



ADDIS ABABA UNIVERSITY COLLEGE OF TECHNOLOGY AND
BUILT ENVIRONMENT DEPARTMENT OF URBAN AND REGIONAL
PLANNING

INSTITUTIONAL LEVEL LAND USE LAND COVER GREEN INFRASTRUCTURE
ASSESSMENT AS A MEANS FOR STORM WATER RUNOFF MANAGEMENT: A CASE
STUDY OF ADDIS ABABA UNIVERSITY SIDIST-KILLO MAIN CAMPUS

BY:

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THIS THESIS IS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS
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Abstract

The rising population the need for living facilities, prompting the development of essential infrastructure such as roads, buildings, parking areas that increases the imperviousness of the surfaces. Increase impervious surfaces and the presence of inefficient drainage systems significantly intensify the volume of storm water runoff, leading to frequent flooding and limit the ability of stormwater to infiltrate the ground. This situation not only heightens the risk of flooding but also exacerbates water pollution. In response, Green Infrastructure (GI) has become a sustainable and effective approach for managing urban storm water by reducing runoff flow rates, retaining excess water, and enhancing groundwater recharge. The study areas have encountered problems of aging of infrastructure and inadequacy of drainage line outlet points. This thesis aims to constructively explore the spatial distribution of areas within the study areas of Addis Ababa university sidist kilo main campus and assess the potential of green infrastructure to mitigate stormwater runoff volume. Descriptive analysis method was used by leveraging both quantitative and qualitative methods, assessed the potentials of green infrastructure for stormwater runoff management. Graphs, maps, and tables were used to show the extent of development and the special arrangements. Using the rainfall data acquired from metrological agency for the maximum rainfall intensity and obtain the total runoff volume for the maximum generation of stormwater runoff with in the study areas. The green infrastructure covers approximately 49.81% of the total land use in the study area, demonstrating a significant contribution to stormwater runoff conservation and reduction. The development of infrastructure and the changes made at three different years 2012, 2017 and 2022 G.C shows the changes in land use land cover and GIS software were used for classification. The result depicts that the implementation of green infrastructure with in the study areas have positively impacted for the reduction of the volume of stormwater runoff; and has enhanced the capacity of existing stormwater drainage points, ensuring their adequacy. In conclusion, the proactive development of green infrastructure has demonstrated significant effectiveness in reducing stormwater runoff volume. This initiative not only contributes to improved drainage and flood prevention but also fosters a healthier environment, highlighting the importance of sustainable practices in urban planning.

Keywords: Green infrastructure; stormwater management, stormwater runoff, impervious surfaces, Addis Ababa University

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List of Acronyms

BMP	Best Management Practice
CWA	Clean Water Act
EPA	Environmental Protection Agency
EU	European Union
GI	Green Infrastructure
GIS	Geographic Information System
GPS	Global positioning System
LULU	Land Use Land Cover
LID	Low Impact Development
SWM	Storm Water Management
RI	Rainfall Intensity
SG	Smart Growth
SUDS	Sustainable Urban Drainage Systems
WSUD	Water Sensitive Urban Design

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Urbanization leads to an increase in impervious surface area, which has a corresponding and substantial impact on the hydrologic cycle. It seems sense that a larger percentage of impervious surface would result in shorter lag times between the start of precipitation and higher runoff peaks and overall runoff volume in receiving waterways (Shuster et.al, 2005). The existing grey infrastructure within the catchment has underperformed during significant events, leading to high peak flows and overland flow. This inadequacy has resulted in channel flow increases during minor rainfall events and altered the locations of flooding (Gurug et al., 2025).

Changes in land use and land cover resulting from urbanization will significantly impact these dynamics. The conversion of highly pervious areas to impervious surfaces leads to an increase in surface runoff volume and a decrease in the infiltration rate (Dennis et al., 2019). Urbanization also alters drainage patterns, causing faster overland flow, increased flooding, and rising environmental issues such as land degradation (Bekele, 2021).

Storm water runoff has affected the environment it takes all debris, soils, and eroded the surfaces if not properly conserve and manage. This and other factor coupled with the demand requires efficient management of the storm water runoff. Issaka & Ashraf, 2017 vegetated basins help manage storm water more sustainably by creating a hydrological functional landscape that reduces flooding and improves the environment (Baker, 2022). Green infrastructure (GI) is an environmentally sustainable alternative to traditional methods of storm water management, Rain gardens, swales, detention ponds etc. (Sharma, 2021). Clean water act defines the term green infrastructure as “the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, storm water harvest and reuse, or landscaping to store, infiltrate, or evapotranspiration storm water and reduce flows to sewer” (EPA, 2025). Therefore, several different strategies and technologies have been developed in some countries, such as the low impact development in the United States, the water sensitive urban design (WSUD) in Australia

and the Sponge City in China, which providing a broader framework with a holistic urban water cycle for storm water management issues (Huang et al., 2015).

Green infrastructure can be designed to soak water into the ground, which can increase the recharge rates of groundwater, helping to replenish groundwater reserves and maintain base stream flows (EPA, 2025). The green infrastructure has many advantages unlike the grey infrastructure, it serves as beautification, creating livable environment, aesthetics, avoid destruction that results from flooding, increase the time of concentration, quality and quantity of water, and helps to increase for the ground water table and green infrastructures offer sustainable, cost-effective solutions with added benefits, enhancing ecosystem services and societal well-being (Paredes Méndez, 2025).

Green Infrastructure refers to projects that include vegetated design elements such as natural, semi- natural and artificial spaces, urban forests, parks, greenbelts, alleys, woodlands, private gardens, street trees, allotments, playing fields, cemeteries and newer innovations such as vertical and horizontal gardens and planters, green roofs, etc.(Addis Ababa urban age task force, 2022). In adequacy of drainage system coupled with increase impervious areas with in the study areas Addis Ababa University sidist kilo increases a storm water runoff and flooding. Due to the limited sections and outlet points of the flood which come up from the storm, the study areas need to be planned for its storm management to properly manage without any damage.

In Ethiopia we have laws for the management of runoff water; however, no enforcement has been practiced in the city. Dealing with the benefits of the green infrastructure helps to the policy makers for their decisions of the future implementation. Trees can play a substantial role in reducing storm water runoff via canopy interception loss, transpiration, facilitating infiltration.

1.2 Statement of the Problem

An increase of imperviousness of surface areas due to the development of parking lots, buildings, roads result an increase in the volume of storm water runoff. When a lot of precipitation of water falls in a short amount of time it becomes problem especially when

the area of the surface is impervious and steep slope. In areas where impervious surface, the need to recuperate green space is becoming increasingly critical to maintain environmental quality and most importantly green infrastructure development for storm water management; which has a dual benefit for conserving water and environment.

Hence in the study areas there are only two drainage outlet points / exit points with the current drainage system; despite less capacity of the exit points flood accumulation is not observed with in the study areas during heavy rainfall. This happens due to the existence of enough portion of green infrastructure which can give us the best lesson and model in order to identify the benefits of green infrastructure development for storm water runoff management. The reason why fewer floods occurred at the study area despite less drainage outlet is that due to the green infrastructure development which helps to lower the instantaneous flow volume of runoff water.

Therefore, the result from assessment of green infrastructure development and its contribution for storm water runoff management with in the study area helps for application of the system in high scale label. And hence, Study of the development of green infrastructure and identification of how effective they are, helps for policy makers and for further study of the benefit of green infrastructure in this matter.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of the study is to assess the potential of green infrastructure to manage storm water runoff: the case of Addis Ababa University, sidist kilo campus.

