



ADDIS ABABA UNIVERSITY
Ethiopian Institute of Architecture, Building Construction
and City Development

**Green Infrastructure Retro-fitting to Protect Urban
Streams from Non-point Source Pollutions**

The case of Sub-watershed around Bole-Egziabheab Church

By
Emebet Tsegaye

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Title of the Thesis: Green Infrastructure Retro-fitting Design to Protect Urban Streams from Non-point Source Pollution

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By
Emebet Tsegaye
ID No. GSR/1130/08

Approved by Examining Board:

	Name	Signature	Date
1	Chairman person <hr/>	<hr/>	<hr/>
2	Advisor Alazar Assefa (PhD) <hr/>	<hr/>	<hr/>
3	External Examiner Dagnachew Adugna (PhD) <hr/>	<hr/>	<hr/>
4	Internal Examiner Hayal Desta (PhD) <hr/>	<hr/>	<hr/>
5	Graduate Program Director Dagnachew Adugna (PhD) <hr/>	<hr/>	<hr/>

I, the undersigned, declare that this thesis is original and work of my own and never been presented for a degree or diploma in other institution or university and that all sources of material used for the thesis have been duly acknowledged following the scientific guidelines of the institute.

Addis Ababa

October 2020

Name: Emebet Tsegaye G/Michael

ID. No. GSR/1130/08

Signature:

Confirmation

I state that, Emebet Tsegaye G/Michael has carried out this research on topic “Green Infrastructure Retro-fitting to Protect Urban Streams from Non-point Source Pollutions: The case of Sub-watershed around Bole-Egziabheab Church” under my supervision and it is sufficient for submission for the partial fulfillment for award of degree of Masters in Urban Design and Development.

Advisor: Alazar Assefa

Signature:

Date:.....

ABSTRACT

Uncontrolled urbanization causes serious quality degradation of surface waters through covering natural land by impervious surfaces that greatly increases the volume and velocity of stormwater runoff as well as transportation of pollutants from point and non-point sources. Therefore, sustainable water management is essential. This study focuses on non-point source pollutants having an objective of identifying Green Infrastructure retro-fitting options to protect the stream water from these pollutants in the localized sub-watershed around Egziabherab church in Bole sub city of Addis Ababa. Both primary and secondary data were consumed for this study. The secondary data include contour map and base map collected from Addis Ababa plan commission, rain fall data from National Meteorological Agency and other related literatures. The primary data were the land use/cover, street surfacing and stormwater sample directly collected from selected sites. Software such as GIS, spread sheet, ArchiCAD, AutoCAD, Scketchup and laboratory taste were used for analysis and designing purpose. The result indicates that Total Suspended Solids exceed the limit of the recommended standard. Applying permeable pavers on private plots, 21–33.3% of the stormwater runoff and 68–86% of Total Suspended Solids generated from the entire development can be reduced. Rainwater Harvesting from roofs of institutional plots can reduce 6.4–9% of the total runoff. 100% of Total Suspended Solids can be reduced by vegetated swale, rain garden and riparian buffer. Generally, green infrastructure retro-fitting should be an integral part of urban plan and design at all scale to reduce runoff volume and improve stream water quality.

Key Words: Green infrastructure, Retro-fitting, Non-point source, Pollutant, water quality

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ACRONYMSAND ABBREVIATIONS

AACRA	Addis Ababa City Road Authority
AALDMO	Addis Ababa Land Development & Management Office
AAU	Addis Ababa University
ATs	Alternative Techniques
BMP	Best Management Practices
CTs	Compensatory Techniques
DEM	Digital Elevation Model
EIA	Environmental Impact Assessment
EiABC	Ethiopian Institute of Architecture, Building Construction and City Development
EPA	Environmental Protection Authority
FDRE	Federal Democratic Republic of Ethiopia
GI	Green Infrastructure
GIS	Geographic Information System
Ha	Hectare
IUWM	Integrated Urban Water Management
NMA	National Meteorological Agency of Ethiopia
SCMs	Stormwater Control Measures
SDG	Sustainable Development Goals
SQIDs	Stormwater Quality Improvement Devices

SUD	Sustainable Urban Design
SUDS	Sustainable Urban Drainage Systems
UGI	Urban Green Infrastructure
UN	United Nations
UNEP	United Nations Environmental Programme
USA	United States of America
USGS	United States Global Survey
WSUD	Water Sensitive Urban Design

1. INTRODUCTION

Urbanization affects the natural water cycle and both the surface and ground water quality through deforestation, increasing sealed surface and pollutant discharge from different sources. As a result of this, cities like Addis Ababa face problems like water scarcity, flooding, reduced biodiversity and ultimately threatening human wellbeing. Therefore, applying small scale GI retro-fitting strategies at the local watershed level to protect rivers from pollution is manageable and effective to take part in alleviating this problem.

Addis Ababa is the main city of Ethiopia as well as a seat for African Union, a habitat to one-fourth of the urban population. Even though three quarters of the Earth's surface is water, only 2.8 percent of it can be consumed by human beings as fresh water (Iskandar, 2010).The UNEP report of 2002 indicates that the worldwide freshwater consumption increased six fold between the years 1900 and 1995 which is more than twice the rate of population growth (UNEP, 2002).

In addition to this, it is estimated that 83% & 53% of the developed and developing world respectively will be dwellers of urban areas by 2030(Cohen, 2004). In line with this, globally there is lack of potable water supply, poor sanitation facility and little emphasis or practice on stormwater management. For example: 3 in 10 people lack access to safe drinking water, 6 in 10 people lack safe sanitation facility and only 59% of all wastewater is safely treated (UN, 2018).Between 2000 and 2015, the proportion of global population accessing safe drinking water facilities increased from 61 to 71 per cent (UN, 2019).Contrary to water scarcity, for the past 50 years flood-related disasters in Africa showed an increasing trend and since 1981, and floods account about 50% of the disaster recorded in Sub-Saharan Africa (UN, 2018).Unlike the presence of water in different forms

and sources, surface waters (rivers, streams, and lakes) have been the most available sources of water for household use in the developing countries especially in Sub-Saharan Africa but these sources are contaminated by pollutants from different sources (Ayeni, 2014). The other problem is an increase in runoff/flooding due to an increase of sealed surfaces caused by urbanization. For example, in Europe between 1980 and 2000, the spread of built-up areas increased by 20% while population density only rose by 10% (Rodriguez, 2014).

In Ethiopia, the spatial distribution of water resources is uneven throughout the country with respect to climatic situations and geographic factors. For instance, between 80-90% of the water resource is found in the four river basins namely, Abay, Tekeze, Baro-Akobo, and Omo-Gibe in the west and south-western part of the country where only 30 – 40% of the population of the country, is facing recurrent flooding as a development challenge. Urban flooding is more increased dramatically in impervious areas, in addition to heavy rainfall and extreme climatic changes (Derege & Hyeonium , 2016). But, the urbanization impact is more dominant when it is compared with the climate change impact and the combined effect will be much more severe, which intensifies the risk of flooding (Derege & Hyeonium , 2016). Addis Ababa has several rivers, which are the tributary of Akaki River, which flows into lake Aba-Samuel in the southern fringe areas of the city. They used to be key sources of water for household and industrial uses of the city but newly contaminated as a result of rapid urban expansion coupled with poor solid and liquid waste management system. For example, 2256 m³ or 851 tons of solid waste is generated of which 76% comes from households, 18% from institutions, commercial centers, factories, and hotels; and the rest 6% from street sweeps. Among this 65% is collected and dumped into

dump site, 5% is recycled, 5% is composted and the rest 25% is not collected properly. Moreover, about 4 million m³ of wastewater is emanated from industrial discharge, and 49 million m³ from toilets, kitchens, barns and other domestic area. All these in turn contribute to contamination of the water bodies. Worku & Giweta stated the situation saying that

“Can we Imagine Pollution Free Rivers around Addis Ababa City, Ethiopia?”

(Worku & Giweta, 2018).

The rapid urbanization causes soil sealing and river water pollution (Ali, 2012). The soil sealing produces numerous environmental impacts such as loss of flora and fauna, degradation of the landscape, inhibition of the infiltration of rain water, reduction the evapotranspiration and increases stormwater runoff, increases absorption of solar energy and heightening the urban Heat Island, and so on (Rodriguez, 2014). Furthermore, the pollution of the river water causes loss of aquatic plants and animals, increases prevalence of water borne diseases, environmental pollution, worsens the quality of water sources, etc. Therefore, it is very important and timely to intervene to improve the health of urban river water to improve water supply and management, environmental quality, aesthetic of the city, well-being of the people, and minimize the impact of flooding; to make the city more resilient in general.

Since green infrastructure retro-fitting is a recent practice globally, in Addis Ababa green infrastructure is being used for a single purpose, not well integrated with grey infrastructure, less attention is given them to make them multi-functional. and more efficient.

1.1 Background

“Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services.” (UN, 2019)

Therefore, green infrastructure was established for several purposes including environmental, economic and social benefits. The presence of well-designed green infrastructure protects river water from being polluted by different pollutants from different sources carried by stormwater. The site under study has some green infrastructures planted within compounds as well as few parts of the streets aiming to aesthetics and shading purpose only. The Addis Ababa city green infrastructure development and beautification office is also working on planting street trees in walkways, street medians, roundabouts plus dedicated areas for greenery. The main objective of this institution is protecting aesthetics and atmosphere. This indicates that the relationship between green infrastructure and stream water quality is not considered. As all rivers of Addis Ababa the river under study is seriously polluted, has bad odor, no aquatic plant or animal in it. Besides this the water in the rivers is not serving for any purposes since its pollution level is very serious. There is also a discrepancy between demand and supply of potable water; the demand exceeds the supply. The same potable water is being used for non-potable purpose such as gardening, car washing cleaning of compounds etc. which aggravates the scarcity of water.

1.2 Problem Statement

In most developing countries, including Ethiopia, huge volumes of discharges of untreated wastewater released into water bodies. The situation accompanied with uncontrolled

urbanization and inadequate sanitation which emanate from the increasing human population causes serious quality degradation of surface water (Worku & Giweta, 2018). Similarly, as all rivers of Addis Ababa the tributary of big Akaki within the sub-watershed under study which is found around Egziabherab church in Bole sub-city is also seriously polluted, has bad odor, unpleasant, not used for any purpose and has no living thing in it due to pollutants that emanate from different sources.

The Environmental Protection Authority of Ethiopia (EPA) states that water resource management ensures social equity, economic efficiency, systems reliability and sustainability. However, based on its recent establishment and limited experience the focus of the Ethiopian EIA is limited only in few sectors (Agriculture, Industry and Transport) particularly on projects with big size and sensitivity to the environment. For example, a scheme with a dam and reservoir is more likely to require an EIA than a runoff river scheme (FDRE, 2001). This low implementation level and narrow scope of EIA accompanied with low or poor practice of sustainable urban design resulted in less emphasis on water resource management practices. In other words, only little of the point sources of contaminants are addressed by EIA whereas the non-point sources which have influence on river water quality are not taken into consideration.

There are few research works related to Water Sensitive Urban Design conducted by graduate students of EiABC. Some of these include academic researches that mainly focused on designing stormwater management in institutional compounds for non-potable water demand to reduce water scarcity(Kagnew, 2016), evaluating the capacity of bio-retention for stormwater management in institutional compounds(Dufer, 2018), designing water sensitive urban design around lakes(Wossen, 2018) and improving quick

deterioration of cobble-stone paved local streets(Fikreselam, 2016). But, the influence of urbanization and urban land uses on the contamination of water bodies and how to improve the situation is not yet studied. Therefore, this study tries to identify the potential pollutants from non-point sources in dense urban catchments like Addis Ababa, evaluate their contribution and identification of site-specific GI retro-fitting options to reduce non-point source water pollutants in urban areas particularly in a sub-watershed around Bole Egziabherab.

1.3 Objectives

1.3.1 General objective

To identify GI retro-fitting options to improve the quality of stream water in Addis Ababa particularly in a sub-watershed of tributary of great Akaki river around Bole Egziabherab church.

1.3.2 Specific objectives:

1. To identify the runoff volume and potential pollutants generated
2. To evaluate the contribution of different land use &land covers in increasing runoff and pollution level of urban stream water
3. To identify and propose appropriate types GI retro-fitting option to reduce stormwater runoff volume and pollutant entering into local stream
4. To integrate the identified GI retro-fitting into the existing urban fabric without compromising the public safety and aesthetic performance of urban spaces.

1.4 Research question

1. How much volume of stormwater runoff, and what kind of pollutants generated from the sub-watershed under study?
2. To what extent different land use & land covers contribute to increased runoff volume and degradation of stream water quality within the study sub-watershed?
3. What types of GI retro-fitting are appropriate to moderate runoff volume and pollutants entering into the local stream within the study sub-watershed?
4. How can the selected GI solutions fit into the existing urban fabric without compromising the public safety and aesthetic performance of urban space?

1.5 Significance

The main focus of the research is to realize the contribution of the existing land uses in stormwater runoff and stream water quality in a sub-watershed around Bole Egziabherab church having the following significance.

- It will provoke the interest of decision-makers and stakeholders about the contribution of pollutants from non-point sources in urban areas.
- It will serve as a base for those who are interested in studying more on pollutants from non-point sources and initiate designers and planners to consider and integrate stormwater management elements as the integral part of their design and plan.
- It will help the community in providing safe living environment, taking part in making urban stream water useable and improving flooding as well as water scarcity.

1.6 Scope of the Study

Spatially the research covers the entire land and built-up area within the sub-watershed under study. The thematic scope is restricted in analyzing the impact of the existing land use within the sub-watershed on runoff volume and stream water quality from urban hydro-ecological design and planning perspective.

2. LITERATURE REVIEW

The quality of natural resources and their services have been significantly degraded by increased urban populations, sprawl of settlements, development of transportation networks and industrial activities. The poor water quality in the river system is attributed as cause for health problems of developing countries like Ethiopia. For example in Ethiopia, 60%- 80% of transmissible diseases are recognized to inadequacy of safe water supply for sanitation and hygiene. To alleviate this problem, the approach known as Sustainable urban development (SUD), the management of cities with adequate infrastructure to support the needs of its population for the present and future generations as well as maintain the sustainability of its ecosystems, is introduced. In line with this, Urban Green Infrastructure (UGI), an Ecological approach aims to develop networks of green and blue spaces in urban areas, designed and managed to deliver a wide range of ecosystem services and other benefits at all spatial scales is one of the aspects of SUD that helps to ensure the resilience of natural resources and ecosystems. (Hansen et al, 2017)

2.1 Stream Water Quality in Urban Area

Water Pollution in Urban Areas

Urbanization is creating a very high proportion of impervious area that significantly altered the hydrology and ecology of urban streams. Water is fundamental for sustainable development and it is important for socio-economic development, health of the ecosystems and for survival of all living things including human itself (UN-Water, 2014). The consumable freshwater on Earth is limited and its quality is under constant pressure due to human intervention as urbanization grows. Similarly, urban rivers that were offering many kinds of services to the dwellers as well as to the environment are increasingly in danger.

It is difficult to imagine a pollution-free river in Addis Ababa due to the uncontrolled urbanization triggered by the rapid economic development, population growth, and poor urban planning land development practices throughout the city (Worku & Giweta, 2018). This situation in turn affects not only the water quality but also aquatic habitats and public health (Worku & Giweta, 2018).

Even though three quarters of the Earth's surface is water, only 2.8 percent of it can be consumed by human beings as fresh water (Iskandar, 2010). The UNEP report of 2002 indicates that the worldwide freshwater consumption increased six fold between the years 1900 and 1995 which is more than twice the rate of population growth (UNEP, 2002).

In addition to this, it is estimated that 83% & 53% of the developed and developing world respectively will be dwellers of urban areas by 2030 (Cohen, 2004). In line with this, globally there is lack of potable water supply, poor sanitation facility and little emphasis or practice on stormwater management. For example: 3 in 10 people lack access to safe drinking water, 6 in 10 people lack safe sanitation facility and only 59% of all wastewater is safely treated (UN, 2018). Between 2000 and 2015, the proportion of global population accessing safe drinking water facilities increased from 61 to 71 per cent (UN, 2019). Contrary to water scarcity, for the past 50 years flood-related disasters in Africa showed an increasing trend and since 1981, and floods account about 50% of the disaster recorded in Sub-Saharan Africa (UN, 2018). Unlike the presence of water in different forms and sources, surface waters (rivers, streams, and lakes) have been the most available sources of water for household use in the developing countries especially in Sub-Saharan Africa but these sources are contaminated by pollutants from different sources (Ayeni, 2014). The other problem is an increase of runoff/flooding due to an increase of sealed

surfaces caused by urbanization. For example, in Europe between 1980 and 2000, the spread of built-up areas increased by 20% while population density only rose by 10% (Rodriguez, 2014).

