 4: >=500m^2

Total Plot Area = 643m^2	Paved area = 202m^2	
Built up Area = 297m^2	Green area = 144m^2	
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	((144-36=108 m^2=0.0108 ha) *0.2*1.45)* 0.0028	0.0000087696
Paved Area	(202 m^2=0.0202 ha*0.35*1.45)* 0.0028	0.0000287042
Built-Up Area	(297 m^2=0.0297 ha*0.75*1.45)* 0.0028	0.0000904365
Total		

Figure 7-13: Plot map and estimated runoff for Dera Sefer watershed area 643m^2 plot after implementation of GI(Author, 2020)

A runoff coefficient of 0.2 was used for the green area as it is expected there was sandy soil with slope of 7% and above in the area. A runoff coefficient of 0.35 was used for the pervious pavement area, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units within the area.

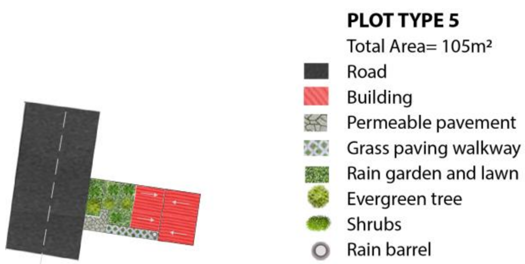
Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as: (0.0000087696*3600)+(0.0000287042*3600)+(0.0000904365*3600)= 0.46047708 m^3 is generated in one hour of rainfall.

Rain Garden = 36m^2, ponding depth = 0.15m; Volume that can be held at rain garden: The ponding depth * surface area = 36*0.15 = 5.4m^3

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there are three barrels, hence 624.594 liters (0.624594 m^3) are saved.

Selected samples from Lebu Varnero apartments area

Plot 1: <110m^2



Total Plot Area = 105m^2	Paved area = 12m^2	
Built up Area = 60m^2	Green area = 33m^2	
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	((33-6=27 m^2=0.0027 ha) *0.22*1.45)* 0.0028	0.00000241164
Paved Area	(12 m^2=0.0012 ha*0.35*1.45)* 0.0028	0.0000017052
Built Up Area	(60 m^2=0.006 ha*0.60*1.45)* 0.0028	0.000014616
Total		

Figure 7-14: Plot map and estimated runoff for Lebu Varnero watershed area 105m^2 plot after implementation of GI(Author, 2020)

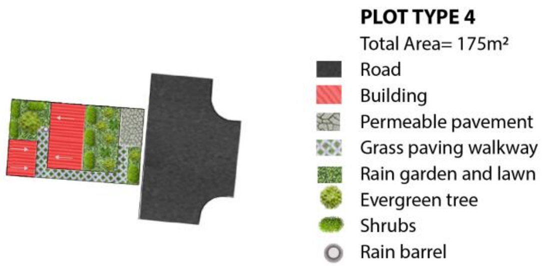
A runoff coefficient of 0.22 was used for the green area as it is expected there was heavy soil with slope of 2-7% in the area. A runoff coefficient of 0.35 was used for the pervious pavements, while 0.6 was used as runoff coefficient for the built-up area as there are multiple units in the area

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as: (0.00000241164*3600)+(0.0000017052*3600)+(0.000014616*3600)= 0.067438224 m^3 is generated in one hour of rainfall.

Rain Garden = 6m^2, ponding depth = 0.15m; The volume that can be held at rain garden: The ponding depth * surface area = 6*0.15 = 0.9m^3 (900 liters)

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there is one barrel; hence 208.198 liters (0.208198 m^3) are saved.

Plot 2: 110-199m^2



Total Plot Area = 175m^2		Paved area = 43m^2
Built up Area = 98m^2		Green area = 34m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	((34-15=19 m^2=0.0019 ha) *0.17*1.45)* 0.0028	0.00000131138
Paved Area	(43 m^2=0.0043 ha*0.35*1.45)* 0.0028	0.0000061103
Built Up Area	(98 m^2= 0.0098 ha*0.75*1.45)* 0.0028	0.000029841
Total		

Figure 7-15: Plot map and estimated runoff for Lebu Varnero watershed area 175m^2 plot after implementation of GI (Author, 2020)

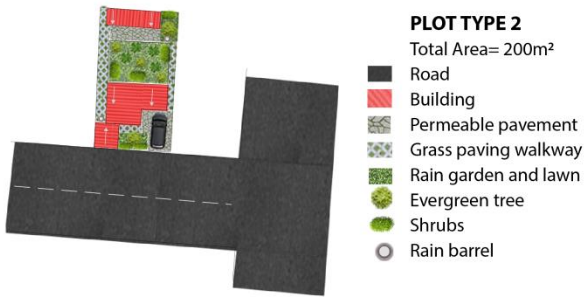
A runoff coefficient of 0.17 was used for the green area as it is expected there was heavy soil with slope of 2% in the area. A runoff coefficient of 0.35 was used for the pervious pavements, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as: (0.00000131138*3600)+(0.0000061103*3600)+(0.000029841*3600)= 0.134145648 m^3 is generated in one hour of rainfall.

Rain Garden = 15m^2, ponding depth = 0.15m; Volume that can be held at rain garden: The ponding depth * surface area = 15*0.15 = 2.25m^3

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there is one barrel; hence 208.198 liters (0.208198 m^3) are saved.

Plot 3: 200-299m^2



Total Plot Area = 200m^2	Paved area = 42m^2	
Built up Area = 102m^2	Green area = 56m^2	
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(56-15=41 m^2=0.0041 ha) *0.22*1.45)* 0.0028	0.00000366212
Paved Area	(42 m^2=0.0042 ha*0.35*1.45)* 0.0028	0.0000059682
Built Up Area	(102 m^2=0.0102 ha*0.75*1.45)* 0.0028	0.000031059
Total		

Figure 7-16: Plot map and estimated runoff for Lebu Varnero watershed area 200m^2 plot after implementation of GI (Author, 2020)

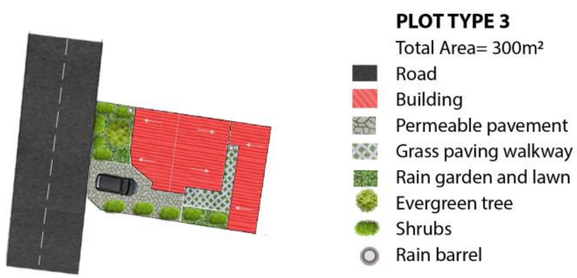
A runoff coefficient of 0.22 was used for the green area as it is expected there was heavy soil with slope of 2-7% in the area. A runoff coefficient of 0.35 was used for the pervious pavements, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.00000366212*3600)+(0.0000059682*3600)+(0.000031059*3600)= 0.146481552 m^3 is generated in one hour of rainfall.

Rain Garden = 15m^2, ponding depth = 0.15m; Volume that can be held at rain garden: The ponding depth * surface area = 15*0.15 = 2.25m^3

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there are two barrels; hence 416.396 liters (0.416396 m^3) are saved.

