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

Passive Rainwater Harvesting Structure for Stormwater Management and Green Areas Improvement of Institutional Plots in Urban Areas:

The case of EiABC Campus

By

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Declaration

I, the undersigned, declare that this thesis is my own and original work and has not been presented for a degree or diploma in any 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.

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I state that Dufera Demu Tura has carried out this research work on the topic "Passive Rainwater Harvesting Structure for Stormwater Management and Green Areas Improvement of Institutional Plots in Urban Areas: The case of EiABC Campus" under my supervision and it is sufficient for the partial fulfillment for award degree in Urban Design and Development.

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Abstract

Stormwater runoff is the major challenge in urban areas due to the increase in impervious surfaces, higher rate of urbanization and rapid economic growth. EiABC campus is, among institutional plots in Addis Ababa, recently has been transformed into more impervious surfaces characterized by 46% of surfaces developed as buildings, roads, parking lots and pedestrian walkways. The stormwater runoff generated from these impervious surfaces transported into municipal drains and roadway without any interventions that are found to result in chronic impairment of surface water quantity and quality. The objective of this study is to investigate the opportunity of the passive rainwater harvesting system from the impervious ground surfaces of institutional plots in urban areas for its stormwater management and green area improvement.

The GIS and remote sensing were used to produce a suitability map for selecting the ideal location for the placement of water harvesting structures in the EiABC campus. The Bio-retention system was selected among the others Best Management Practices and eventually developed at the selected site within the compound. The quantity of stormwater was estimated by a rational method and the quality parameters were collected on site and processed in the laboratory. The study estimated that 620.4m^3 of surface runoff was harvested through Bio-retention system from 4122m^2 drains area. The Bio-retention average removal rates for pollutants of TSS, TDS and Turbidity were 76.92%, 59.2%, and 45.67% respectively. This indicated that the quantity and quality of stormwater were managed through the development of simple rainwater harvesting structure as a Bio-retention system.

Key words: *Runoff, Bio-retention, Stormwater quality, Stormwater quantity.*

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Acronyms and Abbreviations

BMPs	Best Management Practices
DEC	Department of Environment and Conservation.
DEM	Digital Elevation Model
DEQ	Department of Environment Quality
DTM	Digital Terrain Model
EC	Electrical Conductivity
EiABC	Ethiopian institute of Architectural, Building Construction and City Development
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GI	Green Infrastructure
G.C	Gregorian Calendar
MCDA	Multi-criteria decision analysis
MODT	Michigan Department of Transportation
MPCA	Minnesota Pollution Control Agency
NRCS	Natural Resources Conservation Service
NJDEP	New Jersey Department of Environmental Protection
RWH	Rainwater Harvesting
RCD	Resource Conservation District
TDS	Total Dissolved Solid
TSS	Total Suspended Solid
UNEP	United Nations Environment Program

US EPA	United State Environment Protection Agency
USGS	United State Geological Survey
WGA	Water Resilient Green Cities in Africa
WSUD	Water Sensitive Urban Design

CHAPTER ONE

INTRODUCTION

1.1 Background

Sustainable water resource management and the associated environmental crisis in urban areas are becoming the major issues of countries in the world. Over 50% of the global population lives in urban centers and, therefore, an understanding of the processes acting upon urban systems is a global issue (Owens, 2009). Urbanization disrupts natural soil profiles, increases impervious surfaces and decreases vegetative cover which contrasts significantly with those with more natural (Day and Dickinson, 2008). The replacement of vegetated land with the roof, roads, and other impervious surfaces that characterize urban settlement results in a large increase in runoff volume (Christopher et al., 2012). The volume of runoff is governed primarily by infiltration characteristics and is related to land slope and soil type as well as to the type of vegetative cover. It is thus directly related to the percentage of the area covered by roofs, streets, and other impervious surfaces at times of hydrography rise during storms (Leopold, 1968). Hence the rapid urbanization increases the imperviousness of an urban area that aggravate the stormwater runoff.

Historically, the primary concern about stormwater was to remove it from a developed area as quickly as possible after a storm event for flood protection. Unfortunately, this led to drains systems that maximize local convenience and protection, without considering other important factors such as off-site damage from accelerated flow, water pollution, or even the loss of a water resource, increased channel erosion, flooding, and deposition of sediment with a resulting loss of property, wildlife habitat and natural vegetation (Carron, 1990). In urban and suburban areas, conventional urban stormwater drains systems often route runoff directly to streams and rivers, thus exacerbating pollutant inputs and hydrologic disturbance, and resulting in the degradation of ecosystem structure and function (Allison et al., 2008). Standard Gray infrastructure solutions to these challenges, including the expansion of water drains infrastructure, can in some instances further exacerbate the problem (UNEP, 2014). Decentralized stormwater management tools, such as low impact development or water sensitive urban design, may offer a more sustainable solution to stormwater management if implemented at a watershed scale (Allison et al., 2008). These tools can be designed to pond, infiltrate, and harvest water at the source that encouraging evaporation, evapotranspiration, groundwater recharge, and re-use of stormwater through harvesting.

Passive rainwater harvesting systems use land shaping and other techniques to direct, collect and infiltrate rainwater directly into the soil and storages for beneficial use. It manages the stormwater quantity, quality and support vegetation growth (Anitra A., 2015). In the study area these systems retain rainwater on-site, reducing off-site runoff that can contribute to pollution and flooding.

In the context of Ethiopia, the runoff problem was mitigated by massive harvesting effort undertaken in the dry lands aimed to improve the livelihoods of people, who are suffering from environmental problems such as drought and flooding (RCD, 2005). Stormwater harvesting and reuse has emerged as a new field of sustainable water management that offers both a potential alternative water supply for non-drinking uses and a means to further reduction of stormwater pollution in the waterways. It complements other approaches to sustainable urban water management, including rainwater tanks, gray water systems, effluent reuse and demand management (Department of Environment and Conservation, 2006).

Climate change, as well as surface condition change, are the factors for the production of stormwater runoff. The impact of flooding caused due to the expansion of the built environment is found to be more significant in a shorter term than climate change. Addis Ababa city shows unusual expansion of the built environment and imperviousness of the surface condition. As Moges et al. (2013) discussed, due to the surface condition change, runoff generation potential has shown a significant increase from 28% to 45% showing over 60% change in the runoff volume. Similarly, the climate change increases the peak flow by 10%, and a comparable in flooding (Dereje et al., 2016).

Within the Ethiopian Institute of Architecture, Building Construction and City Development (EiABC) compound, buildings and ground paving materials such as roads, parking lots, and the pedestrian walkways are impervious surfaces. Runoff generated from these surfaces, transported into municipal drains and roadway without any intervention to reduce flooding and contaminations. Harvesting the stormwater runoff generated from the compound using the different natural and man-made system can reduce the downstream flooding and associated environmental crisis.

1.2 Problem statement

Urban development directly affect or create a negative impact on the natural system within or out of the urban areas (Adam et al., 2000). Construction of roads or buildings significantly changes the hydraulic properties of an area. Typically, these layers are rendered less permeable or even impermeable by their peculiar nature. Such surfaces and conduits are constructed to drain runoff more efficiently. Ultimately, natural vegetation often removed, causing reduced interception and transpiration by plants. Limited vegetation cover exposes the soil to the impact of rain, which may lead to increased erosion. Natural meandering water courses may be canalized to more effectively route flows through the development.

Likewise, Addis Ababa the capital city of Ethiopia is facing a serious challenge from increments in stormwater runoff and associated flooding due to the rapid economic growth and urbanization. Recently, the city landscape facing riverine as well as flash flooding due to climatic variability and upper catchment intensive construction activities. The vulnerability to flooding is more aggravated due to a high level of imperviousness of the built environment in the upper catchments. Addis Ababa is located in the upper part of the Awash River basin within Akaki catchment. The Akaki catchment characterized by urbanization rate increments by 10% and with this rate of urbanization, a rise in peak flow is increased by 25% only from 1993 to 2002 (Dereje, et al., 2016).

The stormwater generated from the EiABC campus create inundation on the adjacent pedestrian walkway and driveway and eventually reaches the Little Akaki River. Streets and roadways with the immense size of impermeable surfaces together with parking lots and rooftops are collecting massive amounts of rainwater during every rain event (Figure 1.1). When all of this stormwater flows across the pavement, it collects and accumulates pollutants from soil particles and pebbles to garbage and automotive fluids. This mixed with chemicals and debris carried to the lowest point of the watershed eventually transported to a larger water body mainly in the downstream areas. Recent increments in the level of imperviousness due to new construction of buildings and parking areas within the campus mainly aggravate the problems.

Figure 1.1: Stormwater flows from EiABC campus (Photo taken in August ,2017).

The estimated land use, land cover inventory shows that the total area of the impervious surface of the EiABC campus was 46.2% and the natural area accounts 53.8%, which is found to result in chronic impairment of surface water quantity and quality. Stormwater management through developing passive rainwater harvesting structure is, therefore, a well-proven solution that had been developed and tested in urban centers of North American and Europe. In this regard, the study focused on catering for the hydraulic needs of a development while minimizing the associated negative environmental impacts through nature-based design solution. Developing a Bio-retention system within the available spaces is helpful to reduce the negative impacts of stormwater runoff and able to enhance the spatial quality of the landscape. There is very limited research on applications of nature-based stormwater management design solutions and performance evaluation of the system in the context of cities in developing countries. In this regards, this research will give insight for the applicability of the system for stormwater management as well as Green Infrastructure development in the context of tropical highland urban centers of Ethiopia.

1.3 Objective

General objective

- To investigate the opportunity of applying passive rainwater harvesting system on impervious surface of institutional plots in urban areas for its stormwater management and green areas improvement.

Specific objectives

- To identify the appropriate green open spaces (site) for rainwater harvesting structures within the EiABC campus.
- To design and develop options for passive rainwater harvesting structures.
- To estimate the performance of rainwater harvesting structure for stormwater management and green area improvement.

1.4 Research questions

- Where are the appropriate green open spaces (site) for rainwater harvesting within the EiABC campus?
- How options are designed and developed for passive rainwater harvesting structures?
- What are the estimated performances of rainwater harvesting structure for stormwater management and green area improvement?

1.5 Significance of the study

Passive rainwater harvesting for stormwater management and green areas improvement is used for sustainable water management in urban areas by mitigating the volume of stormwater runoff. It can also act as an alternative water supply sources as well as controlling ground and surface water pollution. In addition, it is used to enhance the spatial quality of open spaces in the institutional plots and other urban areas. The study will also provide information to policy makers how the problems of stormwater in urban areas would be addressed. Moreover, it serves as a reference for the researcher and others who are interested in the field for further research.

1.6 Scope of the study

This study was geographically limited in the Ethiopian Institute of Architecture, Building Construction and City Development campus, which covered an area of 7.8 hectares and its watershed. Thematically, it addresses issues related to passive rainwater harvesting structure, for stormwater management and green area improvement of an urban area.

1.7 Limitation of the study

Some limitations need to be noted regarding the present study. The data used in this research were obtained through field observation and laboratory analysis. However, soil laboratory for permeability test of the soil mix was not done due to limited access to the laboratory. The other constraint was limited access and funds to biological and others metals laboratory for further testing the performance of the Bio-retention system. Because of these problems the number of tests for chemical and physical properties of the stormwater runoff before and after entering of the Bio-retention system had been reduced.

1.8 Organization of the paper

The paper is divided into six chapters. The first chapter gives background knowledge on the design intervention of passive rainwater harvesting structure for stormwater management and green areas improvement of institutional plots in urban areas. It also indicates the problem statement, objectives, research questions, significance of the study and the scope of the study. The second chapter reviewed the academic discourses that were importance to the research study. It also contained the theoretical foundations of the study that were directed to giving information needed in answering the research questions.

The third chapter forwarded the methods and materials that were used in the study, specifying the study area, research design, source of data, data collection tools and data analysis methods that were adopted by the study in order to arrive at the conclusion of the objectives of the study. The fourth chapter analyzes the data that were collected from the field. It described and analyzed the data based on the objectives of the study and answering the research questions. The fifth chapter discusses the results found in the data by linking the results and the existing theories to other research studies, articles or journals of similar topics. It also discussed the inferences of the results that was obtained. The last chapter had consisted of a finding, conclusion, and recommendations and/ or suggestions for additional information for further research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The literature review was structured to support the objectives outlined by the research questions: appropriate site for rainwater harvesting structures, options to develop and design rainwater harvesting structure, and performance of rainwater harvesting structures for stormwater management and green area improvement. So that the following literature reviews synthesizes the literature surrounding and related to passive rainwater harvesting structure used as a stormwater management tool and green area improvement.

2.2 Factors affecting stormwater runoff

Apart from rainfall characteristics such as intensity, duration and distribution, there are a number of site (or catchment) specific factors which have a direct bearing on the occurrence and volume of runoff. These include Vegetation, slope and catchment size and soil type (Will and Klaus, 1991).

i. Vegetation

The amount of rain lost in interception storage on the foliage depends on the kind of vegetation and its growth stage. A cereal crop, for example, has a smaller storage capacity than a dense grass cover. More significant is the effect the vegetation has on the infiltration capacity of the soil. A dense vegetation cover shields the soil from the raindrop impact and reduces the crusting effect. In addition, the root system as well as organic matter in the soil to increase the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow, particularly on gentle slopes, giving the water more time to infiltrate and to evaporate. In general, an area densely covered with vegetation, yields less runoff than bare ground.

ii. Slope and catchment size

The quantity of runoff decreased with increasing slope length. This is mainly due to lower flow velocities and subsequently a longer time of concentration (defined as the time needed for a drop of water to reach the outlet of a catchment from the most remote location in the catchment). This means that the water is exposed for a longer duration to infiltration and evaporation before it reaches the measuring point. Similarly, the runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency.

iii. Soil type

The infiltration capacity is among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. Porosity differs from one soil type to the other. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have considerable smaller infiltration capacities (Table 2.1).

Table 2.1: Basic infiltration rates for various soil types

Soil type	Basic infiltration rate (mm/hour)
Sand	less than 30
Sandy loam	20 - 30
Loam	10 - 20
Clay loam	5 - 10
Clay	1 - 5

Source :(Brouwer et al., 1989)

2.3. Passive rainwater harvesting for stormawater management and green area improvement

Passive rainwater harvesting systems use land shaping and other techniques to direct, and infiltrate rainwater directly into the soil for beneficial use and manage stormwater and support vegetation growth. These systems also retain rainwater on-site, reducing off-site runoff that can contribute to pollution and flooding, collect leaves, twigs and fruits that drop off plants to the soil below (Anitra, 2015).Passive Rainwater harvesting can be used to encourage plant growth in landscapes and natural areas, healing erosion cuts, and can even replace the need to irrigate with tap water (Cado and Cyndi, 2012). According to Michigan Department of Transportation (2006), the benefits of RWH storage facilities can be divided into two major control categories of quality and quantity.

i. Quality

Control of stormwater quality using storage facilities offers the following potential benefits:

- Decrease downstream channel erosion;

- Control sediment deposition, and
- Improve water quality through (Stormwater filtration and capture of the first flush with detention).

The impact on the receiving water of untreated stormwater discharges are largely dependent on climate patterns and land use activities. The frequency, duration and intensity of precipitation events relate to the quantity of stormwater runoff. The land use, population activities, industrial activities contribute to the quality of the stormwater runoff. Increases in impervious surfaces following development result in accumulated pollutants deposited from the atmosphere, leaked from vehicles, or windblown in from adjacent areas (Schueler and Holland, 2000). The primary non-point pollution sources that typically accompany urbanization are caused by increases in traffic, street litter, fertilizer use and pesticide use (Karen et al., 2005). The most common pollutants in urban stormwater and the sources are provided in Table 2.2.

Table 2.2: Stormwater pollutants and sources

Contaminants	Sources
Pesticides and Herbicides	Residential lawns and gardens, roadsides, utility right-of-ways, commercial and industrial landscaped areas.
Organic Materials	Residential lawns and gardens, commercial landscaping, animal wastes.
Metals	Automobiles, bridges, atmospheric deposition, industrial areas, soil erosion, corroding metal surfaces, combustion processes.
Oil and Grease/Hydrocarbons	Roads, driveways, parking lots, vehicle maintenance areas, gas stations illicit dumping to storm drains.
Bacteria and Viruses	Lawns, roads, leaky sanitary sewer lines, sanitary sewer, cross-connections, animal waste, septic systems.
Nitrogen and Phosphorus	Lawn fertilizers, atmospheric deposition, automobile exhaust, soil erosion, animal waste, detergents

Source: (US EPA, 1999).

ii.Quantity

Controlling the quantity of stormwater using storage facilities can provide the following potential benefits:

- Prevention or reduction of peak runoff rate increases caused by urban development,
- Mitigation of downstream drains capacity problems,
- Recharge of groundwater resources,
- Reduction or elimination of the need for downstream outfall improvements, and

- Maintenance of historic low-flow rates by controlling the discharge from storage (Michigan Department of Transportation, 2006).

The 1960s, management of stormwater quantity for flood prevention was the only imperative, but in subsequent decades objectives for stormwater management have diversified quality control, recreation and aesthetic, ecosystem health and reuse (Figure 2.1) (Whelans et al.,1994 cited by Allison et al. ,2008).

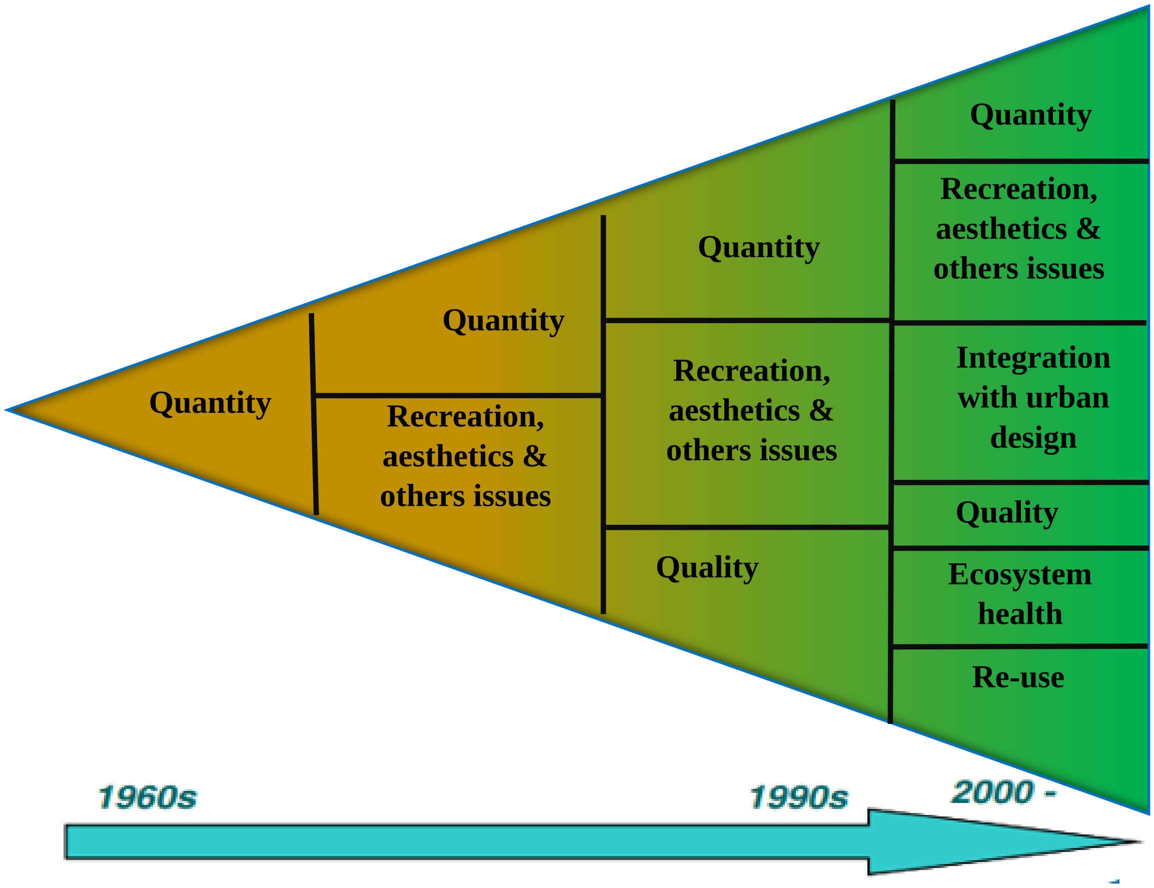


Figure 2.1: The subsequent decade's objectives for stormwater management.

2.4 Stormwater runoff quantity computation methods

As described in the New Jersey Stormwater Best Management Practice (2004), there are three general stormwater runoff quantity computation methods used to compute runoff rates and volumes. These are the NRCS methodology, the Rational Method and the associated Modified Rational Method.

i. Natural Resources Conservation Service(NRCS) methodology

Natural Resources Conservation Service methodology is the most widely used methods for computing stormwater runoff rates, volumes, and hydrographs. It uses a hypothetical design storm and an empirical nonlinear runoff equation to compute runoff volumes and a dimensionless unit hydrograph to convert the volumes into runoff hydrographs. The methodology is particularly useful for comparing pre- and post-development peak rates, volumes, and hydrographs. The key component of the Natural Resources Conservation Service runoff equation is the Natural Resources Conservation Service Curve Number which is based on soil permeability, surface cover, hydrologic condition, and antecedent moisture. Watershed or drains area time of concentration is the key component of the dimensionless unit hydrograph.

ii. Rational Method

Rational Method is useful in estimating runoff from simple, relatively small drains areas such as parking lots. Use of the Rational Method should be limited to drains areas less than 20 acres with generally uniform surface cover and topography.

As Idowu, et al. (2013) discussed, Rational Method is the process of determining the maximum surface runoff in a drains area. Functionally, it relates the quantity of surface runoff (Q) of the watershed area (A), the rainfall intensity (I) and the runoff coefficient (C) which is determined based on land use land cover, topography, soil type and storm period within the study area as shown in Equation-1

$Q = 0.0028CIA$……………………………………………………..……….Eq. (1)

A Rational Method is simplifying assumptions which include uniform rainfall with uniform intensity over the entire watershed for the particular time of rainfall concentration (Rossmiller, 1980 cited by Idown et al., 2013).