In Ethiopia, the spatial distribution of water resources is uneven throughout the country to respect to climatic situations and geographic factors. For instance, between 80-90% of the water resource is found in the four river basins namely, Abay, Tekeze, Baro-Akobo, and Omo-Gibe in the west and south-western part of the country where only 30 – 40% of the population live while only 10 - 20% of the water resource is available in the east and central river basins where the population accounts about 60% (FDRE, 2001).

Sources of Water Pollutants

Water pollutants in urban area emanated from both point and non-point sources. Point source pollution comes from specific points like industrial and sewage treatment plants. Whereas non-point source pollution generally comes from many point sources and results from non-point sources like land runoff, rainfall, atmospheric deposition, drainage, leakage or hydrologic alteration(EPA Victoria, 2019).

Types of Water Pollutants in Urban Areas

Toxic substances that come from different point sources like industrial treatments and pollutants from urban runoff destroy habitats, kill native vegetation, foul drinking water and make recreational areas unsafe and unpleasant(EPA Victoria, 2019). Among these pollutants, the common knowns from urban runoff include sediment, oil, grease, toxic chemicals from motor vehicles, pesticides and nutrients from lawns and gardens, viruses, bacteria and nutrients from pet waste and failing septic systems; road salts and heavy metals from roof shingles, motor vehicles and other sources; and thermal pollution from

impervious surfaces such as streets and rooftops (EPA Victoria, 2019). See Table 2 below for details by category.

Table 1: Sources of Contaminants in Urban Stormwater Runoff

No	Contaminant	Contaminant Sources
1	Sediment and floatables	Streets, lawns, driveways, roads, construction activities, atmospheric deposition, drainage channel erosion
2	Pesticides and herbicides	Residential lawns and gardens, roadsides, utility right-of-ways, commercial and industrial landscaped areas, soil wash-off
3	Organic materials	Residential lawns and gardens, commercial landscaping, animal wastes
4	Metals	Automobiles, bridges, atmospheric deposition, industrial areas, soil erosion, corroding metal surfaces, combustion processes
5	Oil and grease/ hydrocarbons	Roads, driveways, parking lots, vehicle maintenance areas, gas stations, illicit dumping to storm drains
6	Bacteria and viruses	Lawns, roads, leaky sanitary sewer lines, sanitary sewer cross-connections, animal waste, septic systems
7	Nitrogen and phosphorus	Lawn fertilizers, atmospheric deposition, automobile exhaust, soil erosion, animal waste, detergents

Source: Nationwide Urban Runoff Program (US EPA, 1993)

Transportation of Pollutants to Water Bodies

Stream water pollutants can be transported to water bodies either by over flow or sub-surface flow. Those that are transported by overland flow corridors into receiving river include all suspended sediments, nutrients in the particulate phase including particulate phase of phosphorus. Whereas those that can be transported by subsurface flow include finer sediments, dissolved nutrients, nitrogen and phosphorus. But, mobilized salts can be transported in both ways the proportioning of which depends on specific landscape a feature (Lintern et al, 2018). Similarly, the proportion of dissolved nutrients in the subsurface flow pathway depends on landscape characteristics (Lintern et al, 2018).

Relationship between Impervious Area and Stream Water Quality

Different researchers witness that evaluated watershed imperviousness can help as a predictor of hydrologic, physical, chemical, habitat and biotic stream health indicator (Schueler, 2000,WP, 2003, Schueler & et al, 2009).The relationship between Total Impervious Area (TIA) and stream water pollution is summarized in the following table.

Table 2: Total Impervious Area Impact on Water Quality

No	Total Impervious Area (TIA)	Category	Remark
1	<10%	Sensitive	Excellent
2	10%–25%	Impacted	Very good
3	25–60%	Non-supporting	Fair
4	>60%	Urban drainage	Poor

Source: (Schueler, 2000)

From this, it is possible to understand that the concept of quantification of impervious area for restoration planning and as a guide for determining the potential to meet GI retrofit goals within existing stormwater impaired streams.

Besides, as the impervious area increases the base flow water temperature which has significant influence on aquatic plants and animals as well as human being using the water.

The following figure illustrates the relation between impervious area and water temperature.

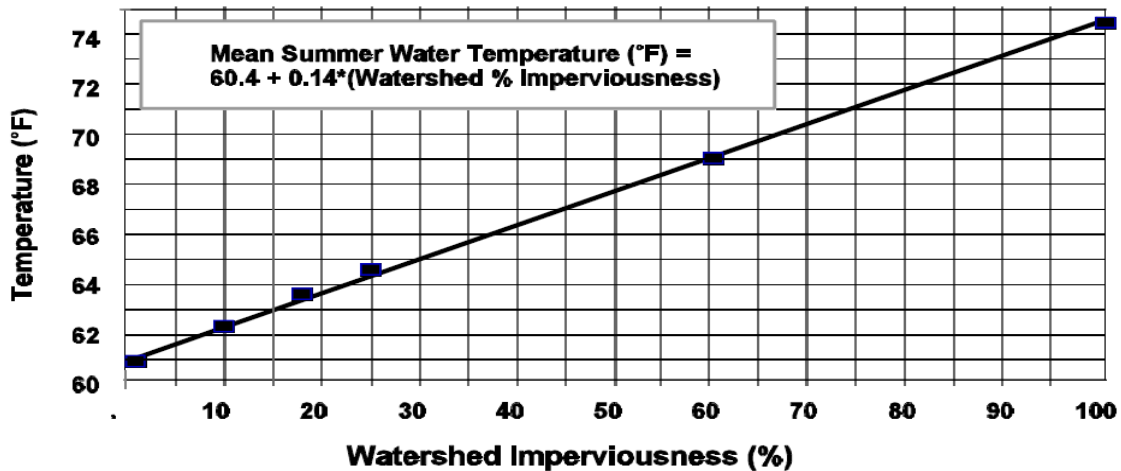


Figure 1: Relationship between Watershed Imperviousness and Base flow Water Temperature

Moreover, the increase of impervious area increases runoff volume, peak flow, peak duration, temperature and pollutant loading which in turn results in loss of habitats. Details are presented in Table 4 below.

Table 3: Impacts of Increase in Impervious Surfaces

Increased Imperviousness Leads to:	Resulting Impacts				
	Flooding	Habitat loss	Erosion	Channel widening	Stream bed alteration
Increased Volume	✓	✓	✓	✓	✓
Increased Peak Flow	✓	✓	✓	✓	✓
Increased Peak Duration	✓	✓	✓	✓	✓
Increased Stream Temp.	☐	✓	☐	☐	☐
Decreased Base Flow	☐	✓	☐	☐	☐
Changes in Sediment Loading	✓	✓	✓	✓	✓

Source: (EPA, 1997)

2.2 The contribution of Urban Land Use for Stream Water Quality

The Correlation between Landscape Characteristics and Water Pollution

As Lintern (2018) reported, the slope of undeveloped area, rainfall in developed area and diffused sources have direct/positive correlation with water pollution level (see figure 5 below).

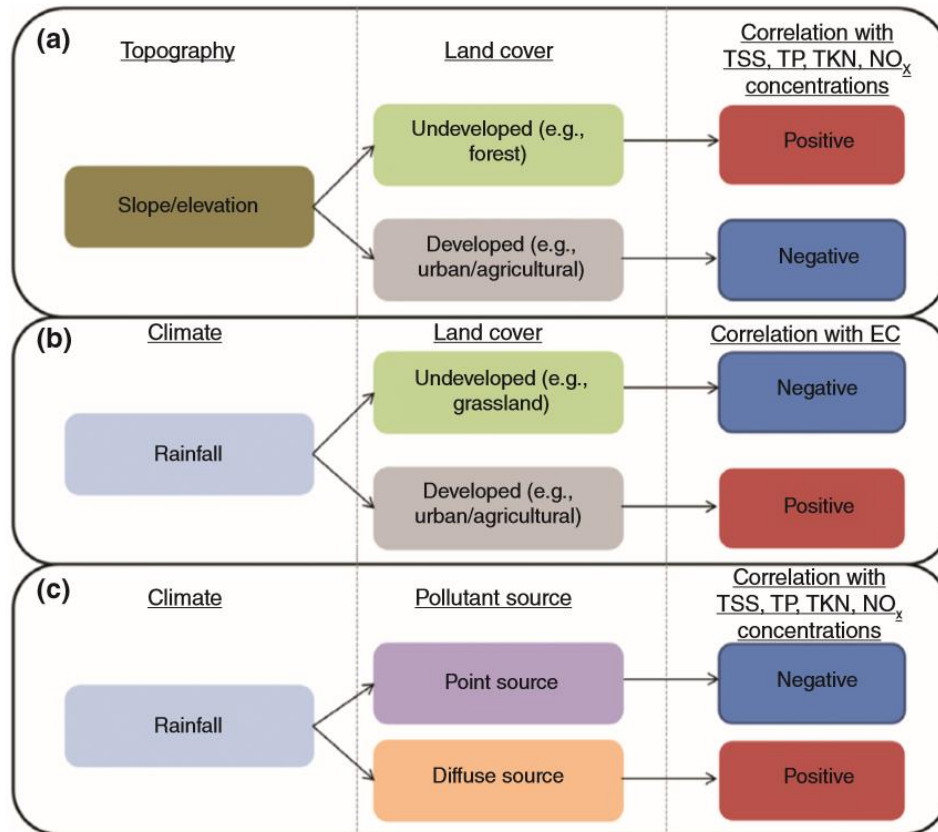


Figure 2: Interaction between Landscape Characteristics and Pollutants (Lintern et al, 2018)

The Influence of Land Cover and Land Use

Land Cover

Land cover is the amount and type of vegetation present in a certain catchment area. Soil nutrient levels within catchments can decrease due to the uptake of bioavailable phosphorus and nitrogen by terrestrial vegetation in the catchment and aquatic plants within the water body itself (Reddy et al, 1999). In addition to this, vegetation cover also affects the mobility of water pollutants from their source to the receiving water body.

Land Use

The degree and type of human actions in the catchment (i.e. the land use) can influence the concentration of pollutant sources (Lintern et al, 2018).

Industrial and farming land uses usually produce excessive concentration of sediment, nutrients, and salts in the form of discharge of wastewater, and the application of manure and fertilizers on lawns and parks also polluting streams and create atmospheric deposition of greenhouse gases in urban areas. Similarly, salts can also be contained in domestic wastewater. Besides this, land use and land cover also influence the delivery of suspended sediments, nutrients, and salts from the catchment to rivers and streams.

A decrease of vegetation increases integral delivery due to reduction of channels and surface roughness (Lintern et al, 2018). The decreased surface roughness of the urban areas increases the runoff velocity of stormwater runoff and lower sediment trapping capacity and biogeochemical transformations of pollutants before reaching the receiving water body. As a result of this, the concentration of sediments and nutrients will be very high in the stormwater reaching the river or stream. The connectivity between the catchment and receiving water body with impervious drainage networks also inhibits removal of contaminants by infiltration or evapotranspiration, accelerates runoff velocity and increases the concentration of sediments and nutrients reaching the receiving water body (Lintern et al, 2018).

Factors Affecting the Pollutant Concentration

The landscape characteristics consist land cover, land use, land management, atmospheric deposition, geology and soil properties, climate and topography have their own influence on mobilization of pollutants from their sources to the receiving water body. Catchment hydrology can also play a significant role in the delivery of constituents of pollutants from the catchment to receiving waters. The following figure illustrates that the impact of

different landscape characteristics on the concentration of pollutants in their source, their mobility to the water body and arrival to the water body.

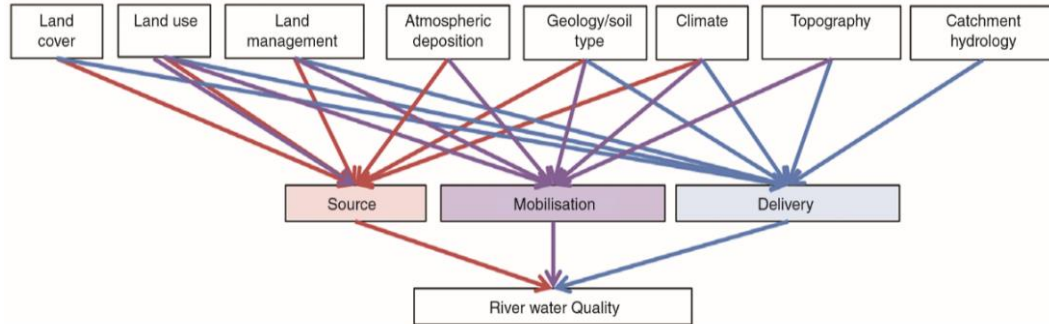


Figure 3: Influence of Landscape on Source, Mobilization & Delivery of Pollutants (Lintern et al, 2018)

In general, EPA of United States summarized the average pollutant concentration in different land uses of urban areas as indicated in the following table.

Table 4: Median Event Mean Concentrations for Urban Land Uses

Pollutant	Unit	Residential		Mixed		Commercial		Open Non-Urban	
		Median	cov	Median	Cov	Median	cov	Median	cov
BOD	mg/l	10	0.41	7.8	0.52	9.3	0.31	...	....
COD	mg/l	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/l	101	0.96	67	1.14	69	0.85	70	2.92
Total Lead	µg/l	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper	µg/l	33	0.99	27	1.32	29	0.81	...	...
Total Zinc	µg/l	135	0.84	154	0.78	226	1.07	195	0.66
Total Kjeldahl Nitrogen	µg/l	1900	0.73	1288	0.5	1179	0.43	965	1
Nitrate + Nitrite	µg/l	736	0.83	558	0.67	572	0.48	543	0.91
Total Phosphorus	µg/l	383	0.69	263	0.75	201	0.67	121	1.66
Soluble Phosphorus	µg/l	143	0.46	56	0.75	80	0.71	26	2.11

COV = Coefficient of variation

Source: Nationwide Urban Runoff Program (US EPA, 1993)

Table 5: Fecal Coliform Concentrations in Urban Land Uses

Type of Land Use	Median (MPN/100 ml)	Range (MPN/100 ml)
1. Unpaved driveways and storage areas	26	0.02 – 300
2. Roof runoff	16	0.56 -2.6
3. Sidewalks	55	19 -90
4. Paved parking and driveways	2.8	0.03– 66
5. Paved roads	19	1.8 – 430

Note: MPN= Most Probable Number

The other significant result observed is that there is variation between the Ethiopian standard (mandatory pollutant limit) and EPA standard. For example the Recommended or Mandatory Limit Values of BOD in Surface Water Regulations of USEPA is 2mg/l while it is 80mg/l in the Ethiopian draft document. The limit of TSS in the Ethiopian case is 100mg/l whereas in the case of USEPA it is unstated.

Table 6: Limit Values for Discharges to Water

Industry	Temperature	pH	BOD₅ at 20°C	COD	Suspended solids
Tanning and Leather Finishing	40 °C	6 – 9	90% removal or 200 mg/l, whichever is less	500 mg/l	50 mg/l
Manufacture and Finishing of Textiles	40 °C	6 – 9	90% removal or 50 mg/l, whichever is less	-----	30
Production and Processing of Iron and Steel	40 °C	6 – 9	-----	-----	20 mg/l

Industry	Temperature	pH	BOD₅ at 20°C	COD	Suspended solids
Metal Working, Plating and Finishing	40 °C	5.5 – 9.5	-----	-----	25 mg/l
Base Metal and Iron Ore Mining	40 °C	6 – 9	25 mg/l	150 mg/l	50 mg/l
Malting, Brewing, Distilling, Production of Wines and Other Alcoholic Liquors	40 °C	6 – 9	90% removal or 60 mg/l, whichever is less	90% removal or 250 mg/l, whichever is less	50 mg/l
Manufacture of Dairy Products	40 °C	6 – 9	90% removal or 60 mg/l, whichever is less	90% removal or 250 mg/l, whichever is less	50 mg/l
Manufacture of Sugar	40 °C	6 – 9	90% removal or 60 mg/l, whichever is less	90% removal or 250 mg/l, whichever is less	50 mg/l
Slaughtering Meat Processing and Rendering	40 °C	6 – 9	90% removal or 80 mg/l, whichever is less	90% removal or 250 mg/l, whichever is less	80 mg/l
Timber Preservation	40 °C	6 – 9	-----	80% removal or 150 mg/l, whichever is less	100 mg/l
Phosphate Fertilizer plants	40 °C	6 – 9	-----	-----	50 mg/l
Ammonium Sulphate Plant	40 °C	6 – 9	49 mg/l	-----	50 mg/l
Pulp and Paper	40 °C	6 – 9	90% removal or 50 mg/l, whichever is less	75% removal or 300 mg/l, whichever is less	50 mg/l
Cement Manufacturing	-----	6 – 9	25 mg/l	150 mg/l	50 mg/l

Industry	Temperature	pH	BOD₅ at 20°C	COD	Suspended solids
Petrochemical Manufacturing	40 °C	6 – 9	90% removal or 50 mg/l, whichever is less	75% removal or 200 mg/l, whichever is less	50 mg/l
Pesticide Manufacturing	40 °C	6 – 9	90% removal or 50 mg/l, whichever is less	75% removal or 200 mg/l, whichever is less	20 mg/l
Pesticide Formulation	40 °C	6 – 9		75% removal or 250 mg/l, whichever is less	30 mg/l
Pharmaceutical Manufacturing	40 °C	6 – 9	90% removal or 50 mg/l, whichever is less	75% removal or 250 mg/l, whichever is less	30 mg/l
Printing and Surface Coating	40 °C	6.5 – 10	90% removal or 50 mg/l, whichever is less	75% removal or 250 mg/l, whichever is less	50 mg/l
Summary	41 °C	6 – 10	90% removal or 25 mg/l - 200 mg/l,	75% - 90% removal or 150 mg/l - 500 mg/l	20 mg/l - 100 mg/l

Source: Provisional Standards for Industrial Pollution Control in Ethiopia, draft document.