Plot 4: 300-499m^2



Total Plot Area = 300m^2		Paved area = 62m^2
Built up Area = 180m^2		Green area = 58m^2
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	((58-24=34 m^2= 0.0034 ha) *0.17*1.45)*0.0028	0.00000234668
Paved Area	((62 m^2=0.0062 ha)*0.35*1.45)* 0.0028	0.0000088102
Built Up Area	((180 m^2=0.018 ha)*0.6*1.45)* 0.0028	0.000043848
Total		

Figure 7-17: Plot map and estimated runoff for Lebu Varnero watershed area 300m^2 plot after implementation of GI (Author, 2020)

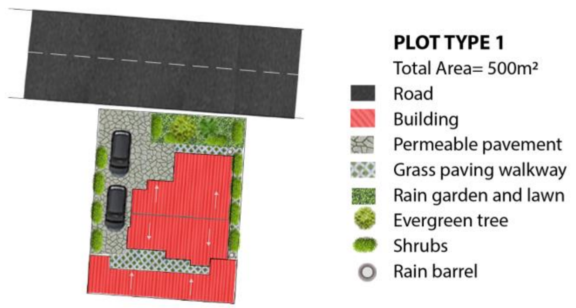
A runoff coefficient of 0.17 was used for the green area as it is expected there was heavy soil with slope of 2% in the area. A runoff coefficient of 0.35 was used for the pervious pavements, while 0.6 was used as runoff coefficient for the built-up area as there are multiple units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.00000234668*3600)+(0.0000088102*3600)+(0.000043848*3600)= 0.198017568 m^3 is generated in one hour of rainfall.

Rain Garden = 24m^2, ponding depth = 0.15m; Volume that can be held at rain garden: The ponding depth * surface area = 24*0.15 = 3.6m^3

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there are two barrels; hence 416.396 liters (0.416396 m^3) are saved.

Plot 5: >=500m^2



Total Plot Area = 500m^2	Paved area = 66m^2	
Built up Area = 350m^2	Green area = 84m^2	
Runoff volume for each part of the area is calculated as:		
Part of Plot	Calculation (Area * coefficient * rainfall intensity)	Runoff rate (m^3/s)
Green Area	(84-32=52 m^2=0.0052 ha) *0.22*1.45)* 0.0028	0.00000464464
Paved Area	(66 m^2=0.0066 ha*0.35*1.45)* 0.0028	0.0000093786
Built Up Area	(350 m^2=0.035 ha*0.75*1.45)* 0.0028	0.000106575
Total		

Figure 7-18: Plot map and estimated runoff for Lebu Varnero watershed area 500m^2 plot after implementation of GI(Author, 2020)

A runoff coefficient of 0.22 was used for the green area as it is expected there was heavy soil with slope of 2-7% in the area. A runoff coefficient of 0.35 was used for the pervious pavements, while 0.75 was used as runoff coefficient for the built-up area as there are multiple detached units in the area.

Using 1 hour (3600s) as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014), the total volume that is generated in this plot area is calculated as:
(0.00000464464*3600)+(0.0000093786*3600)+(0.000106575*3600)= 0.434153664 m^3 is generated in one hour of rainfall.

Rain Garden = 32m^2, ponding depth = 0.15m. The volume that can be held at rain garden: ponding depth * surface area = 32*0.15 = 4.8m^3

By using a standard 55-gallon storage barrel, 208.198 liters of water can be saved. In this case, there are two barrels; hence 416.396 liters (0.416396 m^3) are saved.

Appendix 3: Recommended values of Runoff Coefficients

Table 7-1: Runoff Coefficients used in this study

Type of drainage area	Runoff coefficient (C)
Lawns: Sandy soil, flat 2% Sandy soil, average, 2 - 7% Sandy soil, steep, 7% Heavy soil, flat, 2% Heavy soil, average, 2 - 7% Heavy soil, steep, 7%	0.05 - 0.10 0.10 - 0.15 0.15 - 0.20 0.13-0.17 0.18 - 0.22 0.25 - 0.35
Business: Downtown areas Neighborhood areas	0.70 - 0.95 0.50.0.70
Residential: Single-family areas Multi-units, Detached Multi-units, Attached Suburban Apartment dwelling areas	0.30 - 0.50 0.40 - 0.60 0.60 - 0.75 0.25 - 0.40 0.50 - 0.70
Industrial: Light areas Heavy areas	0.50 - 0.80 0.60 - 0.90
Parks, cemeteries	0.10 - 0.25
Playgrounds	0.20 - 0.35
Railroad yard areas	0.20 - 0.40
Unimproved areas	0.10 - 0.30
Streets: Asphaltic Concrete Brick	0.70 - 0.95 0.80 - 0.95 0.70 - 0.85
Drives and walks Roofs	0.75 - 0.85 0.75 - 0.95

Source: (USDA, n.d.)

Appendix 4: Interview for individual households

Dear Ms./Mr.,

With the support of the EiABC MSC program in Landscape Architecture, I am conducting a study titled **Landscape Based Stormwater Management Design solutions For Residential Areas: The case of two selected sub-cities in Addis Ababa.** You have been selected in the survey because of your potential to provide the required information. I am aware that you are very busy, but I would be grateful if you could take the time to respond to the questions in this questionnaire.

This survey is anonymous and your answers will be included in the collective only. There is an option to leave contact information at the end of the questions to allow follow-up, but this is voluntary.

I would like to thank you in advance for your time and participation in this research study.

Thank you,

Yewbneh Getamesay

MSC candidate

Questionnaires for Residents

Date: _____________Time: _____________Place _______________

1. For how many years did you live in this neighborhood?
   ☐< 1 year ☐2 – 5years ☐> 5years
2. Are you the owner of this household's plot?
   ☐ Yes ☐No
3. How much is the plot area ___________________
4. Form the following compound types which type yours look like?
   ☐Covered by building
   ☐ I have a compound and the entire area is sealed surface
   ☐ I have a compound and the surface are both green area and sealed surface
5. Do you know about stormwater?
   ☐ Yes ☐No
6. If your answer is yes please explain your knowledge?
   ____
7. Are there stormwater problems so far in this residential neighborhood area?
   ☐Yes ☐No
8. If your answer is Yes, in which spots or location on your compound?
   ____
9. Which of the following; have you observed in the single-family plot compound?
   ☐Water logging ☐ dissected Fragmented surface ☐ eroded Washed away surface

☐other_______________________________________

10. What do you think is the possible cause of the stormwater runoff in this neighborhood?

    ☐Heavy Rain ☐Type of surface material ☐Lack of drains

    ☐other____

11. How do you manage the problem to minimize/scoping measures?

    ____

12. Were the measures taken effective?

    ☐Yes ☐No

    If no, what were the reasons?____

13. Do you have a garden/open space on your compound?

    ☐Yes ☐No

    If yes, how do you water it?

    ☐ using rainwater ☐ I use tap water ☐another method

14. What kind of surface material do you use for your compound?

    ☐ Covered by Concrete tile ☐ covered by grass ☐ both type

15. What do you think should be done to reduce stormwater runoff for the future?

    ____

Appendix 5: Interview for selected stakeholders offices

Dear Ms./Mr.,

With the support of the EiABC MSC program in Landscape Architecture, I am conducting a study titled **Landscape Based Stormwater Management Design solutions For Residential Areas: The case of two selected sub-cities in Addis Ababa.** You have been selected in the survey because of your potential to provide the required information. I am aware that you are very busy, but I would be grateful if you could take the time to respond to the questions in this questionnaire.

This survey is anonymous and your answers will be included in the collective only. There is an option to leave contact information at the end of the questions to allow follow-up, but this is voluntary.

I would like to thank you in advance for your time and participation in this research study.