Table 2.3: Runoff coefficients for urban watersheds

Ground Cover	**Runoff Coefficient**
Grasses	0.05 - 0.35
Playgrounds	0.30-0.40
Forest	0.05 - 0.25
Cultivated land	0.08-0.41
Parks	0.1 - 0.25
Residential areas	0.3 - 0.75
Business areas	0.5 - 0.95
Industrial areas	0.5 - 0.9
Asphalt streets	0.7 - 0.95
Cobble stone	0.60-0.70.
Brick streets	0.70 - 0.85
Roofs	0.75 - 0.95
Concrete streets	0.7 - 0.95

Source: (LMNO Engineering Research and software, 2013).

iii. Modified Rational Method

The Modified Rational Method is a somewhat recent adaptation of the Rational Method that can be used to not only compute peak runoff rates, but also to estimate runoff volumes and hydrographs. This method uses the same input data and coefficients as the Rational Method along with the further assumption that, for the selected storm frequency, the duration of peak-producing rainfall is also the entire storm duration. Since theoretically, there are an infinite number of rainfall intensities and associated durations with the same frequency or probability, the Modified Rational Method requires that several of these events be analyzed in the method to determine the most severe. Use of the Modified Rational Method should also be limited to drains areas less than 8 hectares with generally uniform surface cover and topography.

2.5 Contribution of Green Infrastructure on stormwater management

Urban stormwater management options include the implementation of Green Infrastructure, which is designed to reduce or delay peak flow and volume of runoff by holding stormwater on-site, encouraging infiltration, and enhancing evapotranspiration (USGS, 2016).Green Infrastructure is an effective integrative stormwater management for all types of development that will minimize the amount of pollutant discharges to the waterways and significantly reduce the rate of degradation. It can also help to reduce loads and discharges in retrofit situations, although prevention versus retrofitting is less costly (US EPA, 2012). The types and scales of green infrastructure options are numerous and varied, and ideally each is engineered to fit local conditions such as space limitations, climate, slope, drains area, soil, and geologic materials. Common Green Infrastructure options include bio swales, rain gardens (Bio-retention), and converting impervious to pervious surfaces (USGS, 2016).

2.6 The role of green spaces in urban stormwater runoff management

Urban green space is an element of Green Infrastructure that provides multiple ecological benefits, among which the reduction of rainfall runoffs important for sustainable urban development, particularly for cities experiencing severe flooding and water hazards. In central Beijing City, a total of 97.9 millionm^3 of excess surface runoff was retained by urban green space in 2012; adding nearly 11% more tree canopy was projected to increase runoff retention by >30%, contributing to the considerable benefits of urban rainwater regulation (Lei et al.,2015).

Green Infrastructure emphasizes the importance of open space and green spaces that are protected and managed for ecological benefits they provide and used for stormwater management which is considerable as cost effective (Ashley et al., 2013). However, the aesthetic impacts associated with urban stormwater and Green Infrastructure are often difficult to quantify, aesthetic impacts are often very visible to the general public. EPA reports that “people have a strong emotional attachment to water, arising from its aesthetic qualities--tranquility, coolness, and beauty (US EPA, 1995).

2.7 Stormwater management approaches

According to U.S National Research Council (2008), stormwater control measures are grouped into nonstructural and structural. Nonstructural stormwater control measures include a wide range of actions that can reduce the volume of runoff and pollutants from a new development. For example, new developments that have fewer hard surfaces; the disconnection of downspouts from hard surfaces to instead connect with porous surfaces; the conservation of natural areas; improved watershed and land use planning. Structural stormwater control measures are designed to reduce the volume and pollutants of small storms by the capture and reuse of stormwater, the infiltration of stormwater into porous surfaces, and the evaporation of stormwater. The rainwater harvesting systems that capture runoff from roofs and surfaces use the structure of permeable pavement, rain barrels, tanks, or cisterns; the rain gardens, Bio-retention, infiltration trenches, swales, green roof, detention and retention pond.

i. Pervious Pavements

Pervious pavements can be used to infiltrate or store water. Because pervious pavement systems include a permeable paving surface and a subsurface material that can hold water, they can reduce runoff peak and volume (Ann, 2014). Voids created in the pavement matrix provide stable pockets which allow stormwater to flow through the pavement into an aggregate bed. The storage bed typically has a deeper profile than standard pavement subbases in order to store, and filter stormwater before percolating into underlying soils are being recollected in a system of underdrains and conveyed to a storm sewer or overland channel (Kinzelman, 2011).

ii. Storage tank

Storage tank or recharge tank can be stationed above ground, partly underground or fully underground depending on the design and spatial arrangements and can be made of reinforced cement concrete, ferro cement, masonry, plastic (polyethylene) or metal (galvanized iron) sheets. It can be classified broadly as above ground, called tanks and below ground called cisterns. They are the systems of harvesting rainwater from the roof and surfaces which manage stormwater runoff effectively.They are not effective in pollutant removal and not aesthetically pleasing. However, it is relatively less health risk if managed properly (Sisuru, 2016).

iii. Rain garden/Bio-retention

Rain garden and Bio-retention areas are landscaped depressions typically employed to manage the runoff from rainfall by passing the runoff through several natural processes which is effective in managing stormwater runoff from minor and more frequent rainfall events. The processes include filtration, absorption, biological uptake, sedimentation, infiltration and detention (Endicott and Walker, 2003). It is applicable for managing stormwater runoff on many sites, such as: between residential plots, parking lots, adjoining roadways, and within large landscaped impervious areas (Neil et al., 2013). Bio-retention systems applicable in highly urbanized areas may not be appropriate for infiltration due to high pollutant loads and potential for groundwater contamination. It is effective in the drains area of 2 to 5 acres with the land area requirement of 2 to 3% of the total drains areas which is effective in narrow urban space where the slope is 5% or less. The Bio-retention system should be 7.5m far from the building structure to minimize the damage (Kinzelman, 2011).

Figure 2.2: Bio-retention system (Source:NRCS, 2005)

iv. Vegetated Swale

A Vegetative Swale is a broad, shallow channel with a dense stands of vegetation covering the side slopes and bottom (US EPA, 1999). Dense vegetation or turf covering the side slopes and bottom of the Swale trap particles which carry biological and chemical pollutants. (Kinzelman, 2011). It can be natural or man-made and are designed to trap particulate pollutants (suspended solids and trace metals), promote infiltration, and reduce the flow velocity of stormwater runoff (US EPA, 1999). Swales offer an extremely practical and low cost alternative for infiltration of stormwater flow originating from rooftops, roads, and drives and parking areas.It is effective in drains area of 5 acres or less that ranges from 2 to 7% of drains areas (Kinzelman, 2011).

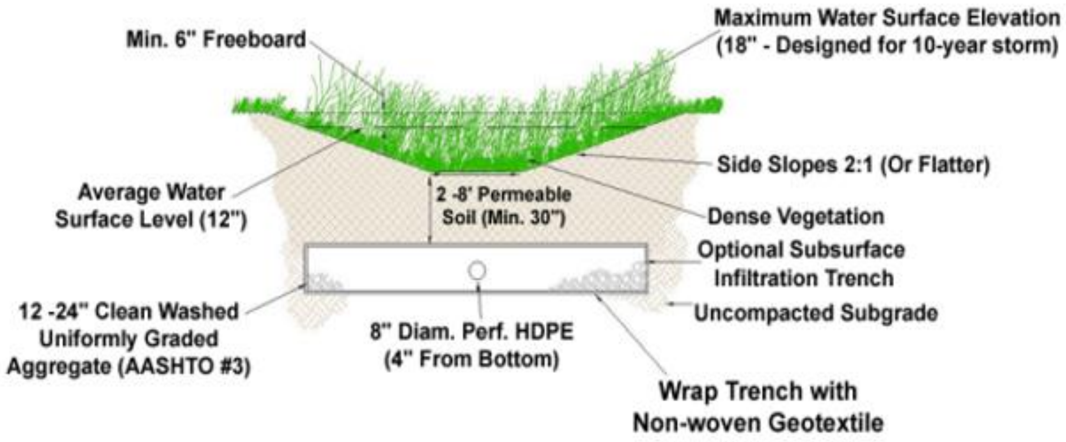


Figure 2.3: Section of Bio-retention system .(Source: Pennsylvania stormwater management manual, 2005).

v. Infiltration trenches

Infiltration trenches are shallow excavations that are filled with uniformly crushed stone (similar to soak pits) to create underground reservoirs for stormwater runoff. The runoff gradually infiltrates through the bottom of the trench into the subsoil and eventually into the water table. The walls and the top are lined with geotextile to avoid sediment penetration. Trench designs may be modified to include vegetative cover and other features, establishing a bio-filtration area. They are often constructed beside outdoor parking lots or beside streets. Treatment occurs during infiltration into the soil. However, there is a risk of clogging where the sedimentation concentration in runoff is high (Parkinson et al., 2010**).** Infiltration trenches are applicable for land uses that do not contribute heavy pollutant loads. It is effective in drains area less than 5 acres with high impervious cover with a land requirement of 5 acres which is 2-5% of drains areas at slope of not greater than 1 %(Kinzelman, 2011).

Figure 2.4: Infiltration trench (Source:Portland Water District, 2006).

vi. Green roofs

Green roofs are competent of removing 50% of the annual rainfall volume from a roof through retention and evapotranspiration, which is used as a component of a comprehensive stormwater management system (Tapaswini, 2015). Green roofs can reduce the peak flow discharge of rainfall events through their ability to absorb, detain, and slowly release stormwater through evapo-transpiration. It also further benefit the local environment by providing a greening effect, reducing glare and diminishing a building's contribution to the urban heat island effect (Kinzelman, 2011).

Figure 2.5: Green roofs (Source:https://www.americanforests.org.)

vii. Detention basin/pond

Detention ponds or Detention basins are temporary storage facilities that are ordinarily dry, but are designed in such a manner that they are able to store stormwater runoff for short periods of time. It can be utilized in areas where:

- Suitable depressions occur or can be constructed.
- Acceptable inflow and outflow conditions can be achieved.
- From a cost standpoint, the basin should be placed where the least amount of earth moving is required to obtain the necessary basin volume.
- Soils are able to provide a stable embankment.

Storage volume and the surface area for pollution abatement are adequate to detain the runoff from a specified storm event (Michigan Department of Transportation, 2006).

Figure 2.6: Detention pond (Source: https://int.search.myway.com/search/AJimage)

viii. Retention ponds

Retention ponds are usually capable of handling relatively large quantities of stormwater runoff, which provide a medium to high pollutant removal capacity (Woods-Ballard et.al.,2007). They normally utilize a combination of sedimentation, filtration, infiltration and biological uptake processes to remove pollutants from stormwater runoff (Stahre, 2006).

Figure 2.7: Retention pond (Source: EPA, 2009)

2.8. BMP selection in urban area

Stormwater harvesting Best Management Practice can be selected in urban areas bases on different factors such as ease of maintenance, community acceptance, construction cost, habitat quality and Nuisances (Table 2.4). Hydrological factors such interception, infiltration evaporation reduction and pollutant factor like Total Suspended Solid, Nitrogen, Phosphorus, Metals and Temperature are also other factors used to select the stormwater harvesting BMPs (Table2.5).

Table 2.4: Selecting BMPs based on community and environmental factors

BMP group	Ease of maintenance	Community acceptance	Construction cost	Habitat quality	Nuisances
Bio-retention	Medium	High	Medium	Medium	Mosquitoes, overgrown vegetation
Vegetation swale	Medium	Medium	High	Low	Filter media replacement, Underground practices not seen and maintained
Infiltration trench	Difficult	High	High	Low	Susceptible to failure if poorly installed or maintained
Stormwater pond	Easy to medium	Medium to high	Low	Medium	Grease, odors, mosquitoes and floatables
Wetland	Medium	Medium to high	Medium	Medium	Overgrown vegetation and mosquitoes

Source: (Minnesota Pollution Control Agency, 2018).

Table 2.5: BMPs screening matrix for hydrologic and pollutant factors

Structure practice	Hydrologic factor				Pollutant factor			
	Interception	Infiltration	Evaporation	Reduction	Total suspended solid	Nitrogen &Phosphorus	Metals	Temperature
Bio-retention	H	M	M	M	H	H	H	H
Dry detention	L	L	M	H	L	L	M	M
Vegetative swale	M	M	L	L	M	L	H	M
Green roof	H	L	H	M	L	L	L	H
Infiltration trench	L	H	L	M	H	H	H	H
Underground storage tank	M	M	L	H	H	H	H	H
Permeable pavement	M	M	M	M	L	M	L	M
Stormwater wetland	M	M	M	M	L	M	M	M
Wet pond	L	L	H	H	H	H	H	L

L: Low, poor, or no influence **M**: Moderate influence **H**: High influence

Source: (US EPA, 2008).

2.9 Selection of appropriate site for rainwater harvesting.

Selection of suitable urban stormwater harvesting sites is often complex due to spatial, temporal, economic, environmental and social factors, and associated various other variables. Moreover, the planning of stormwater harvesting projects essentially involves the engagement of diverse stakeholders in the decision making, who may have conflicting views on stormwater harvesting sites and approaches (Inamdar, 2014)**.**

a. GIS techniques and Remote Sensing

Remote Sensing and GIS technologies can be used to determine the suitable positions to construct the proper water harvesting structures in a watershed (Khalid et al., 2017). A Geographic Information System based decision support system that uses Remote Sensing, limit field survey to identify potential sites for RWH technologies. The input into the GIS include maps of rainfall, slope, soil texture, soil depth, drains and land use/cover and the outputs are factors use to select potential sites of water storage systems(Mbilinyi et al., 2007).

The selection of suitable urban stormwater harvesting sites is generally based on the judgement of water planners, who are faced with the challenge of considering multiple technical and socio-economic factors that influence the site suitability. (Inamdar et al., 2013).The landscape characteristics such as land cover, slope information, geological setup, soil and drains characteristics are defined as important criteria for identifying suitable rainwater harvesting sites by using Landsat, Satellite images used for land use/land cover, DEM, used for slope, drains density and hydrological analysis (Surajit and Mobin, 2016),

b. Multi-Criteria Decision Analysis methods.

The Multi Criteria Decision Analysis can used in ranking the rainwater harvesting sites under economic, environmental and social objectives, representing the sustainability of stormwater harvesting systems. Performance measures were identified to characterize the objectives and system performance related to the alternative stormwater harvesting sites for the demonstration of the application of the developed methodology. A technically robust and pragmatic methodology for evaluating rainwater harvesting potential and identifying suitable sites for RWH and artificial recharge structures using Geographic Information System based Multi-Criteria Decision Analysis methods (Inamdar, 2014).

This method proposes an approach to prioritize zones/sites for RWH and recharge structures, which is great importance for the effective implementation of RWH strategies. The derived themes ‘runoff coefficient’ and the basic themes of ‘slope’ and ‘drains density’ were used for mapping rainwater harvesting potential. Thereafter, suitable zones and sites for feasible RWH and recharge structures were identified using suitability criteria and GIS-based framework. The prioritization of suitable zones/sites for RWH and groundwater recharge is proposed by integrating ‘rainwater harvesting potential’ and ‘rainwater harvesting demand’ maps. The integrated geospatial and MCDA approach is not only time saving and cost-effective but also very helpful for the efficient planning and management of rainwater at a larger scale (Laishram et.al, 2017).

c. Criteria considered in selection of suitable sites for surface water harvesting structure.

The following factors defined the criteria in locating suitable sites for the passive water harvesting structures

- The site should be greater than 7.5 m far from the buildings and not more than 50m far from the potential areas (Tennessee Department of Environment and Conservation,2014)

- It should be on a level to the gently sloping ground (1-5%) (Virginia DEQ stormwater specification, 2011).
- It should be located where the soils are fine loamy to clay and the land use, land cover that has low runoff coefficients (grass lands,) (Livingstone A., 2015).

2.10 Steps to select a passive rainwater harvesting system

In order to select any passive mechanism in rainwater harvesting, the following steps are necessary.

1. Calculate the amount of rainwater that could be harvested from each area.
2. Identify areas such as rooftops, paved areas, slopes, or compacted soils from which rainwater could be harvested.
3. Calculate the required capacity (size) a rainwater harvesting system needs to catch and store enough rainwater from the site.
4. Evaluate the amount of maintenance each rainwater harvesting system requires and the willingness and ability to properly monitor and maintain the system.
5. Based on these evaluations, consider which type of system (or multiple systems) to use for harvesting rainwater from the site.
6. Analyze the suitability of the site specifically for the harvesting system(s) being considered.
7. If a storage method is to be used, determine:
   - How water would be moved from the collection site to the storage tank.
   - How the water will be used and how quickly it can be used.

- How and where overflow would be directed when there is heavy rainfall or when rainstorms occur in close succession to one another (Kelly, 2012).

2.11 Design and develop stormwater runoff harvesting structures.

i. Design approach of stormwater management through WSUD

Open Space – Integrate public open space with conservation corridors, stormwater management systems and recreational facilities.

Housing layout – Integrate residential blocks with the surrounding drains function and public open space. Such housing layouts often include a more compact form of development, which reduces impervious surfaces.

Road layout – Incorporate the natural features and topography of a site into the development i.e. Locate roads beside public open spaces wherever possible, enhance visual and recreational amenities, retain temporary storage, accommodate infiltration at or close to the source and preserve water quality.

Streetscape - Integrate road layout and vehicular and pedestrian requirements with stormwater management needs using design measures such as reduced frontages, zero lot-lines, and local detention of stormwater in road reserves and managed landscaping (Westhoff Engineering Resource, 2007).

ii. Design consideration for stormwater management structures to remove gross pollutants

Stormwater for harvesting and reuse is likely to need pre-treatment to remove gross pollutants, including litter, organic matter and coarse sediment before it enters a storage or downstream treatment measures. Several types of proprietary and non-proprietary gross pollutant traps are available which could be used for this purpose. As the level of gross pollutants in stormwater and the efficiency of gross pollutant traps are variable, the scheme should be designed on a contingency basis such that the scheme's operation is not compromised by the presence of gross pollutants (Department of Environment and Conservation, 2006).The potential of BMPs structures in pollutant retention such Total Suspended Solid, Total Nitrogen, Total Phosphorus and Turbidity is high in Bio-retention, followed by sand filter and pond (Table 2.6)**.**

Table 2.6: Indicative level of pollution retention for different stormwater treatment measure

Stormwater treatment measure	**Suspended Solids**	**Total Phosphorus**	**Total Nitrogen**	**Turbidly**
Bio-retention system	70-90%	50-80%	30-50%	55-90%
Swale	55-75%	25-35%	5-10%	44-77%
Sand filter	60-90%	40-70%	30-50%	55-90%
Pond	50-75%	25-45%	10-20%	35-88%
Wetland	50-90%	35-65%	15-30%	10-70%

Source: (Fletcher et al., 2004 cited by the DEC, 2006).

2.12 Design of the Bio-retention system

Bio-retention gardens are an ornamental and planted in landscape depressions designed to hold and infiltrate stormwater runoff within a short period of time (Kelly et al., 2012). Bio-retention systems, also known as biofiltration systems which are common stormwater mitigation measure (William et al., 2015). Bio-retention systems are used to remove a wide range of pollutants, such as Suspended Solids, nutrients, metals, hydrocarbons, and bacteria from stormwater runoff. They can also be used to reduce peak runoff rates and increase stormwater infiltration when designed as a multi-stage, multi-function facility (New Jersey Stormwater BMP, 2009). Bio-retention practices, provide additional benefits, including cleaner air, carbon sequestration, improved biological habitat, and aesthetic value (Minnesota Pollution Control Agency, 2018).

i.Sizing and design criteria of Bio-retention

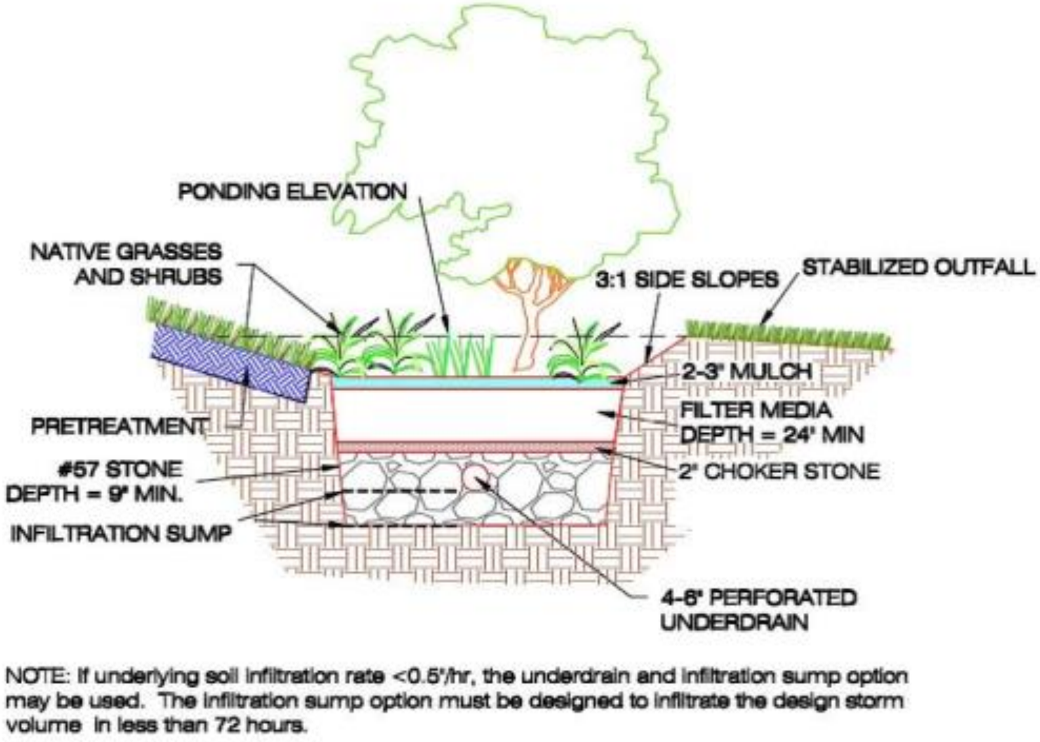
The Surface area of Bio-retention is dependent upon storage volume requirements, but should generally not exceed a maximum loading ratio of 5:1 (impervious drains area to infiltration area).Surface side slopes should be gradual. For most areas, maximum 3:1 side slopes are recommended, however, where space is limited, 2:1 side slopes may be acceptable. Surface ponding depth should not exceed 12 inches in most cases and should empty within 72 hours. The subsurface storage/infiltration bed is used to supplement surface storage where feasible (Stormwater management design assistance manual, 2006).