As can be seen in the table above, the limit value of a pollutant allowed to be discharged to the rivers varies from one industry to the other in the case Ethiopia. For instance the limit of BOD focuses on 90% removal which varies from 25 mg/l for Base Metal and Iron Ore Mining and Pulp and Paper industry up to 200mg/l for Tanning and Leather Finishing

industry. And COD limit for Tanning and Leather Finishing is 500 mg/l while for Cement Manufacturing industry 150mg/l. similarly, total suspended solid limit value ranges from 20 mg/l for Pesticide Manufacturing up to 100 mg/l for Timber Preservation.

2.3 GI retro-fitting to prevent Pollutants from Non-point Sources

Parameters of Water Quality

There are many sources of water quality criteria and standards which originated from member States of the European Union, or adopted by the Council or Parliament of the EU, or by individual countries, or issued by international bodies. The US EPA has compiled water-based standard upon its classification (EPA, 2001). The requirements of water quality differ according to its use such as for industrial use, for drinking, for boilers and so on. But, the ultimate objective of the imposition of standards is the protection of the end uses. In the present context, the main considerations are in regard to safeguarding public health and the protection of the whole aquatic environment (EPA Victoria, 2019).

Criteria for Surface Water Quality Classifications

According to EPA, surface water is classified into five classes based up on their uses and standards are summarized as follows.

Table 7: Criteria for Surface Water Quality

No	Pollutant type	Occurrence/Origin	Health/Sanitary Significance	Recommended or Mandatory Limit Values (Surface Water Regulations)
1	BOD	Naturally occurring trace element. Used in cleaning compounds and in alloys.	Excessive amounts of boron can cause nervous problems; danger to crops when present in irrigation water at the 1 - 2 mg/l concentration range	2 mg/l
2	COD	Faecal coliforms originate in human and animal waste. Total coliforms include faecal and also other bacteria with similar properties which originate in soil and are non-faecal.	Indicators of possible presence of pathogenic micro-organisms	1,000mg/l
3	Cu	Ores; industrial wastes.	Copper is not particularly toxic to humans (indeed, it is an essential dietary requirement) and medicinal doses up to 20 mg/l. However, astringent tastes in water can be caused by levels above 1 mg/l Cu.	0.05mg/l
4	NH ₃ -N	Oxidation of ammonia: agricultural fertilizer run-off	Hazard to infants above 11 mg/l N [50 mg/l NO ₃]	50mg/l
5	Pb	Leaching from ores; effluent discharges; attack on water pipes.	Toxic cumulative poison	0.05mg/l

No	Pollutant type	Occurrence/Origin	Health/Sanitary Significance	Recommended or Mandatory Limit Values (Surface Water Regulations)
6	TKN	Principally from organic matter naturally present (e.g. from peat, falling leaves etc.) or added in discharges	No direct significance but parameter is an indication of the overall purity of a water.	1mg/l
7	TP	Natural or added organic matter (wastes, vegetation etc.).	Indirect - indicates overall water quality	0.2 mg/l for salmonid and of 0.4 mg/l for cyprinid waters
8	TSS	Natural and added solids present in water	Primarily of organoleptic concern	.....
9	Zn	Natural geological occurrence and from wastes	Inhalation of zinc-containing fumes can cause a variety of physiological effects, but principal significance of excessive amounts in water is that emetic effects occur.	3mg/l

Source: (EPA, 2001)

Improving Urban Stream Water Quality

The technology development, transfer, adoption and dissemination as well as the integration of scientific methods with indigenous and local knowledge are important to minimize water scarcity and quality (Mulatu Wubneh, 2019). But, the implementation of appropriate technologies is limited not only in developing countries but also in high-income countries.

Even though the concepts and functionalities are similar, the approach to sustainable water cycle management and integrated urban water management has different naming in different parts of the world. It is referred as WSUD, best management practices, LID (low impact development), GI (green infrastructure), sustainable urban drainage systems, and low impact urban design and development (Ashok et al, 2019).

The term Low Impact Development (LID) has been most commonly used in North America and New Zealand and it attempts to minimize the cost of stormwater management, by taking a “design with nature approach” (Fletcher et al, 2015). Moreover, it was characterized by small scale stormwater management like bio-retention, green roofs and swales located near the source of runoff (Fletcher et al, 2015). Even though its scope and definition varied throughout time, finally its use was codified in legislation and became mainstream (Fletcher et al, 2015). Water Sensitive Urban Design (WSUD) is also a term that began to be used in the 1990s in Australia having an objective of managing the water balance and enhancing water quality, encouraging water conservation and maintaining water-related environmental and recreational opportunities (Fletcher et al, 2015).

Sustainable Urban Drainage Systems (SUDS) or Sustainable Drainage Systems (SuDS) is also another term that has been used in countries like UK and England concerning water quality and quantity.

There are also other terminologies used to express the concept with a slight variation in scope and point of interest such as integrated urban water management (IUWM), Best Management Practices (BMP), Stormwater Control Measures (SCMs), alternative techniques (ATs) or compensatory techniques (CTs), Source control, Green Infrastructure (GI) and Stormwater Quality Improvement Devices (SQIDs). The overall evolution of the

concept of urban drainage and its scope from 1960 through 2013 is summarized in the figure below.

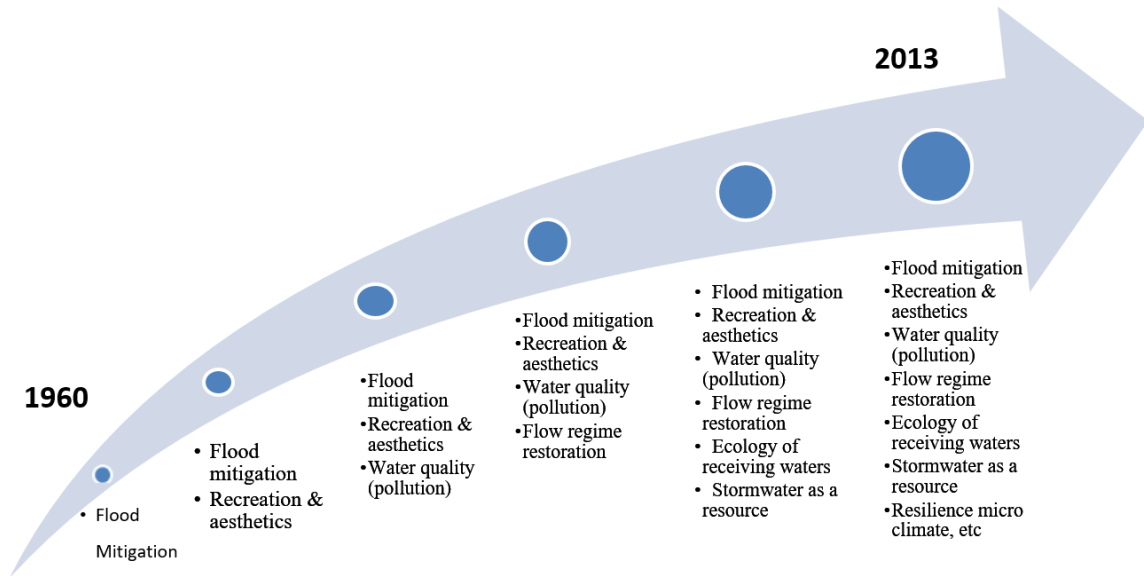


Figure 4: Evolution of Terminologies related to Drainage

Green infrastructure retro-fitting

The report of World Bank 2010 indicates that the size of cities will double and add 400,000 square kilometers of built-up area by 2050. The traditional stormwater management system was just collecting and conveying stormwater away from its source through “grey infrastructure” such as ditches, manholes, underground piping. That practice caused serious flooding and erosion towards downstream. To tackle these problems, green infrastructure is first discussed as the central approach in the late 1990’s and implemented in the UK, Western Europe and North America. It is a recent approach and has become a stronger component of any resilience plan. But so far it has not been holistically tried as a part of retro-fitting (Hazarika & Sharma, 2016)

Even though, Africa is astonishingly urbanizing. Review of research papers entitled with “Urban green infrastructure and ecosystem services in sub-Saharan Africa” conducted on 68 papers, 20 countries and 74 urban areas indicates that Africa has less practice of green infrastructure retro-fitting. Only 38% of sub-Saharan countries had any research carried out in them. As can be seen in the following figure, among these the highest number of papers are conducted in South Africa and the others have less number of papers conducted in this area (Toite tal, 2020).

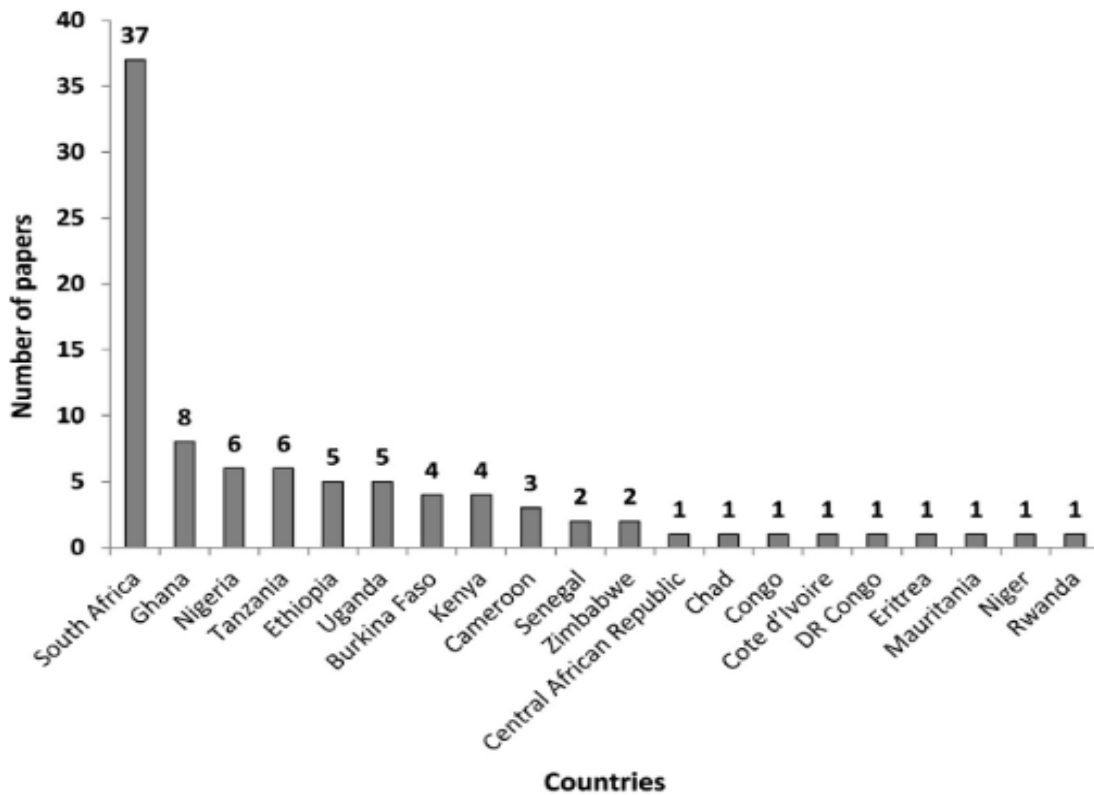


Figure 5: Countries and Number of Research Papers Conducted on Green Infrastructure (Toite tal, 2020)

Among the reviewed literature, the majority are conducted recently particularly after 2013. The following figure best illustrates it.

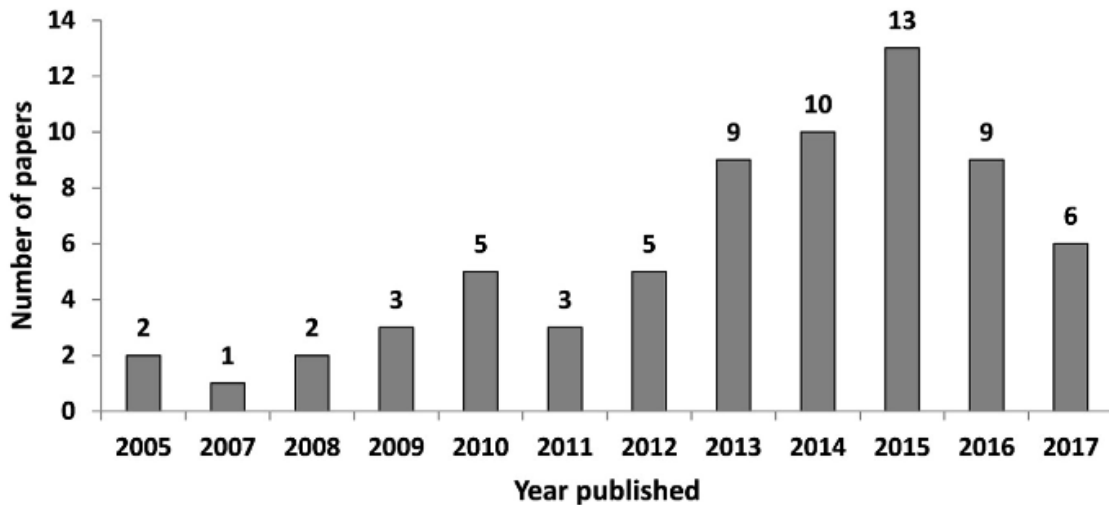


Figure 6: Number of Research Papers Conducted on Green Infrastructure and Year of Publication (Toite tal, 2020)

In the case of Ethiopia the issue of green infrastructure retro-fitting is too young since a program known as “The Resilient Cities Program” first launched in December 2013 by the World Bank Group. It has an intension to help cities strengthen their ability to prepare for and adapt to changing conditions, to withstand and recover rapidly from disruptions caused by climate change, natural disasters and other shocks and stresses (World Bank, 2015). In addition to this, the existing green spaces of Addis Ababa were designed for mono-function and they are not integrated with the grey structure (Girma etal, 2019). The master plans of Addis Ababa were vague about the role of green infrastructure, outdated before finalized and inefficient to cope up with the fast urbanization. The report indicates that the adaptive capacity for retaining green infrastructure is weak, the awareness of green infrastructure potential is emerging and retaining green infrastructure has limited power in daily management of urban development (Herslund etal, 2018).

The land use of Urban Green Infrastructures of Addis Ababa, from 2003 to 2016 is decreased by 9.2%. The city’s park per capita was very small (0.37 m²) compared to

Ethiopian UGI standards (15 m²) and above 90% city's population has no access to existing parks (Aragaw, 2020).

Installation of treatment plants for each point source pollutants in their origin can resolve their impact on stream water impairment. But, this cannot assure the health of the stream water unless the pollutants that emanate from non-point sources be managed well. According to EPA, the expected pollutants from non-point sources of urban area are sediments, particulate and dissolved nutrients and salts (EPA Victoria, 2019). Even though GI retro-fitting is situation dependent, based on the existing land use, topography, soil type, climate, land ownership, appropriate GI retro-fitting can help to mitigate the problem of urban stream water impairment. Some of LID or WSUD technologies are permeable pavements, infiltration systems, bio-filters, constructed wetlands, and rainwater tanks, etc (EPA Victoria, 2019). Some of these are described below.

DCIA Reduction

Directly Connected Impervious Area (DCIA) reduction has a potential of improving water quality that are polluted by stormwater and reduction of stormwater runoff volume (Malinowski & et al, 2018). The potential of DCIA reduction of different land uses is summarized in the table below.