1.3.2 Specific Objectives

The specific objectives of the study include:

1. To map and compute the area of the existing green infrastructure at sidist kilo campus.
2. To quantify the volume of storm water runoff under the existing condition
3. To analyze the campus practices that influences GI adoptions

4. To propose GI strategy tailored to the campus.

1.4 Research Questions

The study has the following research questions:

1. What portion of the Sadist kilo campus is covered by green infrastructure?
2. How much volume of storm water runoff can be reduced (or managed) due to the existing green infrastructure at sidist kilo campus?
3. What strategy shall be taken for the maximum benefit of existing green infrastructure for storm water runoff management?

1.5 Significance of the Study

The study is of significant importance as it explores the benefits and practices of green infrastructure (GI) for stormwater management. Currently, there is a minimal emphasis on implementing green infrastructure practices for effective stormwater management. Despite its notable aesthetic value, the development of green infrastructure is often overlooked and not adequately enforced in the planning sector. There is a pressing need for heightened awareness and commitment to integrating green infrastructure as a viable solution for managing stormwater runoff. The advantages of green infrastructure extend beyond simply reducing stormwater runoff; they encompass economic, social, and environmental benefits that are crucial for sustainable urban development.

Green infrastructure components such as green roofs, rain gardens, and permeable pavements not only mitigate flooding and reduce the burden on traditional drainage systems but also enhance urban biodiversity and improve air quality. Furthermore, these systems can provide significant cost savings over time by reducing the need for expensive grey infrastructure and lowering water management expenses. The substantial impact of green infrastructure systems helps prevent pollutants from entering water bodies, thereby preserving aquatic ecosystems and promoting a cleaner, healthier environment. Overall, it is essential to recognize and implement green infrastructure as a critical component of contemporary stormwater management practices for the sake of ecological integrity and urban resilience.

1.6 Scope of the Study

Thematic Scope: This study aims to provide a comprehensive institutional-level assessment of green infrastructure practices designed to effectively manage stormwater runoff at the sidist kilo Campus of Addis Ababa University.

Spatial Scope: The research will thoughtfully analyze land use and land cover classification within the study area. It will evaluate the coverage of green spaces and assess impervious surfaces, including buildings, roads, and parking lots, to gain insights into the extent of development and identify opportunities for enhancing sustainability.

1.7 Limitation of the study

- Although an investigation into soil types is warranted this study will not encompass an analysis of soil types due to its limited scope.
- The analysis is limited to the comparison of the generated runoff from rainfall data and the special analysis of green space within the study areas.
- Factors such as type of soils which differs the infiltration capacity, and slope which increase the stormwater runoff did not consider here.

1.8. Organization of the Study

The document is organized by five chapters, chapter one discusses an Introduction part which include the back ground of the study, statement of the problems general and specific object of the study.

Detail analysis and description of the study sites presented in the analysis and discussion in chapter four, the possible ways and issues with the current practice of management of storm water runoff will be discussed, the storm water runoff and the green infrastructure best practices will be dealt with separately in the literature review in chapter two, detail review of the storm water runoff , its effect, the impacts which imposed in the surrounding, different kinds of management of the storm water runoff and application of green infrastructure for storm water management practices in chapter three. And, the final conclusion and recommendation will be given in chapter five.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Green Infrastructure as Stormwater runoff Management

2.1.1 Definitions and Terms

Green infrastructure is an approach to water management that protects, restores, or mimics the natural water cycle. Green infrastructure is effective, economical, and enhances community safety and quality of life.

EPA (Environmental Protection Agency) defines Stormwater runoff as “Stormwater runoff is generated from rain and snowmelt that flows over land or impervious surfaces, such as paved streets, parking lots, and building rooftops”.

Stormwater is one of the biggest threats to water quality in the United States. It can transport trash, bacteria, heavy metals, and other pollutants through storm sewers and into local waterways. Heavy rainstorms can cause flooding that damages property and infrastructure.

Runoff refers to water flowing over the land surface, particularly after precipitation like rain or snowmelt, when it cannot be absorbed into the ground. This excess water then moves towards rivers, lakes, and other bodies of water. Runoff can also carry pollutants from the land into these water sources, contributing to water pollution.

2.1.2 Stormwater runoff Causes and Impacts

Stormwater runoff can have significant impacts on the health of our water resources, due to changes in both water quality and water quantity. The additional impervious surface created causes significant increases in peak flows and total runoff volume. In addition, the additional runoff picks up greater concentrations of many pollutants, degrading water quality in receiving waters (Kumar, 2024). If impervious surfaces created by development produce stormwater runoff that harms the environment due to substantial increases in peak flow (Loh, 2012).

2.1.3 Principles and types of green infrastructure

Green Infrastructure principles for stormwater management focus on using natural or nature-based systems to manage runoff instead of traditional grey infrastructure, like pipes and concrete channels. This involves a variety of practices that promote infiltration, reduce runoff volume, improve water quality, and provide additional benefits like green space and habitat (Sun, 2020).

Permeable Pavements Captured surface runoff percolates into the ground, replenishing aquifers and helping maintain groundwater levels, especially in overexploited areas. Gebreslassie, 2025 vegetated channels can improve water quality by infiltrating the first flush of storm water runoff and filtering the large storm flows (Baker · 2022). Vegetated roofs can reduce runoff volume by absorbing and evaporating rainwater, while also providing additional benefits like insulation and habitat (Mihalakakou, 2023). Constructed wetlands, infiltration basins and ponds are engineered features allow for controlled infiltration of stormwater into the soil (Wang, 2020). Strategic planting of vegetation can help intercept runoff, reduce soil erosion, and improve water quality (Zhou, 2024). Green infrastructure is considered some environmental resources such as forests, rivers, lakes, wetlands aquifers, soils, and landscapes which sustain our lives (Walfer, 2015).

Green infrastructure uses plants, soils, landscape design, and engineered techniques to retain, absorb, and reduce polluted stormwater runoff. Green infrastructure prevents or reduces the amount of runoff that flows directly into storm drains and can be a vital tool for cities to address combined sewer overflows and nutrient impairment. It provides many environmental, social, and economic benefits that promote urban livability, such as improved surface water quality, water conservation, and improved aesthetic and property value. EPA is developing innovative tools for communities to use for planning and installing green infrastructure for achieving its many benefits (EPA, 2010).

The European Union describes green infrastructure as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation. This network of green (land) and blue

(water) spaces can improve environmental conditions and therefore citizens' health and quality of life. It also supports a green economy, creates job opportunities and enhances biodiversity. The Natura 2000 network constitutes the backbone of the EU green infrastructure (European Commission 2016).”

2.1.4 Green infrastructure effectiveness in stormwater runoff

Green infrastructure techniques for stormwater management in an urban context finds that they can reduce runoff by several orders of magnitude, enhance water quality, and offer a wide array of environmental, social, and economic benefits. Techniques that include green roofs, permeable pavements, rain gardens, and bio swales have demonstrated positive impacts on the effects of storms as well as improvements in urban cooling, enhancement of biodiversity, and aesthetic improvement. But their performance is different and depends on various points of consideration like climatic variation, available space, and maintenance requirements. Gideon, 2024 urban heat island mitigation, improved air quality, expanded recreational green spaces, and enhanced community well-being through stress reduction and mental health improvements. This holistic perspective highlights GI's multifunctional potential, addressing both disaster resilience and the improvement of urban quality of life (Mendez, 2025).

2.1.5 Institutional scale application

Green infrastructure at institutional scale is designed to provide multiple benefits, including stormwater management, air and water quality improvement, temperature regulation, biodiversity enhancement, and recreational opportunities (Wang, 2024).