The filter media layer provides the majority of the pollutant treatment function, through fine filtration and also by supporting vegetation. The vegetation enhances filtration, keeps the filter media porous, provides substrate for biofilm formation and provides some uptake of nutrients and other stormwater pollutants. As a minimum, the filter media is required to have sufficient depth to support vegetation. Typical depths are usually between 400-1000 mm with a minimum depth of 400 mm for grasses and shrubs and a minimum depth of 800 mm for tree species to avoid roots interfering with the perforated under-drain system (WSUD guidelines, 2005)

The filter media soils should be amended with a composted organic material and a typical organic amended soil is combined with 5-10% organic material (compost), and 70-80% sand and 10-15% silt. Planting soil should be approximately 4 inches deeper than the bottom of the largest root ball. Soils should also have a pH of between 5.5 and 6.5 (better pollutant adsorption and microbial activity), a clay content less than 10% (low clay is beneficial to adsorb pollutants and retain water). (Stormwater management design assistance manual, 2006).

The design permeability rate through the planting soil bed must be sufficient to fully drain the stormwater runoff volume within 72 hours. This permeability rate must be determined by field and/or laboratory testing. Since the actual permeability rate may vary from test results and may also decrease over time due to soil bed consolidation or the accumulation of sediments removed from the treated stormwater, a factor of safety of two shall be applied to the tested permeability rate to determine the design permeability rate. Therefore, if the tested permeability rate of the soil bed material is 4 inches/hour, the design rate would be 2 inches/hour. The maximum allowable design permeability shall be 10 inches/hour for any permeability at 20 inches/hour or greater (New Jersey Stormwater BMP, 2009).The maximum saturated hydraulic conductivity should not exceed 500 mm/hr (and preferably be less than 200 mm/hr) (WSUD, 2005).

Vegetation is critical for stormwater treatment. Vegetation takes up nutrients, supports biological growth (critical for pollutant removal), maintain and enhances the porosity of soil, and continuously breaks up the surface of the filter media to help to prevent surface clogging. Vegetation in Bio-retention systems (grasses, sedges, shrubs and trees) must be tolerant to extended dry periods and periodic inundation (Water by design, 2014). Mulch or leaf composts (or other comparable product) should be uniformly applied immediately after shrubs and trees are planted to prevent erosion, enhance metal removals, and simulate leaf litter in a natural forest system. Mulch / compost layer should not exceed 3 inch in depth so as not to restrict oxygen flow to the roots. Under drains should not be used except where in-situ soils fail to drain surface or where storage of water is needed (Stormwater management design assistance manual, 2006).



NOTE: If underlying soil infiltration rate <0.5"/hr, the underdrain and infiltration sump option may be used. The infiltration sump option must be designed to infiltrate the design storm volume in less than 72 hours.

Figure 2. 8: Bio-retention design with an underdrain and infiltration storage (Source: Department of Environmental Quality, 2011).

ii. Bio-retention site integration and applicability

According to Environmental Services Division (2007), Bio-retention system can be incorporated or integrated into new residential developments, commercial, industrial developments, roadway projects, institutional developments, redevelopment communities, urban retrofit stormwater management projects, streetscaping projects, parks and trailways, to improve water quality and contain increased quantities of runoff.

New developments provide perfect opportunities to employ Bio-retention facilities for meeting stormwater management requirements. New Commercial and industrial sites also provide an excellent opportunity to employ the use of Bio-retention. Many commercial and industrial sites use and incorporate Bio-retention into the landscaping buffers, parking lot islands, perimeter landscaping, entrance gardens, treebox areas (green space area between sidewalk and roadway), or even rooftops. Transportation safety and right-of-way limitations tend to take precedence over stormwater management concerns. For these types of situations, Bio-retention facilities, strategically placed to intercept street runoff can be the solution. Bio- retention facilities have the additional benefit of providing roadside landscaping variety. Institutional settings are owned by government or private organizations and offer many opportunities for the installation of Bio-retention (MPCA, 2018).

2.13 Conceptual framework

The conceptual frameworks in Figure 2.9 indicates the framework of passive rainwater harvesting structure for stormwater management and green area improvement effectiveness in urban areas.

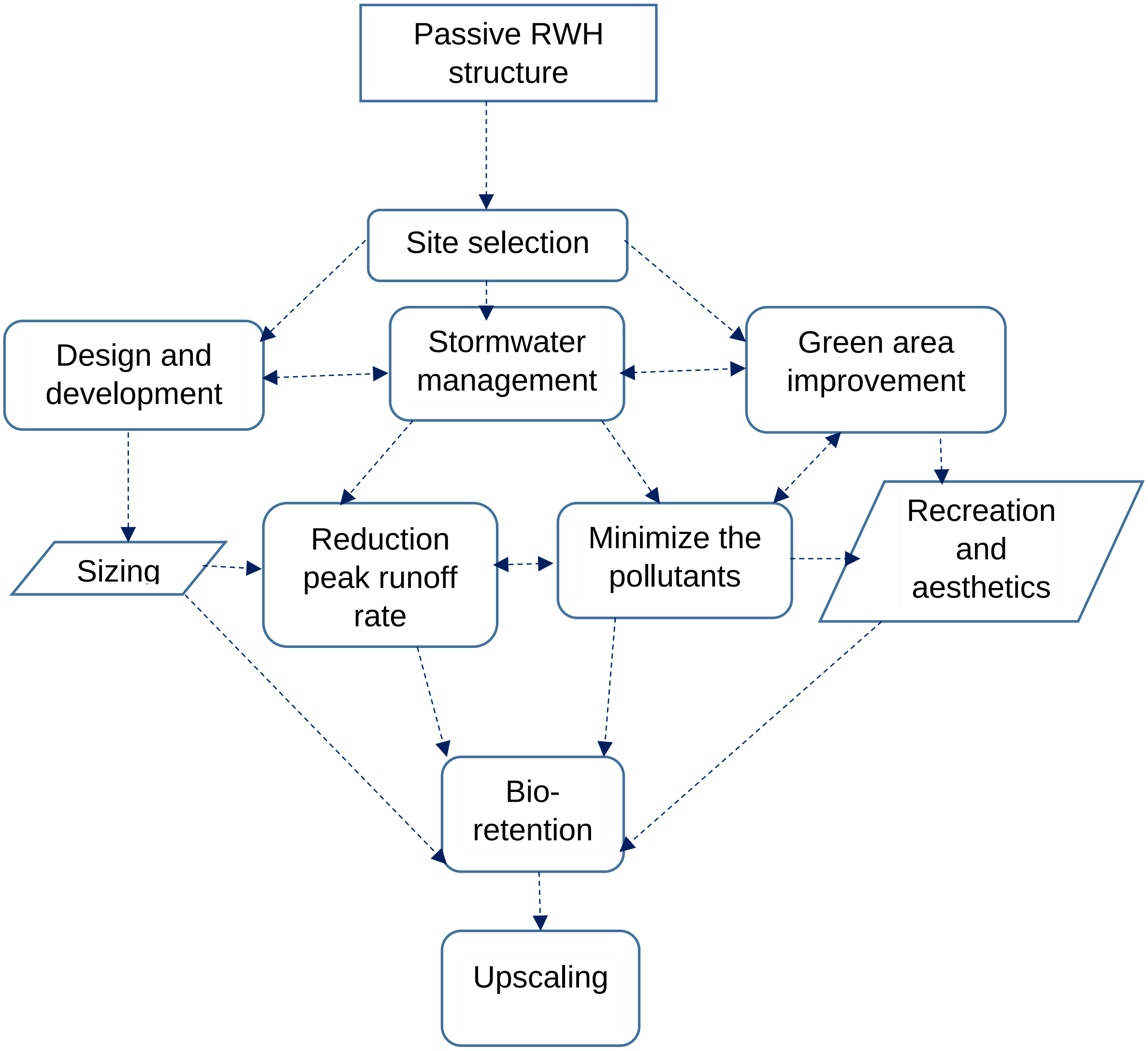


Figure 2.9: Conceptual framework

SUMMARY

The appropriate site for rainwater harvesting structure is selected by using GIS technologies, Landsat, and Satellite images that are used for the suitability analysis and identification of land use/land cover, slope, soil, drains area, density and hydrological analysis. Rainwater harvesting structures are designed to reduce the volume and pollutants of storms by the capture and reuse, infiltration into porous surfaces, and evaporation. These structures include Rain barrels, Tanks, or Cisterns; Rain Gardens, Bio-retention Permeable pavement, Infiltration trenches, Swales, Green roof, Detention and Retention pond.

The effectiveness of stormwater management practices are basis on the pollutant removal performance, the volume of stormwater intercepts, maintenance burden, acceptance by community, aesthetic value ,reduction of urban heat island effects and other urban amenities. The Best Stormwater Management practice structure in urban areas based on the community acceptance and environmental factors are Bio-retention, Pond, Wetland, Infiltration trench and Vegetation Swale. The potential of BMPs structures in pollution retention such Total Suspended Solid, Total, Nitrogen Total Phosphorus and Turbidity is high in Bio-retention, followed by Sand filter and Pond.

The sizing and design criteria of Bio-retention system depends on the nature and benefits of the structures and storage volume requirements with the maximum loading ratio of impervious area to infiltration area is not exceeded of 5:1, maximum side slope 3:1, surface ponding depth is not exceeded 12cm, and planting soil depth would be based on the types of plant species. The stormawater

management structures are applicable in urban areas by integrating into new residential developments, commercial/industrial developments, Roadway projects, Institutional developments (such as, places of Worship, Schools, Universities, Community centers, and Administration), streetscaping projects, parks and parking areas.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area description

The study was conducted at the Ethiopian Institute of Architectural, Building Construction, and City Development campus. It is found in Addis Ababa City Administration, Lideta Sub City and being confined by astronomical grids of 9 ^{0} 00′ 43″-9^{0} 00' 51″N and 38^{0}43' 44'' - 38^{0} 43′ 51″E (Figure 3.1). The Altitude of the EiABC campus is 2341m as low in the Southwest and 2375m as high in the Northeast above sea level. According to data obtained from nearest station called Tekur Anbesa meteorology station (2017), the maximum average annual rainfall was 1352.9 mm and minimum average was 1080.8 mm with 60% of the rainfall occurring during June, July and August. Similarly the average yearly relative humidity of the area ranges between 60-69.5% (computed from 30 years meteorology data (1993-2017) of Tikur Anbsea Station).

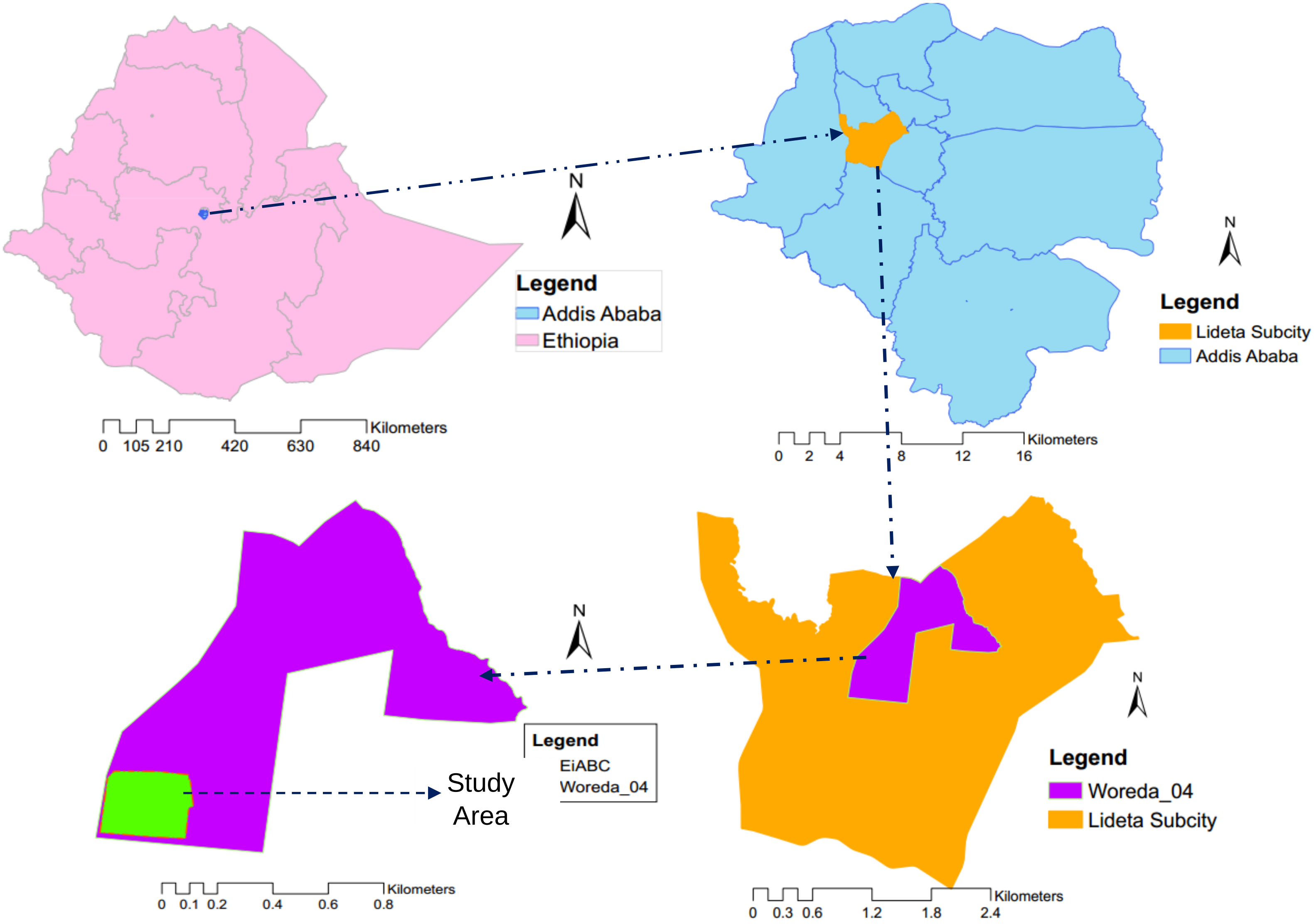


Figure 3.1: Location map of the study area

Topographically, the majority of the EiABC campus falls in the gradient of 2-15%, which covers an area of 6.26 hectares (80.46%) from the total area of 7.8 hectares. Whereas 14% and 5.54% is within a gradient of less than 2% and greater than 15% respectively (Figure 3.2)

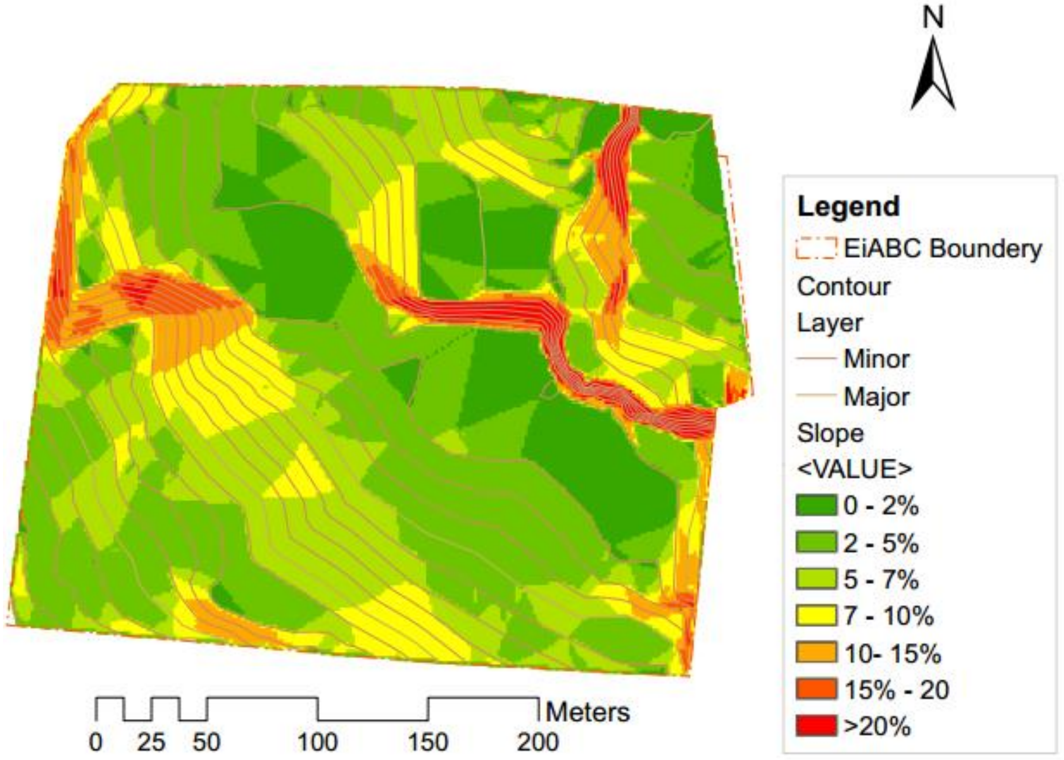


Figure 3.2: Slope category of the EiABC campus

EiABC is found in the Akaki River catchment. Akaki River is a part of the Awash River basin, which drains the eastern, and western part of Addis Ababa. The Akaki river catchment consists of two main branches, namely large Akaki and Little Akaki River, which converging at the Aba-Samuel Lake (Figure.3.3).

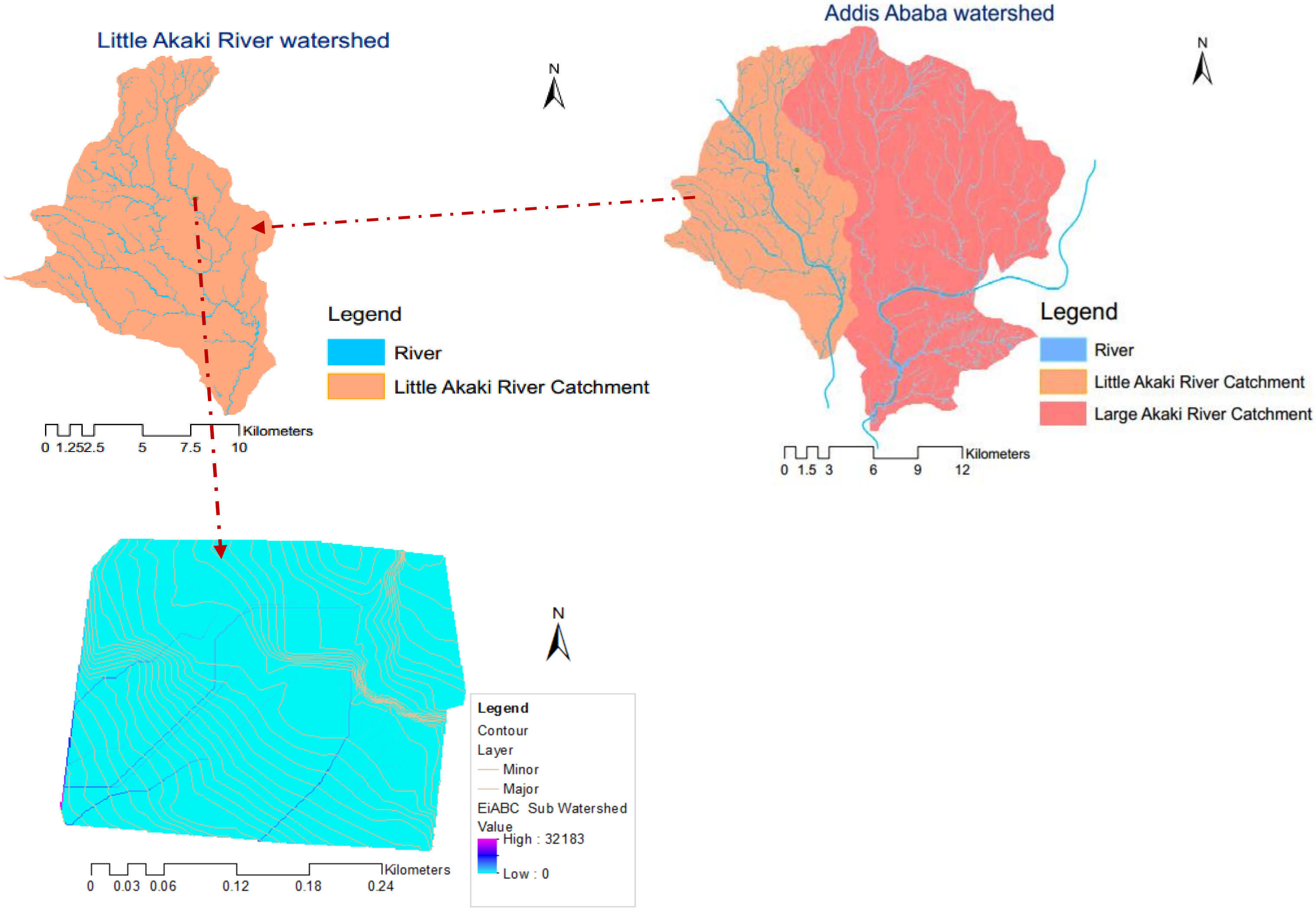


Figure 3.3: Watershed of EiABC campus

EiABC campus has three sub catchments having different water outlets. These are labeled as Administration office sub catchment, Play field sub catchment, and urban building sub catchment which covered an area of 2.47, 1.8 and 3.51 hectares respectively (Figure 3.4). Of these, 53.85% of urban building, 23.6% of administration office and 39.83% of play field sub watershed areas were impervious surfaces (Figure 3.5).