Bio retention in landscaped areas, medians, and roundabouts

Bio retention, which is sometimes known as rain gardens or bio infiltration, is taken from mimicking of natural hydrology by infiltrating and evapotranspiring stormwater runoff and has aesthetics value(LID, 2019).It is ideal to collect runoff from rooftop, yards and walkways. It is also good for collecting runoff from roads and small parking lots and

appropriate for an intermediate scale intervention is suitable for residential and commercial settings (Chelsea et al, 2015).

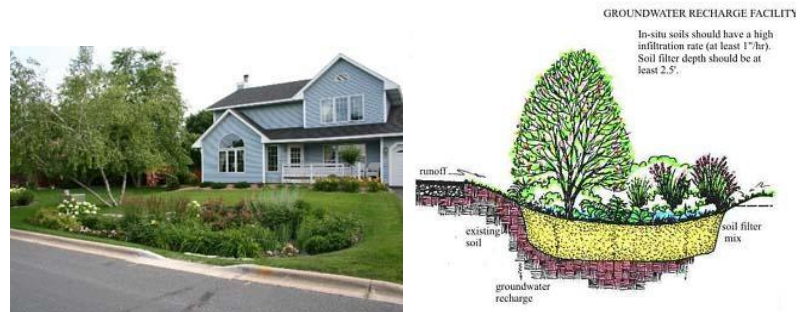


Figure 7: Rain Gardens (LID, 2019)

The result obtained from different researches indicate that the reduction of runoff volume and peak flow rate using bio-retention systems range from 40% to 97% and in a recent field study, a retrofit bio-retention cell was shown to reduce by 97% and 99% flow volumes and rates from a parking lot (Laurent et al, 2012).

The pieces of literatures reviewed on the effectiveness of low impact development indicates that a large number of studies also have credited bio-retentions as a best management practice capable of reducing up to 99% of sediment and nutrient losses. For example: 84% to 50% of TN and TSS, respectively, were retained by the bio-retention systems. Other studies reported up to 76% reduction for TSS, between 70% and 85% of phosphorus (P), and 55% to 65% of Total Kjeldahl Nitrogen (TKN) using bio-retention facilities. Mixing newspaper with the sand layer in a bio-retention cell improved NO₃-N reduction to 80% removal. Average heavy metal reduction in bio-retention ranges from 30% to 99% (Laurent et al, 2012).

Bio-swales

These are vegetated and mulched channels that retain stormwater and treat it. They are best applicable along streets and in parking lots.



Figure 8: Bioretention cell schematic (LID, 2019)

Swales slow runoff velocity and improve water quality and their average retention varies between 14% and 98% for nutrients and TSS, and up to 93% for metals. In addition to this, its pollutant removal efficiency will be improved when it is filled with dense and fully developed vegetation. For example, swales have been shown to trap 99% of TSS, TP, TKN, TN, and Fe at the field scale (Laurent et al, 2012).

Permeable pavement

Permeable pavements can be used in parking lots, alleys, walkways and some open circulation areas and help to reduce stormwater runoff volume and improve stream water quality by temporarily storing surface runoff and allowing slow infiltration into the subsoil (EPA Victoria, 2019). The average runoff reduction from porous pavements varies between 50% and 93% 3

.(Laurent et al, 2012). Moreover, permeable pavements and concrete grid pavers were able to retain up to 6 mm of rainfall with no runoff and permeable pavements can also eliminate runoff generation and many studies reported that its average TSS and nutrients removal capacity ranging up to 94%(Laurent et al, 2012).

Green roofs

Green roof is building rooftop partially or completely covered with vegetation over high quality waterproof membranes (EPA Victoria, EPA Victoria, 2014). It is also named as

vegetated roof cover, eco-roof or nature roof. It helps to alleviate the effects of urbanization on the quality of stream water by purifying, absorbing or detaining rainfall. It also controls runoff volume, improves air and water quality, and promotes conservation of energy and its average rainfall retention varies between 20% and 100% (Laurent et al, 2012).

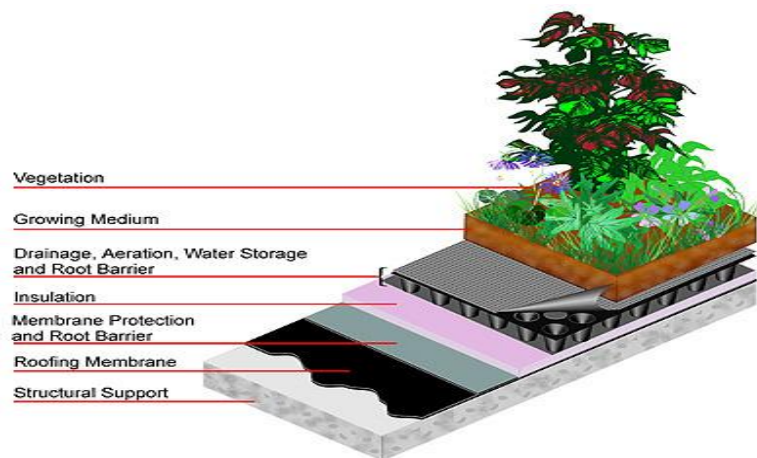


Figure 7: Typical Green Roof (LID, 2019)

Benefits of LID Technologies

Anne Guillette, LEED Accredited Professional, summarized the benefits of LID technologies as follows on the website known as Low Impact Design Studio (the former Low Impact Development Center). Their major benefits are stormwater peak flow reduction, volume reduction, water quality improvement and water conservation. A single technology can have one or more benefits from these as summarized in Table below (Guillette, 2016).

Table 8: LID Practices and Benefits

LID PRACTICE / DEVICE	PEAK FLOW CONTROL	VOLUME REDUCTION	WATER QUALITY IMPROVEMENT	WATER CONSERVATION
Bioretention Cell	•	•	•	
Cistern	•	•		•
Curbless Parking Lot Islands	•	•	•	
Downspout Disconnection	•	•	•	
Grassed Swale	•	•	•	
Green Roof	•		•	
Infiltration Trench	•	•	•	
Narrow Road Design	•	•	•	
Permeable Pavers/Pavement	•	•	•	
Rain Barrel	•	•		•
Rain Garden	•	•	•	
Sand Filter	•		•	
Tree Box Filter	•		•	
Tree Planting	•	•		

Source: (Guillette, 2016)

Another study by Chelsea and his group members indicates that the effectiveness of LID techniques in removal of pollutants as illustrated in the table below.

Table 9: Estimated percent removal efficiency of LID techniques

LID Type	TP	TN	TSS
Green roof	0	0-91%	0-93%
Porous pavement	25-50%	0-42%	68-86%
Bioretention/rain garden	0-42%	0-58%	69-89%
Vegetated swale	0	0-32%	6-65%

Source: (Chelsea et al, 2015)

2.4 GI retro-fitting into the existing urban fabric

In order to control the identified potential pollutants in the target area, they should be fitted to the existing urban fabric without negatively affecting their function and aesthetics, the wellbeing of the dwellers as well as the sustainability of the city. The selected GI and their ideal location have been illustrated in the following table.

Table 10: Appropriate Site Selection Criteria

No	Selected Technology	Appropriate Site
1	Rain barrel	Ideal for collecting rooftop runoff
2	Porous pavement	Ideal for highly developed areas: parking lots, driveways and low-volume roads
3	Rain garden	Ideal for collecting rooftop runoff and runoff from yards, sidewalks, roads and small parking lots
4	Vegetated swale	Ideal for collecting sheet flow runoff from roads, highways and runoff from subdivisions
5	Riparian buffer	Ideal for land directly adjacent to streams and rivers

Source: (Chelsea et al, 2015)

To make the approach more sound combining green and grey infrastructures (Green-grey integration), creating green space networks (Connectivity), delivering and enhancing multiple functions and services (Multi-functionality) and collaborative and participatory planning (Social inclusion) should be taken as principles.

3. RESEARCH METHODOLOGY

3.1 Description of the study area

Addis Ababa is located at the center of Ethiopia and inside Awash River drainage basin. The city's stormwater drain by a number of rivers and streams which flow either to big Akaki or little Akaki rivers which both jointo the greater Akaki River system. The sub-watershed under study is situated in the watershed of big Akaki that covers the eastern part of the city and the total area is about 198.11ha. The following figure illustrates the location of the study area.

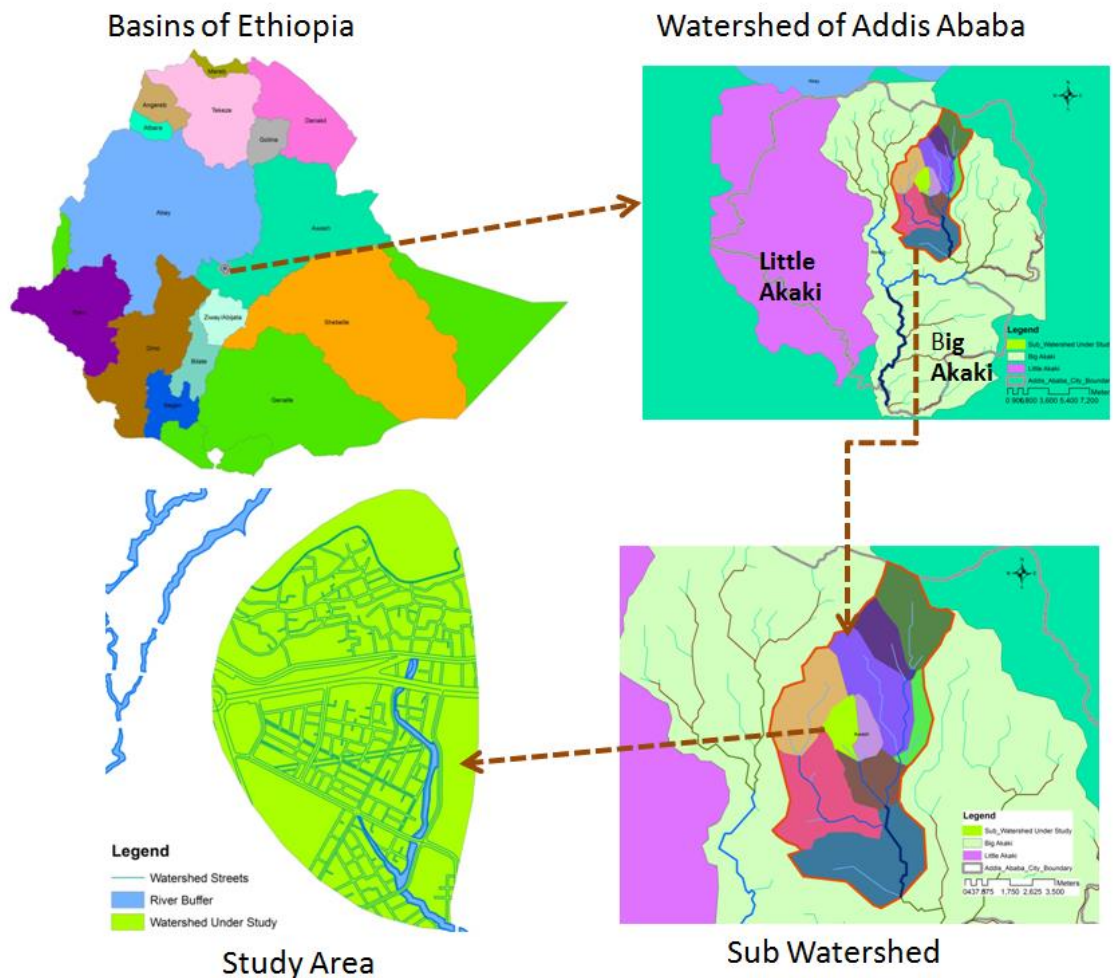


Figure 8: Location map of the study area

3.2 Data Type

Both secondary and primary data have been used for this research. The secondary data collected include contour map/DEM, base map, 30 years (1989-2018) rainfall data, different related literatures reviewed. The primary data include the land use/land cover data, road surfacing data collected through site observation and stormwater sample collected from purposively selected sites for laboratory taste.

3.3 Data Source

The contour map and base map of the area is collected from Addis Ababa Plan and Development Commission and the DEM is obtained from United States Global Survey web site. The rainfall data is collected from National Meteorological Agency of Ethiopia. The revised related literatures are obtained from different web sites such as science get and other scientific journal publishing sites. The primary data are collected through site observation and manually collecting the storm water.

3.4 Sampling Design

Concerning the sampling technique, several sub-watersheds of great Akaki river was generated using contour map of Addis Ababa using Arc GIS software. Among the generated sub-watershed that is near Egziabher church has been selected purposively since it is near to the researches resident to minimize transport cost and make easy repeated site observation with limited manpower, time and budget. Then the entire land uses in the sub-watershed was considered to estimate the runoff volume and the type of pollutants generated from the sub-watershed. Refer, the analytical procedure illustrated in figure-2 below

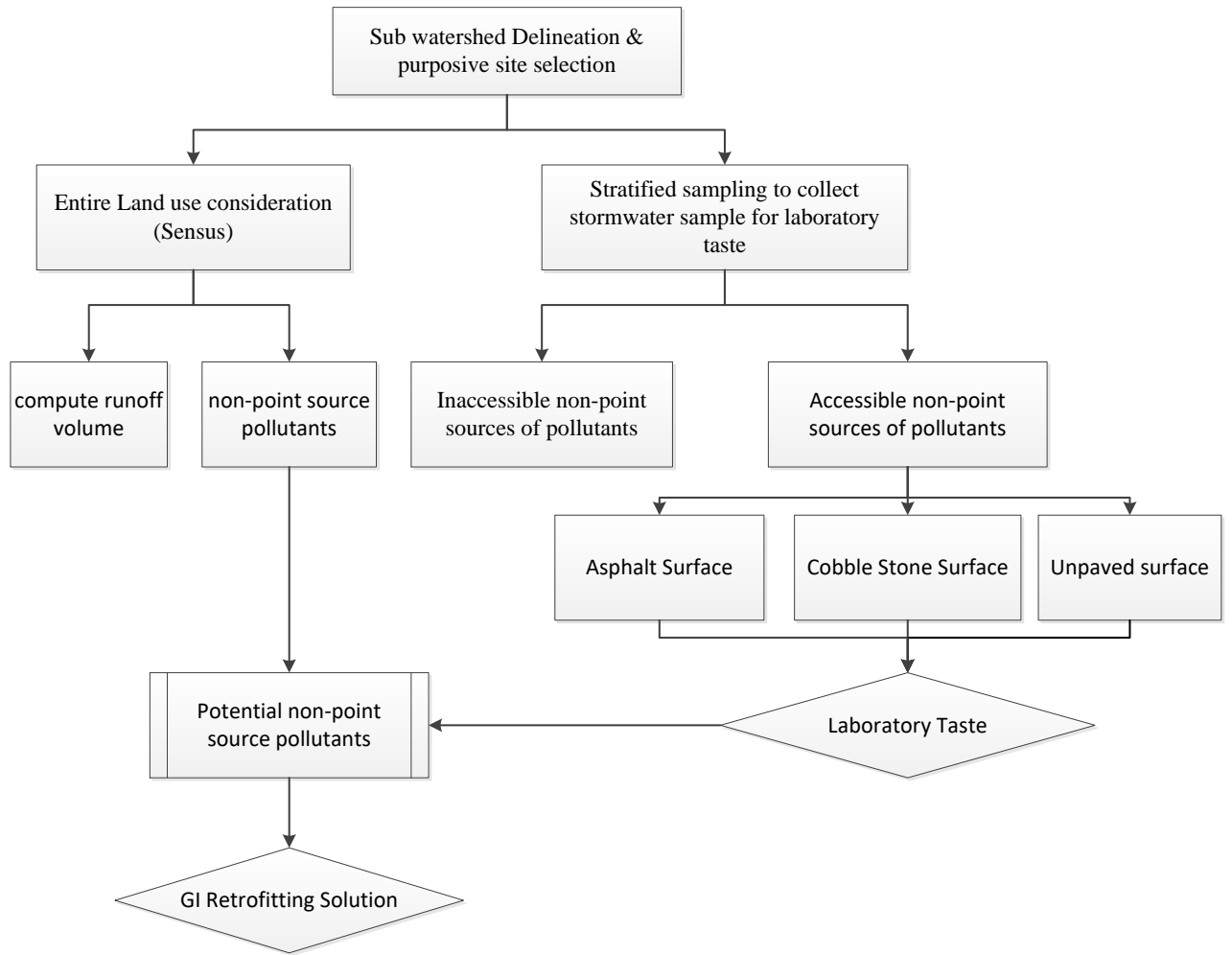


Figure 9: Sampling design and procedure

Since different urban source areas contribute disproportionate amounts of pollutants to receiving waters. It's important to target source control efforts that prevent pollutants from entering stormwater runoff. Hence using group sampling technique the site has been divided into three categories based on its cover. Then two sampling areas are selected from each category. And the samples are collected manually.