Thank you,

Yewbneh Getamesay

MSC candidate

Questions for selected offices

Date: _____________Time: _____________Place _______________

1. What is your position in this organization? _____________________________
2. Profession ___________________________
3. Are there any site specific local residential plot guidelines for SWM? _______________
4. What are the factors for the Cause of stormwater in Addis Ababa Generally?
   ____
5. What do you think is the reason for the stormwater problem in an individual residential plot?
   ____
6. What problems have been encountered / have you observed so far? _________________
7. Do you think that that individual residential plot is a reason for the current stormwater problem in the city?
   ☐Yes ☐No
   If yes, how? ____
8. In your view, what are the reasons for surface runoff within the residential plots?
   ____

9. In which area of the compound did you observe the problem?
____

10. What could be the consequence if the stormwater runoff continues in the residential neighborhood?
____

11. What do you recommend to minimize stormwater from the individual plot compound?
____

Appendix 6: Publishable Manuscript

Landscape Based Stormwater Management Design solutions For Residential Areas: The case of two selected sub-cities in Addis Ababa, Ethiopia

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Yewbneh Getamesay

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January 2021

Addis Ababa, Ethiopia

Abstract

Addis Ababa has undergone several changes concerning its built environment which has culminated in the devastation of natural vegetation, conversion of green spaces, and the development of the built environment which has translated to stormwater runoff problems. Hence, this study aimed at identifying opportunities for stormwater runoff reduction through landscape-based stormwater management design solutions within selected residential areas of Addis Ababa.

Hence, to assess Landscape stormwater management (LSM) Technologies on individual plots of the residential areas of Addis Ababa, both qualitative and quantitative research methods were employed, while both primary and secondary data were collected. Moreover, the study areas selected for this study were Lebu Varnero watershed area from Nefas Silk Lafto Sub city and Dera Sefer watershed area from Arada Sub city. Different data collection methods such as field observation, questionnaires and interviews were employed in this study.

The selected residential plots were analyzed based on factors that dictate the applicability of landscape-based stormwater management mechanisms such as precipitation, vegetation, land (plot) size and use, soil type, slope, and drainage. The level of imperviousness in selected plots was assessed and problems of stormwater runoff were observed in both study areas; while it was seen that not enough support was provided from authorities to the study areas regarding stormwater. Moreover, potential green infrastructure recommendations were put forward for the plots and surrounding watershed area (Lebu Varnero Apartments study area). Moreover, the amount of stormwater that can be reduced in the selected watershed areas through the implementation of the recommended green infrastructure practices was estimated and presented.

In addition to potential Green Infrastructure mechanisms proposed in this study for residential plots, the government, policymakers, and other relevant stakeholders should consider problems of stormwater on areas near streams and rivers on the low catchment area, which receive the stormwater runoff generated from sealed surfaces in upper catchment areas. Also, more should be done on promoting stormwater management mechanism use in residential plots.

Keywords: Stormwater, Green Infrastructure, Landscape based stormwater management, on-source stormwater control

1. Introduction

The high rate of urban development along with the increment of impermeable surfaces is one of the major causes of flooding in urban areas. Consequently, urban areas are predominantly covered by roads and buildings, which have less capacity to store rainfall. In urban areas, flood effects can be worsened by existing paved streets and roads, which can intensify the speed of flowing water (Mukherjee, 2016). This flowing water that freely roams over the impervious areas of cities and is a significant source of flooding is termed stormwater runoff. It causes major damages to different infrastructures and the natural flora and fauna in many communities worldwide (Pazwash, 2011).

For decades, Addis Ababa has been one of the rapidly developing cities of Africa. The city has undergone several changes concerning its built environment and provision of basic infrastructure services. According to (Desta et al., 2011), this rapid development has culminated in the destruction of natural vegetation, conversion of green spaces, and the development of the built environment, which has exhibited adverse effects on the environment. Intensified development changes of the natural landscape that can manage stormwater runoff naturally into the sealed surface covered with the hard impervious surface, Lead to the amount of water that infiltrates to decrease and the amount that runs off to increase (Kombe et al., 2015); where, as a result, flooding becomes eminent in the different built-up parts of the city. Hence, urbanization, its impermeable structures, and improper design can be considered one of the major factors influencing flooding in most developing urban areas including Addis Ababa (Adugna, 2011).

On the issue regarding urban-meditated impacts of climate change in Addis Ababa, the existing sealed surfaces, from each plot to the densely urbanized city level are more vulnerable to flooding due to relative increases in the intensity of rainfall and under-design of open spaces and current road networks. Moreover, in the design as well as the construction process of housing areas in Addis Ababa, especially in the low density and single-family housing development, some environmental aspects seem to be neglected. For example, in the emerging residential areas of the city, lack of green areas (like trees, plants, lawn, and other vegetation) and proper integration to the storm-water drainage facilities appear to be a serious problem. It is common to see drainage problems in old and new housing areas where residents rely on storm drains to carry a large amount of runoff generated from their compounds. However, the significant amount of runoff generated from roofs and the paved surface of their compounds creates significant damage on local streets and properties at the lower catchment areas of neighborhoods during highly rainy seasons. Consequently, this kind of development, where stormwater mitigation strategies are neglected on an individual plot level, may deteriorate the local street and buildings within a short period after construction. Thus, if appropriate measures are not taken, the problem would create further damage on buildings, infrastructure and eventually lead to the entire environmental degradation.

Hence, the development of proper techniques to mitigate stormwater on the residential plot level in addition to the identification of the different factors that affect the deployment of these techniques should be given due attention. Therefore, this study will mainly focus on the integration and use of

Landscape stormwater management (LSM) Technologies on individual plots of residential areas of Addis Ababa and identifying the major factors that affect the applicability of these technologies. More specifically, the study was conducted, among other objectives:

- To develop and design potential LSM technologies and solutions for various residential plot categories and the surrounding watershed areas.
- To estimate and describe the contribution of LSM in terms of flood reduction as well as green area improvement of the entire local watershed.

1.1.Green infrastructure and landscape-based stormwater management as flood protection

In addition to intensity, coverage, and duration of precipitation (rainfall), factors are seen to influence stormwater runoff and the implementation of proper mitigation techniques include vegetation, Soil type, Slope, Land (Plot) size and use, and Drainage. Considering these factors, Green Infrastructure (GI) is an essential mechanism in handling stormwater management.

Green Infrastructure (GI), a term used for a network of different vegetation systems (for example forests, gardens, or scrublands) which, in interconnect, solve urban and climatic challenges. Moreover, green infrastructure is used for describing specific and bundled vegetation systems in general. GI is essential for our ecosystem services, and it is scientifically proven.