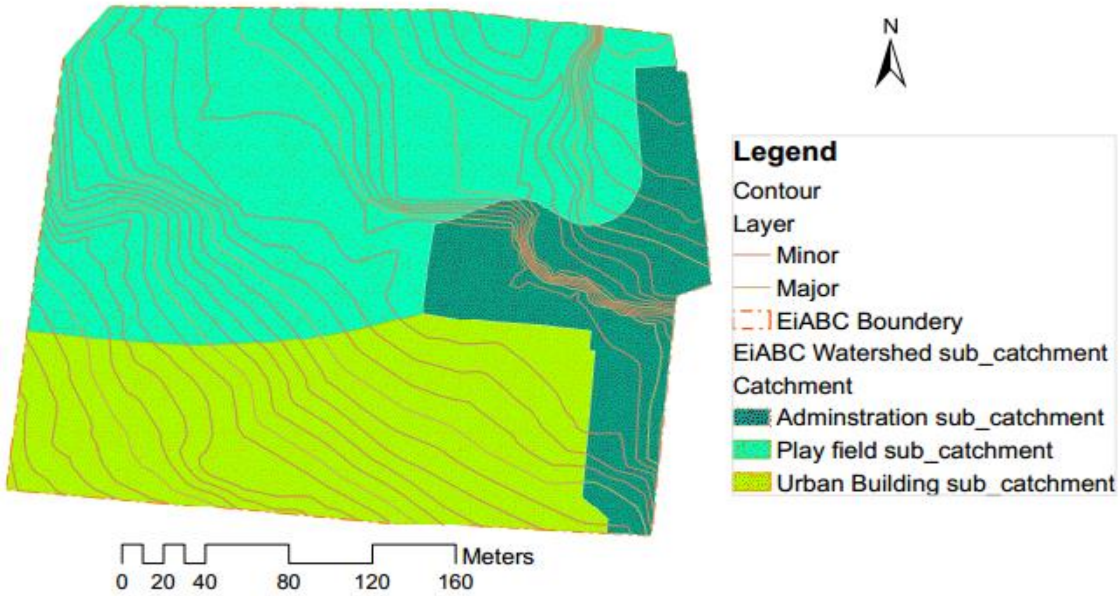


Figure 3.4: EiABC campus sub-watershed

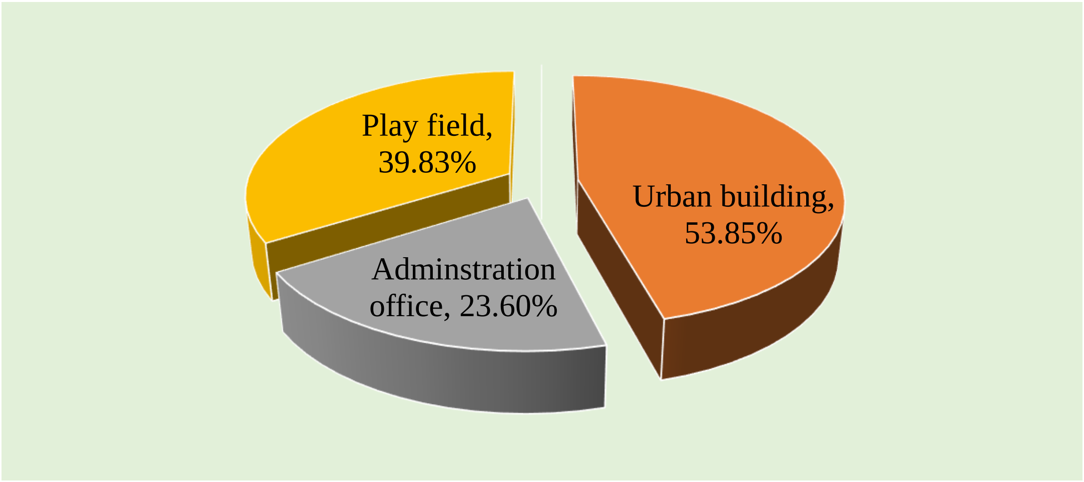


Figure 3.5: Imperviousness level of EiABC campus sub-watershed

3.2 Research design

According to Kothari (1984), research design is the arrangement of condition for collection and analysis of data in a manner that aims to combine relevance to the research purpose. It is the conceptual structures within which research is conducted. The quantitative and qualitative research design was conducted to realize the research. Generally the conceptual structure of the research design is indicated in the Figure 3.6.

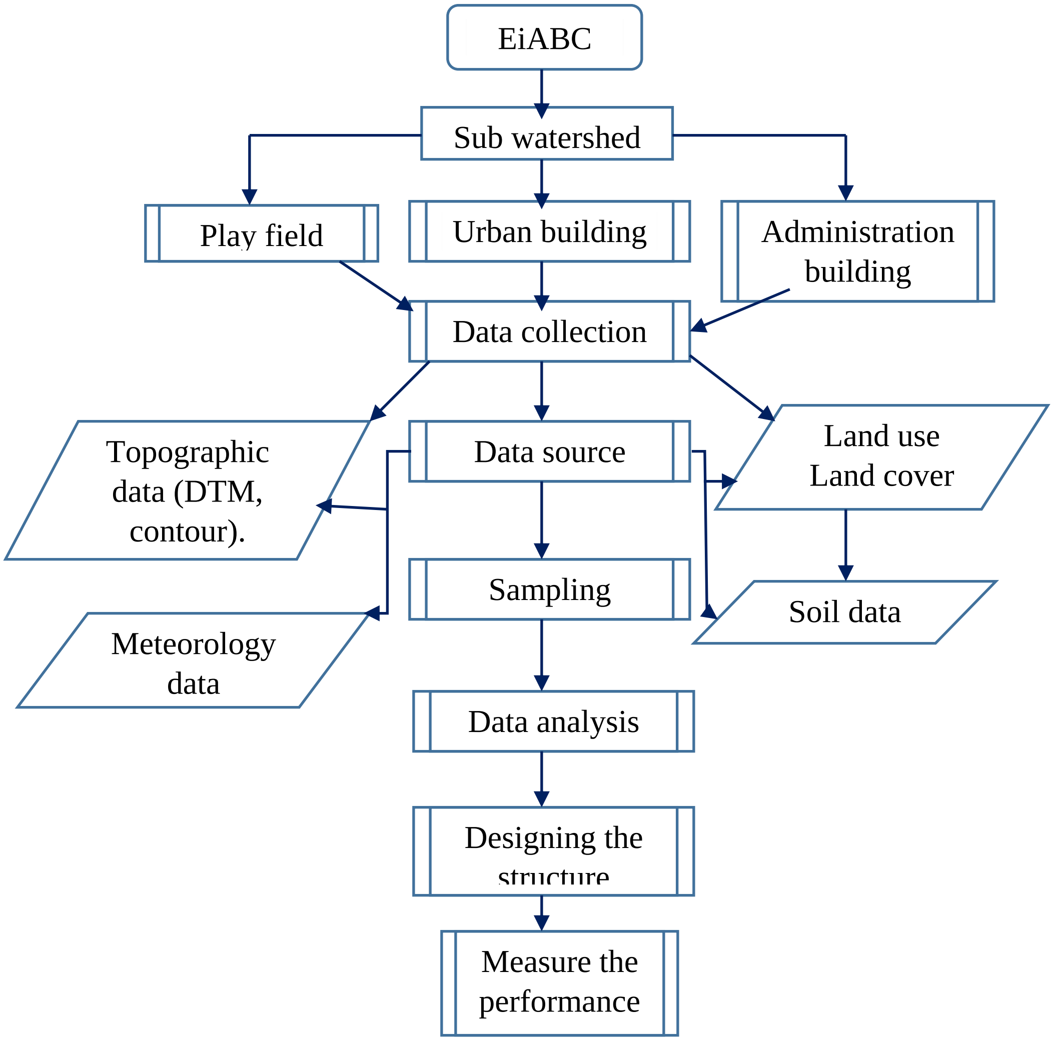


Figure 3.6: Research design diagram

3.3 Source of data

The data used for this study had been obtained from the Addis Ababa City, the National Meteorological Agency of Ethiopia, reports as well as from published and unpublished documents. It had been also obtained from field observation, land use, land cover inventory and stormwater samples.

3.4 Data collection

Data that had been collected include: built up areas, vegetation cover, open spaces which contains all undeveloped land without vegetation cover, streets, rainfall, soil,drainage areas and DTM data. Stormwater samples were collected manually from the site before entering and after entering of the Bio-retention system. Ten samples five before and five after were collected in a single 2 liter bottle and were transported to the Addis Ababa University, Department of Biology Laboratory for TSS and TDS water quality processing and Turbidity, Conductivity and pH were tested in site.

3.5 Data analysis and procedures

The stormwater potential, and the suitable site were analyzed to design and develop the Bio-retention structure. The quantity and quality performance of the Bio-retention system was also analyzed in the study area.

i. Stormwater potential estimation

Runoff calculation was conducted by taking 30 years consecutive rainfall data to enhance the accuracy and was calculated by taking every year’s average repetitive rainfall which had a high probability of occurrence. The annual average and daily maximum depth of rainfall was analyzed to identify the potential of the study site for stormwater harvesting. Finally, the annual average and daily maximum volume of runoff generated was estimated by Rational Methods using the existing land use, land cover of the drains area, average annual and daily maximum rainfall and respective runoff coefficient as an input to design and develop the Bio-retention system.

Rational equation: $Q = C_f * I * A$……………………………………………….….Eq. (2)

Where: Q: Volume of runoff,

I: Rainfall intensity,

Cf: Runoff coefficient, and

A: Catchment area.

ii.Site selection analysis

The potential site of rainwater harvesting structure for stormwater management was identified using Geographic Information Systems and Remote Sensing data that had led to the appropriate location on the selection of suitable sites. The site was analyzed by suitability analysis using a multi criteria method and weighted overlay of existing buildings, soil, and topography and land use, land cover of the sub catchment area which are the factors. To weight overlay, the first stage was determine criteria/factors for suitability of water harvesting structure. The second stage involved the preparation of maps/layers for each criterion using the respective dataset obtained. The third stage was weight each criterion in a multi criteria analysis using the weighted overlay tool in Arc GIS 10.3 and hence come up with the required suitability map.

iii.Performance analysis

The quantity of stormwater that was harvested through Bio-retention system and stored for reuse was estimated. The samples of stormwater runoff collected from the inlet and outlet of Bio-retention system was analyzed for TSS, TDS and Heavy metals in laboratory for water quality performance of the system. The water quality parameters (Turbidity, pH, and Conductivity) were also analyzed on the site as soon as the samples were collected. The change in contaminant concentration which is based on the performance of the Bio-retention system was calculated to compare both the inlet and outlet concentrations.

Table 3.1: Summary of methods

Methodology				
Specific objectives	**Types of data**	**Methods of data collection**	**Data collection instruments**	**Analysis methods**
To identify the appropriate site for rainwater harvesting structure within the EiABC campus.	Existing Land use, land cover, topographic data, soil type,	Field observation, land use, land cover inventory,	Observations, measuring, document review.	Suitability analysis using Arc GIS desktop tool
To design and develop options for passive rainwater harvesting structure	Sub watershed area, land use, slope, rainfall depth	Field survey, observation	Measuring, document review .	The components of the stormwater harvesting structure (inlets, outlet, and the layers) were sized and analyzed quantitatively based on specified daily rainfall events and sub catchment area.
To estimate the performance of rainwater harvesting structure for stormwater	Stormwater runoff volume and its samples	Estimation, and sampling	Measuring, laboratory test,	EPA analytical methods for TSS, Turbidity sensor (Nephelometry) methods for Turbidity, gravimetric analysis methods for TDS, and metal

management and green area improvement		electrode methods for pH measurement and analysis were used to identify the stormwater quality performance of the surface water harvesting structure. The quantity and green areas improvement performance of the stormwater harvesting structure was estimated and analyzed.

CHAPTER FOUR

DATA ANALYSIS

4.1 Selection of suitable site for stormwater harvesting structure

The suitability of the site for stormwater harvesting structure was defined by using a building linear buffer, land use, land cover, slope and soils types’ as a criteria. Criteria layers are a raster file that shows a scale of suitability and define the influence of each criterion on the positioning of the surface water harvesting structure. The weight influence for each criterion was assigned 25 for building buffer, 35 for land use, land cover, 30 for slope and 10 for soil types. In this thesis, the scale of suitability ranges from 1 to 5 with 5 as the most suitable while 1 is the least suitable (Table 4.1).

Table 4.1: The feature weights applied for suitability analysis

Criterial layer	Weight % influence	Class of feature	Feature weight class
Building linear buffer	25	**Linear buffer**	
		Less than 7.5 m	1
		7.5-25m	5
		25—50m	4
		Greater than 50m	2
Land use, land cover	35	**Classes**	
		Buildings (roofs)	1
		Asphalt roads	1
		Cobbles and paved stones	2
		Gravels	3
		Trees	5
		Grasses	5
		Playfields	4
Slope	30	**Slope structure**	
		Flat slope (0-1%)	3
		Gentle slope (1-5%)	5
		Moderate slope (5-10%)	4
		Steep slope (10-15%	3
		Very steep slope (>15%)	2
Soil type (FAO classification)	10	Nitisols (permeable)	4

Suitability Level: 5: very high, 4: high, 3: moderate, 2: low and 1: very low

a. Slope suitability map

The identified slope that was suitable for developing stormwater harvesting structure was the gentle sloping with the gradient of 1% to 5% and assigned as the suitability level of 5. In contrast, the site which has the slope of less than 1% and greater than 15% is the lowest suitable areas for developing stormwater structure with the suitability level of 3 and 2 respectively (Figure 4.1). The slope map generated indicating that 55.6% of the study area were suitable for surface water harvesting with the slope ranging from 1% to 5% .While the site that is not suitable for the surface water harvesting was 5.4% (Figure 4.2).

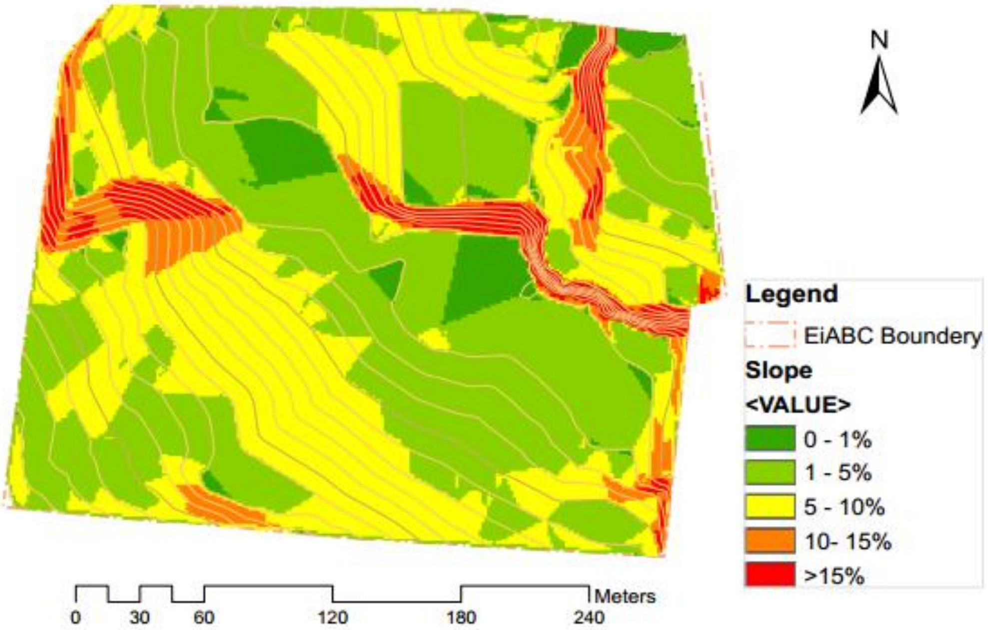


Figure 4.1: Slope suitability map

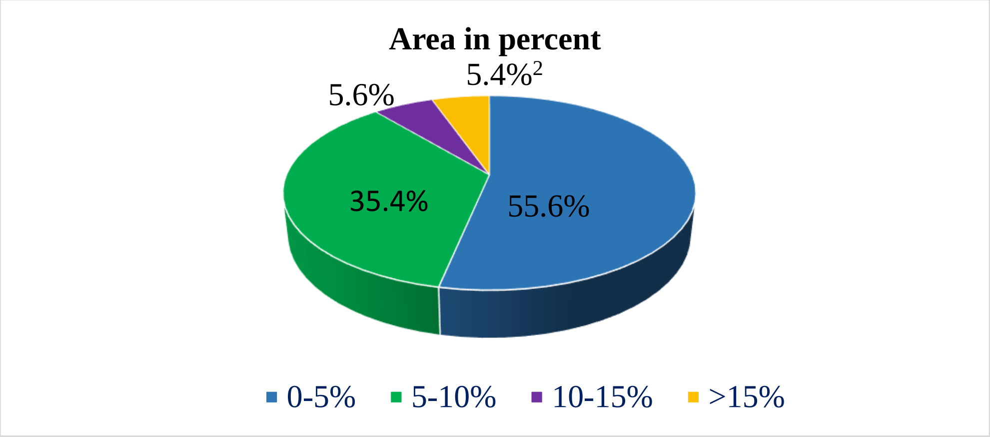


Figure 4.2: Area of slope suitability maps

b. Buffer suitability

The buffer plays a major role in the selection of the site for rainwater harvesting structures because it is identifying a collection site for water when it rains. Most rainwater harvesting structure harvests water from the rooftops and surfaces and should therefore be constructed near them. However, it has not been very close to especially, when the catchment of rainwater harvesting is a rooftop for the safety of buildings. The rasterized buffer map of the buildings that is shown in Figure 4.3 indicates the area that was suitable for rainwater harvesting structure. The area that is very suitable for rainwater harvesting structure is an area found within a distance of 7.5m to 25m. Hence, the weight given for an area located within this respective distance was 5 as of the most suitable site. While the area that was found within below 7.5m was not suitable for rainwater harvesting structure, especially in underground rainwater harvesting structure as it can affect the building structure.

The harvesting site greater than 50m far from the potential harvesting surface areas was not suitable as it needs high construction cost to develop and install the stormwater conveyance line. Of the total area, 48.7% was very high suitable and 13.6% was high suitable in case of buffer suitability. While 37.7% was not suitable for developing rainwater harvesting structure.

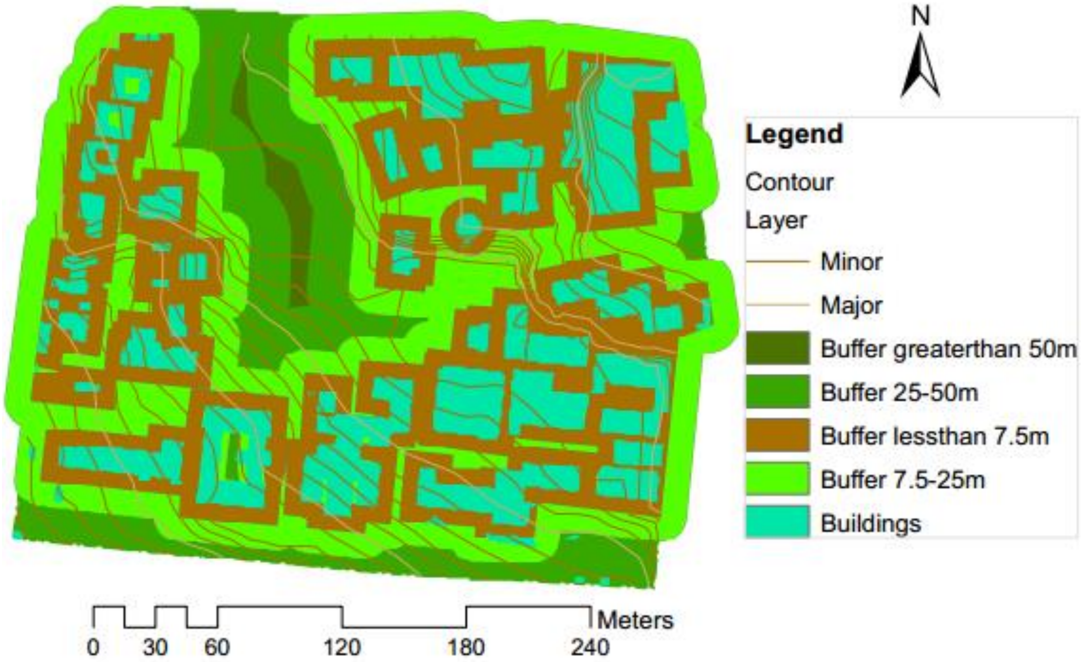


Figure 4.3: Building buffer suitability map

c. Land use, land cover suitability

The land use and land cover characteristic can be categorized as into both constraints and opportunity layer. The building sites are the constraint part of the layer and are therefore given the least suitability. The roof tops and impervious pavement areas are the potentials to harvest and store for use of rainwater. While the pervious areas like land covered by trees and grasses are less potential to harvest rainwater for use as it is percolated and recharge groundwater. However, this respective land use is the highest potential to minimize stormwater runoff by infiltrating and detaining the stormwater through the soil media even if the types of the soils are also other determinant factor. Figure 4.4 shows that the area occupied by the land use of grasses and trees was 45.77%, which is very high suitable for developing the surface water harvesting structure. Similarly, the site of play field was the high suitable land use, which cover 8.58% of the total area of the EiABC campus. In contrast, the land use, land cover of buildings, and streets which cover 45.66% were not suitable to develop the stormwater harvesting structure. However, this respective land uses were the potential to harvest the stormwater from the site. Generally, 54.35% of the total area of EiABC campus land use were suitable and 45.65% of the land use were not suitable for developing stormwater harvesting structure.

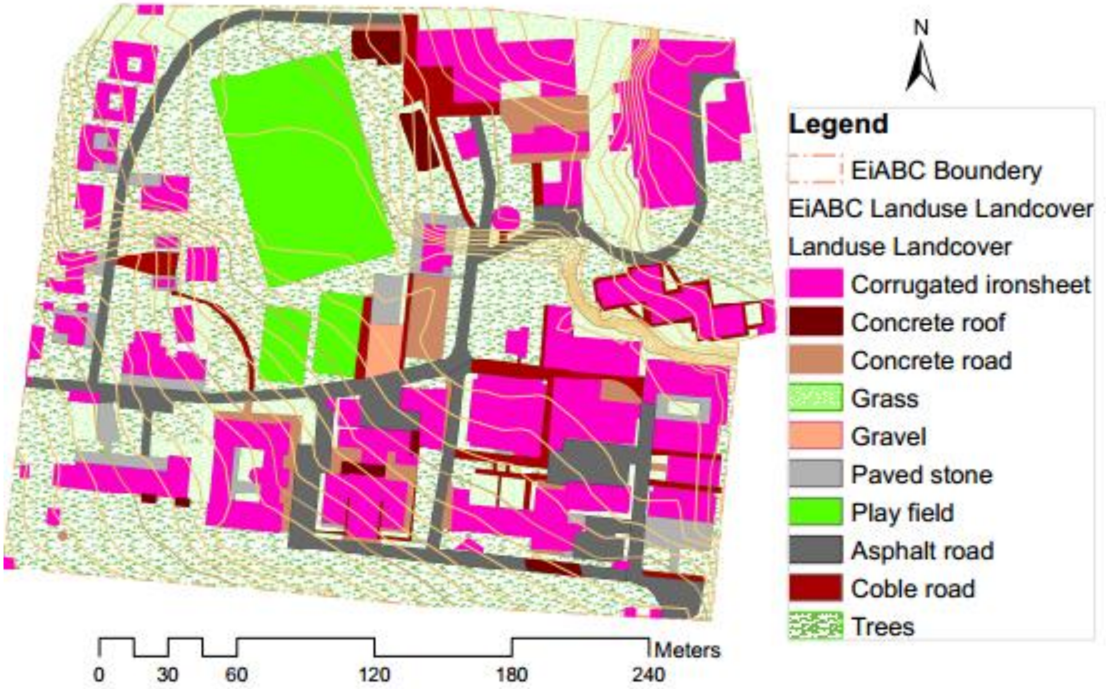


Figure 4.4: Land use, land cover suitability map

d. Soil suitability map

Soil texture plays a critical role in the selection of water harvesting structure. Clay soils are the best for water retention while sandy loams are good at allowing infiltrating to the aquifers. The area covered by clay soils is highly suitable due to the water retention capacity of clay soil that make it good for structure that hold water as pans. The soil type of EiABC campus is nitisols

(Figure 4.5) which has more than 30 percent clay which is well drained and easily retain stormwater. So that it was the potential for harvesting the stormwater from the impervious areas in the campus.