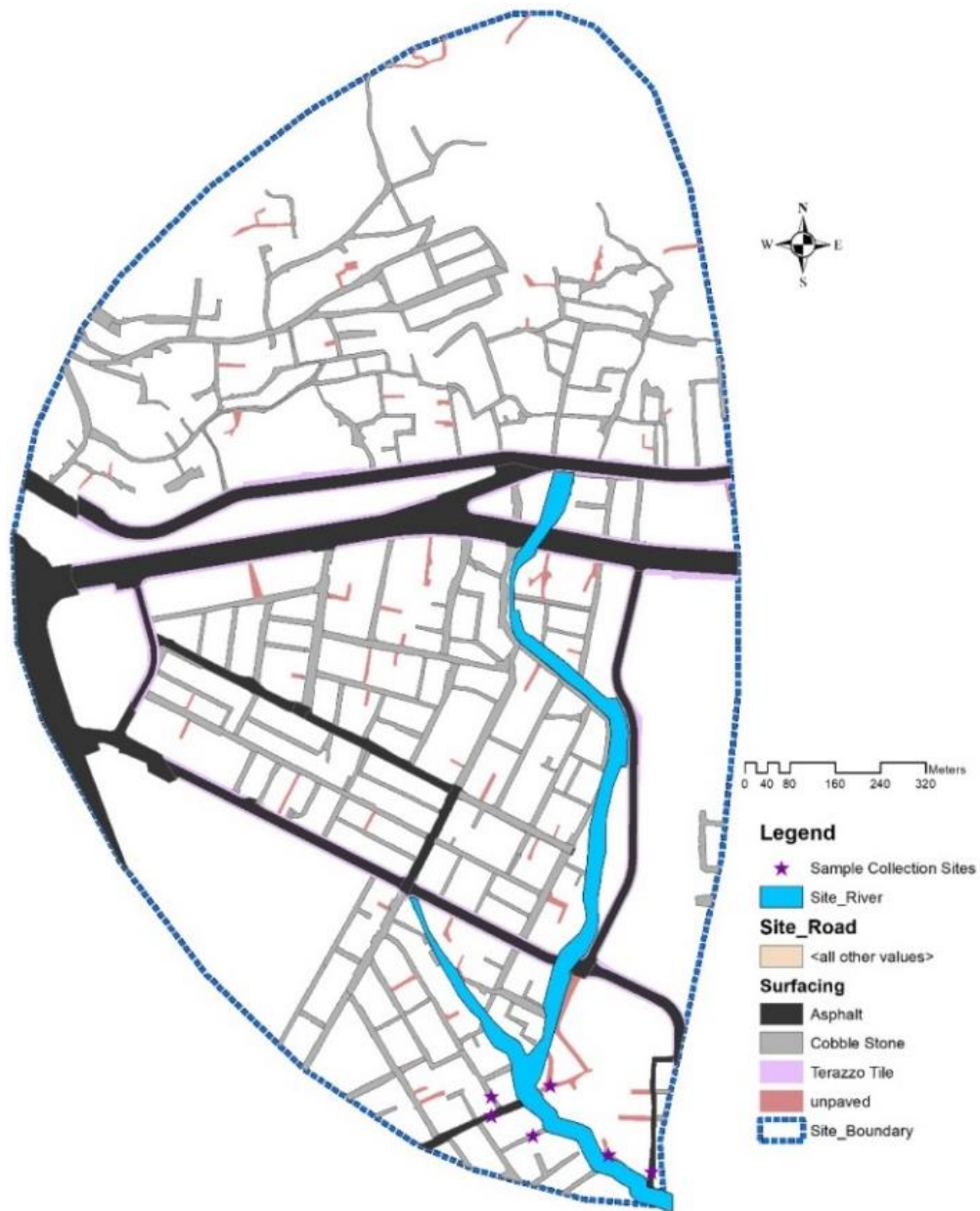


Figure 10: Sample Collection Sites

To make the sample representative and reliable

- The samples were collected before entering into the nearby ditch.
- The samples were collected after at least 24 hours of no measureable precipitation occurred prior to the storm event.
- Samples were collected through the entire event, including first flush up to the last flash since Pollutant concentrations vary during a storm event.
- Multiple samples were collected from similar sources throughout the storm.
- To reduce sampling and taste costs, samples from multiple source areas (of the same type) are combined into one sample before lab taste.

3.5 Methods of Data collection

The contour and the base map of Addis Ababa were collected from Addis Ababa Plan Commission/Land Development and Management office through questionnaire. Then using the contour/DEM from USGS, GIS software has been used to delineate the spatial scope of the study area. In addition to this, the collected base map of the area overlaid on Google earth to update the built-up area and paved roads. Moreover, site observation has been held to actualize the land use, land cover and the surfacing of the streets for the evaluation of the imperviousness level of the site and runoff volume. Besides this, the 30 years (1989-2018) precipitation data of the area has been collected from National Meteorological Agency of Ethiopia (NMA) for the computation of the runoff volume from the study area.

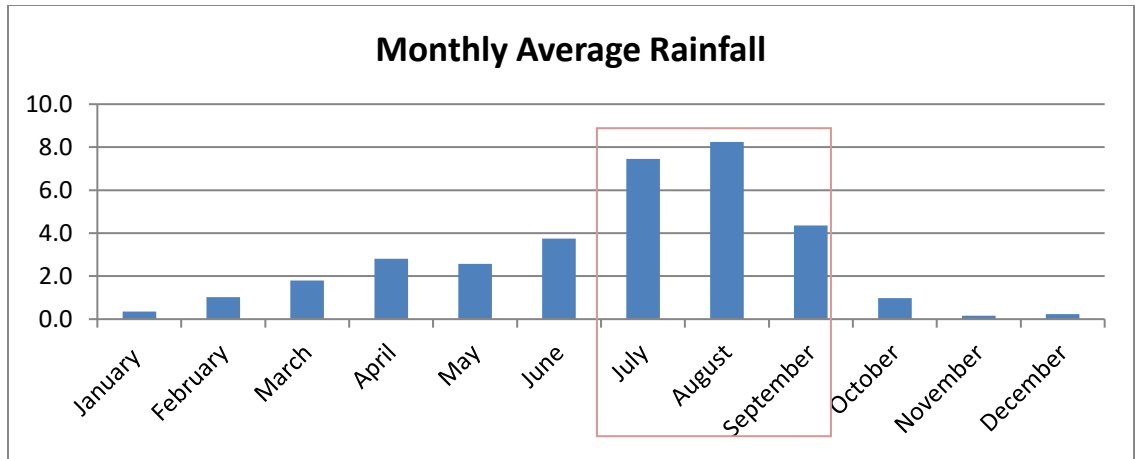


Figure 11: Average monthly rainfall

Based on the 30 years data of rainfall obtained from National Metrological Agency, the highest rainy months of the year are July, August and September and the average daily maximum precipitation has been computed using spreadsheet (XL) and ranked. The first two ranks have 60 and 20 years of return period and the third one is 61.7mm with 9 year of return period and the average annual rainfall is 996.9mm. These selected figures have been taken into consideration for all required computation as well as designing of the proposed GI.

Table 11: Maximum Daily Precipitation of Study Area

Year	Maximum Precipitation	Rank	Frequency of Occurrence	Return Period
1989	48.4	13	41.7	2
1990	37	23	75.0	1
1991	59.6	8	25.0	4
1992	44.3	16	51.7	2
1993	40.6	18	58.3	2
1994	38.2	19	61.7	2
1995	64.7	2	5.0	20
1996	52	10	31.7	3
1997	37.3	21	68.3	1
1998	60.1	6	18.3	5
1999	37.8	20	65.0	2
2000	47	14	45.0	2
2001	32.4	27	88.3	1
2002	28.6	29	95.0	1
2003	34.6	25	81.7	1
2004	29	28	91.7	1
2005	44.5	15	48.3	2
2006	61.7	4	11.7	9
2007	71.2	1	1.7	60
2008	37.2	22	71.7	1
2009	51.2	11	35.0	3
2010	54.4	9	28.3	4
2011	36.9	24	78.3	1
2012	64.7	2	5.0	20
2013	42.6	17	55.0	2
2014	27.2	30	98.3	1
2015	60.5	5	15.0	7
2016	33	26	85.0	1
2017	49.1	12	38.3	3
2018	60	7	21.7	5

Source: (NMA of Ethiopia, 2019)

To identify the types of pollutants from non-point sources and evaluate their impact on stream water quality, different literatures were downloaded from different important websites and reviewed.

In addition to this, stormwater sample has been collected from purposively selected sites of non-points sources of pollutants for laboratory taste to check the pollutant type and concentration level that flow to the nearby stream.

Table 12: Data collection methods and tools

No	Specific objectives	Types of data	Source of data	Collection methods	Instrument used	Analysis
1	To identify the runoff volume and potential pollutants generated within the study sub-watershed area.	Map, contour, DEM, Land use of the area, literatures and sample of stormwater	USGS, Plan commission/ AALDMO, selected sample collection sites	Digitizing by using GIS, site observation & lab taste	Computer, A3 size map, templates Laboratory instruments	Categorizing land use/land cover calculating runoff volume, and identifying pollutants
2	To evaluate the contribution of different land use/ land covers in increasing runoff and pollution level of urban stream water within the study sub-watershed area.	Secondary data from literatures and laboratory taste	Books, journals and research articles from library and internet	Browsing and reading & lab taste	Computer Laboratory instruments	Summarizing the key findings of reviewed literatures according to the theme of the study
3	To identify and propose appropriate types GI retro-fitting option to reduce stormwater runoff volume and pollutant entering into local stream within the study sub-watershed.	Secondary data from literatures	Books, journals from library and internet	Browsing and reading	Computer	Prioritizing
4	To integrate the identified GI retro-fitting into the existing urban fabric without compromising the public safety and aesthetic performance of urban spaces	The updated & actualized Land use Map	AALDMO, Google Earth, and site observation	Overlaying, digitizing	Computer (AutoCAD, GIS, Sketch Up)	Designing

3.6 Method of analysis and Presentation

Digital Elevation Model (DEM) with 12x12 meters resolution obtained from the United States Global Survey (USGS) and the 1m contour map of Addis Ababa has been obtained from Addis Ababa Plan and Development Commission. Using the DEM, the entire watershed area of Addis Ababa, big Akaki River and sub-watershed areas were generated using Arc GIS software. The sub-watershed under study has been selected purposively due to proximity for data collection and frequent observation for missing data. The imperviousness levels of the streets and the land use/land cover within the study sub-watershed categorized using a combination of an aerial photograph of the site, Google Earth imagery, and site visit. Runoff volume estimated based upon analyzed on spreadsheet using 30 years (1989-2018) rainfall data collected from the National Meteorological Agency (NMA) of Ethiopia. Then identification of potential non-point source pollutants on the stream water that is generated from the impervious surfaces conducted using comparative analysis study from universally accepted standards on the contribution of different types of urban land surfaces from different pieces of literature. The sample stormwater collected has been tested in laboratory to identify the concentration of different pollutants. For example for heavy metals Double Acid Digestion +ICP-OES Determination method was used; for TSS Gravimetric method was used. Finally, possible GI based retrofitting strategies and design options identified and adapted to the context of the study sub-watershed. The result has been presented in the form of maps, tables, figures and discussion. Refer, the analytical procedure illustrated in figure-3 below