2.1.6 Maintenance challenges in GI adoption

Residents' flooding perception and experiences influence their intention to adopt green stormwater infrastructure (Ureta · 2021). Relatively poor integration of regulatory bodies into a system that fully appreciates the multidimensional benefits of urban GI remains a key challenge (Kremer et al., 2016).

2.2 GI as Storm-water Management in Developed Countries

2.2.1 Green Infrastructure practice for stormwater management in the USA

In the United States, municipalities have made noteworthy progress protecting the nation's waters through the implementation of the Clean Water Act (CWA) by using green infrastructure to comply with CWA requirements, treat stormwater, improve water quality, and mitigate flooding while also beautifying the communities. The United States, to accommodate new growth and development, cities are continually expanding the built environment, including roadway infrastructure and parking lots which comprise a large portion of impervious surfaces on the ground. On such impervious surface, rainwater and snowmelt cannot infiltrate into the ground but rather runs offsite at levels that are much higher than they would naturally occur" (water science school, 2018).

Currently, It has been increasingly acknowledged and improvement has been made in most cities of the United States that the optimal way to reduce storm water runoff and sewer overflow is onsite source control of storm water by using green roofs, rain gardens, street trees, vegetated swales, wetlands, and porous pavements, which are referred to as "green infrastructure" to infiltrate and retain the rainwater and snowmelt onsite before they enter the municipal sewer system. Hence, a shift from grey infrastructure to green infrastructure development is received high attention and accepted which can address the root causes of storm water issues which help to keep the natural hydrologic system and reduce the runoff from impervious surface (Oates et al., 2020).

According to the study by Oates et al., 2020 The city of Philadelphia has the most ambitious storm water management plan (City of Philadelphia, 2009) aimed at turning 1/3 of the city's impervious asphalt surface into green spaces, which is expected to absorb 50 percent of the city's storm water runoff. New York City has proposed the NYC green infrastructure Plan to control runoff from 10 percent of impervious surfaces through green infrastructure; and the outcome from their studies Green Infrastructure designed to reduce storm water runoff in forms of natural landscaping and vegetation is believed to be more cost-effective than conventional storm water management solutions.

Other environmental issues are more likely to be mitigated with increased green infrastructure, such as urban heat island effects, degraded air quality, and energy consumption in buildings. Social and economic benefits can also be achieved simultaneously by creating outdoor recreation opportunities, enhancing city aesthetics and community livability, increasing property value and occupancy rate of commercial uses, and attracting and retaining business.

The Low impact development is a highly feasible solution to achieve integrated water management to achieve the sustainable development goals outlined (Oates et al., 2020). Wong, 2006 in his study of the values and benefits of the management of storm water runoff, storm water is used for an alternative means of sources of water for industrial and various domestic uses especially for non-potable water supply which is used directly. Hence, the use of LID systems for storm water runoff management will serve as a treatment media which can trap pollutants and slowing down the runoff (Barbosa et al., 2012).

The study by Gulati & Scholtz, 2020 shows how green infrastructure benefits cost wise; they stated about their finding on cost saving for the implementation of green infrastructure: “Green infrastructure delivers cost savings to cities many cities are already experiencing the benefit of cost savings. Examples can be found from as early as the 1990s. New York City avoided spending USD6–8 billion on new grey infrastructure water filtration and treatment plants by instead purchasing and protecting watershed land in the Catskill Mountains for USD1.5 billion. Green roofs in the City of Chicago have the potential to yield annual savings ranging from USD29.2 million to USD111 million. The City of Portland estimates that eco-roofs generate a net benefit of USD404000 over a 40-year lifespan on account of a one-off and ongoing reduction in storm water management fees, cooling and heating costs and HVAC (heating, ventilation and air conditioning) equipment sizing costs, as well as avoided storm water management facility costs and roof replacement costs” (Gulati & Scholtz, 2020).

The effect of the rapid pace of population growth and urban sprawl cities in the United States are facing the challenges of protecting water resources, drinking water and public health. Due to an increase of imperviousness on urbanized watershed results large quantities of storm water runoff which causes an overflow from municipal sewer system

and causes an overflow of untreated storm water into waterways, of Large quantities of storm water runoff arising from increased imperviousness on urbanizing watershed will cause municipal sewer system overflow and discharge of untreated runoff into waterways, and as a result, pollute local water bodies and affect the quality of drinking water in the long run” (Oates et al., 2020).

According to Philadelphia’s Green City, Clean Waters Plan “Philadelphia has launched an ambitious, 25-year plan called Green City, Clean Waters to achieve compliance with the Clean Water Act (CWA) by establishing binding targets to transform approximately 10,000 acres about one-third of the impervious area in combined sewer areas of the city into “greened acres,” on which the first inch of rainfall from any given storm is managed on-site. The city plans to reach its goal through a combination of greened public spaces and regulatory changes intended to induce private investment in green infrastructure development. The plan has been formalized in a Consent Order and Agreement entered into by the city and the state of Pennsylvania in 2011 and an Administrative Order for Compliance and Consent between the city and EPA that was signed in October 2012. The city’s overall long-term plans to control CSOs are estimated at \$1.2 billion. The city has committed to expenditures of approximately \$1 billion of green infrastructure to be implemented through the plan (Oates et al., 2020).

A key aspect of Philadelphia’s plan is that it leverages private investment in green infrastructure to help satisfy CWA obligations. It will take advantage of storm water improvements that private property owners will install over time, as private-sector redevelopment occurs and is subject to the city’s on-site storm water management rules. Philadelphia estimates that at a roughly 1% projected annual redevelopment rate, the storm water rule requiring on-site management could generate 2,500 to 5,500 green acres in the city over 25 years. The balance of the greened acres would come from investments by the city in retrofits on publicly owned land, such as city properties, streets, and rights-of-way (Oates et al., 2020).

While green infrastructure practices may be more cost-effective in the long run, installation of technologies can require large up-front investment. Recognizing that fact, Philadelphia’s storm water utility fee system offers fee discounts to commercial property owners who

reduce impervious area or otherwise manage runoff onsite. The incentive to property owners comes in the form of a credit against future storm water fees for properties that install storm water retrofits. Under the credit structure, the property owner receives a reduction in the monthly stormwater fee proportional to the amount of impervious area from which the entire first inch of runoff is managed onsite, up to 100% of the fee for management or retention of the first inch of storm water over 100% of the impervious area of the site (a monthly minimum charge prevents storm water fees from being reduced entirely). The plan provides that once a stormwater fee credit is approved by the Philadelphia Water Department, the fee reduction is fixed for a four-year period, at which point the property owner may reapply for the credit, based on a showing that the retrofit has been properly inspected and maintained and remains fully functional” (Tian & Shaojing, 2011).

Benefits and acceptability of the storm water management practices in US cities: Portland, Seattle, and Milwaukee have demonstrated that public engagement and awareness can lead to widespread support for WSUD. Chicago, like many other U.S. cities, is trying to cope with one of the many problems caused by worsening climate change increasingly intense downpours that inundate the urban landscape with storm water that sometimes overwhelms sewer systems designed many years ago; inland rainstorms cause a phenomenon called urban flooding, in which excess rainfall causes sewers to overflow, flooding streets and homes around them. Other cities of the United States besides Chicago, are adding green infrastructure to their storm water management strategies (Tian & Shaojing, 2011). For example, in Detroit, the Detroit Water and Sewerage Department plans to spend \$50 million by 2029 to build green infrastructure projects. The agency already has completed 12 projects with the capacity to manage 61 million gallons (231 million liters) of storm water.