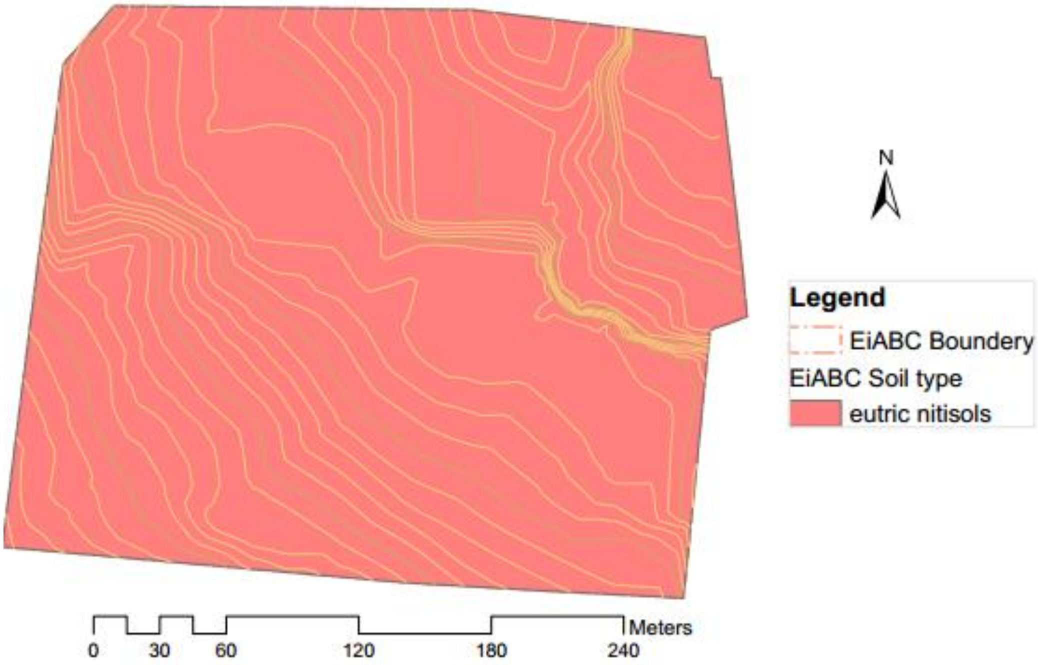


Figure 4.5: The soil suitability map

e. Weighted Overlay

The weighted overlay tool was used in combining the influence of each criterion (slope, building buffer, land use, land cover, and soil type) into one map. This involved the assigning of weight/scale values to each criterion and its respective influence in the overall suitability maps. The maps depict clear zones that met all the very high suitability criteria (Figure 4.6).

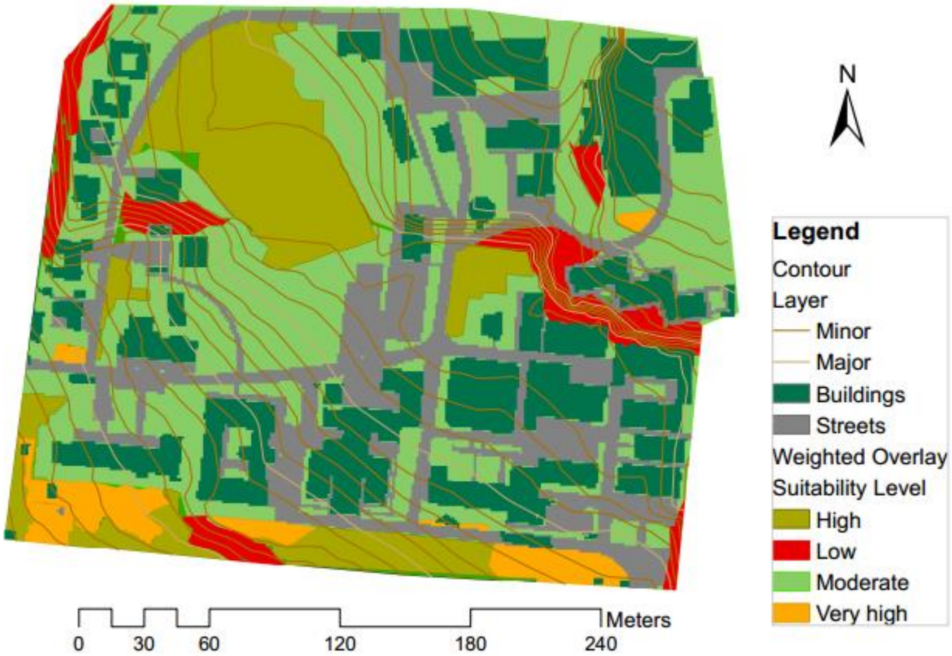


Figure 4.6: Weighted overlay map

4.2. Design and develop options for passive rainwater harvesting structures

i. Potentiality of passive rainwater harvesting in the EiABC campus.

The passive rainwater harvesting potentiality of the study area was identified by using pertinent factors such as rainfall data, catchment area, and land use, land cover with different runoff coefficients.

a. Rainfall

The passive rainwater harvesting potential of the EiABC campus varies due to the change of rainfall pattern. To calculate the potential of the campus, rainfall data from 1987 to 2017 was obtained from the nearest station which is Tikuranbesa station. This rainfall data provided by the station recorded and organized on a daily basis. In this regards, 71.2% of the annual rainfall occurs during the rainy season starting from June, up to the end of September. While the remaining 28.8%of the rainfall occurs during the dry season starting from October up to the end of May. In this case the monthly average rainfall depth was ranging from 11.2 mm to 302.3mm and maximum monthly average rainfall occurred in August and July which accounts 302.3mm and 278.1mm respectively (Figure 4.7).

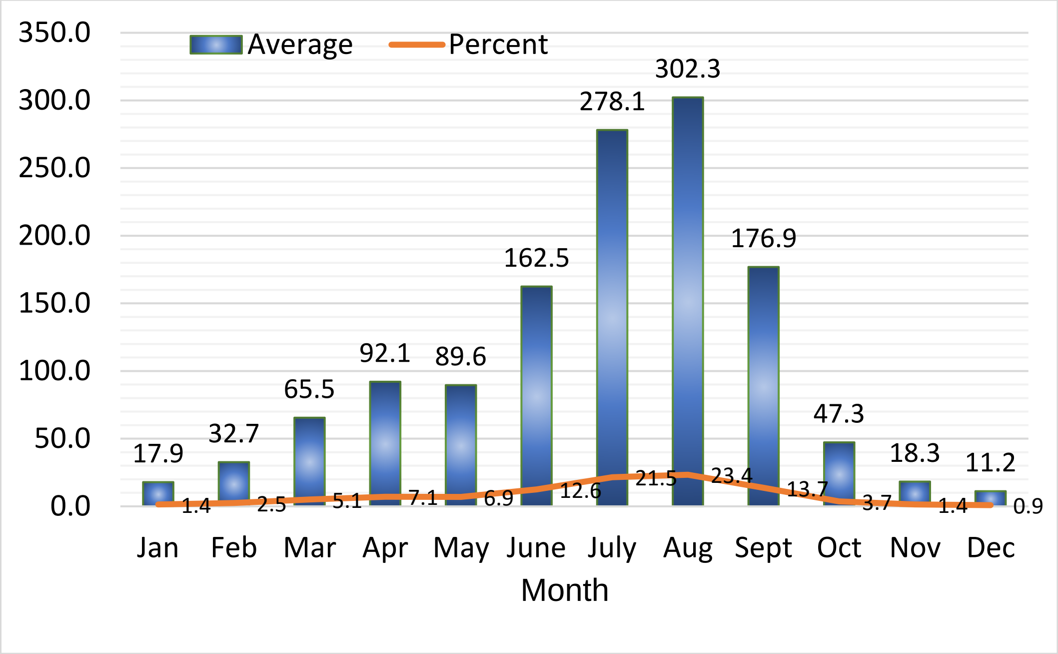


Figure 4.7: Monthly average rainfall variations of 30 years

The annual rainfall of the study area also used to calculate the potential of rainwater harvesting within the study area. The cumulative annual rainfall varies from 929.4mm to 2696mm during the period. From this data, the average annual rainfall for runoff calculation for the EiABC campus was estimated to be 1294.3mm (Figure 4.8).

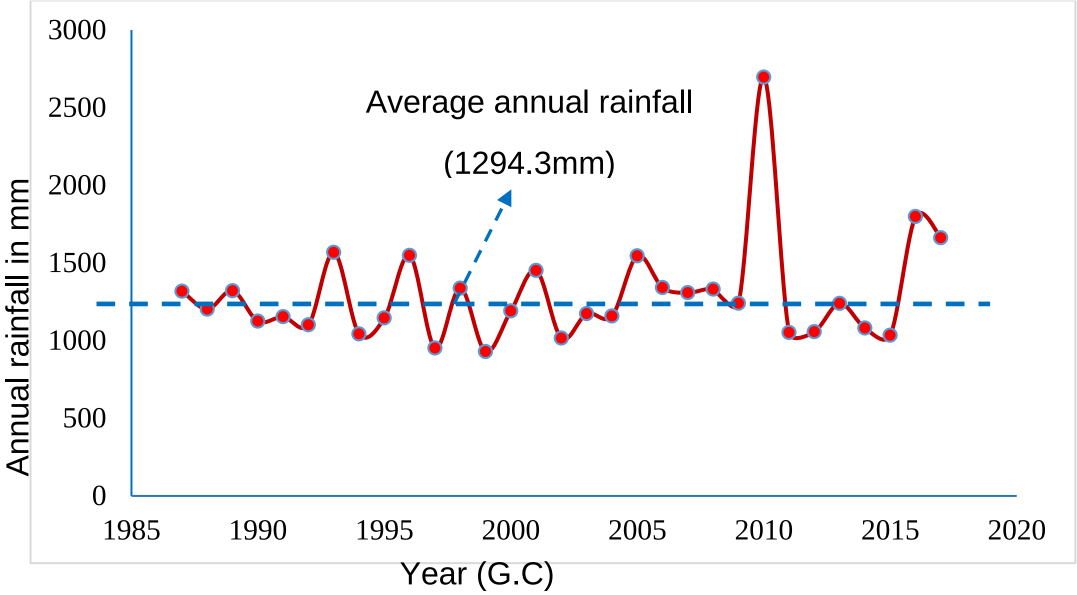


Figure 4.8: Average annual rainfall

It can be observed from the Table 4.2 that the depth of maximum rainfall event occurred is more than three times the depth of the minimum rainfall events. The maximum depth of rainfall registered within the 30 yrs.' data is 96.3mm (9. Mar. 2001) with a return period of 60 years, having a probability of 1.67% and the minimum rainfall depth registered was 29.5mm having the probability of occurrence of 98.5% with a return period of 1year. The 40 mm rainfall data are the daily rainfall data which are registered with 1years return period having 83.3% average probability of occurrence. Therefore, the yearly return period of daily rainfall depth was used to calculate the potentiality of the EiABC campus for passive rainwater harvesting and used to design the stormwater management structure.

Table: 4.2: Occurrence and return period of daily rainfall over 30 years

Year	Depth (mm)	Rank	Probability of occurrence	Return period
1987	56.8	10	31.7	3
1988	35.5	29	95.0	1
1989	49.2	17	55.0	2
1990	39.6	25	81.7	1
1991	47.3	20	65.0	2
1992	51.4	16	51.7	2
1993	53.5	14	45.0	2
1994	57	9	28.3	4
1995	85.3	2	5.0	20
1996	67	5	15.0	7
1997	46.3	22	71.7	1
1998	78.3	3	8.3	12
1999	37.4	26	85.0	1
2000	37.1	27	88.3	1
2001	96.3	1	1.67	60
2002	29.5	30	98.3	1
2003	54.9	12	38.3	3
2004	44.2	24	78.3	1
2005	58.6	8	25.0	4
2006	70.9	4	11.7	9
2007	64	7	21.7	5
2008	53.3	15	48.3	2
2009	54.7	13	41.7	2
2010	44.6	23	75.0	1
2011	55.8	11	35.0	3
2012	36.4	28	91.7	1
2013	47.2	21	68.3	1
2014	65.4	6	18.3	5
2015	47.8	18	58.3	2
2016	47.7	19	61.7	2

Source: Computed from Ethiopian Meteorology Survey precipitation year data collected.

a. EiABC sub catchment area land use, land cover

Within the three sub catchment areas of EiABC campus, ten land use, land cover types were identified. These are roofs cover, streets cover, grass, play field and trees cover (Table 4.3).

Table 4.3: Land use, Land cover of EiABC campus

No	Land cover	Area in m^2	Percent
	Roofs		
1	Corrugated iron sheet	18027.72	23.05
2	Concrete roof	669.81	0.86
	Streets		
3	Concrete road	2227.65	2.85
4	Paved stone	2405.44	3.08
5	Gravel	319.60	0.41
6	Cobblestone	3590.95	4.59
7	Asphalt	8461.62	10.82
	Other land cover		
8	Grass	8543.92	10.92
9	Play field	6708.25	8.58
10	Trees	27254.27	34.85
	Total	78209.23	100.00

b. Land use, land cover of the selected catchment area

Streets, parking areas and roofs cover have the highest share in the contributing surface runoff within the case site. In contrast, they have good potential for rainwater harvesting. The catchment areas include, roof catchment of one side of the urban building, the library, administration offices and female dormitory building as well as the streets, parking lot and open spaces between the buildings, and the entire catchment estimated to cover an approximately the total area of 4122.2m^2.From this, 77.14% was the potential for stormwater harvesting which was covered with roofs and roads. While 22.86% of the sub-catchment was used to develop the stormwater harvesting structure as it was covered with grasses and trees (Table 4.4 and Figure 4.9).

Table 4.4: Land use, land cover area of the selected catchment

No	Land use, land cover	Area in m^2	Percent
1	Corrugated Iron Sheet roof	590.1	14.32
2	Asphalt Road	2249.5	54.57
3	Concrete Road	340.0	8.25
4	Grass	418.8	10.16
5	Trees	523.8	12.71
	Total	4122.2	100.00

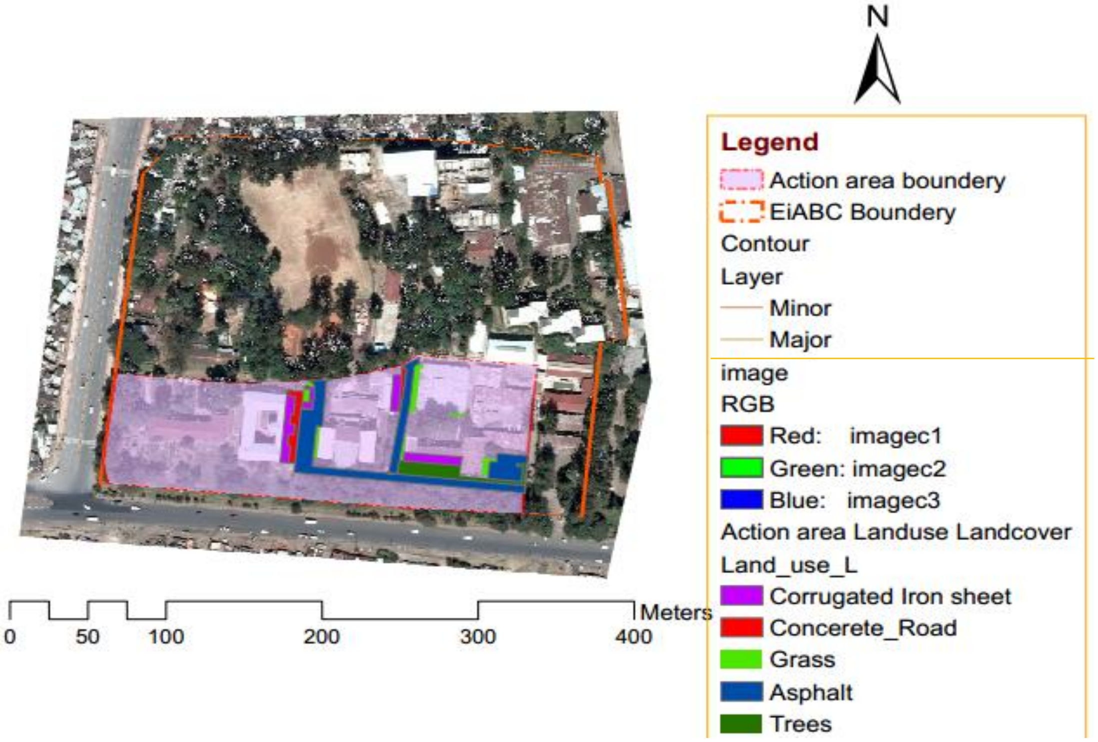


Figure 4.9: Land use, land cover of the selected catchment area

c. Quantity of stormwater generated from the EiABC

The average annual rainfall in the EiABC campus was estimated to be 1294.3mm.The area of each land use, land cover was calculated and its runoff coefficient was identified. Runoff coefficient is the factor which accounts for the fact that all the rainfall falling on a catchment cannot be collected. Rainwater yield varies with the size and texture of the catchment area. Loss is negligible for roofs and asphalt roads with an average of less than 5 per cent. While the cobble stone loss with a maximum of 30% percent. Accordingly, the volume of stormwater generated from the EiABC campus was calculated as indicated in the Table 4.5

Table 4.5: Volume of stormwater generated from the EiABC campus

		Slope of the surfaces												
		0-2%				**2-7%**				**>7%**				
Land use, land cover	**Area in (m^2)**	**Area(m^2)**	**Run of Coef**	**Rain intensity(m)**	**Stormwater volume(m^3)**	**Area(m^2)**	**Run of Coef.**	**Rain intensity(m)**	**Storm water volume(m^3)**	**Area(m^2)**	**Run of Coef**	**Rain intensity(m)**	**Storm waterr volume(m^3)**	**Total Volume of stormwater (m^3)**
Corrugated Iron Sheet Roof	18027.7	0	0.95	1.294	0	0	0.95	1.294	0	18027.	0.95	1.294	22161.	22161.5
Concrete Roof	669.8	669.81	0.95	1.294	823.4	0	0.95	1.294	0	0.0	0.95	1.294	0.0	823.4
Concrete Road	2227.7	2227.7	0.95	1.294	2738.5	0	0.95	1.294	0	0.0	0.95	1.294	0.0	2738.5
Paved stone	2405.4	2405.4	0.75	1.294	2334.5	0	0.75	1.294	0	0.0	0.75	1.294	0.0	2334.5
Gravel	319.6	319.6	0.4	1.294	165.4	0	0.4	1.294	0	0.0	0.4	1.294	0.0	165.4
Coble Road	3591.0	800	0.7	1.294	724.64	2097.7	0.7	1.294	1900.1	582.4	0.7	1.294	527.5	3152.2
Asphalt Road	8461.6	644.31	0.95	1.294	646.6	6475.8	0.95	1.294	6478.0	1341.6	0.95	1.294	1649.2	8773.8
Grass	8543.9	2284.3	0.25	1.294	739.0	4586.3	0.3	1.294	1780.4	1673.2	0.4	1.294	866.1	3385.5
Play Field	6708.3	6700	0.4	1.294	3467.92	0	0.4	1.294	0	0.0	0.4	1.294	0.0	3467.9
Trees	27254.3	2789.9	0.35	1.294	1263.6	16500	0.25	1.294	5337.	9700.0	0.3	1.294	3765.5	10366.8
Total	**78209.**													**57369.6**

The volume of stomwater runoff generated from the specific action area was calculated using land use, land cover, rainfall data, runoff coefficient and respective slope of the sub catchments as an input as shown in the Table 4.6.

Table 4.6: Volume of stormwater generated from the selected site annually.

		Slope of the surfaces												
		0-2%				2-7%				>7%				
Land use Land cover	**Area in (m^2)**	**Area (m^2)**	**Run off Coef**	**Rain intensity(m)**	**water volume(m^3)**	**Area(m^2)**	**Run off Coef.**	**Rain intensity(m)**	**water volume (m^3)**	**Area (m^2)**	**Run of Coef**	**Rain intensity(m)**	**Water volume(m^3)**	**Total volume (m^3)**
Corrugated Iron Sheet Roof	590.1	0	0.95	1.294	0.0		0.95	1.294	0.0	590.1	0.95	1.294		725.4
Asphalt Road	2249.5	609.9	0.95	1.294	749.8	65.66	0.95	1.294	80.7	1574.	0.95	1.294	1935.	2765.3
Concrete Road	340.0	2227.	0.95	1.294	2738.	0	0.95	1.294	0.0	0.0	0.95	1.294	0.0	2738.5
Grass	418.8	157.0	0.25	1.294	50.8	145.9	0.3	1.294	56.7	302.1	0.4	1.294	156.4	263.8
Trees	523.8	119.0	0.35	1.294	53.9	33	0.25	1.294	264.0	371.7	0.3	1.294	186.2	504.2
Total	**4122.2**													**6997.2**

The daily volume of stormwater that can be harvested from the identified sub catchment was calculated by using the average of 1 year's rainfall depth return period. This volume was estimated to be 134.69m^3 as indicated in Table 4.7

Table 4.7: Volume of stormwater generated from the selected site per day

		Slope of the surface												
		0-2%				**2-7%**				**>7%**				
Land use Land cover	**Area in (m^2)**	**Area (m^2)**	**Run of Coeff**	**Rain intensity (m)**	**Water volume (m^3)**	**Area (m^2)**	**Run of Coef.**	**Rain intensity (m)**	**Water volume (m^3)**	**Area (m^2)**	**Run of Coeff**	**Rain intensity (m)**	**Water volume (m^3)**	**Total Volume (m^3)**
Corrugated iron sheet roof	590.1	0	0.95	0.04	0.00	0	0.95	0.04	0.00	590.1	0.95	0.04	22.30	22.30
Asphalt Road	2249.5	609.9	0.95	0.04	23.05	65.6	0.95	0.04	2.48	1573.9	0.95	0.04	59.48	85.01
Concrete Road	340	340	0.95	0.04	12.85	0	0.95	0.04	0.00	0	0.95	0.04	0.00	12.85
Grass	418.8	157.03	0.25	0.04	1.56	145.9	0.3	0.04	1.74	302.1	0.4	0.04	4.81	8.11
Trees	523.8	119.07	0.35	0.04	1.66	33	0.25	0.04	0.33	371.7	0.3	0.04	4.44	6.42
Total	**4122.2**													**134.69**

ii. Selection of appropriate surface rainwater harvesting structure

In section of site selection analysis, the site labeled as “very high and high suitability “were suitable for the design and development of different rainwater harvesting structures such as Detention pond, Bio-retention /Raingarden, Infiltration trench, Swale, and Tanks. Therefore, to design and develop one of the rainwater harvesting structures for EiABC campus stormwater management, a matrix on a range of factors was done. The matrix’s of factors affecting the surface rainwater harvesting structure in Table 4.8 shows that Bio-retention rainwater harvesting structure was the best option with fewer overall restrictions. So that Bio-retention with underdrain and tanks which store the rainwater for reuse was developed and designed in the selected site of the EiABC campus (Table 4.8).