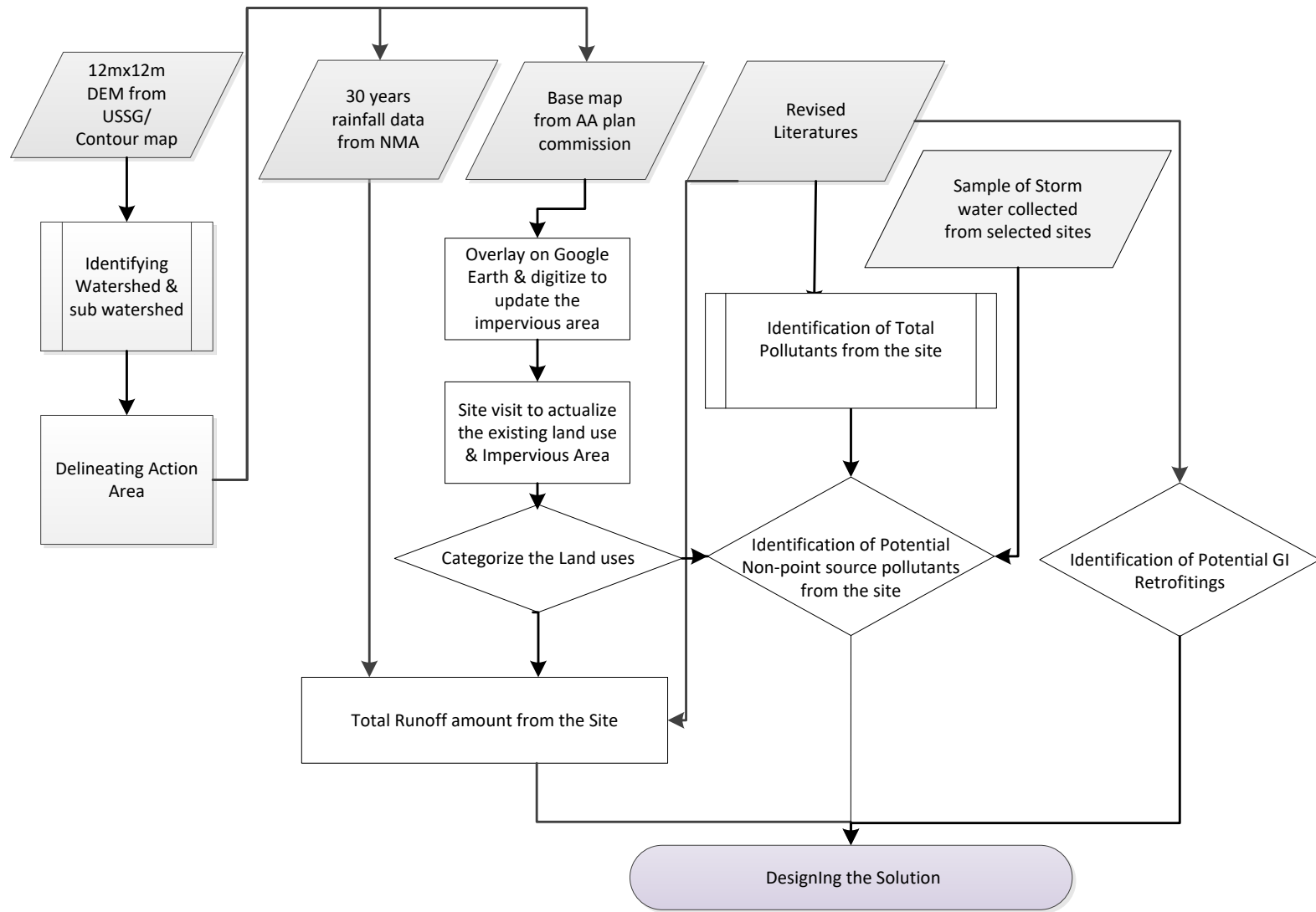


Figure 12: Analysis method

4. RESULT & DISCUSSIONS

4.1 Runoff and Pollutants Generated from the Study Area

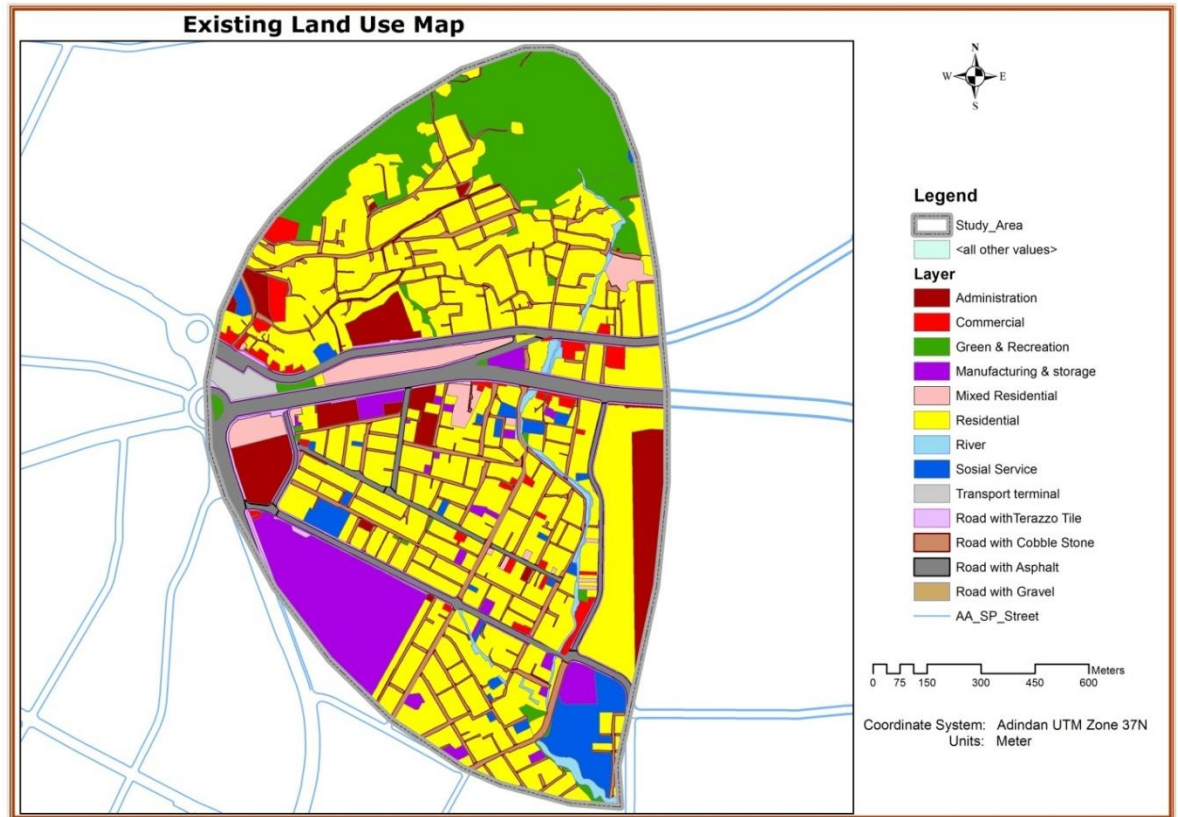
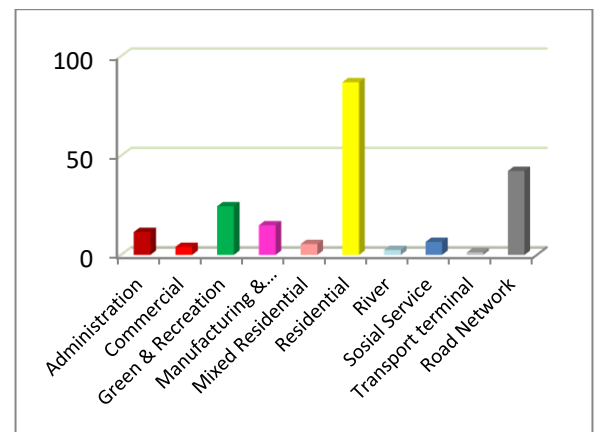


Figure 13: Existing Land Use

Table 13: Land Use/ Land Cover

No	Land Use Type	No of Plots	Total Area (ha)	Total Area (%)
1	Administration	16	11.5	5.8
2	Commercial	39	4.0	2.0
3	Green & Recreation	36	24.5	12.3
4	Manufacturing & storage	24	14.9	7.5
5	Mixed Residential	15	5.5	2.7
6	Residential	186	86.8	43.5
7	River	17	2.5	1.2
8	Social Service	27	6.6	3.3
9	Transport terminal	1	1.3	0.6
10	Road Network	....	42.2	21.1
11	Total Area of Sub-watershed	....	199.7	100

Figure 14: Land Use Proportion



Using the annual rainfall calculated from rainfall data from NME, runoff coefficient obtained from literature and the land use of data collected from site collected through field observation the runoff volume has been computed using rational method. The result indicates that the maximum and the minimum runoff volume generated from the site are found to be 1,089,005.7m³ and 738,209m³ respectively. The details can be seen in the following table.

Table 14: Runoff Volume generated from the study site

No	Land use	Area (m ²)	Min Runoff Coefficient	Max Runoff Coefficient	Annual rainfall intensity (mm)	Minimum Runoff (Q=CIA)	Maximum Runoff
							(Q=CIA)
1	Administration	115094	0.6	0.75	996.9	68842.33	86052.91
2	Commercial	40229	0.5	0.7	996.9	20052.15	28073.00
3	Green	244723	0.2	0.35	996.9	48792.87	85387.53
4	Manufacturing	148908	0.5	0.7	996.9	74223.19	103912.47
5	Mixed	54559	0.5	0.7	996.9	27194.93	38072.91
6	Residential	868186	0.25	0.4	996.9	216373.66	346197.85
7	River buffer	24904	0.2	0.35	996.9	4965.36	8689.38
8	Social Service	65559	0.5	0.8	996.9	32677.88	52284.61
9	Terminal	12502	0.3	0.7	996.9	3738.97	8724.27
10	Road Gravel	1574	0.3	0.7	996.9	470.74	1098.38
11	Road Cobble Stone	215932	0.5	0.75	996.9	107631.31	161446.96
12	Road Asphalt	177688.57	0.75	0.95	996.9	132853.30	168280.85
13	Unpaved	1574	0.25	0.5	996.9	392.28	784.56
Total						738,208.96	1,089,005.68

According to the reviewed literature residential lawns and gardens, commercial landscaping, roads, driveways, and parking lots are commonly known non-point sources of stream water pollutants in urban areas. The pollutants that originate from these sources are sediment and floatables, organic materials, metals, oil and grease/hydrocarbons,

nitrogen, phosphorus, and so on. Among these, the common stream water quality indicators include BOD, COD, Cu, NH₃-N, NO₂+ NO₃-N, Pb, TKN, TP, TSS and Zn. The concentration of these pollutants determines the quality of water for the required use.

In addition to this, the result of the analysis of field observation of the site shows that the dominant land use of the area under study which covers nearly 45% is residential. The second level of land use is road that covers about 21% of the site.

4.2 The Contribution of Land Use to Stream Water Quality

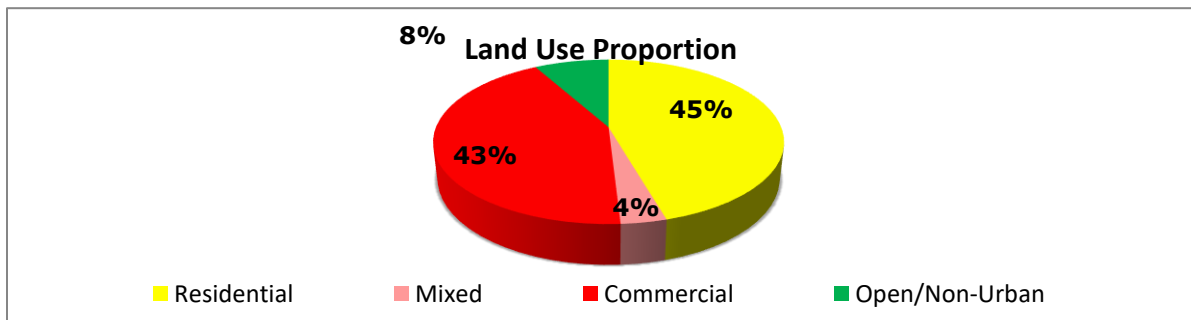
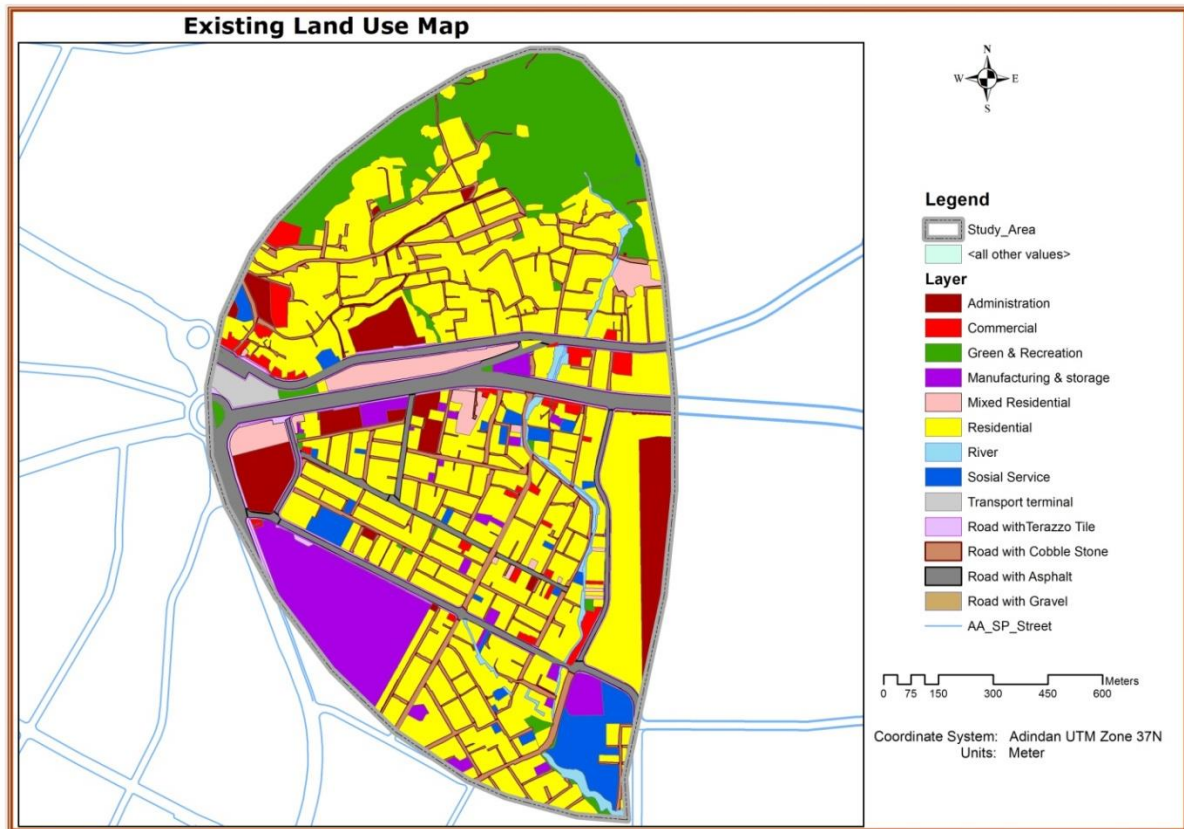


Figure 15: Existing Land Use

The identified & presented land use types are regrouped into four main land use categories: residential, mixed, commercial and none urban/open and their proportion is indicated in the figure above to evaluate the contribution of different land uses for the stream water quality. Based on this, the pollutant concentration of the runoff generated from the site is computed in the following table.

Table 15: Stream Water Quality Indicators of pollutants generated from the site

Pollutant	Units	Residential			Mixed			Commercial			Open/Non-Urban			Amount of Pollutant per liter of runoff
		Median	Runoff	Amount of Pollutant per liter of runoff	Median	Runoff	Amount of Pollutant per liter of runoff	Median	Runoff	Amount of Pollutant per liter of runoff	Median	Runoff	Amount of Pollutant per liter of runoff	
BOD	mg/l	10	0.46	4.6	7.8	0.04	0.3	9.3	0.43	4.0	....	....	.....	8.8
COD	mg/l	73	0.46	33.2	65	0.04	2.3	57	0.43	24.4	40	0.08	3.26205741	63.2
TSS	mg/l	101	0.46	46.0	67	0.04	2.4	69	0.43	29.5	70	0.08	5.70860047	83.6
Total Lead	µg/l	144	0.46	65.5	114	0.04	4.1	104	0.43	44.5	30	0.08	2.44654306	116.5
Total Copper	µg/l	33	0.46	15.0	27	0.04	1.0	29	0.43	12.4	...	...	...	28.4
Total Zinc	µg/l	135	0.46	61.4	154	0.04	5.5	226	0.43	96.6	195	0.08	15.9025299	179.5
Total Kjeldahl Nitrogen	µg/l	1900	0.46	864.8	1288	0.04	46.0	1179	0.43	504.1	965	0.08	78.697135	1493.6
Nitrate + Nitrite	µg/l	736	0.46	335.0	558	0.04	19.9	572	0.43	244.6	543	0.08	44.2824294	643.8
Total Phosphorus	µg/l	383	0.46	174.3	263	0.04	9.4	201	0.43	85.9	121	0.08	9.86772367	279.5
Soluble Phosphorus	µg/l	143	0.46	65.1	56	0.04	2.0	80	0.43	34.2	26	0.08	2.12033732	103.4

The obtained pollutant concentration from computation is compared to the mandatory pollutant level of surface water and the serious pollutants of the site have been identified.

Table 16: Pollutant Gap Analysis of the study area based upon Literature

No	Pollutant	Recommended or Mandatory Limit Values (Surface Water Regulations)	Amount of Pollutant per liter of runoff	Gap Analysis
1	BOD	2 mg/l	8.8 mg/l	Beyond the limit
2	COD	1,000mg/l	63.2mg/l	Under the limit
3	Cu	0.05mg/l	28.4 µg/l	Under the limit
4	NH ₃ -N	50mg/l	643.8µg/l	Under the limit
5	Pb	0.05mg/l	116.5µg/l	Under the limit
6	TKN	1mg/l	1493.6µg/l	Under the limit
7	TP	0.2 mg/l for salmonid and 0.4 mg/l for cyprinid waters	279.5µg/l	Under the limit
8	TSS	.....	83.6mg/l	Beyond the limit
9	Zn	3mg/l	179.5µg/l	Under the limit

As can be seen from the table above, BOD and TSS are the serious pollutants that are generated from non-point sources of the area under study that take significant roles in degradation of the stream water quality.

Biological Oxygen Demand (BOD) is the amount of biochemically degradable organic matter present in water. It is also defined as the amount of oxygen required for the aerobic micro-organisms present in the water to oxidize the organic matter to a stable inorganic form. When its presence in water is beyond the standard limit (i.e. 1-2mg/l), it can affect growth of plants and crops as well as health of animals.

Similarly, Total Suspended Solids (TSS) is defined as the dry-weight of suspended particles that are not dissolved in water. Solids occur in water in two types as solution and suspension. These solids can be identified by using a glass fiber filter that the water passes through.

The suspended solids retain on the top of the filter and the dissolved solids pass through the filter paper with the water. TSS is an important parameter to evaluate water quality analysis that indicates physical and esthetic degradation of surface water quality as well as the presence of other pollutants. Generally, the presence of excess suspended solids prevents penetration of light to the submerged plants leading to reduced rates of physiological processes such as photosynthesis and respiration in aquatic organisms.

Therefore, GI retro-fitting mechanism that can control these problems should be installed in the appropriate site for better stormwater management. By doing so we can improve the stream water quality and use it for non-potable water purposes to take part in minimizing water scarcity.

To confirm the above situation samples of stormwater collected from selected sites and have been tasted in laboratory and analyzed. The details of the results can be seen in the following table.

Table 17: Pollutant Gap Analysis of the study area based upon Lab Taste

No	Pollutant	Recommended or Mandatory Limit Values (Surface Water Regulations)	Amount of Pollutant per liter of runoff	Gap Analysis
1	BOD	2 mg/l	32.2mg/l	Beyond the limit
2	COD	1,000mg/l	250mg/l	Under the limit
3	Cu	0.05mg/l	< 0.006mg/l	Under the limit
4	NH ₃ -N	50mg/l	32.1mg/l	Under the limit
5	Pb	0.05mg/l	< 0.001mg/l	Under the limit
6	TSS	.....	80.1mg/l	Beyond the limit
7	Zn	3mg/l	< 0.008mg/l	Under the limit

There is little variation between calculated values of pollutants based up on literature and the laboratory taste result of sample stormwater. But both of them have almost similar status when it

is compared to the surface water pollutant limit of EPA. Therefore, a certain intervention is needed to improve this high concentration of pollutants in the stormwater that leads to the nearby stream. The other significant result observed is that there is variation between the Ethiopian standard (mandatory pollutant limit) and EPA standard. For example the Recommended or Mandatory Limit Values of BOD in Surface Water Regulations of USEPA is 2mg/l while it is 80mg/l in the Ethiopian draft document. The limit of TSS in the Ethiopian case is 100mg/whereas in the case of USEPA it is unstated.

Therefore, according to Provisional Standards for Industrial Pollution Control in Ethiopia, draft document, the limit value of pollutants that can be discharged to stream/river mainly focuses on the percentage that they should control rather than the limit of pollutants that should join to the stream water. This does not guarantee the quality of the stream water.

Moreover, the imperviousness level of the site in different years have been evaluated based on the available data and the result is shown in the maps and graphs presented below.