Hence, some of the GI based stormwater management techniques that can be implemented on a watershed level include:

v. **Bio retention Pond:** Bio retention ponds help store and infiltrate stormwater through the use of permeable soils, vegetation, and organic matters for treating runoff from paved surfaces. They are effective as stormwater pollutant removals; they remove heavy metals as well as unnecessary oil and grease. They also increase water treatment which results in significant water quality benefits (Shafique, 2017).

vi. **Road Side Vegetated Swale:** Helping treat both quality and quantity of stormwater runoff, vegetated swales allow the infiltration and evapotranspiration of stormwater while filtering pollutants and providing tall grasses and flowers that are aesthetically pleasing. (Penn's Corner Conservancy and Charitable Trust, n.d.).

vii. **Green Gutter:** Used for quality stormwater treatments for runoff from the bike, street, vehicle, or pedestrian lanes, green gutters help in the infiltration and filtration, soil adsorption, and plant uptake of stormwater. Through increased vegetation, they provide functionality and capture stormwater on roadways while also providing aesthetic attractiveness by integration with the overall streetscape (City and County of Denver, 2015).

viii. **Previous Driveways and Walkways:** Previous driveways and walkways help in improving groundwater recharge and infiltration while reducing runoff volume by allowing stormwater to soak through them and be released to the surrounding soils and other stormwater draining systems (Penn’s Corner Conservancy and Charitable Trust, n.d.).

ix. **Trees:** Trees are easier to plant than other options. Well, looked-after Trees can adapt to the climate and better withstand extreme weather conditions. Canopies and leaf litter of trees can cushion the impact of rainfall on the ground, which reduce soil erosion and allow more soil penetration by the water, while Roots absorb water from runoff, natural drainage, and rain and help hold soil in place (City of Roanoke, 2014)

x. **Rain collection Barrels:** This type of runoff management is associated with catching rainwater from the rooftops at the bottom of downspouts and storing it in large water collection containers for further use. Very traditional and easy to build, rain barrels are ideal for plots that are relatively small in area and do not have many green spaces, while they can also be used for households with low income and those that use much tap water to irrigate their green areas. (Kalamazoo river watershed Council, n.d.)

xi. **Vegetated filter strips:** Vegetated filter strips are gently sloped areas designed to receive stormwater as sheet flows from adjacent impervious surfaces to slow runoff. They are covered with grass and other vegetation and reduce the speed of stormwater through infiltration and temporary storage in the soils below the vegetation. They decrease the velocity of stormwater runoff, and infiltrate stormwater runoff into the soil, reducing its adverse impacts (City of Roanoke, 2014).

xii. **Rain Garden:** Rain gardens are areas landscaped with different types of vegetation to soak up rainwater and infiltrate it into the soil. They have the aim of capturing runoff from various impervious surfaces, such as pavements, roofs, and driveways. Rain gardens fill with few inches of water after a storm which becomes a pool and then the runoff water is soaked into the ground, rather than running off to a drain, reducing the amount of runoff and Filter pollutants (City of Roanoke, 2014).

xiii. **Green Roofs:** Green roofs are "contained" living systems on top of human-made structures. Also known as vegetated roofs or living roofs, Green roofs are specially designed roofs that accommodate different types of vegetation to capture rainfall to reduce runoff on impervious surfaces. However, in Addis Ababa, green roofs are not commonly practiced (Vijayaraghavan, 2016)

1.2.The practice of Stormwater management in Addis Ababa

Addis Ababa, the capital of Ethiopia, is one of the fastest-growing cities in Africa based on the 2014 Ethiopian Central Statistical Agency report. The city, in 2013, had an estimated population of 3.2 million. The total surface area of the city is 540 kilometers square with mixed land uses and composed of formal and informal/unplanned settlements (McFarland et al., 2019). Addis Ababa is undergoing rapid urbanization with a very high rate of road and building constructions, increasing sealed surfaces, and generation of significant amounts of stormwater(Adugna, Lemma, Jensen, et al., 2019).

The problem of poor stormwater drainage management and facilities is worsening by the fast rate of urbanization and the inability of related authorities to develop and manage the physical infrastructure to keep pace with the increase of population and increase of basic needs. The lack of financial and human resources increases the problem, especially in the development of stormwater drainage systems which have been viewed as a solution for urban stormwater(Fryd et al., 2016). Stormwater management has not been given much attention when compared with other urban development activities, resulting in flash flooding, and degradation of urban infrastructure. Apart from few data collected in small neighborhoods of the oldest part of the city, the coverage of the traditional piped drainage systems and their respective hydraulic capacity in Addis Ababa is largely unknown (Adugna, Lemma, Jensen, et al., 2019).

1.2.1. Watershed Level Analysis (On sub-city level)

Addis Ababa is divided into ten sub-cities to have an efficient, effective management system and better serve the inhabitants. As drainage is used as the primary method through which urban storm runoff is managed, there are limited data in regards to the housing units connected to drainage lines. The main aspect of sub-cities is that drainage systems are underdeveloped by any standard. Within this matter, things are even in critical conditions whereas improperly disposed of solid wastes blocks existing drainage channels mainly in and around the inner-city slums. Within this context, it is common to see streets that are becoming significantly damaged by overflowing runoff. Torrential rainfalls that last for hours leading to floods have inflicted damages to humans and property (Kloosterboer, 2019). With the watershed level analysis, the major factors related to the applicability of landscape-based stormwater management practices for the watershed areas were analyzed and discussed. The watershed analysis locations were found in the two sub-cities selected for the study, namely: Arada sub-city and Nefas Silk Lafto sub-city, as will be explained in the methodology section of the study.

1.2.1.1. Soil characteristics of watershed areas

According to (Mezgebe, 2009), even though there isn’t enough data to accurately pinpoint the soil characteristics of the city, a classification using the FAO soil characteristics and USDA soil hydrology groupings can be made. Hence, the types of soils generally seen to be found in Addis Ababa include CAMBISOLS (CM), NITOSOLS (NT), VERTISOLS (VR), and LUVISOLS (LV)(Akalu, 2017).

1.2.1.2. Precipitation in watershed areas

For this study, the researcher has taken the maximum average daily precipitation recorded in June 2018, which was observed to be one of the months with the highest intensity of rainfall. The selected recording was taken as 34.7mm. Maximum daily rainfall intensity is selected as runoff generation is increasing with the increase in the intensity of rainfall. (National Meteorology Agency, 2018)

1.2.1.3. Increase in imperviousness in watershed areas

The increasing level of imperviousness is more evident in how the Lebu Varnero Apartments watershed area transformed through decades. Vast areas of land that were covered by green areas are now replaced by impervious structures that contribute heavily to stormwater runoff problems observed in the area. In the Dera Sefer watershed area, although most of the built structures have been around for many years and have covered most of the watershed area for decades, the green areas that existed in compounds and in between streets and homes have been minimized and are being replaced by impervious surfaces.

2. Materials and Methods

2.1.Research Design

This research employed triangulation research method, where these methods were used to collect both primary and secondary data regarding stormwater management in residential plots (which include both qualitative and quantitative data) through the implementation of data collection methods such as case study analysis, interviews, questionnaires, review of the literature and relevant documents, and observations.

2.2.Data type and sources

In this study, both primary and secondary types of data were collected. Primary data were used to bring first-hand experiences on stormwater management, while secondary data were collected to enable the researcher to have information about cases of stormwater management practices.

To collect primary data, questionnaires were conducted with the plot owners, physical measurements of built structure and non-built areas using maps and personal observations with regards to issues associated with stormwater management and its factors were conducted, in addition to interviews with officials in the selected different local authority's offices like Beautification, Parks and Cemetery Development and Administration Agency of Addis Ababa (BPCDAA), and Arada and Nefas Silk lafto sub-cities' administrations. Furthermore, a land-use map was collected from the Addis Ababa city administration, construction permit, and control authority, and additional data regarding annual rainfall was collected from National Meteorology Agency (NMA).

The secondary data was collected from books, journals, documents, reports, and other relevant sources. The published journals were obtained from reliable sources such as universities and peer-reviewed open-access journal publication websites, while relevant documents and reports were collected from associated governmental offices in the Addis Ababa city administration and selected sub-city administrations.