Kiger, 2021 in his study of storm water runoff mitigation measures, implementing of green infrastructure from door to door unlike its implementation has smaller in size, due to its distribution of the green infrastructure the cost of investment is much lower than building gray infrastructure at every points. Hence, green infrastructure provides benefits that go beyond controlling storm water. Maintaining green infrastructure can provide jobs for

residents and promote economic equity in disadvantaged neighborhoods, as well as improve the quality of life there.



Figure 2. 1: An illustration of various storm water management projects

(Source, EPA, 2010)

Shaoxing, 2011 reveals the benefits of the green infrastructure in a project that is found in Detroit involved and costed an \$8.6 million transformation of traffic medians along Oakman Boulevard, the building of the green infrastructure combines vegetation with an underground storage tank and able to manage for conservation of 37 million gallons (140 million liters) of storm water each year. In the Chicago area, the Nature Conservancy and the Metropolitan Planning Council are involved in a different sort of effort to promote green infrastructure. In 2020, they launched Storm Store, a pilot program that enables developers to trade credits for storm water management features that they are required to put on their properties. The goal is to ensure that green infrastructure is built where it is needed most rather than just to comply with regulations.

In the United States “an ecological paradigm emerged in the 1990s that placed storm water quantity and quality within the context of integrated watershed management and low impact development. Storm water quantity can be reduced and water quality can be improved by

mimicking natural hydrology, enhancing biodiversity, linking ecological and economic sustainability, taking an integrated approach at manageable scales, and viewing storm water as a resource (Debo & Reese, 2002).

Green Infrastructure systems are designed to address these concerns by mimicking natural systems by infiltrating runoff, facilitating groundwater recharge, and increasing storage volume. Additionally, GI systems reduce stress on wastewater systems, decrease combined sewer overflows, modulate peak flow during storm events, restore impaired urban waters, and improve watershed health (Tedoldi et al., 2016).

By the initiation of the EPA, study was taken to examine the potential impacts using green infrastructure for the ground water quality has been made as part of the safe and sustainable water resource program. Accordingly, “an overarching objective of the SSWR program is to support increased adoption of green infrastructure into community storm water management plans and watershed / sewer shed sustainability goals by providing information and guidance. And the study was made in three diverse locations, which were selected based on climate, geology, type of infrastructure used, and geographic location as a basis of criteria. Due to differ in climate, geology and land use the values of the storm water runoff management has been found different. And the report concludes that the nature and existence of the green infrastructure has an influential effect on the quality of the ground water (EPA, 2010).

The three sites are Louisville Kentucky, Fort Riley Kansas, and Yakima Washington. The Louisville site is located in the CSO-190 sewer shed and primarily uses underground storage galleries as the GI to capture the storm water runoff. The Louisville study site has a humid sub-tropical climate. The Yakima site has an arid climate and the study is unique because wastewater is being infiltrated on the flood plain of the Yakima River. The Fort Riley site has a permeable pavement system that infiltrates storm water runoff and is located at Seitz Elementary School on U.S. Army Fort Riley post. Fort Riley is in north eastern Kansas which has a humid sub-tropical climate. The purpose of this report is to draw conclusions from these studies to provide an initial assessment on the influence of GI on groundwater quality. This assessment will look at the individual site monitoring data through the autumn of 2018 (USA and the linking of smart growth with GI; USEPA, 2005)”.

Green Infrastructure Practices in USA; the images below illustrate some green infrastructure practices and techniques being utilized by US cities.



Figure 2. 2: Green Roof in Chicago

(Source: National Geographic Magazine, "Up on the Roof," May 2009)



Figure 2. 3: Rain Garden

(Source: Water Environment Research Federation, May 2009)



Figure 2. 4: Vegetated wales

(Source: Water Environment Research Federation, May 2009)



Figure 2. 5: Infiltration planter

(Source: Lawrence Berkeley National Laboratory, Campus Planning and Design Guidelines, 2018)



Figure 2. 6: Permeable pavement

(Source: Water Environment Research Federation, 2018)



Figure 2. 7: Constructed wetland for storm water management

(Source: Lake County Illinois Storm water Management Commission, 2018)

2.1.3 GI Practice for Storm Water, Management in Australia

The population changes and lifestyle expectations, continuing growth and urbanization, climate change, economic challenges, resource challenges, those are the key challenges of the modern city, that are related with land uses. The concepts and related measures of storm water harvesting and storm water management in Australia to deal with urban flooding and runoff pollution has got attention by the Government and working to disseminate and aware to the public through various policies for its implementation.

In Australia the low impact development is called water sensitive urban design, the drought in recent years and growing concerns for the security of water supplies as a result of climate change has increased public awareness and acceptability of WSUD; which is now in great advance in Melbourne, Australia in the range of community and organizations (Pittock, 2003). “Both the Victorian Storm water Initiative and the Healthy Waterways Partnership are large, regional efforts that have arisen from a gradual building of knowledge and concern for downstream waters, culminating in government-level efforts to address storm water issues”.

In Australia, national guidelines have been prepared (ARMCANZ & ANZECC, 2000; Engineers Australia, 2006) and there is guidance for municipal engineers and others through the recent design manuals (Argue 2004; Melbourne Water 2005). Design manual Handbook Argue 2004; Melbourne Water 2005, design and procedures that includes information on design of bio-filtration systems, rain gardens, infiltration systems and storage and reuse of storm water.

The Australian government has recently established an inter-governmental committee for “Water Sensitive Cities” to provide strategic guidance on how to best advance

WSUD practices, which may bring about some federal oversight. Similarly, Australia’s WSUD (Shuhan et al., 2018). The development in flood risk areas must be accepted; many developments are designed to accommodate occasional flooding and may even comprise amphibious buildings as at Massbommel (inhabitant, 2010). Integrating rainwater GI with development on flood plains means the systems will be overwhelmed occasionally, which can compromise their effectiveness (Doncaster et al., 2008).

The WSUD concept has been used in Australia since the 1900s; the use of the WSUD concept in a report prepared for the Western Australian Government is a sign of its widespread use (Whelans et al. 1994). Since then, the concept of WSUD has been continuously expanded and improved (Chesterfield; 2001), becoming a ‘philosophical approach to urban planning and design’ (Chesterfield; 2002). The concept of storm water management in WSUD has multiple connotations, and its aims include flood control, flow control, water quality improvement, and water reuse (Armcanz & Anzecc, 2000).

Australia has implemented WSUD to solve the problem of urban water shortages caused by the vast differences in its national climate. From an urban master planning perspective, this design considers problems related to the hydrological cycle and water conservation measures before implementing regional planning and construction (Ahammed, 2017).

2.1.4 GI Practice for Storm Water Management in the United Kingdom

Because of its potential to deliver more than one function, GI produces a range of environmental, economic and social benefits in conjunction with water and flood risks

management. Incorporating the value of those benefits in to life cycle cost benefit analysis is essential in comparing GI and conventional gray infrastructure. (Wise et. al., 2010).

The United Kingdom current planning policy defines green space by its primary function, such as park, protected area, etc. making it difficult to provide integrated approaches to urban planning with diverse range of benefits that include GI as a component of storm water management.

More modern UK development tend to be either terraced or surrounding a courtyard to meet density requirements (Lauchlan, 2006). Invariably there is some aesthetic green planting and this can also be designed to have some rain water capture/ GI functionality The population changes and lifestyle expectations, continuing growth and urbanization, climate change, economic challenges, resource challenges, those are the key challenges of the modern city, that are related with land uses (Asheley et al., 2011).