Table 4.8: Matrix’s of factors affecting the surface rainwater harvesting structure.

Types of rainwater harvesting structure	Storage capacity	Space required	Pollutant removal	No Health risk	Multi-functionality (aesthetics, storage capacity, pollutant removal)	No Cost	Total
Detention pond	5	3	3	4	4	5	24
Bio-retention	4	5	5	5	5	3	27
Infiltration trench	3	3	5	5	3	4	23
Swale	5	3	2	5	4	2	21
Tank	5	4	1	5	2	3	20

Scale: 5-Very high 4-High 3-Medium 2- Low 1-Very low

4.3 Bio-retention Design

The Bio-retention system was sized to detain and filter a required volume of stormwater runoff generated from the sub catchment area of EiABC campus. The dimension of the Bio-retention was decided based on the sub catchment area which cover 0.85% of the total drains area. The components of Bio-retention system (coarse sediment controller, inlet, stormwater energy dissipater, layers, outlet and overflow controller) were designed and developed at the study area.

i. Design coarse sediment controller.

The coarse sediment controller was designed and developed at where stormwater runoff from the catchment is delivered directly to the Bio-retention system without pretreatment. Coarse sediments were accumulated near at the inlet of the pipe channels. So that, the coarse sediments controller that made up of the iron wire was installed at the inlet of the Bio-retention system with a size of 30 cm depth and 40cm width at two locations, one at the 40cm far from the inlet and the other was 100cm far from the inlet channel.

ii. Design and development of inlet and stormwater energy dissipater

The conversional drains system that collects and discharge the runoff from the catchment area was directed to the Bio-retention by inlet channel (pipe).The inflow material was the 110mm diameter PVC pipe that was channeled from the conventional drains with a slope of 2%. The size and slope of the inflow channel (pipe) were determined to control the velocity of the inflow stormwater that avoid washing of the filter media and vegetation. Similarly the inlet is not as small as to convey only the minor storm flow and was designed to avoid blockage and flow conveyance (Where the Bio-retention pond is receiving stormwater flows from a piped system. River rocks were used simply for dissipating energy of concentrated inflow and prevent wash of filter media (Figure 4.10).

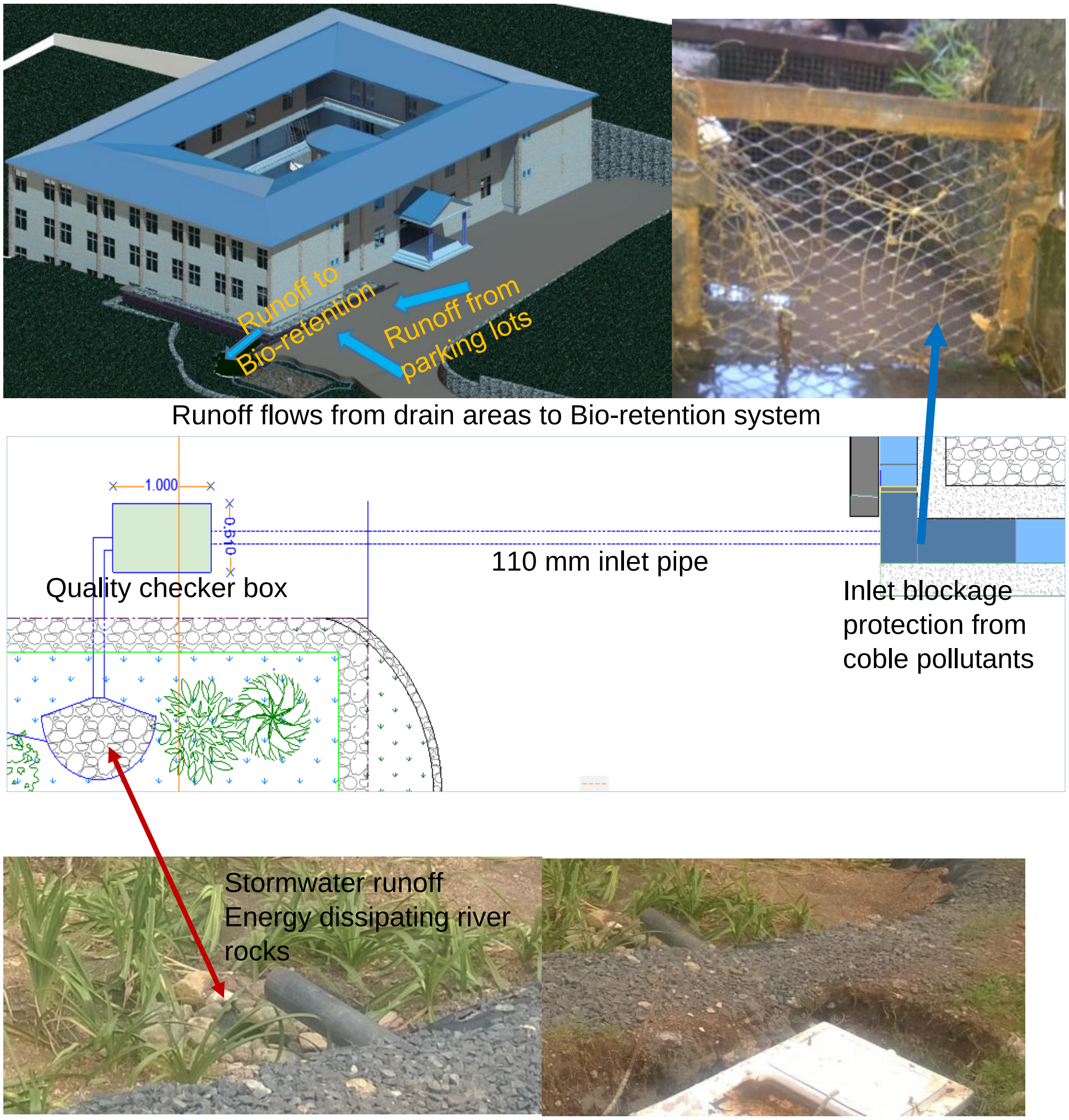


Figure 4.10: Designed and developed inflow channel and inlet

iii. Design and development of Bio-retention system layers

The ponding area, mulch, filter media, transition layer, drain layer, perforated pipes, Impermeable liners geotextile, plants, overflow pipe and outlet design are the main Bio-retention system layers that were designed and developed in the study area (Figure 4.11).

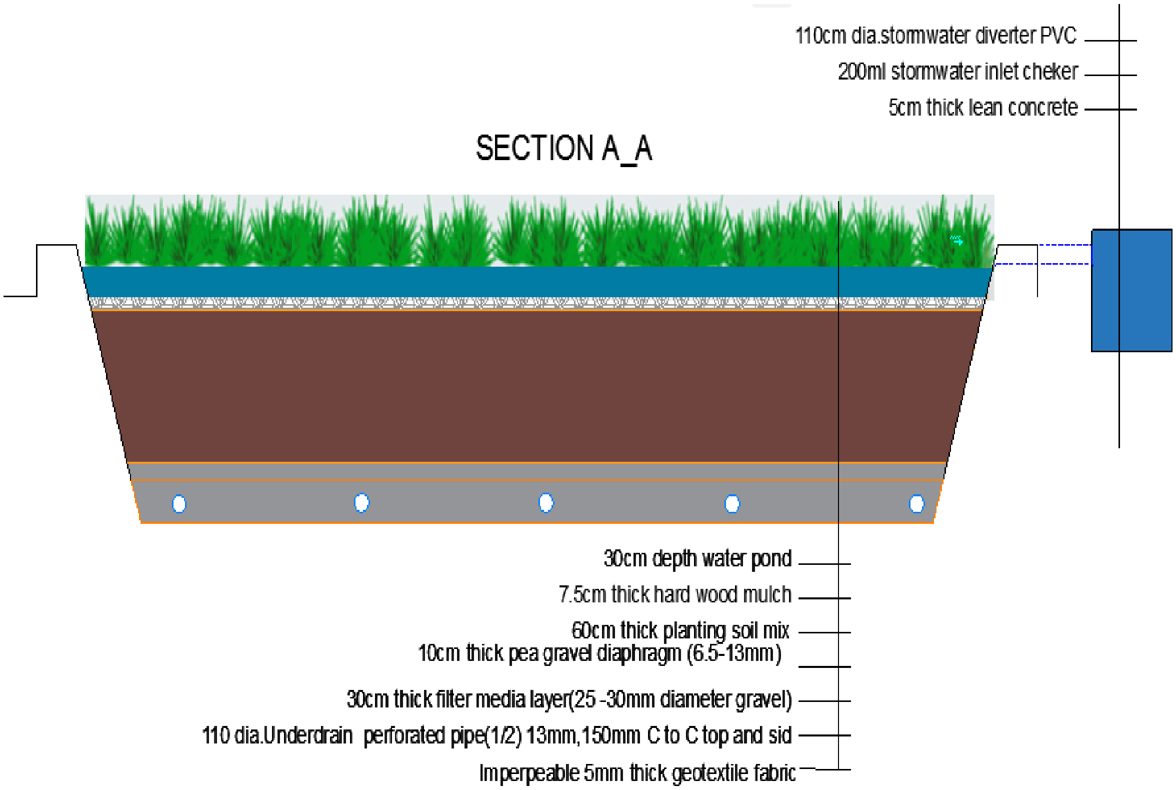


Figure 4.11: Designed and developed Bio-retention layers

The ponding depth was designed to be 30 cm with the area of 33.92m^2 in considerations for aesthetics and public safety. It was designed to occupy a volume of 10.34 m^3 of the stormwater for filtration which can be filtered within 24 hours. The ponding area of the Bio-retention was constructed with side slope of 3:1 which is used to create a stable vertical sidewall of the Bio-retention system.

The 7.5cm thick layer of mulch of scraped hardwood was designed on the surface of the filter media which is used to enhance plant survival, suppresses weed growth, and pretreat runoff before it reaches the filter media.

The filter media were designed to have a depth of 600mm to support shrub vegetation's species. It was the mix of local top soil, sand, and compost with the proportion of 15%, 80% and 5% respectively. The filter media sand was mixed with the topsoil to enhance the filtration capacity of the media. The organic material that was added to the soil mix is used to establish vegetation on the surface of the Bio-retention system. The Transition layer was designed to avoid the filter media being washed through the voids of the drains layer and the perforated pipes**.** Therefore, pea’s size (6.5to 13 mm diameter) gravels were used for the transition layer with 100mm thick. In addition, geotextile was leaned above the pea size gravels to enhance the efficiency of protecting washed fines from the filter media.

The drainage layer was designed under the Transition layer with 30mm diameter of gravels having the thickness of 300mm.The gravels was washed with water prior to placement into a Bio-retention system to remove any dusts and silts with it. Within the drain layer the perforated pipes were designed to be 110mm diameter in size with the spacing of 1220.50mm to each other to enhance the filtration rate. Half (1/2) of the underdrain pipe was perforated with the spacing of 130mm center to center with 10mm in diameter. The slope of the perforated pipes was graded at 0.2% toward the non-perforated collector pipes which collect the filtered water to the storage structure to ensure effective drains.

The geo-fabric was placed above the perforated pipes to increase the capacity of the perforated pipe system to filter the stormwater and protects the perforated pipes from blockage by small gravels. The size and spacing of holes of perforated underdrains pipes was designed to have the maximum filtration rate to ensure the filter media drains freely and does not become stagnant in the Bio-retention system. The impermeable non-woven liner fabric was applied to all sides and bed of the Bio-retention system to collect the filtered stormwater and conveys back to the perforated pipe for channel into the collector pipes. The bed of the impermeable linear was leveled by the sand to distribute the filtered water to all perforated pipes equally which enhance the discharges of the water to the storages.

The overflow pipe was designed with its head raised above the level of the Bio-retention filter media equalizing its height with maximum ponding depth to allow the overflow for discharges. The size of overflow pipe was greater than the inflow pipe and have a diameter of 160mm and slope of 2% to discharge easily the overflow storms from the ponding area. The head of the overflow pipe was designed by wires with 20mm diameter holes to avoid blockages of coble materials with storm water.

Evergreen perennial plants were used in Bio-retention design, as it is often desirable to maintain a continuous foliage cover for aesthetic purposes. The plant species were the Orchid species having different colors and that make the area more attractive and used for stormwater filtration. The outlet non-perforated pipe was designed with grading of 2% to enhance the flow rate of water from Bio-retention to the storage structure (tanks). The pipe was 110mm diameter connected to the ends of the perforated pipes and was channeled to the storage structure.

4.4 The performance of passive rainwater harvesting structure for stormwater management and green area improvement

i. Quantity of stormwater harvested through Bio-retention system

The storage facilities installed for filtered stormawater was finished fiber tanks which is partially above the grounds and partially below the ground surface. The harvested and stored water will be used to irrigate planted areas and gardens during periods of low rainfall. The distribution system of the water from the tanks to the garden area is by gravity as the tanks was developed at the required elevation to enhance the pressure. The storages were provided with the capacity of $20m^3$ (20,000 Liters). This volume of water is very less as compared with the estimated total volume of stormwater that can be harvested and filtered by Bio-retention system within four rainy months which was estimated to be 620m3.

ii. Water quality improvements

Bio-retention system is potentially one of the BMP's in TDS and TSS pollutant removal. In this thesis, the EPA's TSS and TDS method were used by taking 100mL of sample to calculate the TSS and TDS. The concentrations of water quality before and after entering of the Bio-retention system were compared to understand the change in water quality parameter due to the treatment layers within the Bio-retention system. The analysis of the pollutant concentrations, including Turbidity, TSS TDS, pH, Conductivity and some Heavy metals are shown in Table 4.9.

Table 4.9: Water quality concentrations before and after entering of the Bio-retention system**.**

Quality Parameter	Test	Before (A)	After (B)	Variation (C) = (A- B)	Efficiency (D) =C/A*100
TSS (mg/L)	1	30	10	20	66.67%
	2	100	10	90	90%
	3	40	20	20	50%
	4	30	10	20	66.67%
	5	60	10	50	83.30%
Average		52	12	40	76.92%
TDS (mg/L)	1	0.8	0.4	0.4	50%
	2	1	0.5	0.5	40%
	3	1.1	0.3	0.8	72.73%
	4	1.2	0.4	0.8	66.67%
	5	0.9	0.3	0.6	66.67%
Average		1	0.38	0.62	59.2%
Turbidity(NTU)	1	70	53	17	24.29%
	2	93	49	44	47.31%
	3	84	41	43	51.19%
	4	78	39	39	50%
	5	72	32	0.6	55.56%
Average		79.4	42.8	28.7	45.67%
EC(µS/cm)	1	37.3	111.3	74	-198.4
	2	83.6	156.6	73	-87.3
	3	40.5	94.9	54.4	-134.3
	4	57.4	101.2	43.8	-76.3
	5	51.6	117.6	66	-127.9
Average		54.08	116..2	62.24	-124.8
		A	**B**	**Before (A-7)**	**After (B-7)**
pH	1	6.497	7.274	-0.503	0.274
	2	6.480	6.831	-0.52	-0.169
	3	6.810	6.986	-0.19	-0.014
	4	6.598	7.063	-0.402	0.063
	5	6.945	7.045	-0.055	0.045
Average		6.666	7.040	0.334	0.113
Iron(mg/LFe^{2+}Fe^{3+})	1	6.60	0.18	6.42	97.27%
	2	1.50	0.03	1.47	98%
Average		4.05	0.105	3.945	97.40%
Manganese(mg/L Mn)	1	1.80	Trace		
	2	0.8	Trace		
Average		1.3	Trace		
Zinc(Mg/L)	1	Trace	Trace		
	2	Trace	Trace		

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Suitable sites for stormwater harvesting structure

In the study area, six sites were the most suitable areas for developing the passive rainwater harvesting structure. Among these the most suitable areas, "Urban building" sub catchment was selected. This sub catchment is located at the point which water flows out of the drains area through the rectangular stormwater outlet ditch. After selecting of specific areas for the placement of the harvesting system based on suitability analysis, site near to urban building has been more adjusted through expert judgment in utilizing the harvested water for gardening on the available downstream flatland. Eventually, the ideal location has been chosen as a site for stormwater harvesting structure as illustrated in the Figure 5.1.

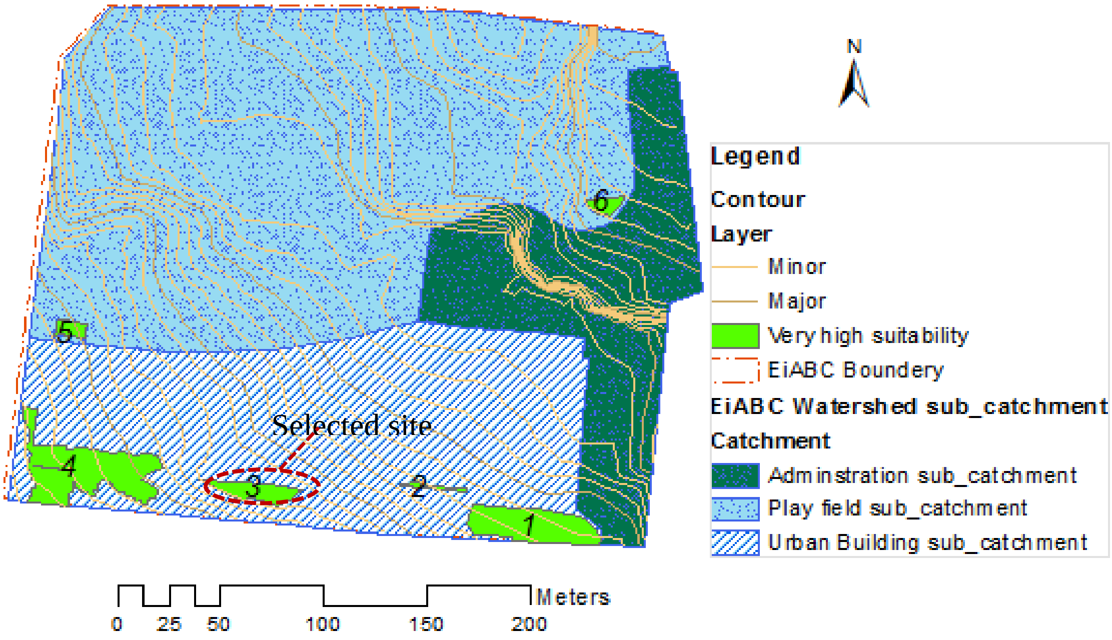


Figure 5.1: The specific site selected from high suitability areas

5.2 Stormwater management performance of the Bio-retention system

i. Quantity

The total volume of stormwater generated from EiABC campus by different land uses land covers with different areas and runoff coefficients was estimated to be 57369.6m3 annually. Similarly, 6997.2m3 estimated volume of storm water was generated from the selected sub catchment. To harvest this volume of stormwater, the trapezoidal shape with the area of 35 m2 at the top and 24.1 m2 at the bottom of Bio-retention system was developed. It has a capacity to filter 10.34m3 estimated volume of stormwater per day. The annual volume of stormwater that can be filtered through Bio-retention system during the rainy months (from June up to September) was estimated to be 620.4m3. Generally, 53.93% of the total potential can be harvested from the sub catchment through Bio-retention system, which can reduce the stormwater runoff by this amount.

The result was small as compared with the annual stormwater runoff harvested and reduced by the Bio-retention system developed at the University of Minnesota, which had an ability to harvest and reduce 88% of the stormwater generated from the sub catchment area (Amy B., 2013). The Bio-retention system designed in Virginia had a performance to harvest and reduce 40% to 80% of stormwater runoff from the sub catchment area (Virginia DEQ, 2011) which is the range at which the developed Bio-retention performance is found.

ii. Stormwater quality improvement performance

a. Total Suspended Solids (TSS)

The pollutant concentration before and after entering of the Bio-retention was different due to the performance of Bio-retention system. The concentrations of TSS after entering was very small as compared with the concentration of TSS before entering of the Bio-retention system. The TSS concentration was between 30gm/L to 100gm/L before entering of Bio-retention system with an average of 52gm/L. This result was decreased to 10gm/L and 20gm/L with an average of 12gm/L after entering the Bio-retention system (Figure 5.2). The removal performance of TSS was 50% to 90% with an average of 76.92%. This showed that a significant decrease ($p<0.05$) of TSS concentration after entering the Bio-retention system.

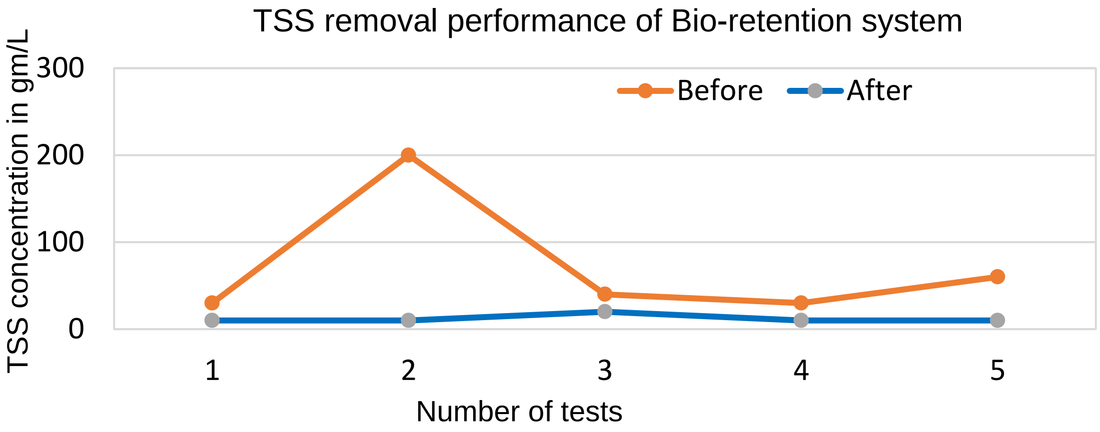


Figure 5.2: The TSS removal performance Bio-retention system

The TSS concentration was reduced effectively by Bio-retention system through sedimentation at entering point and by a filtration process in the media layers. Figure 5.3 shows, as the concentration of TSS before entering the Bio-retention system, increase or decrease, the concentration of TSS after entering of Bio-retention system is almost constant.