2.3.Study Areas

Arada and Nifas-Silk Lafto Sub cities were chosen as case sites for this study based on the criteria:

- Arada Sub City and Nifas-Silk Lafto Sub-city being sub-cities with small and large area coverage respectively that can represent the rest of the sub-cities
- According to the development character; that is Nefas-Silk lafto sub-city represents newly developed areas of the city and the Arada sub-city represents older developments.

- According to the topography type character; that is Nefas-Silk Lafto represents more of flat topography with Arada sub-city as a representative of areas with steep topography.
- Furthermore, the Arada sub-city is chosen as it is one of the sub-cities which have the highest climate change vulnerability, while Nefas-Silk Lafto sub-city is chosen as one of the sub-cities with lower to moderate climate change vulnerability (Feyissa et al., 2018).

2.4.Selection of watershed areas

The watershed areas from both sub-cities were selected as prototypes for other sub-cities and watershed areas for being areas where there are consistent stormwater problems. The two selected watershed areas from each sub-cities were the Dera Sefer study area from Arada Sub-city and Lebu Varnero Apartments Study area from Nefas Silk Lafto sub-city.

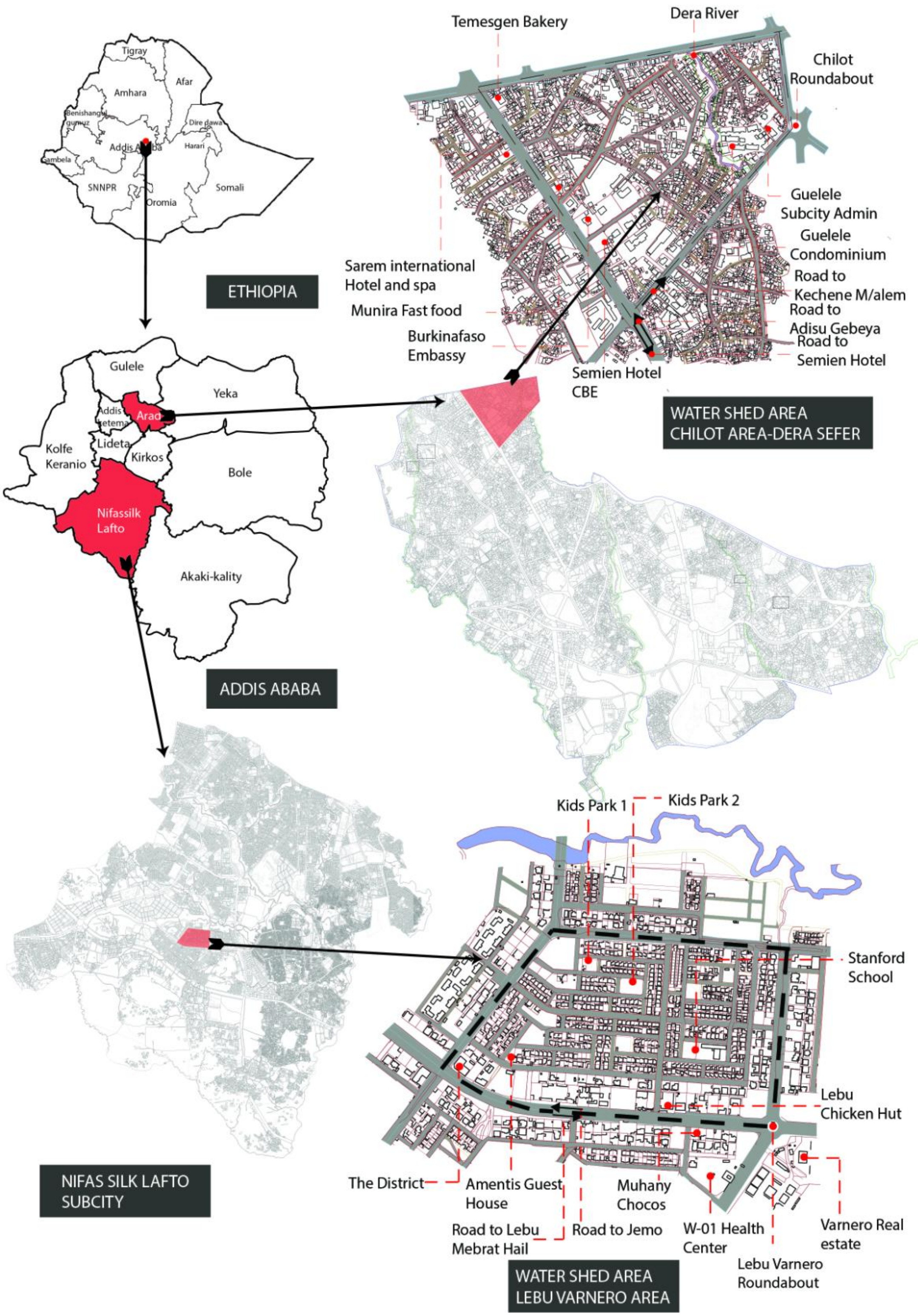

Figure 2-1: Map of the study areas (Author, 2020)

2.5.Selection of case studies for site analysis and follow up design

After the study areas to be included in the study have been identified, the specific case studies for site analysis and design provision were selected as representative from each watershed area as per the following selection criteria:

A. Residential plots of land with different areas, shapes, and sealed surfaces whose building, green and paved layouts are representative of the other residential plots.

The classification was made based on the area size, categorized according to a scale developed by authors and adapted from work done by (Anderson et al., 1976, edited in 2007), but modified to meet and reconcile with the contrasting existing land size situations in the two different watershed areas. The categories are listed as:

- Residential units on areas that are less than $110m^2$.
- Residential units on 110-199 m^2 areas.
- Residential units on 200-299 m^2 lots.
- Residential units with greater than 300-499 m^2.
- Residential units with greater than or equal to 500 m^2.

B. Residential areas that fall on different slope classifications

For this research, the land slope classification system proposed by the Food and Agriculture Organization of the United Nations (FAO) and adapted in the research done by (Feyissa et al., 2018), was adopted and modified to meet the existing situation at the watershed level of both study sites. Hence, the slopes of the residential plots selected for this study were categorized in ranges of 0-4%, 4-8%, 8-12%, 12-15%, and >15%.

Hence, a total of 4 plots from the Arada sub-city (there were no plots with areas below $110m^2$ at this watershed) and 5 plots from Nefas Silk Lafto sub-city were selected.

2.6.Data Collection Techniques

2.6.1. Field Observation

Using maps that were obtained from the study area administrations and digital maps such as Google maps, the individual plot areas selected for on-site analysis and their surrounding watershed areas were located and surveyed. The area was physically measured in length, width, and shape of the plot (rectangular, trapezoidal, etc); while other related dimensions and materials used in the stormwater management practices of the residential plots were also observed and analyzed.

2.6.2. Questionnaires

To gather data regarding LSM in the selected residential neighborhoods, data were collected through open-ended questionnaires, which were administered to selected participants from the residential neighborhoods. Hence, to find the total number of participants of the questionnaires, the above-mentioned size-based classification was used to categorize the different plots and the contact people from each plot. Then, the number of plots to be included in the questionnaire deployment per each category was calculated by using the sample size calculation formula that was developed by (Yamane, 1967). This formula was used for each category separately and it is illustrated as follows:

$$n = N / [1 + N*(e)^2]$$

Where n is the sample size (selected number of plots),

N is population size (total number of plots within a category)

e is the level of precision required (sampling error margin) at a 10% margin of error (e=0.1).