1995



2004



2010



Current

Figure 16: Imperviousness level of study site in different years

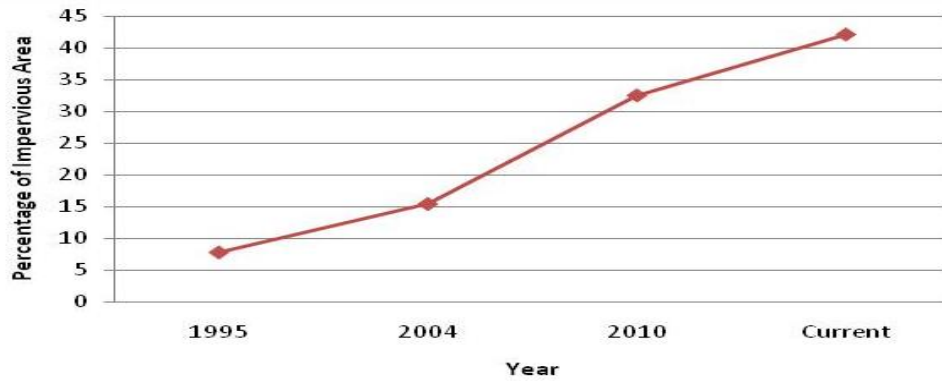


Figure 17: Growth of impervious area in the study area since 1995

Even though the data used to generate the above maps has given less emphasis to the surfacing of individual compounds due to less access to the data, the resulting map and figure indicate the increasing trend of impervious area level in the years 1995 to 2019. This in turn increases the runoff volume of stormwater unless a certain kind of GI retro-fitting intervention is implemented to improve the situation.

4.3 Green Infrastructure that can reduce stormwater runoff volume and pollutant

After identifying the dominant pollutants from non-point sources of the site, suitable GI retro-fitting technology that can improve this problem has been identified. Impervious area reduction is one of the appropriate GI retro-fitting for reduction of runoff and the identified most serious pollutants (BOD and TSS) at local level. The collected data indicates that from the total area (199.7ha) of the sub-watershed, 64.7% is occupied by private owners or organizations (as residential, commercial, manufacturing, etc.) whereas the remaining 35.3% is publicly owned (road, river, recreation, etc.). From private plots 33.4% is occupied by buildings, the remaining 66.6% is an area out of the buildings that have great potential for local level GI retro-fitting (like RWH, Rain garden, and porous pavement). By converting this area into porous pavement rather than making it completely

impervious 21–33.3% of the runoff and 68–86% TSS generated from this area when it is sealed can be reduced. The above performance of applying permeable paving can be enhanced more to 100% by incorporating RWH measures and rain garden development in individual plots.

In Addition to this, organizational compounds such as schools, administration, health center, manufacturing etc. have high potential to implement RWH in their compounds for non-potable water demands. Such compounds in the site occupy about 33ha among which 6.9ha is covered by roofs. From these roofs, about 69,202.7–65,742.5m³ of rainwater can be harvested which accounts 6.4 – 9% of the total runoff generated from the site.

Moreover, vegetated swale and rain garden which are suitable for intermediate level (on public plots at neighborhood level) and collecting runoff from roads, subdivisions and parking lots, the runoff volume and pollutants can be reduced. For example, using swales can help to reduce 6–55% of TSS while rain gardens can reduce 69–89% of TSS. Furthermore, through riparian buffer directly adjacent to streams and rivers from 58–100% of TSS can be removed.

In general, the above mentioned technologies are ideal for the reduction of runoff volume of the Sub-watershed as well as improvement of the stream water quality by reducing the potential pollutants (mainly BOD & TSS) entering from non-point sources.

4.4 Harmonizing the Selected GI with the Existing Urban Fabric

Even though point source pollutants of the site are controlled effectively through EIA, BOD and TSS from non-point sources can also make the stream water impaired. To control these pollutants and reduce stormwater runoff entering the target stream from the site, RWH, rain garden, porous pavement, riparian buffer, and vegetated swale are selected as

technical solutions appropriate for the site. To identify suitable sites, additional variables such as slope and land use/land cover are taken into consideration. The criteria used to select the appropriate location for the selected green infrastructures are summarized in the following table.

In addition to this, taking the land use, slope, road network and the stream order of the site the appropriate site for all selected green infrastructures tried to be selected using GIS multi-criteria site selection method and the result is illustrated in the following figure.

Slope Analysis of study site

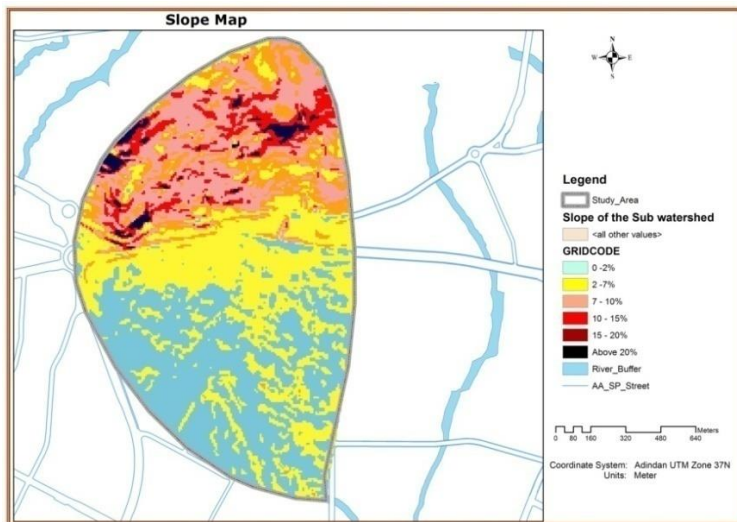


Table 18: Slope Analysis of the study area

No	Slope	Area (ha)	Area (%)
1	0 - 2%	65.4	32.7
2	2 - 7%	63.3	31.7
3	7 - 10%	20.5	10.3
4	10 - 15%	34.7	17.4
5	15 - 20%	12.4	6.2
6	Above 20%	3.5	1.7
Total		199.7	100.0

Figure 18: Slope Map

Profile of the study site

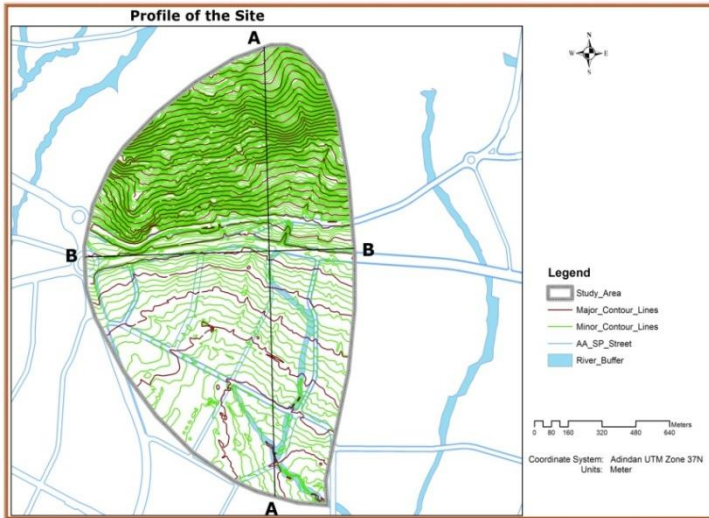
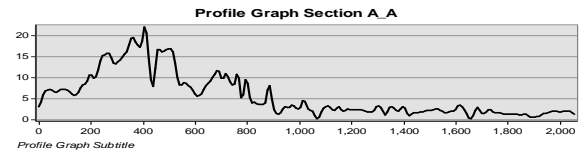


Figure 19: Profile of the study site



Road Map of the Study Area

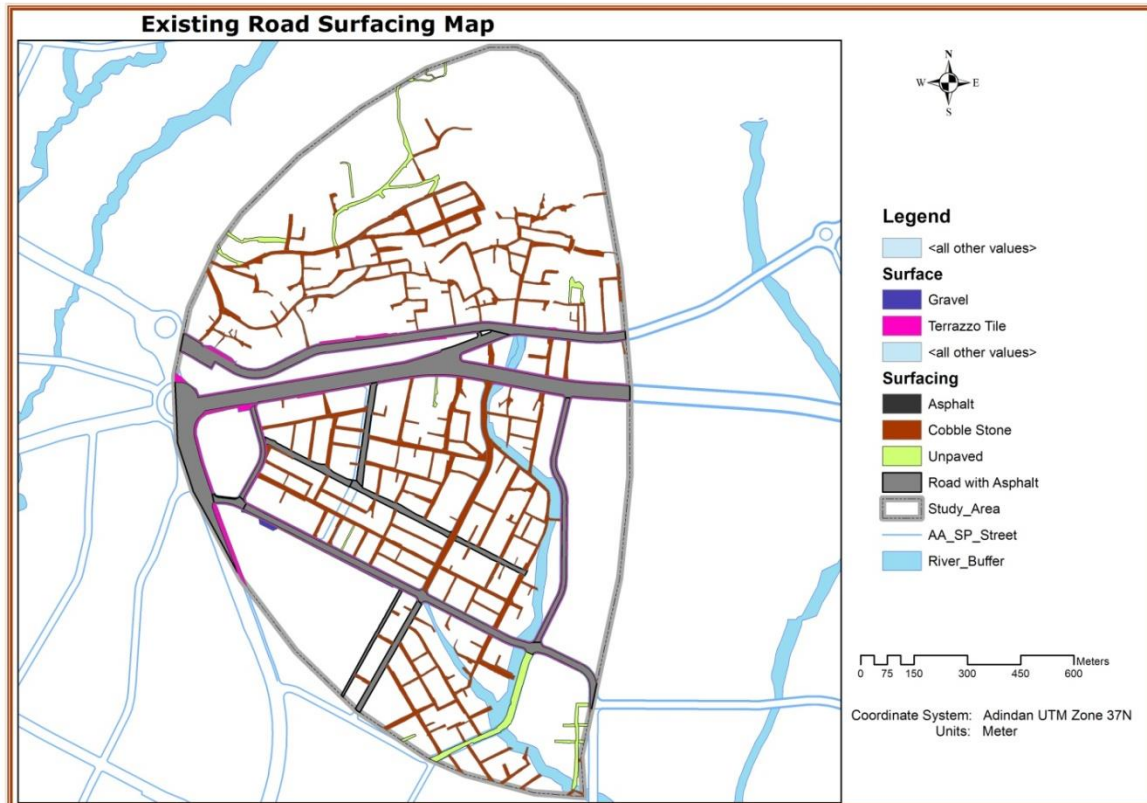
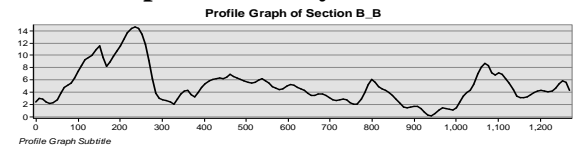


Figure 20: Road Surfacing Map of the study site

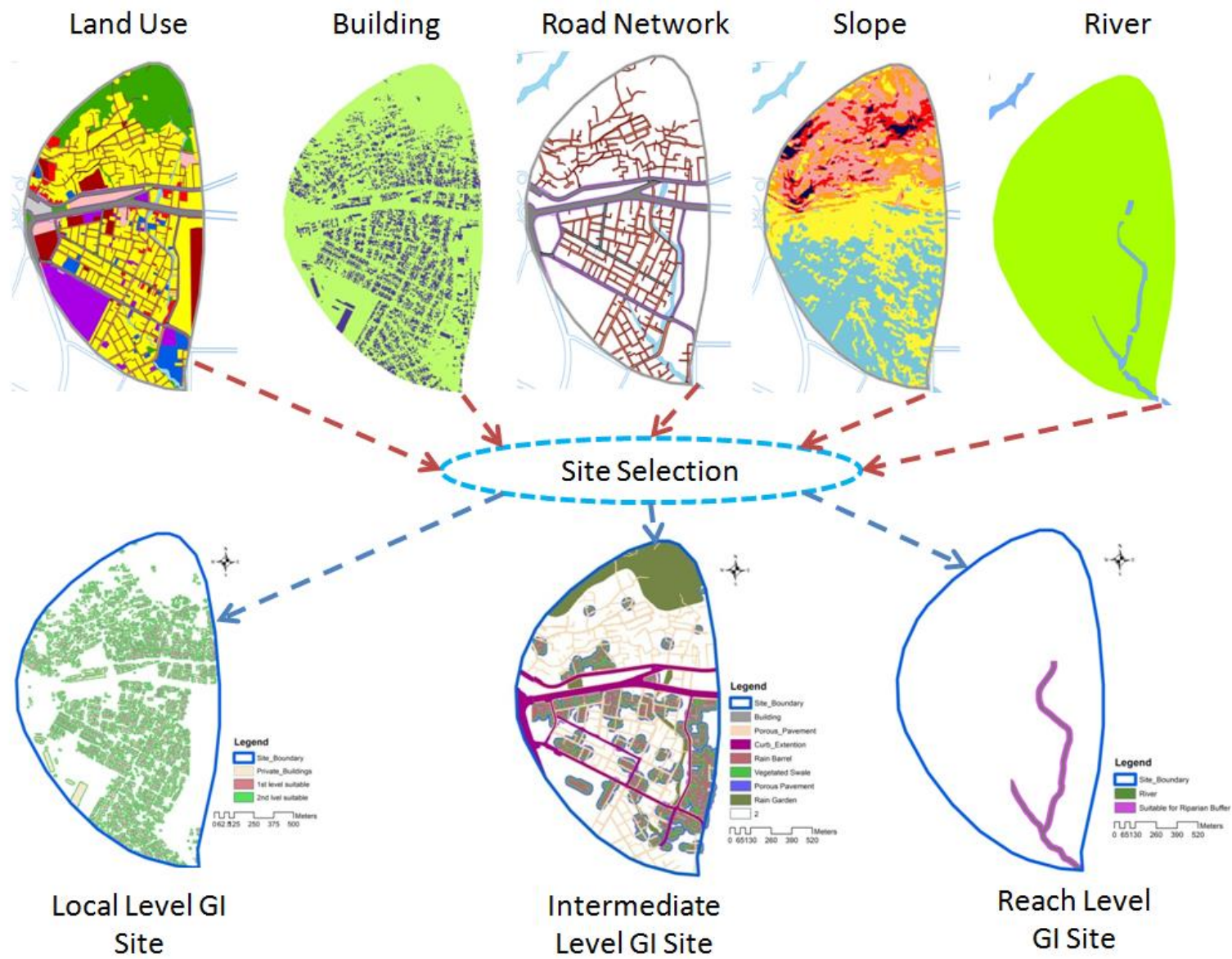


Figure 21: Appropriate site Selection for GI retro-fitting

The following figure indicates that the selected appropriate sites for the selected GI retro-fitting to improve the quality of the stream water under stud.