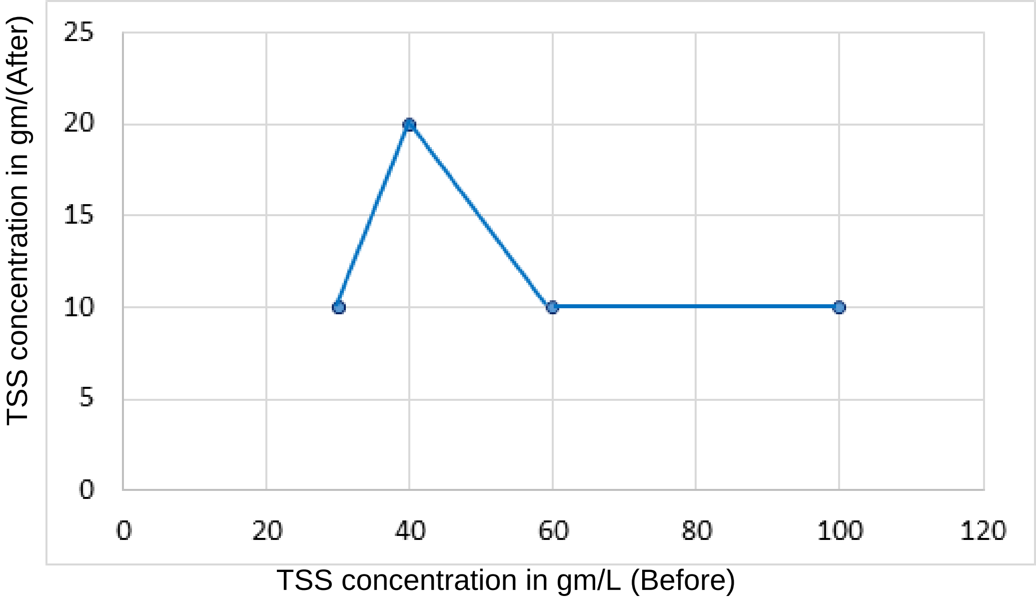


Figure 5.3: Correlation of TSS concentration before and after

The presence of Suspended Solids in the stormwater runoff was a good indicator of the existence of nutrients, organic matter, metals and also other pollutants. These pollutants, especially nutrients, heavy metals and hydrocarbon can closely be attached with suspended solids due to absorption process (Norshafa and Lariyah, 2015). The result was very small as compared with the studies undertaken at Verginia (Debusk and Wynn, 2011), North Carolina and Maryland (Hathaway and Hunt, 2011) were achieved high TSS concentration removal with the performance of 99%, 100% and 99% respectively. In contrast, the result was high as compared with the studies done in North California (Brown and Hunt, 2011) and North Carolina (Hunt et al., 2008) with the TSS removal performance of 58% and 60% respectively.

b. Total Dissolved Solids (TDS)

The concentrations of Total Dissolved Solids (TDS) before entering the Bio-retention system ranged from 0.8gm/L to 1.2gm/L with an average of 1gm/L.

Similarly, the concentration of TDS after entering of Bio-retention system was between 0.3gm/L to 0.5gm/L with an average of 0.38gm/L (Figure 5.4). The concentration of TDS was reduced from 1gm/L to 0.38gm/L on average with the TDS removal performance of 59.2%. The result showed that a significant decrease ($p<0.05$) of TDS concentrations after entering the Bio-retention system. The concentration of TDS after entering of the Bio-retention system was close to the TDS concentration of drinking water, which was 0.5gm/L as the a secondary standard set by the U.S EPA

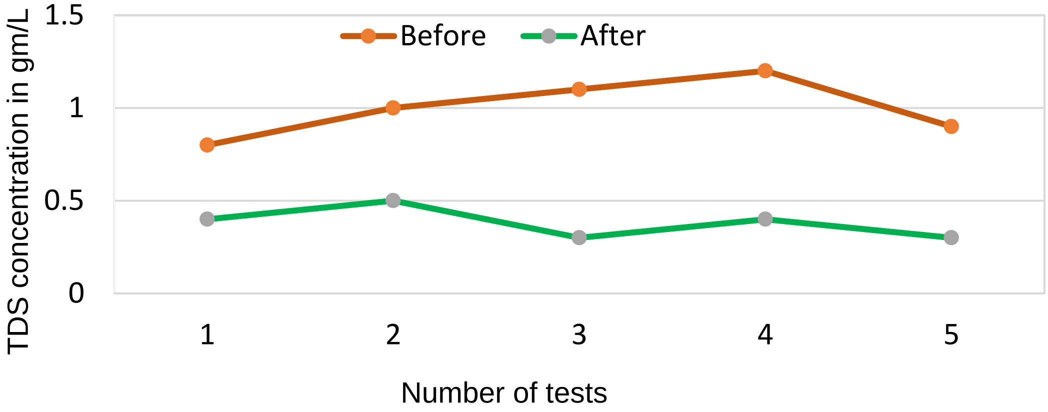


Figure 5.4: The TDS removal performance of Bio-retention system

c. The total concentration TSS and TDS filtered by Bio-retention system

A total of approximately 6997m^3 (6,997,000Litre) of stormwater runoff was estimated to leave the sub catchment area. However the capacity of the Bio-retention system to filter the harvested runoff per year was estimated to 886.29m^3. The total estimated concentration of TSS and TDS carrying with this volume of storms and filtered by Bio-retention was estimated to be 63,813Kg and 886.29Kg respectively, before entering of the Bio-retention system. This was reduced to 10,635Kg and 337Kg respectively, after entering of the Bio-retention system. Generally, the pollutant loading of stormwater generated from the selected catchment area of the EiABC campus was reduced the concentration of TSS by up to 72.33% and TDS by 59.2% after entering and filtered by Bio-retention system.

d. Turbidity

There was a change in concentrations of Turbidity before and after entering of the Bio-retention system. The result showed that the concentrations of Turbidity before and after entering of the Bio-retention system was between 70NTU to 93NTU and 32NTU to 53NTU respectively (Figure 5.5). This result indicates, Turbidity was decreased after entering of Bio-retention system within the removal performance of 24.29% to 55.56% with an average of 45.67%.

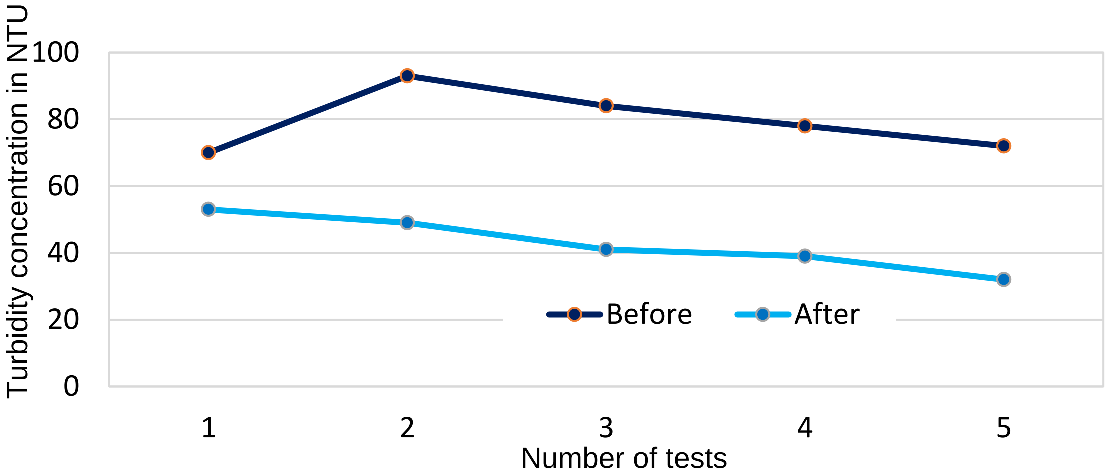


Figure 5.5: The Turbidity removal performance of Bio-retention system

Figure 5.6: Turbidity before and after entering of the Bio-retention system

The result in Figure 5.6 showed that a significant water quality changes occur when the stormwater runoff flows from the inlet to the outlet of Bio-retention system through the depths of filter media. In this regard, there was a significant reduction of pollutants ($p<0.05$) concentrations after entering the Bio-retention system with an average of 45.67%.

The result is less as compared with the study by Norshafa and Lariyah (2015), which is highlighted that Bio-retention systems can reduce the concentrations of pollutants (Turbidity) of runoffs by 93.3% on average. The result of the study area can be increased when the Bio-retention system plants are well developed and soil mix is compacted.

d. pH

The pH value of stormwater before and after entering of the Bio-retention system was measured. The measured pH of harvesting stormwater from Bio-retention was between 6.48 and 6.945 before entering and between 6.831 and 7.274 after entering of Bio-retention system with an average of 6.666 and 7.040 respectively (Figure 5.7). This result was deviated from the neutral (7.00) with an average of

0.334 before entering and 0.113 after entering. This indicated that a significant change ($p<0.05$) of pH after entering the Bio-retention system.

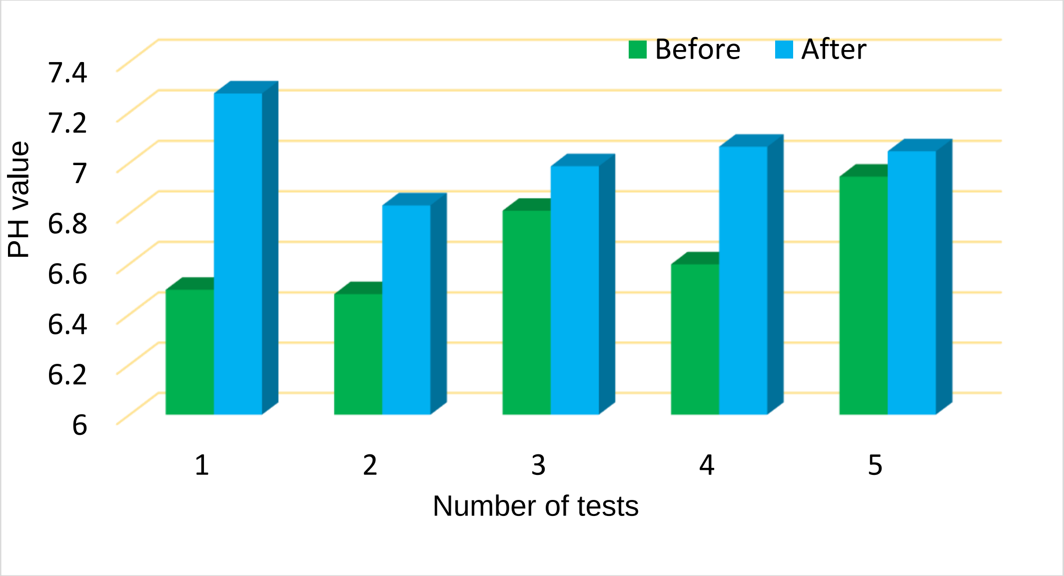


Figure 5.7: The pH value of stormwater before and after Bio-retention system

The study in the Elm Creek Plaza, Grand Lake Association, and Grove High School showed that the pH of the stormwater runoff was increased from 6.8 to 7.7, 7.1 to 7.9, and 6.8 to 7.6 in average respectively (Sheila Y. et al., 2017). According to US EPA (1986), the measured pH of surface water is between 6.5 and 9 which indicates that the pH results of stormswater before and after entering of Bio-retention system are found within this range. The increase of pH after the outlet of Bio-retention might be due to the presence of alkaline in the soil mix of Bio-retention which can neutralize the acidic stormwater.

e. Electrical Conductivity (EC)

Electrical Conductivity (EC) of the stormwater before and after entering of the Bio-retention system was measured in site. It is well known that EC of water depends on temperature, therefore, the EC values were measured at a normalized temperature of 22.5^0C.The values at two sites were different, and the average EC value at before and after was 54.08µS/cm and 116.2µS/cm respectively. The minimum and maximum EC measurements before entering of Bio-retention system were 37.3 µS/cm and 83.6µS/cm respectively, and after entering were 94.9µS/cm and 156.6µS/cm (Figure 5.8).This result shows a significant change ($p<0.05$) of Electrical Conductivity after entering the Bio-retention system.

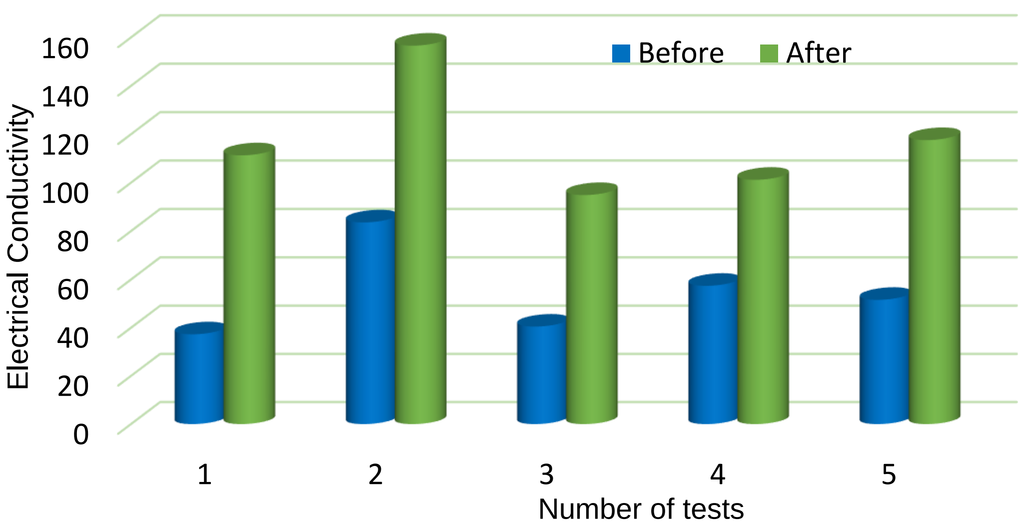


Figure 5.8: The EC of stormwater before and after Bio-retention system

The Electrical Conductivity (EC) of stormwater samples were generally low as compared to many drinking water sources with a median being 183µS/cm (Wolfgang, 2017). The study that had undertaken in the Elm Creek Plaza, Grand Lake Association, and Grove High School showed that the EC of the stormwater runoff was increased from 74 µS/cm to 210 µS/cm, 95 µS/cm to 310 µS/cm, and 160 µS/cm to 175 µS/cm in average respectively (Sheila Y. et al., 2017) which is almost similar to the study area. The increase of EC after entering of Bio-retention than before was probably due to the nutrients such as nitrate ions, salts and other organic matter in the soil media (Hunt, et al, 2006) as the plants are not grown enough to remove the nitrates. A positive relationship was observed between nitrate and EC (Wolfgang, 2017), as nitrate is dissolved in the form of nitrogen and EC measures the total dissolved ions in the water. The plant roots can improve the nitrate removal if grown enough and have provided more efficient nitrate uptake.

f. Heavy metals

Heavy metals (Iron, Manganese and Zinc) concentrations of the stormwater runoff were processed in the Water Quality Laboratory of Ethiopian Construction Design and Supervision Works Corporation. The Result showed that the concentration of Iron (Fe^{2+} and $Fe^{3+)}$ before and after entering of the Bio-retention system was between1.5gm/L to 6.6gm/L and 0.03mg/L to 0.18mg/L with the an average of 4.05mg/L and 0.105mg/L respectively. The average Iron removal efficiency of the developed Bio-retention was 97.40%.

The efficiency was very high as compared with the study that had undertaken in Washington D.C which was 53 % (Glass and Bissouma, 2005). The stormwater contained concentrations of Iron before entering the Bio-retention system was in excess of the drinking water standard of EPA which is 0.3mg/L. However, due to the pollutant removal performance of the Bio-retention system, the concentrations were decreased to 0.105mg/L which is below the standard.

In the study area, there was also the concentration of Manganese (Mn) with the stormwater runoff. The result indicated that the Manganese concentration of the stormwater runoff was 1.3mg/L on average before entering the Bio-retention system which was beyond the standard (0.05mg/L). This result was insignificant after entering the Bio-retention system due to the removal efficiency of Bio-retention system.

Manganese is often regarded as one of the least toxic metals by the oral route because homeostasis limit the gastrointestinal absorption. However, the excess concentration of Manganese in water is increasing evidence of neurotoxicity by the oral route, especially in infants (Karin Ljung and Marie Vahter, 2007). In study area, the concentration of Zinc in the stormwater was insignificant (trace) even before entering the Bio-retention system.

5.3 The benefits of Bio-retention for green area improvement

The stormwater harvesting through Bio-retention system was captured and stored in the tanks for providing an alternative source of water for irrigating the flat landscapes found in the lower parts of the developed Bio-retention system. The harvested water can be easily distributed by gravity to the delivery system for reuse. Using the harvested water for green area can reduce the use of municipal water if utilized potential that can be harvested through Bio-retention system. The utilization of the stormwater for green area can serve to create the attractive open spaces which provide a wide benefit to people. The environmental, ecological and health benefits that trees, grasses, shrubs and flowers provide are well worth the extra effort it takes to create and maintain a landscape.

Planting a plant is one of the most simple and effective activities that can perform to improve the green spaces. The plants used for Bio-retention allowed for the persistence of green spaces in the area. The creation of new green spaces, protecting existing green space and improving the quality of green space, are important in improving the accessibility and increasing the use of green spaces in the campus. The native plant species surrounding the Bio-retention system helped the looser native plants better fit into the campus landscape which improve the green area coverage. This is used to maintain a spatial and visual quality of the space, cleaner air and water, and more appealing recreation spaces in the campus. Hence, the developed Bio-retention system at the selected site of the EiABC campus has the benefit to improve the green area of the surroundings.

CHAPTER SIX

FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 Findings

Based on the results of the study the findings of each objective have been summarized as follows:

- The EiBAC campus has the potential green areas (site) for developing the stormwater harvesting structures. One of the most suitable areas for developing stormwater harvesting structure is found near to “Urban building” sub catchment.
- Bio-retention system was the best option for stormwater quantity and quality management, as well as to improve the green areas in the EiABC campus.
- The estimated quantity of stormwater that can be harvested from an area of 4122m^2 in the sub catchment of EiABC campus through Bio-retention system in the four rainy months (from June up to September) was 620.4m^3.
- The developed Bio-retention system has the capacity to reduce the stormwater runoff by 53.93%.
- There were a significant quality of stormwater changes ($p<0.05$) occurs when the stormwater runoff flows from the inlet point to the outlet point through the depths on filter media of the Bio-retention system.
- The Bio-retention system can reduce the concentration of pollutants with the removal rates of 76.92%, 59.2%, 45.67%, and 97.4% of TSS, TDS Turbidity and Iron respectively.

6.2 Conclusion

This section highlights the conclusions of the study based on the objectives set out at the beginning of the study. The study applied GIS and remote sensing as a tool to identify the best site for developing the stormwater harvesting structure. The tool is commonly applied in the exploration of ideal site in a scientific approach in urban planning and design practices. Hence it was easier and more accurate in decision making on site selection for BMPs than simple expert judgment decision making practices in the past. The Bio-retention system was selected from different type of BMPs tested in different part of the world in order to design and develop on a selected site. The study has proved the great performance of the system within a tropical highland climate to reduce the runoff volume and improve the quality of stormwater by taking case site within the EiABC campus.

The developed Bio-retention system has the potential to harvest and filter an estimated volume of 620.4m^3 of stormwater within the four rainy months. This volume of water is used as the alternative source of water in the EiABC for gardening activities that can improve the green areas in the campus. The result of the study indicates that Bio-retention systems have the ability to remove TSS, TDS, Turbidity and iron significantly. Additionally, the pH value of runoff was improved from acidity to neutral using Bio-retention system. The system can be scalable and applicable at all urban levels, which has similar context with the EiABC campus based on suitability analysis of the specific site. Specifically, the system can be widely applicable in newly developed grand housing project sites, universities, schools, government offices and other institutional plots. Such types of plots are characterized with larger paved parking areas and roof surface with high water demand for cleaning and gardening activities. In this regards, the system will contribute a lot in increasing water supply, runoff reduction and landscape improvements in the entire urban areas through sensitive design and development process.

6.3 Recommendations

Passive rainwater harvesting through Bio-retention system should be promoted in urban areas. It is appeared that not only considered as stormwater management and green area improvement, but also a way to reduce the potable water consumptions in urban areas by offsetting it for gardening, toilet flashing and car washing. So, if passive rainwater harvesting should be further encouraged, the benefits offered by passive rainwater collection systems have to be clearly demonstrated. This is used to increase the uptake of the systems in urban areas, especially in the government institution as the area is the potential site to demonstrate and scale up the system. Generally, the following recommendations would be forwarded based on the result of the study.

- EiABC has great potential in rainwater harvesting as can been seen from the identified suitable water harvesting site. The EiABC campus could therefore use all the potential site for rainwater harvesting structures to minimize dependency on the municipal water supply system.
- Community awareness from top to bottom through training should be conducted to enhance the acceptance of Bio-retention system at all urban levels.

- Inlet point requires careful monitoring, and inspection to insure it is free of blockages of debris. Removal of debris should be done regularly and whenever it is observed on site.
- Replanting of vegetation will be required the time when large loads of sediments could impact on plant growth and reduce the infiltration capacity of the filter media.
- Additional analysis of quantity as well as quality parameters such as other metals, and biological quality must be made for further performance of the system.
- Monitoring and maintenance should be made for the long-term performance of the Bio-retention system.
- Urban and local government must make credible commitments to provide sustained budget funding where the Bio-retentions are intended to develop in the public space.
- The developed and designed Bio-retention system can be applied at any new development and existing of residential areas, commercial, industries, institutions, parks, roadway, streetscapes, parking lots and community centers which have a similar soils, drains, rainfall and topography characteristics with the study area.
- Effective development and deployment of the institution that can carry forward the scaling up of the Bio-retention system is necessary at urban level.