Within 2001 and 2007, there is an increase in average size of the dwellings in UK for the new development of buildings, which increases from 25 to 44 dwellings per hectare. This development and increase of dwelling exacerbates water and flood risk due to the reduction of green spaces and which is replaced by impermeable surfaces. And this results in an increase for flow volume of storm water runoff and risk of flooding is occurred in urban areas (Kellagher & Lauchlan, 2006).

The London Plan (Mayor of London) once states that“ green vegetated roofs, roof terraces and gardens can enhance biodiversity, absorb rainfall, improve the performance of the building, reduce the heat island effect and improve appearance, development should maximize opportunities to orient buildings and streets to minimize summer and maximize winter solar gain; use trees and other shadings; green the building roofs, envelope and environs; maximize natural ventilation ; expand green networks to create ‘breathing spaces’ and whenever possible incorporate a range of public and/or private outdoor green spaces such as garden and terraces. Climate change is identified as a particular challenge in urban areas, where urban heat island effect is already recognized.

The study in United Kingdom about the impact of flooding at the beginning of the 21st century combined with growing housing demand, has led to flood risk guidance that challenges building with in flood plains. In the Netherlands, development in flood risk areas must be accepted; many developments are designed to accommodate occasional flooding and may even comprise amphibious buildings as at Massbommel (inhabitant, 2010). The implementation of the EU floods directive, together with duties placed on lead local flood authorities in England under the flood and water management act 2010

(FWMA).

1. Green infrastructure in the UK – Policy

The inclusion of GI in UK urban areas still predominantly occurs for traditional aesthetic, recreational and biodiversity reasons and is not usually linked specifically with surface water management. The GI initiative promoted in the UK by CABE, Natural England and regional agencies (e.g. Community forests North West et.al, 2010 and 2011; climate east midlands, 2010) all emphasis how existing and new GI networks can be effectively utilized to help to deliver multiple value by including surface water management.

In UK policy, there are complex interacting factors that influence how rain water GI may be implemented and used in relation to surface water management. These may be considered as grouped in to:

Core traditional GI policy – e.g. Biodiversity, recreation

Additional Ecosystem services policy – e.g. Air pollution, urban cooling.

Key influential policy where GI will be integral – e.g. Housing, transport, climate change, sustainable communities

Water policy – e.g. Flood risk assessment, water resources, discharge rates

In England, delivery of GI planning and resourcing is dependent on policy. This could be for larger spatial land use planning scale or at the design scale of individual developments,

for example how water is managed within a housing estate or used for place making within a commercial setting.

Housing policy sets density targets which will influence street scale GI for water management, England PPS3 housing (DCLG, 2010) has constrained street frontage

SuDS resulting in surface water systems that are largely situated on the edges of recent new developments.

2. Photographs of Green infrastructure development



Figure 2. 8: England's Best Kept SuDS Secret / Hydro International, 2022



Figure 2. 9: Wales stems Flood risk through SUDS – UK Construction online, 2018

The United Kingdom has established sustainable drainage systems (SuDS) that consider water quality and quantity as well as public recreation measures (e.g., the rain garden is used to collect, absorb, and purify the rain water from roofs or surfaces, while at the same time being ornamental), with the objective to slow the flow rate, decrease the flow itself, purify the quality of the rainwater entering the pipe network, and preserve the natural environment's water demands (Ellis & Lian, 2016).

The UK guide for rain garden , provide a detail insight from the usage and benefits of the green infrastructure, All the green spaces and other environmental features, which include parks, gardens, green roofs and street trees, which are collectively known as green infrastructure, combine to provide various benefits at minimal cost, which are often described as ecosystem services. Rain gardens help our gardens to deal more effectively with rainfall, but they also filter and clean runoff. By providing more and more rain gardens, we will be able to reduce our risk of flooding and curb urban heat islands. (Leuthvilay, 2022).

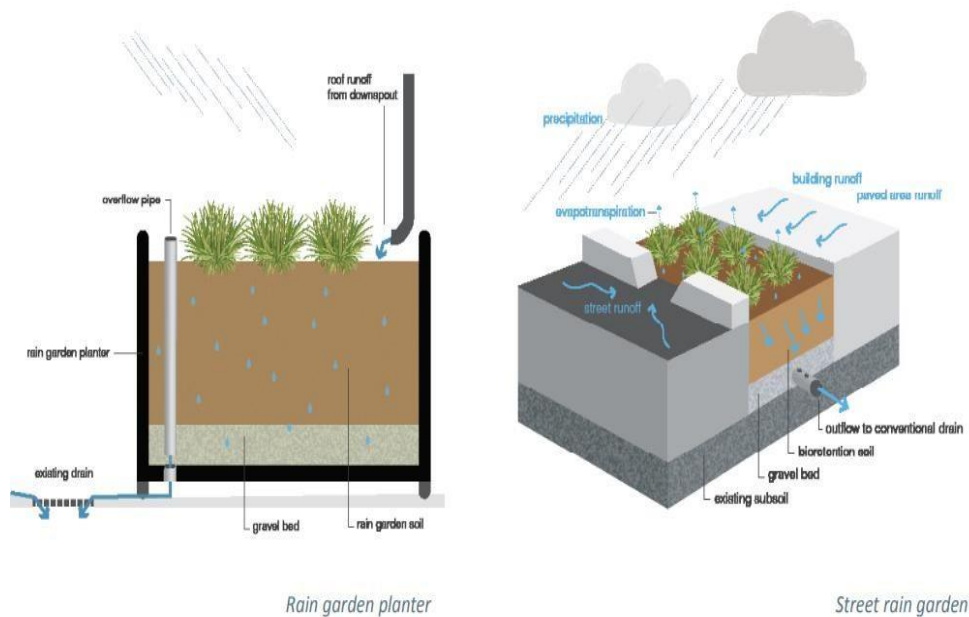


Figure 2. 10: Rain garden

(Source: Rain Garden guide (Bob Bray et al., 2022))

Rain gardens usually absorb all the rainwater that flows into them, but when they do fill up following particularly heavy rainfall, any excess water is redirected to the existing drains. These simple rain gardens do not require any redesign of the existing drainage system and can be installed wherever space permits.

The United Kingdom has established SuDS that consider water quality and quantity as well as public recreation measures (e.g., the rain garden is used to collect, absorb, and purify the rain water from roofs or surfaces, while at the same time being ornamental), with the objective to slow the flow rate, decrease the flow itself, purify the quality of the rainwater entering the pipe network, and preserve the natural environment's water demands (Ellis & Lian, 2016).

2.2 GI as Storm Water Management in Developing Countries

2.2.1 GI practice for storm water management in China

In China due to the rapid increase of urbanization, management of urban water is becoming increasingly important. The issue of water management is especially problematic in large cities, where widespread urban infrastructure has displaced key aspects of the natural system, and thus, disrupting the hydrological cycle. Buildings, Roads, and any impermeable structures built in urban areas prevent water soaking in to the ground. Farm lands, vegetative lands and other areas which were covered by grasses and plants had been destroyed and changed in to impermeable surfaces due to the development of infrastructures in cities, and thereby produce large amounts of storm water. Hence, due to the development of cities and impervious structures, the piped system of structural works becomes over flooded. Currently in China cities flooding is become a regular occurrence which creates problems to the communities (Zurakowsky et al., 2019).

The increasingly extreme global climate is a background that brings new environmental problems for urban development, which is a serious challenge to all urban storm water management. Extensive problems had been occurred in China by the storm water runoff which is created by an increase in the development of urbanization, (Zevenbergen et al., 2018) and thus Serious water issues have accompanied China's rapid urban growth, more

and bigger cities have replaced swathes of absorptive green space with impermeable surfaces (Mees, 2014).