Table 2-1: Sample sizes for each watershed area

Nefas Silk Lafto, Lebu Varnero Apartments watershed area	**Arada Sub-city, Dera Sefer watershed area**
Plots with areas of <110 m^2= 49 plots	-----
Plots with areas of 110-199 m^2= 74 plots	**Plots with areas of 110-199 m^2**= 66 plots
Plots with areas of 200-299 m^2= 60 plots	**Plots with areas of 200-299 m^2**= 60 plots
Plots with areas of 300-499 m^2= 32 plots	**Plots with areas of 300-499 m^2**= 47 plots
Plots with areas of >= 500 m^2 = 33 plots	**Plots with areas of >= 500 m^2**= 37 plots
Total selected plots = 248	**Total selected plots = 210**

Source: (Author, 2020)

The data was collected by the researcher and all data was encoded to data collection sheets and transferred to spreadsheets and word documents on computers. To ensure the validity and accuracy of the data, a pilot study was conducted by taking 5% of the total selected plots from each watershed area.

2.6.3. Interview

In addition to questionnaires administered to residents (participants representing the selected residential plots), interviews were also conducted with selected individuals from different stakeholder organizations that are involved with stormwater management in Addis Ababa and more specifically, in the watershed areas. These stakeholders were selected on the basis that they are the primary organizations that are concerned with the development and maintenance of stormwater managing roadside ditches and other stormwater management methods in the study areas. The selected interviewees from each organization are listed below:

Table 2-2: Officials' (respondents') demographic background

Organization	Position in the organization	Number
Addis Ababa city administration, roads authority	Senior engineer	1
Addis Ababa city administration water and sewerage service authority	Case team leader (Senior Engineer)	1
	Sewerage line design and control Officer (Engineer)	2
	Sewerage information and GIS center Officer (Engineer)	1
Arada Sub-city administration Office	Officer (Engineer)	1
Nefas Silk lafto sub-city administration office	Officer (Engineer)	1
Arada Sub-city beautification, Parks and cemetery bureau	Case team leader (Engineer)	1
	Plant expert	2
Nefas Silk lafto beautification, parks and cemetery bureau	Case team leader (Engineer)	1
	Plant Expert	2

Source: (Author, 2020)

2.7.Calculation of stormwater runoff

To calculate the amount of stormwater generated from each specific residential plot, the rational method of runoff calculation proposed by (Spellman & Whiting, 2014) was used, which is described as:

Q = C*i*A (As this formula uses the US measurement system instead of the SI measurement system, the formula has to be adjusted to Q = 0.0028*C*i*A to use the SI measurement units)(Bengtson, n.d.)

Where,

Q = Runoff rate (m^3/sec)

A = Area of Plot (presented in m^2, but changed to hectares to do the calculations) (classified per the built-up, unbuilt, and green spaces)

C = Runoff Coefficient (runoff coefficients differ based on the land-use and landcover type).

i = Rainfall intensity (mm/hr) (Intensity of rainfall differs from day to day and from month to month. However, for this study, a recording of 34.7mm which was the average daily maximum rainfall amount of June 2018 was used; hence, changing this to mm/hr, it gives us approximately 1.45 mm/hr) (National Meteorology Agency, 2018).

Hence, after calculating the runoff rate for each selected sample plot area of the study area, the volume of runoff generated was identified by, multiplying the runoff rate for each land cover type with the duration of rainfall considered for this study (1 hour (3600s) was used as the duration of rainfall for the purpose of this study, as rainfall durations less than an hour are more likely to cause flash floods (de Paola et al., 2014)). Then, the total of the runoff amount was calculated for the plot category and each watershed area and is presented in m^3.

3. Results and Discussion

3.1.Potential LSM technologies and solutions for various residential plot categories and the surrounding watershed areas

3.1.1. Potential GI technologies recommendations for both sites observed under the study

Based on the results from the study, GI mechanisms were applied to both watershed areas to help mitigate stormwater runoff by reducing it to the lowest amount it can be produced at the residential level. For this purpose, GI mechanisms such as permeable pavements, rain gardens, and rain barrels are used.

Dera Sefer study area

From the plot areas selected for design and implementation recommendation for GI mechanisms, the 643m^2 plot from Dera Sefer watershed area was selected for demonstration.

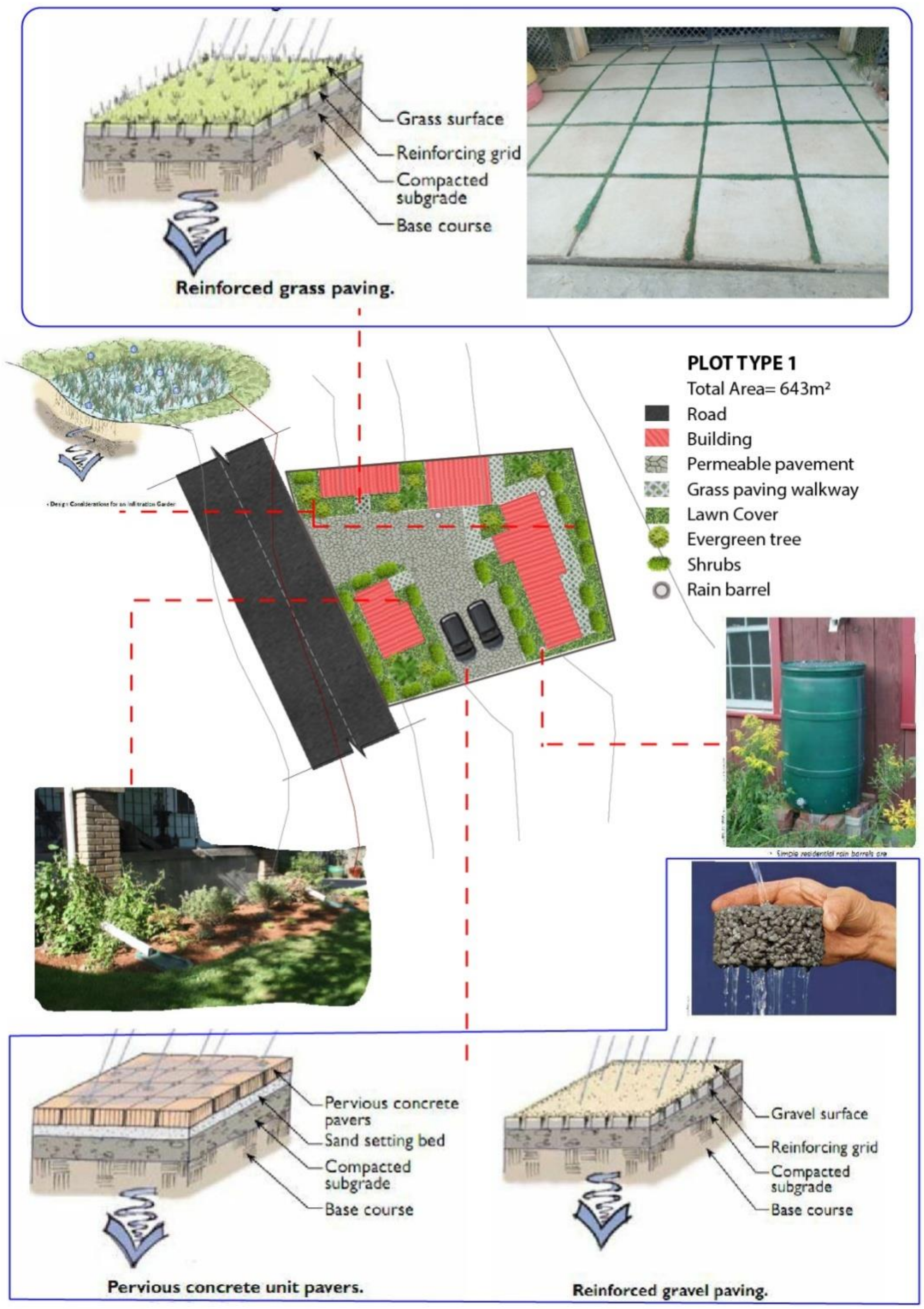

Figure 3-1: Dera Sefer 643m^2 plot detailed GI measures (Author, 2020)