- Urban communities will be allowed and received to expand the development of Bio-retention system at a neighborhood and plot level.
- With more development of Bio-retention system, successful scaling up partnering of local government with national government and external donors in funding for the expansion of Bio-retention system at urban level can drive and sustain the scaling up process.
- An evidence based approach and learning from experience have a great role in the achievement of the scaling up of the Bio-retention. The urban communities and local governments will share the experiences from the developed Bio-retention and can apply accordingly.

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Appendixes

Annex 1: Original Data

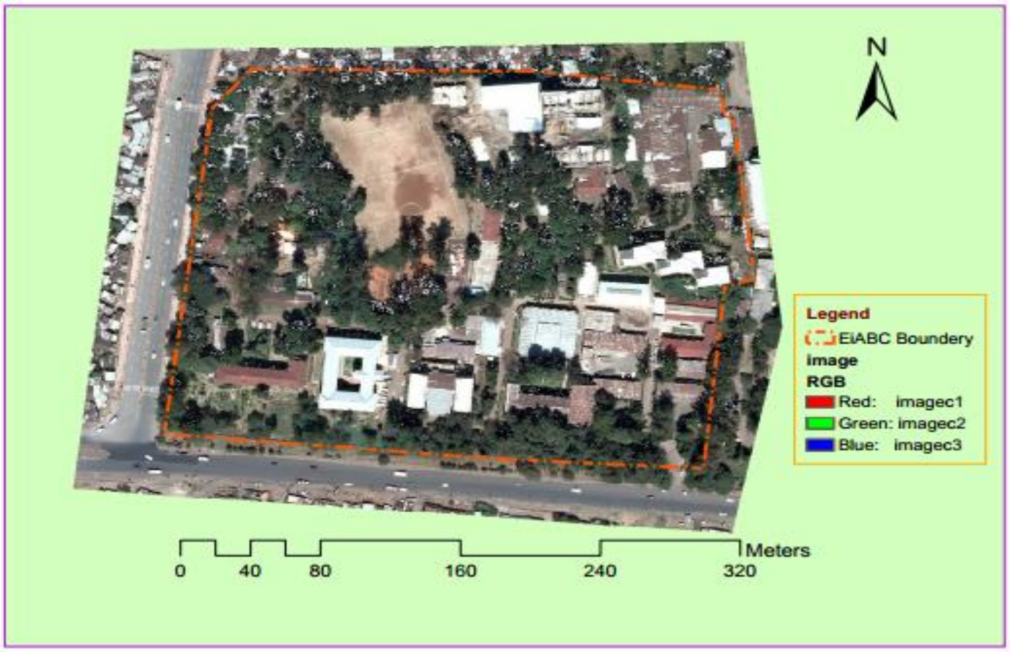
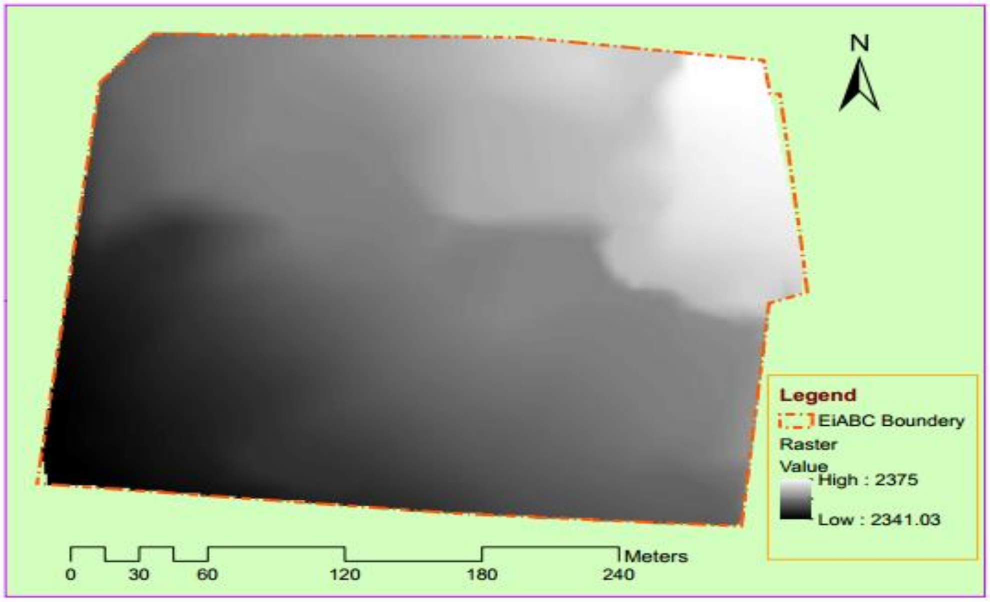


Image of the EiABC campus



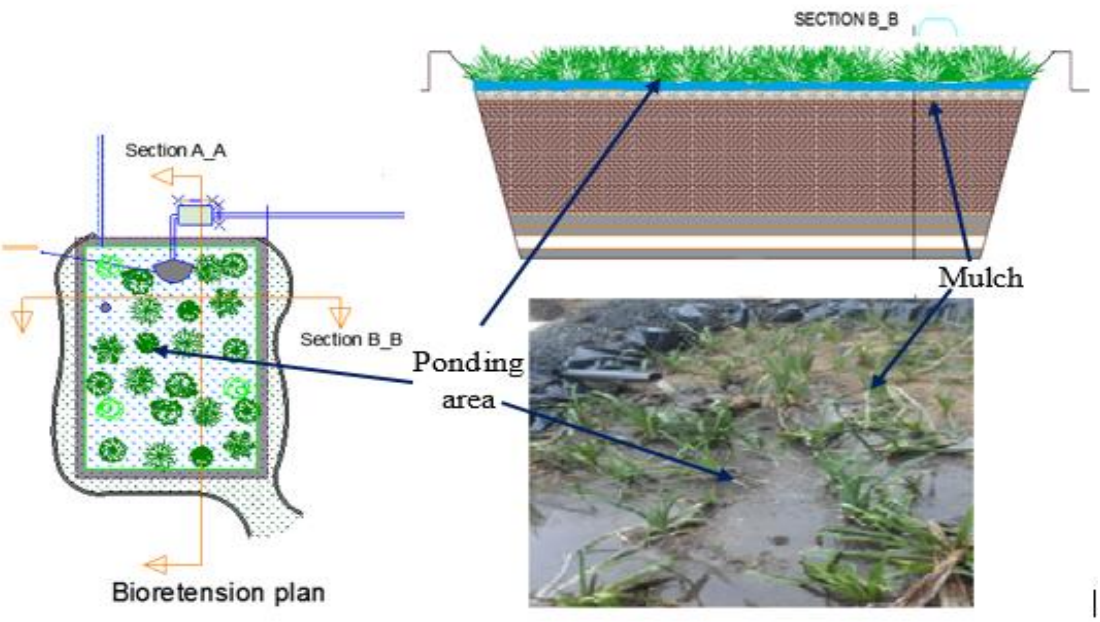
DEM of the study area

Rainfall data

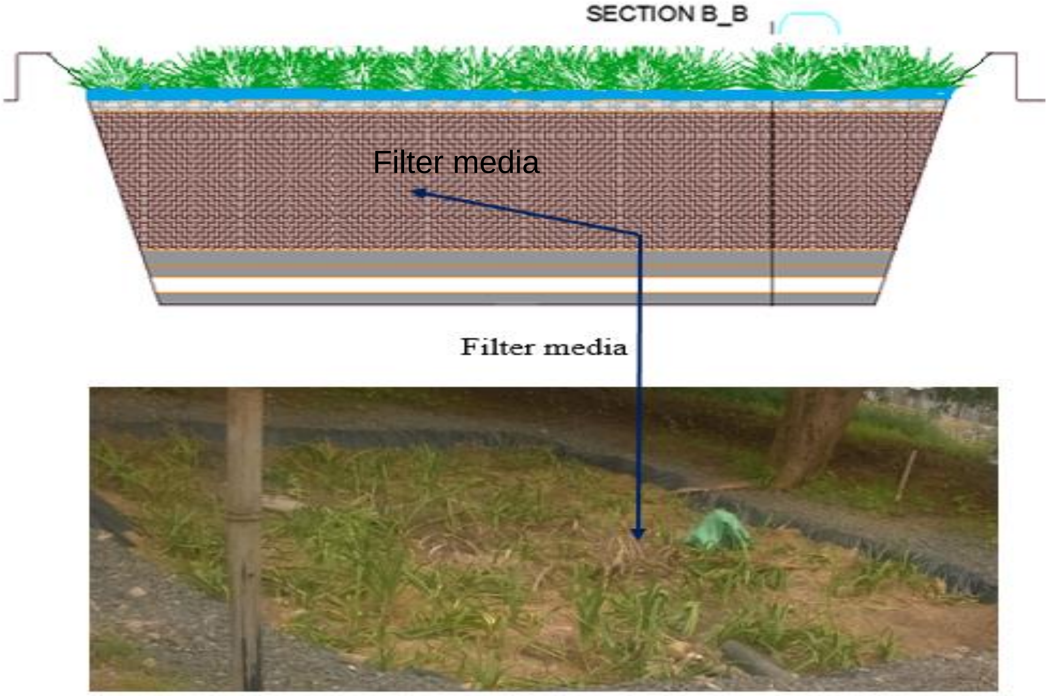
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max	Min	Ave	Grand Total
1987	0.5	63.4	248.9	82.4	241.3	92.9	196.5	254.4	115.2	21.3	0.8	0.3	254.4	0.3	109.8	1317.9
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	229.7	59.9	0	0	299.3	0	100.2	1202.6
1989	0.8	75.9	75.7	154.4	0.5	120.9	357.7	325.3	187.7	14.8	0	7.6	357.7	0	110.1	1321.3
1990	0.8	156	59.2	106.4	20	88.8	218.7	268.6	184	16.2	6	0	268.6	0	93.7	1124.6
1991	0	74.5	106.6	34.7	55.3	191.1	248.9	262.6	126.4	3.4	0	50	262.6	0	96.1	1153.5
1992	20.2	33.7	20.2	41	52	109.1	248.5	294.7	209.4	69.7	0	2.9	294.7	0	91.8	1101.4
1993	10.8	67.2	16.1	157.9	97.2	208.3	274	426.5	243.3	62.1	0	4.5	426.5	0	130.7	1567.9
1994	0	0	82.4	82.3	63.3	123.4	308.9	225	142	0.5	14.7	0	308.9	0	86.9	1042.5
1995	0	69	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0	0	48.4	314.9	0	95.5	1145.6
1996	28.1	5.2	106.8	128.2	122	258.5	266.4	338.7	294.2	0.2	0.2	0	338.7	0	129.0	1548.5
1997	39.2	0	24.5	51.3	38.5	104	272.6	194.3	113.8	62.4	50.3	1.5	272.6	0	79.4	952.4
1998	55.2	20.5	49	48.5	154.2	124.4	285.4	260	213.6	126.9	0	0	285.4	0	111.5	1337.7
1999	2.9	0.3	28.8	16.3	23.8	119.6	268.6	305.3	88.4	75.4	0	0	305.3	0	77.5	929.4
2000	0	0	17.6	49.9	110	144.5	244.8	306.2	250.6	46.4	21.1	0	306.2	0	99.3	1191.1
2001	0	12.2	210.8	25	168	216.2	428	246.4	131.7	13.7	0	0	428	0	121.0	1452
2002	14.7	21	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0	16.5	256.9	0	84.7	1016.1
2003	10.5	53.3	62.6	99.3	20.2	151.8	291.8	233.3	193.3	0.8	1.5	54.9	291.8	0.8	97.8	1173.3
2004	24.8	20.3	49.5	139.9	30.1	141.9	238.5	272.6	164	76.9	0	0	272.6	0	96.5	1158.5

2005	45.9	51.6	83.2	160.9	133.7	179.8	246	315.2	162.5	162.5	4.4	0	315.2	0	128.8	1545.7
2006	0.7	11.2	124.4	78.9	74.6	150.1	356.3	243.6	239.1	54	0.3	8	356.3	0.3	111.8	1341.2
2007	51.3	19.1	59.8	73.8	120.1	169.1	261.8	381.2	147.6	24.8	0	0	381.2	0	109.1	1308.6
2008	0	13	0	49.4	94.3	88.9	277	360.9	50.6	206.7	167	22.9	360.9	0	110.9	1330.7
2009	21.3	2.7	28.4	80.6	58.9	82.6	349.9	388.3	112.7	45.8	4.4	65	388.3	2.7	103.4	1240.6
2010	16.7	92.9	99.8	195.6	148.8	542.2	627.8	411.6	475.6	3.6	51.4	30	627.8	3.6	224.7	2696
2011	14.1	13.1	44.3	22.8	66.1	182	180.9	340.8	146	0	42.3	0	340.8	0	87.7	1052.4
2012	0	0	15.8	71.4	50.2	69.4	324.2	298	215.5	2.3	0	9.8	324.2	0	88.1	1056.6
2013	4.4	0	46.9	92.3	85	153.2	227.6	353.2	196.3	58.4	22.3	0	353.2	0	103.3	1239.6
2014	1.7	47.4	61.5	26.2	93.6	66.7	219.9	262.4	264.7	35	1.7	0	264.7	0	90.1	1080.8
2015	0	0	27.2	0	109.3	213.9	217	309.9	148.9	0	7.7	0.1	309.9	0	86.2	1034
2016	120	24.2	95.8	273.6	265.4	374.6	182.8	299.9	141.8	15.5	3.6	1.9	374.6	1.9	149.9	1798.7
2017	59.8	12.1	47.9	136.8	132.7	187.3										

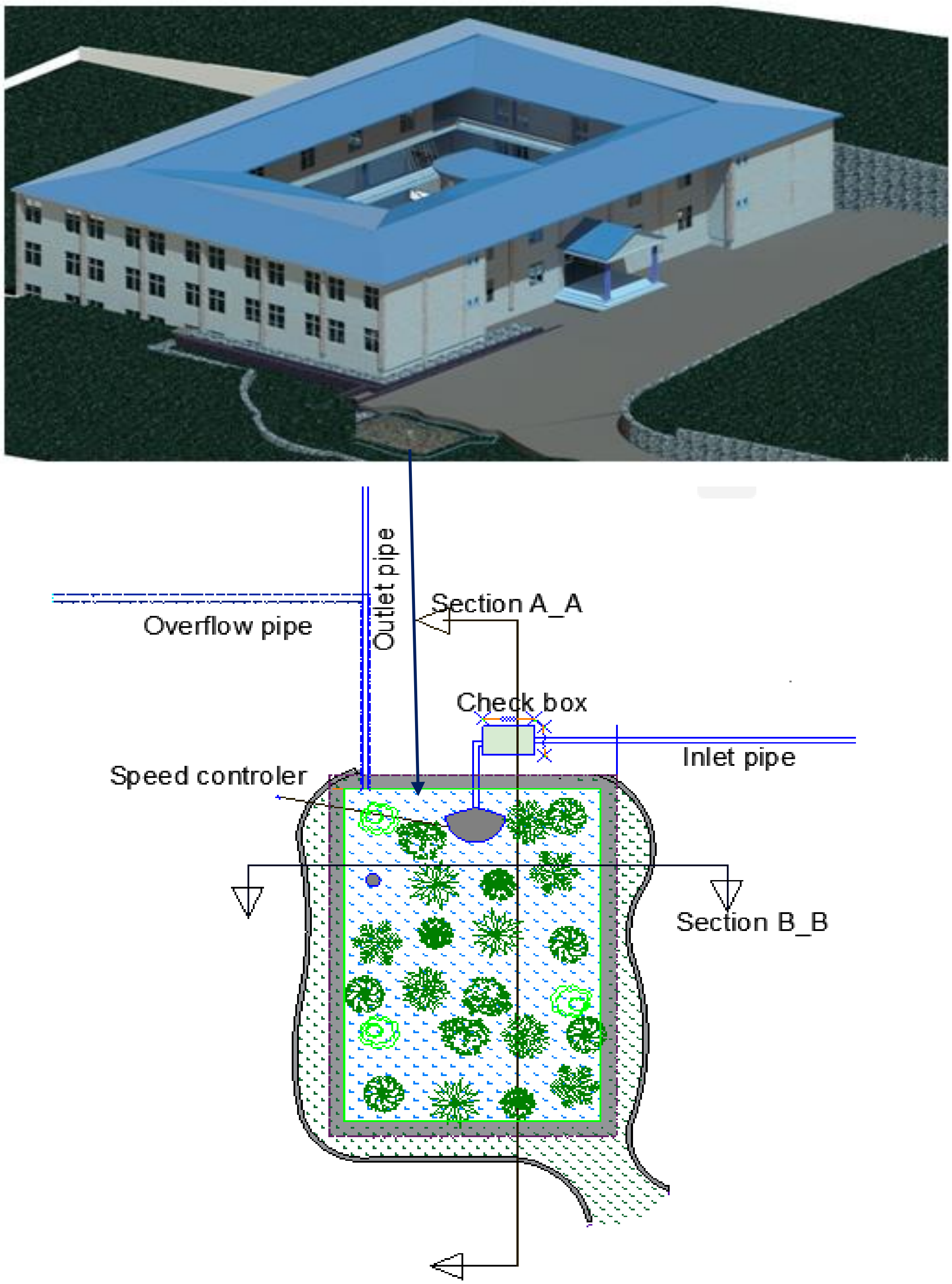
Annex 2: Designed and Developed Bio-retention system



Design and development of ponding area



Designed and developed filter media

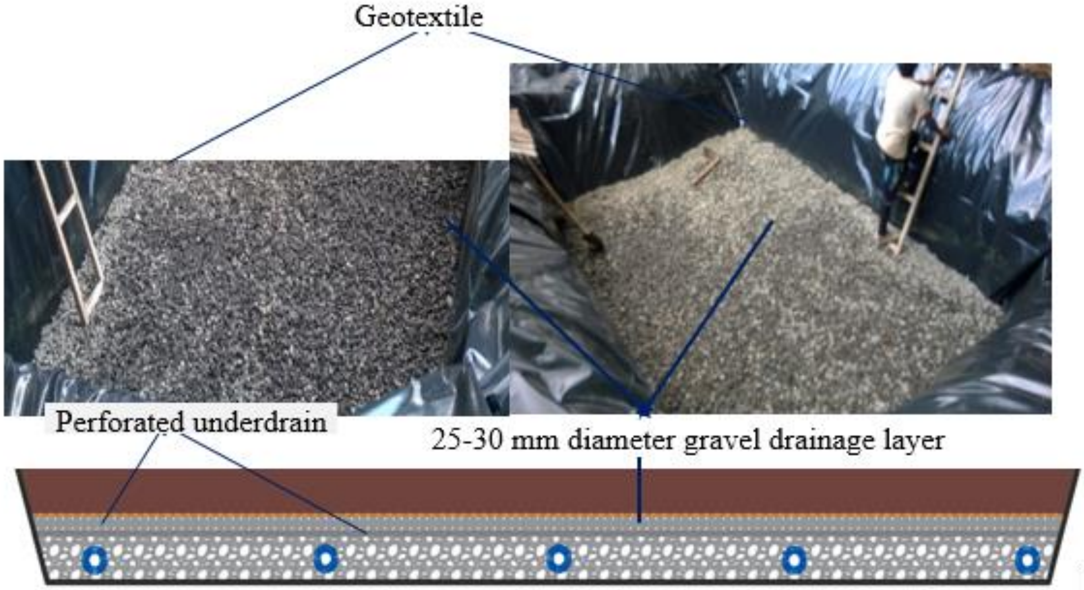


Bio-retention plan

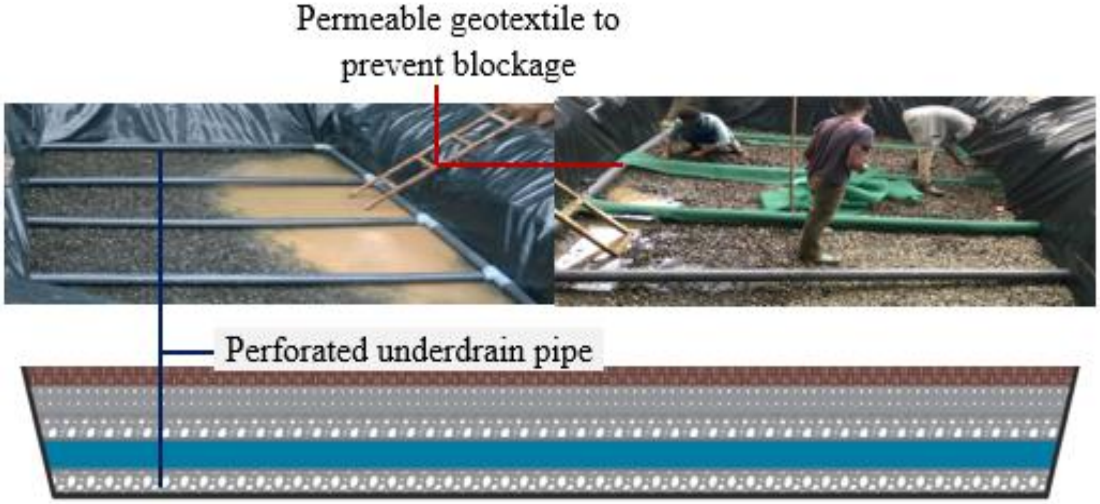
Annex 3: Picture taken during Bio-retention development and testing

Bio-retention development

Ponding area and water storage facilities



Developed and designed drains layer



Developed and designed perforated pipes

Turbidity, PH, and Conductivity testing

TSS and TDS testing

Annex 4: P-test of pollutants after and before entering the Bio-retention system

t-Test: Paired Two Sample for Means of TSS

	Variable 1	*Variable 2*
Mean	52	12
Variance	870	20
Observations	5	5
df	4	
t Stat	2.901905	
P(T<=t) one-tail	0.022017	
t Critical one-tail	2.131847	
P(T<=t) two-tail	0.044034	
t Critical two-tail	2.776445	

t-Test: Paired Two Sample for Means of TDS

	Variable 1	*Variable 2*
Mean	1	0.38
Variance	0.025	0.007
Observations	5	5
df	4	
t Stat	7.75	
P(T<=t) one-tail	0.000747	
t Critical one-tail	2.131847	
P(T<=t) two-tail	0.001494	
t Critical two-tail	2.776445	

t-Test: Paired Two Sample for Means of Turbidity

	Variable 1	*Variable 2*
Mean	70.8	43.2
Variance	358.7	68.2
Observations	5	5
df	4	
t Stat	3.144087	
P(T<=t) one-tail	0.017355	
t Critical one-tail	2.131847	
P(T<=t) two-tail	0.034711	
t Critical two-tail	2.776445	