Currently, China has made responding to urban water management challenges a national priority and the government is seeking to progress “from the traditional sector based, engineering oriented paradigm to a nature-based, holistic approach”. In doing so, it is promoting changes to traditional infrastructure, for example: absorptive roads and permeable pavements; the implementation and expansion of green infrastructure, such as rain gardens, parks and wetlands; and built environment measures such as green roofs and rainwater reuse facilities. The key design feature of this new paradigm – known as the “Sponge City” – is “blending natural features and the city together as seamlessly as possible”. (Oates et al., 2020), and it’s introduced by the Chinese government Sponge city initiative in 2013 with aims to enhance infiltration, evapotranspiration and reuse of Storm water (Zevenbergen et al., 2018). And hence, China is often cited as the birthplace of the sponge city concept, and has begun heavily implementing Green infrastructure into a number of major urban centers as part of its wider “sponge city initiative” (Zurakowsky et.al. 2019).

“Since 1949, China’s management of urban rainwater runoff has generally experienced three stages, namely the direct rain stage (1949~2000), the combined use stage (2000~2013), and the system management stage (2013~present). In 2013, General Secretary Xi Jinping proposed the construction of “Sponge City”, which indicates that

China’s urban rainwater management has entered the stage of system’s management. Beijing has conducted research and applied rainwater utilization since 1989. It is the earliest city in China and has achieved good results” (Zhang et al., 2018).

The Chinese government has set targets for the sustainable development goals of the countries in 2030, which includes creating the safe environment and livable conditions, for the maximum usage of the storm water of which 80% of the urban areas should absorb, retain and reuse 70% of the rainwater (Zevenbergen et al., 2018).

According to the national-level Guidelines for Promoting Sponge City Construction, the primary goals for China's sponge city construction are: retaining 70–90% of average annual rain water onsite by applying the green infrastructure concept and using low-impact development measures, eliminating water logging and preventing urban flooding, improving urban water quality, mitigating impacts on natural ecosystems and alleviating urban heat island effects (Oates et al., 2020).

Hui Li & Minglei Ren, 2017; in their study about the sponge city construction in China, they survey result from 30 different pilot projects and come to the conclusion that the methods have more benefits of safety, greenery and its high contribution for holistic urban environments. In Wuhan city China heavy investment has been made for both the green infrastructure and blue infrastructures in order to solve problems related with water issues (Oates, et.al, 2020).

In China, Wuhan city becomes now a “leading sponge city”, and their plan is to cover more than 38.5 Km² green infrastructures with in two areas as a demonstration in Qingshan and Sixin districts, which comprises 389 separate sponge projects. These projects include the construction of urban gardens and artificial water bodies in parks, roads and buildings; the construction of two rainwater pumps; the repair of 13 water channels; and the ecological restoration of at least one lake (Oates, et.al, 2020).

Sponge infrastructure helps to reduce flooding by serving as a storage reservoir for what would otherwise become runoff, instead allowing water to infiltrate slowly. It can also increase the water supply through retention of precipitation via green roofs and rain gardens, improve water quality by acting as a natural filter for sediment and impurities, and help to improve water quality – both directly by removing pollutants and indirectly by reducing the energy requirements for water treatment, thus reducing emissions from local power plants (Oates, et al., 2020).

The benefits of the green infrastructure for storm water management have now emerge as a basic solution for integrated resource management, it helps to ensure for availability for the management of sanitation, “The development of green infrastructure has led to a concept

now referred to as Sponge Cities, a large-scale, intensive form of green infrastructure strategy that equips entire cities to store and recycle rainwater” (Huang, 2015).

In Shanghai Lingang new city the comprehensive storm water management landscape security pattern is designed with consideration of flood control, storm water control, runoff reduction, water quality protection, and rainwater utilization objectives which could provide guidelines for smart growth and sustainable development of the city (Xu et. al., 2015).

In Beijing, China to address problems related with floods and storm water management, “Beijing is piloting a new permeable city concept called ‘Sponge Cities’”.

A Sponge city is designed to locally absorb, treat, and slowly release captured rainwater to mitigate the impacts of flooding and storm water pollution. This is achieved via implementing a network of permeable surfaces and ‘green-blue’ infrastructure options to help restore the natural water cycle within heavy urbanized areas. These infrastructure options typically include vegetated rooftops, rain gardens, wetlands, and storm water re-use systems.



Figure 2. 11: Kunshan Cultural Plaza. Image: CRC Water Sensitive Cities, 2017

(Source: https://e2designlab.com.au/blog/i_2017-12-05-sponge-cities-chinas-greenblue-approach-to-urban-water-management)

The following Yanweizhou Park in Jinhua (Eastern China), completed in 2014, serves as an example how city spaces can ‘absorb’ water and serve as engines for tourism, city greening and urban wellbeing (CRC Water Sensitive Cities, 2016).