Lebu Varnero Apartments study area

Here, the 500m^2 plot area from Lebu varnero watershed area was redesigned with different GI mechanisms to handle the stormwater runoff that will occur throughout the year.

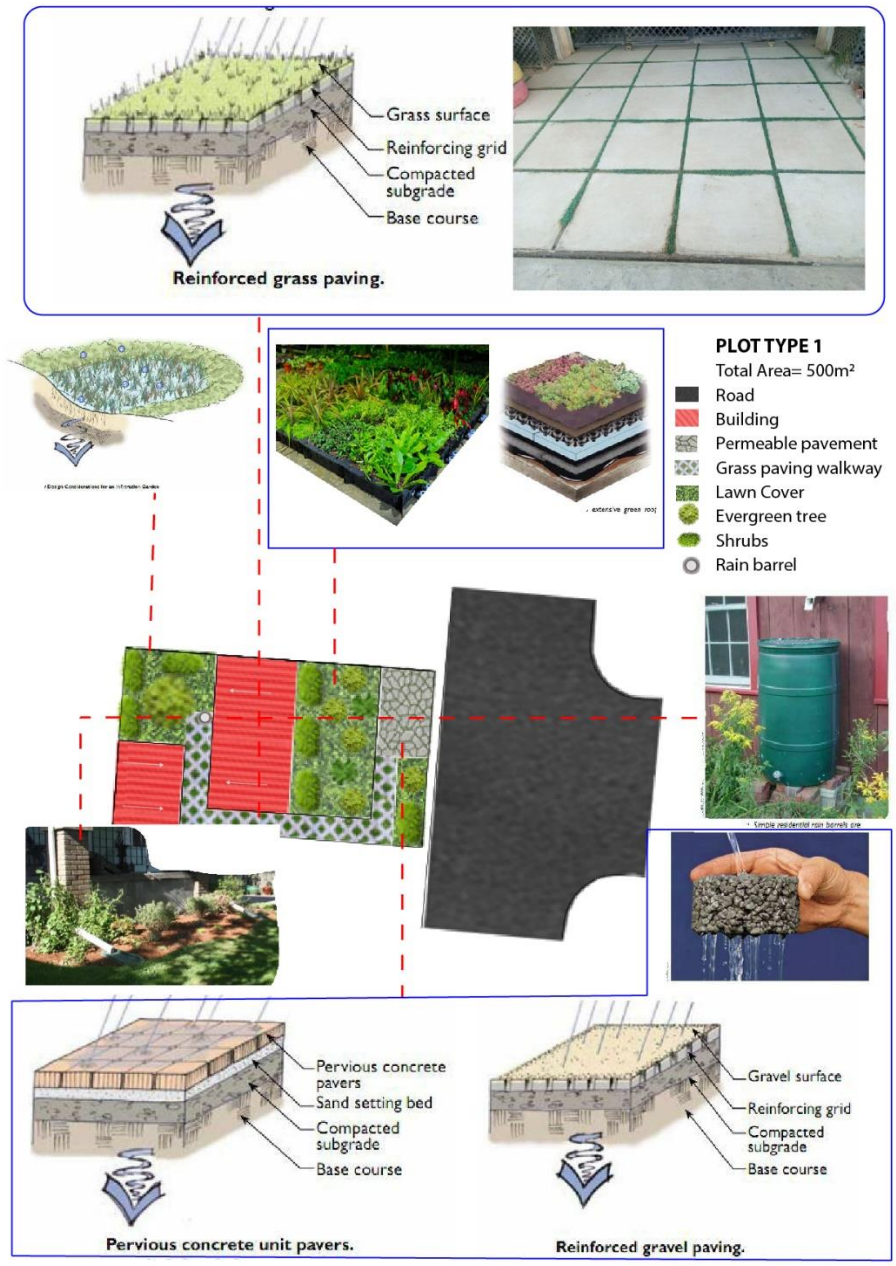

Figure 3-2: Lebu Varnero Apartments 500m^2 plot detailed GI measures (Author, 2020)

After stormwater runoff come out of individual residential plots, it is also necessary to handle the runoff on driveways, walkways, and general open areas of the watershed areas to ensure the continuous reduction of the risk of flooding within the area. The GI mechanisms applied in both study areas, including 3%-sloped green gutters near the pedestrian walkways and pervious pavements for both driveways and walkways, will play a part in enhancing the sustainability of the walkways and driveways and functionality of the open spaces while also being aesthetically pleasing.

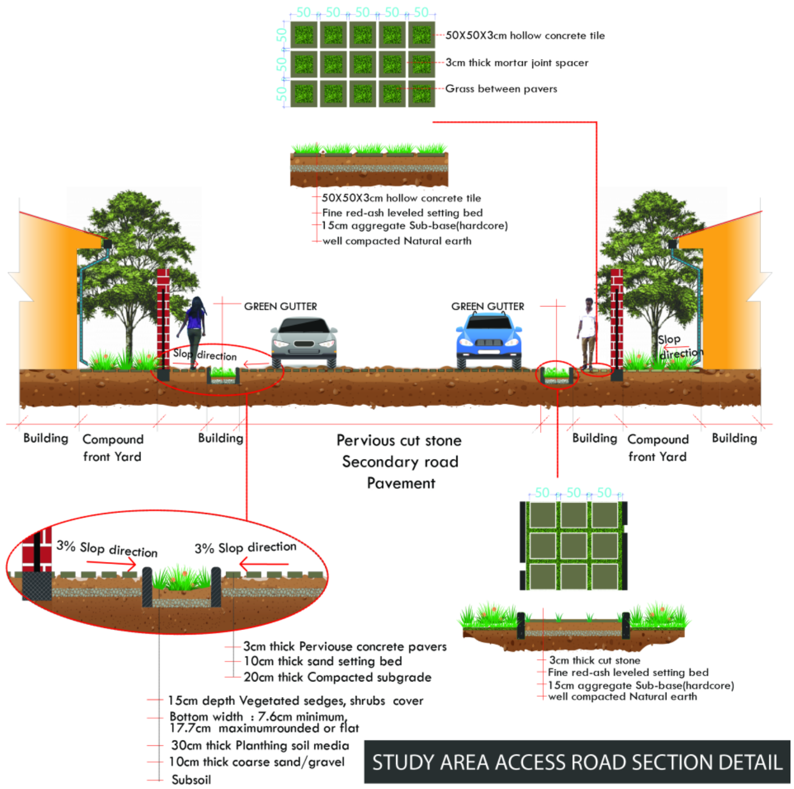

Figure 3-3: Cross-sectional view of proposed driveways and walkways at both watershed areas (Author, 2020)

3.1.2. Watershed area upscale green cover improvement

After controlling the stormwater at the specific residential sites of the two study areas, the leftover stormwater for each plot site will be handled together with the street on the overall watershed area. So based on the study area, observation, and the existing physical characteristics problems, LSM (GI) green street practices such as stormwater trees, bio-retention ponds, roadside vegetated swales, green gutters, and previous driveway and walkways are recommended. At Lebu Varnero Apartments study area, the presence of communal green space enabled the design of a much-developed space that handles runoff efficiently while providing biodiversity and an aesthetically pleasing place useful for any activity.