Figure 22: The selected locations of each types of GI

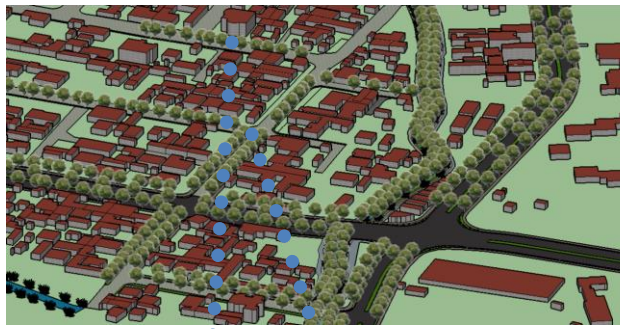


Figure 23: Fitted Porous Pavements & Curve Extensions

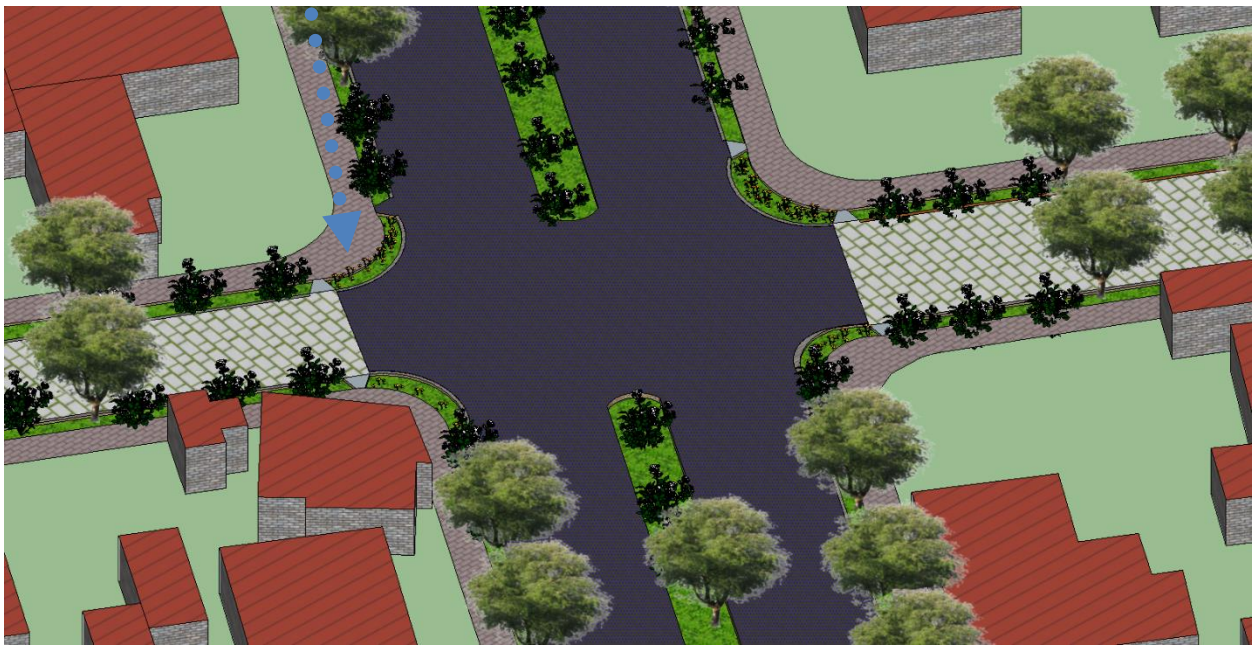
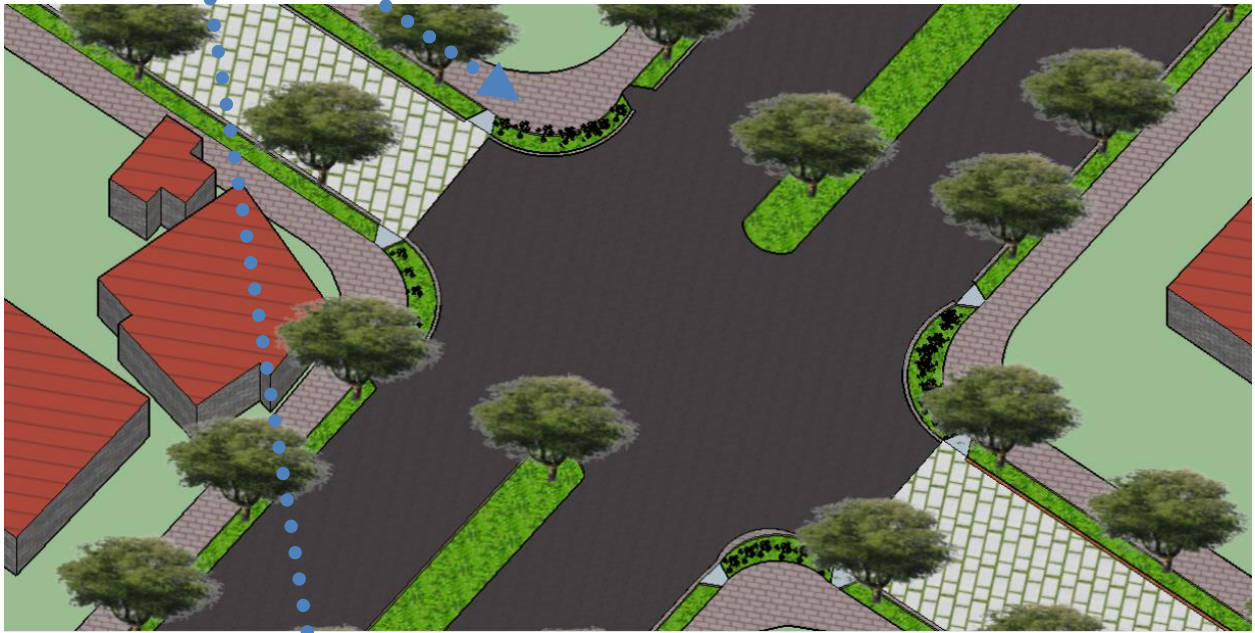


Figure 24: Fitted Green Infrastructure on Road Side & Median

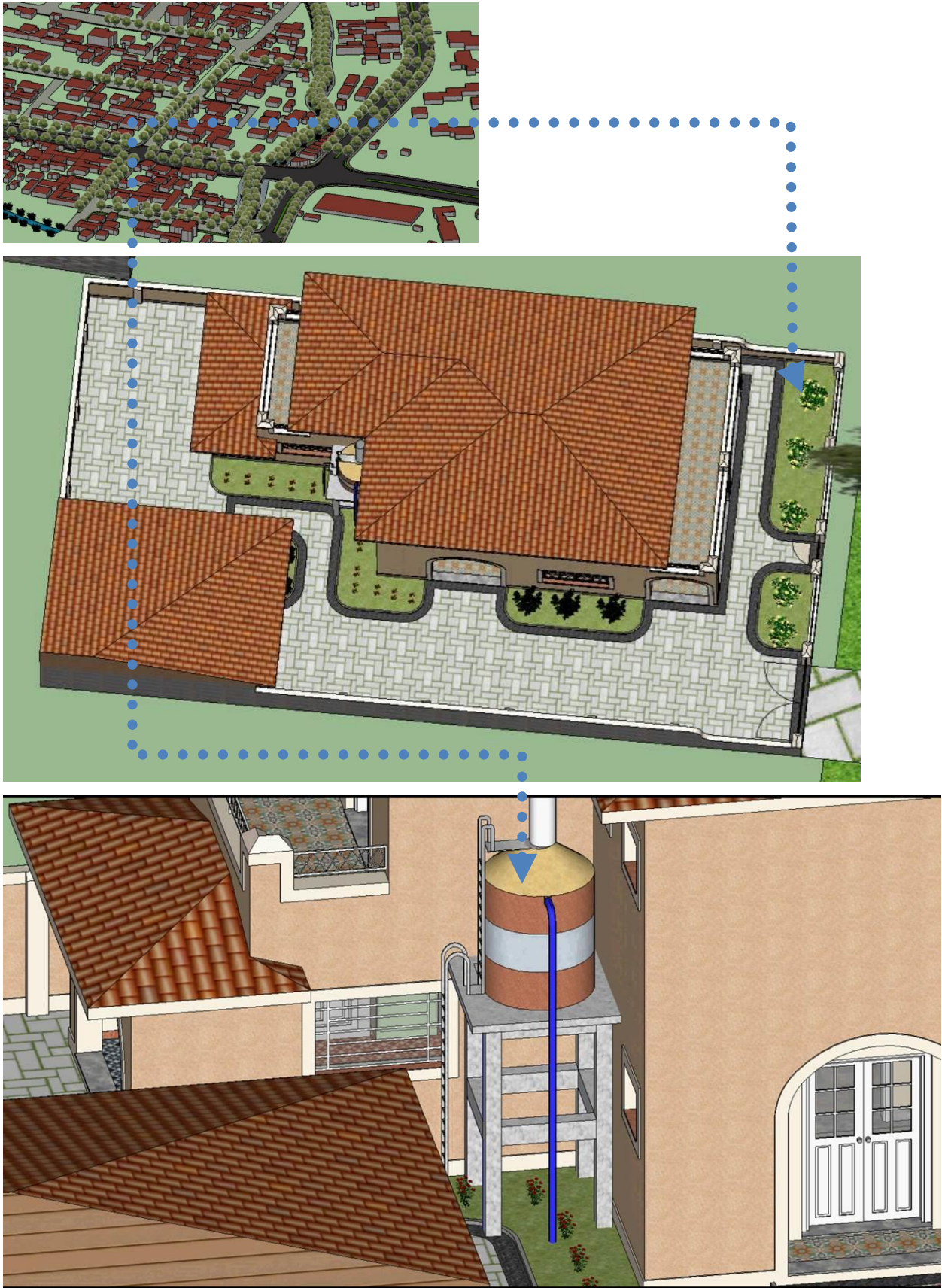


Figure 25: Fitted Green infrastructure in individual Plot

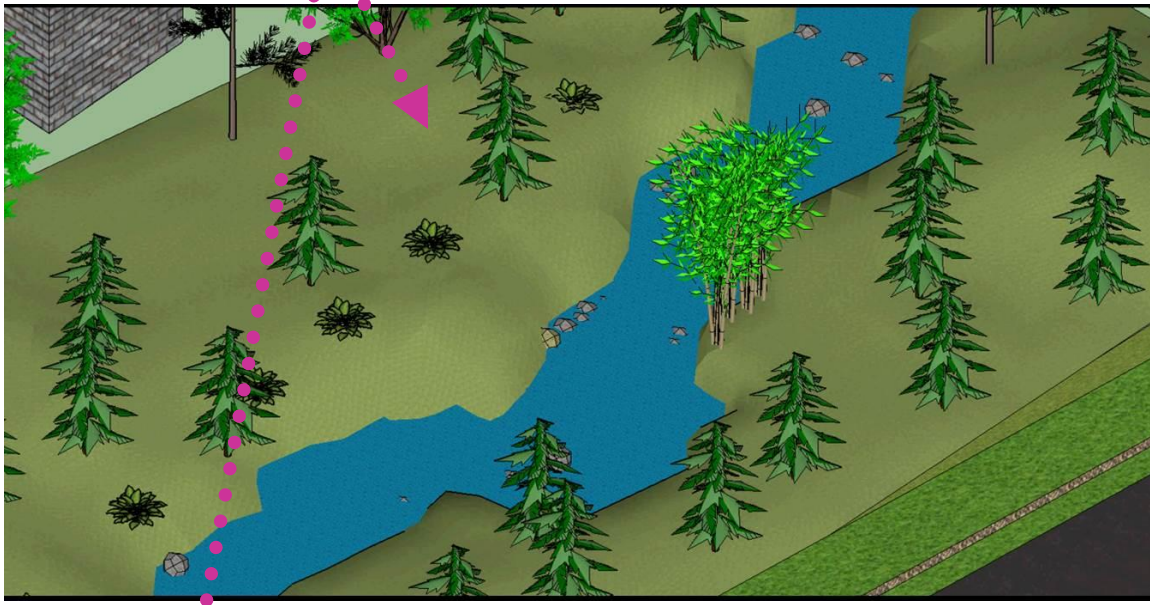


Figure 26: Fitted River Buffer

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The known non-point pollutant sources of the site are residential lawns and gardens, commercial landscaping, roads, driveways, and parking lots. The maximum runoff volume generated from the site is 1,089,005.7m³ and the minimum one is 738,209m³. The land use & land covers of the site shows 45% Residential, 43% Commercial, 4% Mixed and 8% open space/none urban.

Among the calculated and tasted stream water quality indicators, BOD and TSS are the most serious pollutants that are generated from non-point sources of the area under study. The high concentration of these pollutants significantly degrades the stream water quality and affecting aquatic organisms as well as animals and plants that use this water.

Reduction of impervious area is one of the mechanisms that can improve stream water quality and facilitate infiltration. To achieve this, porous pavement, vegetated swale and rain garden are some of the green infrastructure retro-fitting solutions that can be used at local level. The other stream water quality improvement technique is reducing directly connected impervious area to the receiving stream. Instead of collecting stormwater in ditches with high volume creating ground for plain flow at the source of the stormwater helps to decrease pollutant flow to the streams. In addition to this riparian buffer along the stream has great contribution to improve the stream water quality. Rainwater harvesting is the third technique that can help to improve stream water quality by reducing runoff volume and velocity that carry pollutants from non-point sources.

By using porous pavement in privately owned plots 21–33.3% of the runoff and 68–86% TSS generated from the site can be reduced. This performance can also be enhanced more to 100% by incorporating RWH measures and rain garden development in individual plots.

In organizational compounds such as schools, administration, health center, manufacturing and storages have high potential to implement RWH in their compounds for non-potable water demands. From their roofs, about 69,202.7–65,742.5m³ of rainwater can be harvested and this accounts 6.4–9% of the total runoff generated from the site. Using swales on publicly owned plots up to 55% of TSS can be reduced whereas rain gardens can reduce 69–89% of TSS and using riparian buffer directly adjacent to the stream instead of using drainage line directly leading to streams 58–100% of TSS can be removed.

According to the reviewed literatures, rain barrel is ideal for collecting rooftop runoff; Porous pavement is ideal for highly developed areas: parking lots, driveways and low-volume roads; Rain garden is ideal for collecting rooftop runoff and runoff from yards, sidewalks, roads and small parking lots; Vegetated swale is ideal for collecting sheet flow runoff from roads, highways and runoff from subdivisions and Riparian buffer is ideal for land directly adjacent to streams and rivers.

In addition to these harmonizing the proposed GI with the existing urban fabric is very important to achieve the intended performance and maintain the existing esthetic/to make it more attractive for the community who use it.

5.2 Recommendations

Even though the Addis Ababa city administration exerts effort to provide potable water to the community of the city, the demand exceeds the supply. This is because of its no attention to stormwater management and protecting stream water quality in the water supply system. Improving the quality of stream water can improve the supply of water since the community can use them for non-potable services like gardening, car-washing and compound cleaning.

To improve the quality of stream water controlling only point source pollutants is not satisfactory; because there are pollutants such as TSS and BOD that can affect the quality of surface water. Therefore, non-point source pollutants also be controlled using green infrastructure retro-fitting to achieve the minimum surface water quality standard.

Since different urban source areas contribute disproportionate amounts of a specific type of pollutant to receiving waters, source area control is very important to prevent pollutants from entering stormwater runoff and achieve the stream water quality. Therefore, decision makers and stakeholders including urban planners and designers should give due attention to control pollutants from both point and non-point sources at its source area to preserve stream water quality use and maintain healthy ecosystem.

This study is carried on specific area (sub-watershed) focusing on some water quality indicating parameters and laboratory tastes of few samples collected from few selected sites due to time, manpower and financial limitations. Other researchers should be encouraged to work more in this area of study since it is less studied.

Designers and planners should consider and integrate stormwater management elements and green infrastructures as integral part of their design and plan starting from local level to macro urban scale. Policy makers should also incorporate stormwater management mechanisms and green infrastructure retro-fitting technologies to preserve stream water quality as a part of water supply system of the city.

Awareness should be created in the community to use porous pavements on parking lots and circulation areas of individual plots and to harvest rainwater for none potable water

uses like car washing, gardening, toilet flushing, compound and household cleaning purposes.

Model designs for individual plot level rainwater harvesting should be prepared; incentives should be given for those who implement it as a role model and these issues should be included in the building code of the city to improving stream water quality, reduce flooding, and improving water supply, preserve the ecosystem, aesthetics of the area as well as lives in the water and animals including human being who use the water.

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Annex I

Parameter	Conc.1	Conc.2	Conc.3	Mean	Stdv
pH	7.21	7.33	9.07	7.9	0.8
Turbidity	2547.5	3674	3832	3351.2	571.9
Biochemical oxygen demand (BOD)					
Chemical oxygen demand (COD)	452	511	509.5	490.8	27.5
Total Suspended solids (TSS)					
Total ammonia (as N)	11.3	10.2	10.6	10.7	0.5

Annex II

Horticoop Ethiopia (Horticulture) PLC
 Soil and Water Analysis Laboratory
Analysis Certificate

Test Overview

Customer: AUIT (Emebet)

Tel: +251 91 325

Address: Addis Ababa

Country: Ethiopia

Information about sample			
Sampled By	Client	Order Number	161 - HEON/20
Report Date	August 31, 2020	Date Received	August 17, 2020
Location	Addis Ababa		

Lab. Code	Discription	Concentration	Parameters											
			As	Pb	B	Zn	Cd	Hg	Cu	Ni	Co	Fe	Mn	Cr
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
HWA 2464/20	Water Sample	Conc.1	< 0.001	< 0.001	0.004	< 0.008	< 0.009	< 0.003	< 0.006	< 0.001	< 0.003	< 0.002	0.03	< 0.001
		Conc.2	< 0.001	< 0.001	0.006	< 0.008	< 0.009	< 0.003	< 0.006	< 0.001	< 0.003	< 0.002	0.03	< 0.001
		Conc.3	< 0.001	< 0.001	0.006	< 0.008	< 0.009	< 0.003	< 0.006	< 0.001	< 0.003	< 0.002	0.04	< 0.001
		Mean	< 0.001	< 0.001	0.005	< 0.008	< 0.009	< 0.003	< 0.006	< 0.001	< 0.003	< 0.002	0.03	< 0.001
		Stdv	-	-	0.002	-	-	-	-	-	-	-	0.004	-

Analytical Methods	
Parameter	Examination Standards
All heavy metals	Double Acid Digestion +ICP-OES Determination

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Examination is conducted and opinions are only given provided that the constituent distances every right to liability. Information on the applied methods and performance characteristics or general conditions can be obtained on demand.

Zufan GIKIDAN


Lab Head

T: +251 11 652 55 89 P.O.BOX:
 1646DebereZeit, Ethiopia
 E-mail: Laboratory.horticoop@gmail.com