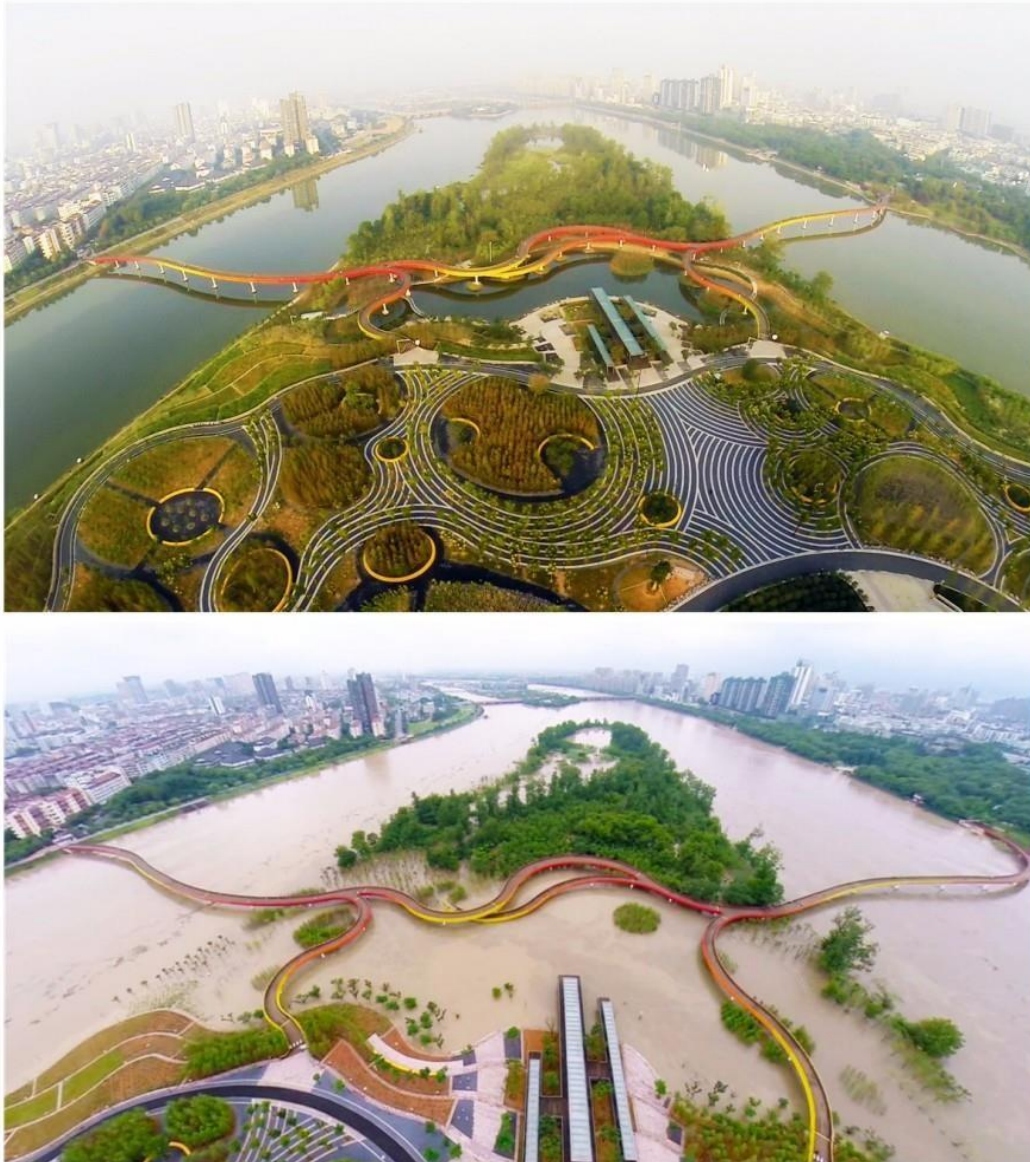


Figure 2. 12: Yanweizhou Park. Designed by Turenscape. Image

(Source: https://e2designlab.com.au/blog/i_2017-12-05-sponge-cities-chinas-greenblue-approach-to-urban-water-management)

The business insider, 2017 reported about the benefits of green infrastructure “As for the green infrastructure work programs that is taken place in China, The Kunshan forest park water management and Eco-restoration project aims to improve the water quality of five large park lakes by transforming traditional green space into multi-functional green infrastructure which provides water treatment, water recirculation, and extra flooding storage, within a versatile landscape. In addition, an ecological restoration zone is planned to protect and remediate the local aquatic and terrestrial habitat, restoring the ecological values and encouraging flora and fauna back to the area”.



Figure 2. 13: Kunshan Forest Park, China, 2017

(Source: Business Insider: <https://www.businessinsider.com.au/china-is-building-sponge-cities-that-absorb-water-201711>)

Serious water issues have accompanied China's rapid urban growth. More and bigger cities have replaced swathes of absorptive green space with impermeable surfaces (Mees, 2014).

Wuhan's sponge city investments offer an opportunity to assess both the narrow financial and wider socio-economic considerations facing policy-makers as they assess different approaches to increasing the resilience of urban water management systems. When the Sponge city Programme is compared to an alternative set of grey infrastructure investments a clear financial case for investing in green infrastructure emerges. Specific projects included urban gardens, parks and green space designed to allow water to infiltrate during regular precipitation and to direct water away from urban areas during flooding, artificial lakes that draw water away from populated areas during downpours and water channels that can safely handle very large volumes of water during flooding (C40, 2016).

Evaluation has been made for the development of green infrastructure, there has been a saving of money's, and suggests that a focus on nature-based solutions has saved Wuhan city a large amount of money, and more importantly, the actual cost of grey investments is likely to be higher than the costs which is used for green infrastructure. This is because large-scale public projects – especially those related to water management – have a long history of going significantly over budget (Flyvbjerg, 2009).

As a country with relatively underdeveloped urban storm water management, China's government has promoted the spongy city program, learning from advanced urban rainwater management experience worldwide (e.g. LID and WSUD) to establish a powerful management model to deal with water-related issues in all Chinese cities. These opportunities mean that the SCP could be a starting point for a new means of urban development that can transform the traditional Chinese infrastructure construction model, establish a more holistic and sustainable viewpoint about urban development, and create a green, comfortable, and harmonious living environment for the Chinese people (Li & Zhang, 2021).

As a country with relatively underdeveloped urban storm water management, China's government proposed an ambitious urban storm water management plan in 2014, called the Sponge City Programme, which means that a city is designed to act like a sponge, with

good ‘resilience’ in adapting to environmental changes and coping with natural disasters. As of 2021, this Programme has led to SCP projects in 30 pilot districts all over China, the Sponge City Programme construction impacts both urban development and residents' lives (Zhang 2021).

Li & Ren, 2017 in their study about the spongy city construction in China, their survey result from 30 different pilot projects and come to the conclusion that the methods have more benefits of safety, greenery and its high contribution for holistic urban environments.

2.2.2 GI practice for storm water management in Kenya

On August 14, 2020, Reuters reported on Nairobi’s increased efforts to expand green infrastructure. The article highlights how such investments address challenges posed by the pandemic and the climate crisis. The Kenyan capital is improving the protection and quality of green spaces, especially along the Nairobi River, while supporting people in need. In March, the city hired jobless former residents of the Michuki Memorial Park to help clean, restore, and guard the area. The park now provides locals with recreational space, while also improving the microclimate and habitat quality for species formerly displaced due to high pollution levels. The city is also pushing toward better road corridors with improved sidewalks and drainage as well as more trees to foster active mobility and avoid flooding events.

Kibera is a large informal settlement in Nairobi, Kenya where annual flash flooding causes significant health, economic, and structural problems in the community. Current drainage infrastructure consists of informal channels that are not designed to handle the volume of water that falls during large rain events. The objective of this project is to work with the community to develop practical design improvements for the existing drainage channels that can be implemented in Kibera, to improve quality of life for residents.

2.2.3 GI practice for storm water management in South Africa

Gulati & Scholtz, 2020 studies how investment in green infrastructure in African cities, due to urbanization there is a devastating condition of alteration from the natural environment

deforestation, habitat fragmentation and loss of soil due to the growing condition of impervious surface and water runoff volume. Unlike the developed world currently African cities has an opportunity to learn the mistakes from them and correct the development of urban infrastructure in such a way that a sustainable development which requires the policy makers to act accordingly; and as part of infrastructure approaches it must involve screening out risky or unsuitable projects.

According to Gulati, 2020 he stated in his study that there has been much acceptance and a growing need for green infrastructure development not only for its value on conservation, reuse and water runoff management in African cities but also it can act as a bulwark against future climate change impacts. And the Policymakers and planners need to factor in the natural environment and the ecosystem services which green infrastructure delivers to urban and peri-urban areas.

Decision-makers will need to apply tools to identify infrastructure projects that pose a risk to the overall resilience of a city and that should be halted, postponed or redesigned to respond to these risks.

Green infrastructure is not simply an alternative way to describe conventional open and green spaces like parks. It includes a wide array of practices such as infiltration, evapotranspiration and rainwater harvesting; preserving and restoring natural landscape features such as forests, floodplains, wetlands, rivers and canals, including their banks; and site-specific features such as bio retention, trees, green roofs, road verges, permeable sidewalks and cisterns. It enhances the livability and prosperity of cities by reducing adverse environmental impacts and increasing resilience. In so doing, it protects existing built infrastructure from the impacts of climate change and advances human and environmental health. Green infrastructure can improve the quality of the urban environment; help to achieve social, economic, public health and environmental goals; help cities to attract investment, revive distressed neighborhoods and encourage redevelopment; and provide recreational opportunities for residents.

Benefits of green infrastructure projects in cities include the provision of ecosystem services, such as regulating urban temperature; augmenting water supply and improving water

quality; strengthening flood protection and supporting sustainable drainage; and improving air quality. There is no coherent narrative supporting the role this infrastructure has to play in promoting more sustainable urban development on the African continent.

In order to change this and prepare the ground for African cities to adopt an integrated and coherent approach towards green infrastructure, the report makes the following recommendations: fostering a better understanding of green infrastructure; developing robust evidence of green infrastructure; building the economic case for green infrastructure; developing frameworks for context-specific green infrastructure; developing frameworks to assess the value of green infrastructure projects; and building a holistic case for green infrastructure in cities (Gulati, 2020).