The open communal space in conjunction with the access roads near it, the adjacent houses, and the walkways were designed in this study to work simultaneously to handle as much amount of stormwater runoff as possible while providing a healthier and comforting space to live in. The implementation of the GI mechanisms proposed in this study is expected to reduce stormwater runoff by more than half, as well as providing residents with an environment filled with an abundance of biodiversity and green structures. The spaces will be both aesthetically pleasing and highly effective at tackling stormwater runoff simultaneously.

Figure 3-4: Views of the communal open space and adjacent streets after implementation of GI mechanisms at Dera Sefer study area (Author, 2020)

3.2.Contribution of LSM in terms of flood reduction as well as green area improvement of the entire local watershed

Before estimating the amount of stormwater runoff that can be reduced by the above-mentioned mitigation strategies, it is first paramount to calculate the amount of runoff that is generated by the existing conditions of the selected case sites of the study.

3.2.1. Stormwater Runoff generated from the existing conditions in selected plots in watershed areas

Here, the calculation for each selected sample plot area of the study area was calculated to identify the amount of runoff generated in each area of both study areas. Hence, using the total runoff amount calculated for each plot, the stormwater runoff generated per day was calculated for both watershed areas.

To do this calculation, the rational method of runoff calculation was used, which is described as Q=(C*i*A*0.0028) (which has been explained in detail in the methodology section)

Hence, the total amount of stormwater runoff generated from the selected plots in the Dera Sefer and Lebu Varnero apartment watershed areas was found to be 1.55547126 m^3 and 1.357358688 m^3 per one hour of rainfall respectively.

From the calculations done, the amount of runoff for each type of part of the plot such as built-up area, vegetation covers, and impervious surfaces (paved areas) was calculated. Hence, the amount of runoff generated from the vegetation covers in Dera Sefer and Lebu varnero apartments study areas is 0.0332514 m^3 and 0.084597408 m^3 per one hour of rainfall respectively.

3.2.2. Stormwater Runoff could be generated after implementation of GI in selected plots in watershed areas

The total amount of stormwater runoff generated in the selected plots from Dera sefer and Lebu Varnero apartment watershed area after implementation of GI mechanisms was found to be 1.0676988 and 0.980236656 m^3 for one hour of rainfall respectively.

With regards to stormwater runoff reduction, the GI mechanisms proposed in this study are estimated to reduce the amount of runoff by an amount of 0.48777246 m^3 and 0.377122032 m^3 per one hour of rainfall for the selected plots from Lebu Varnero apartment and Dera Sefer study areas respectively. Coupled with the upscale watershed level recommendation put forward, the proposed GI mechanisms will improve the green area coverage of the study areas greatly. This will be impactful in ensuring the effectiveness of the implementations and reduction of stormwater runoff.

According to (Zhang et al., 2015), which tried to investigate the changes of urban green spaces in Beijing, China, and estimate their effects on rainwater runoff reduction, showed that runoff reduction rate continuously decreased in conjunction with decrease and composition changes in green spaces throughout the study period. It showed that working on and improving the urban green spaces and infrastructure through recommendation and use of optimal landscape-based solutions improves the stormwater management capacity of the city and reduces urban stormwater runoff. Moreover, at source control of stormwater using stormwater control measures and low impact development are effective in mitigating stormwater flooding in urban catchments, while also mitigating overland flow intensity on roads and reducing building damages (Burns et al., 2015).

4. Conclusions and Recommendations

4.1.Conclusions

The rapid covering of land with impervious surfaces, sacrificing of the natural landscape to give way for towering structures, also, to poorly designed, constructed, and used structures including drainage systems of the city, have been contributing a lot to the Stormwater runoff problems observed in the city. This has given rise to severe flooding in certain parts of the city which has been a recurring scenario every year and creates damage to infrastructure and which can potentially lead to entire environmental degradation. Residential plots of land of the city are one of the sources that contribute significantly to the stormwater runoff.

Hence, by taking specific cases from Arada and Nefas Silk Lafto sub-cities, this study tried to identify opportunities for stormwater runoff reduction through landscape-based stormwater management within individual plots of residential areas of Addis Ababa, while also trying to shed light on the main factors that contribute to stormwater runoff and its mitigation.

Impervious surfaces (including both built-up areas and streets) were observed to cover much of both study areas, due to ever-increasing built-up neighborhoods, which have their impact on stormwater runoff and its management.

Through analysis of the cases, and with the support of relevant literature, the study found that land use and size, imperviousness, soil type, and slope were the major factors that affected stormwater runoff in residential plots and the applicability of GI practices. Furthermore, it was also found that precipitation (rainfall) and current drainage conditions were also seen to affect the GI measure's applicability.

As the main focus of the study was to assess and identify efficient and sustainable landscape-based stormwater management strategies, mitigation mechanisms such as Permeable pavement, Grass Paving walkway, Rain Barrels, Lawn covers, Evergreen trees, and Shrubs were identified, recommended, and designed to help control urban stormwater runoff problem from one of its most significant and contributing sources. Also, LSM strategies such as a Stormwater tree, Bio retention Ponds, Road Side Vegetated Swale, Green Gutter, And Previous Driveway and Walkways were recommended to alleviate stormwater runoff problems in the surrounding open spaces in the neighborhoods in both watershed areas. Also, these mechanisms will increase the green footprint of the area and tackle the observed imperviousness in the residences and the surrounding neighborhoods.

The LSM mechanisms that are proposed in this study are estimated to have a significant contribution to flood reduction through curbing stormwater runoff. The GI mechanisms proposed to handle stormwater is estimated to decrease the stormwater runoff by a significant amount.

4.2.Recommendations

To handle stormwater runoff effectively, due consideration should be given to successfully managing all forms of stormwater runoff. As individual residential plots being one of the major sources of stormwater runoff, the government, policymakers, and other relevant stakeholders should consider the following general recommendations, in addition to the GI mechanisms recommended in this study:

- ✓ Residents near the streams and rivers on the low catchment area, which receive the stormwater runoff generated from sealed surfaces in upper catchment areas, are being increasingly affected by overflowing and subsequent flooding. Hence, stakeholders including governmental and non-governmental organizations, in conjunction with the society, should work together to develop a sustainable solution to alleviate this problem for the residents.
- ✓ As this study only focused on only two specific study areas and could not assess the effect of stormwater runoff from individual residential spaces on either sub-city or city scale, a study to assess this topic on a large scale should be conducted by relevant authorities to assist in drafting future policies and regulations on stormwater mitigation in individual residential plots.

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