Green infrastructure provides context-specific solutions several examples of localized green infrastructure solutions are emerging from South Africa. In the case of Atlas Spruit, a river in Ekurhuleni, Gauteng, green infrastructure took the form of redesigning the river channel and the adjacent park to enhance the functioning of the upgraded storm water culvert. Property values have increased as a result of this intervention and home owners are once again able to reinstate home insurance policies that had been cancelled.

Another example can be found in Diep Sloot in Johannesburg, which is prone to flooding due to the absence of formalized storm water infrastructure. Green infrastructure in the form of soak-away gardens, developed by a community-based organization, has helped to address the challenges and risks from standing water and flooding by absorbing excess surface water. These settlements develop with little consideration for drainage, which has meant poor storm water management and drainage systems in such areas (Parkinson, 2003).

As defined by the Brundtland Report, a development is sustainable when it meets the needs and aspiration of the present generation without compromising the future generations' ability to meet theirs, in the broad social, economic and environmental aspects (WCED, 1987).

This applied to the storm water management realm implies that a storm water management intervention is only sustainable when it is socially just and acceptable, institutionally fair,

economically sound and seeks to conserve environmental and ecological resources rather than destroy them.

1. Planning for green infrastructure options for South African cities

“Some reference to local initiatives include the Johannesburg Eco city initiative where ecological principles were adopted in urban design and renewal processes (UNEP, 2007), the integration of environmental issues in the newest Integrated Development Plan for Durban (eThekweni Municipality, 2012) and the development proposal of Verkykerskop, a small-scale agricultural town in the Free State Province, which recently received an international award from Congress for New Urbanism for creating a plan that successfully integrates sustainable agricultural and environmental management into the larger fabric of the town (DEA, 2012)”.

2.3 Storm water management in Ethiopia

In Ethiopia regulations for green infrastructure in parks, living areas road sides and other places are available but implementations as per the guidelines are not practiced. In addition to this knowledge for using green infrastructure as a storm water management is not yet known or little implemented in some government institutions.

According to the study by (Girma et.al. 2019); social inclusiveness enhances effective management of green infrastructure and promotes community stewardship for green infrastructure components. And it is also important to main the values and practicing of green infrastructure to the best benefits for runoff water management. The results of the document analysis indicates that more than half of the planning documents, which relate to current green space planning practices, have considered the issue of social inclusiveness in different ways.

The Ethiopia national urban green infrastructure standard states that urban green infrastructure shall be managed and administered in the interests of the local community and shall address its needs. The long-term collective interests of the local community shall be prioritized over the interests of any specific interest group or sector of society.

The Growth and Transformation Plan (II) that was formulated in 2016 by the National Planning Commission of Federal Democratic Republic of Ethiopia has planned to increase the coverage of green infrastructure and recreational areas in urban centers of the country. Enhancing the awareness and participation of the community and stakeholders has been identified as an important measure of green space planning in the document.

The urban greenery and beautification strategy have an objective to involve the community and stakeholders in sustainable ways during the development of urban green spaces. Moreover, the strategy states that urban greenery planning can be successful only when there is active participation of the community and the stakeholders.

The participatory urban planning manual that was formulated in 2007 by the Ministry of Urban Development and Housing has the objective of involving disadvantaged groups into decision-making during urban plan preparation, which includes planning of green spaces. Moreover, the manual has an objective to pay attention to the priorities, needs and constraints of the city's population, especially to low income groups during urban plan preparation, which includes green space planning the decision makers and planners lack awareness and understanding that hinders them to integrate green infrastructure planning principles into current planning practices. Moreover, the local authorities and decision-makers view green infrastructure as luxury, allot less budget and resources, and prioritize the land for other basic services.

In Ethiopia, lack of professional skills and experience is one of the challenge; as the environmental advantage and multi-functionality benefits of green infrastructure planning demands skilled professionals equipped with different disciplines such as landscape ecology, urban and regional planning, and landscape architecture. In his research finding Girma et.al. 2019 revealed that few skilled professionals occupy the departments of greenery and majority of the officers are from unrelated disciplines. Therefore growth in the field of the greenery is not effective and developed as expected.

2.3.1 Water harvesting experiences in Ethiopia

One of the issues that are related and commonly used in Ethiopia is rain water harvesting technique broadly includes roof water harvesting, run-off harvesting, flood water harvesting and subsurface water harvesting (Girma et al., 2019).



Figure 2. 14: Photograph showing a water harvesting system in Tigray, a low-potential area

(Source: https://www.researchgate.net/figure/Photograph-showing-a-water-harvesting-system-in-Tigray-a-low-potential-area-Asnake_fig1_317600468 [accessed 24 May 2025])



Figure 2. 15: Typical methods of rainwater harvesting in Ethiopia (Southern Tigray, 2018)

The harvesting of rainwater involves the collection of water from surfaces on which rain falls, and subsequently storing this water for later use. Rainwater harvesting consists of 5 components: 1) rainfall, 2) catchment areas, also called watersheds, onto which the rainwater falls, 3) gutters, or conveying channels, to bring rainwater from a catchment area to storage reservoir, 4) storage reservoirs can be tanks, ponds, dams and in situ storage in sand and soil, 5) retrieval water is extracted from reservoirs either by gravity or by pumps and lifts.

If someone has developing a water pond depth 3m with a length and width 3m; The total volume of water that it can hold will be 27m³ which is equivalent to 270000 m² coverage with a depth of 1mm. “One millimeter of harvested rainwater is equivalent to one liter water per square meter. After collecting and storing the rainwater it can be used as a source in households for drinking, cooking, sanitation, etc.”

From different scholars we found that, ancient buildings in Axum and Gondar Castel there is a mechanism that to collect rain water in to a ground reservoir for latter uses. Nowadays many Ethiopians are using rain water for sanitation, cooking, gardening by collecting directly from the roof using jags or collecting chambers.

According to the study by (Fekadu et al., 2018), In south of the country, the Konso people have had a long- and well-established tradition of building level terraces to harvest rain water to produce sorghum successfully under extremely harsh environment; low, erratic and unreliable rainfall conditions.



Figure 2. 16: Percolation ponds to collect water from road, Zata area, Southern Tigray , 2018

2.4 Storm Water Management Problem in Addis Ababa

In his study of road and urban storm water drainage Dagnachewu, 2011 strongly argued that the impermeable nature of the surface which is expanded in town section resulted a major cause of flood in urban areas.

Adugna et al., 2019 was assessed the hydraulic capacity as well as the storm water management difficulties of existing drain systems in Addis Ababa. His studies' goal was to use thorough field surveys and stakeholder interviews to assess the hydraulic capacity of existing drains and storm water management concerns. Finally study found that, Addis Ababa's storm water management is strictly traditional, with the only objective of collecting and transporting storm water from sources to rivers. According to the two case studies he conducted, the system is insufficient to manage storm water inside the city's boundaries in terms of storm water drain coverage.

Despite the fact that flash flooding is a serious concern in Addis Ababa during the rainy season, an evaluation of the hydraulic capacity of the existing drains in the case studies revealed that more than 72 percent of the drains were excessive. This demonstrated that there was a lack of hydraulic and hydrologic characterization during the construction process.

Due to the increase in urbanization in Addis Ababa the change of green areas (pervious surface) to impervious surface in to roads, buildings and other infrastructure that makes the surface impermeable results in an increase in flood flow. This affects and damages the surrounding areas, creates erosion, carries debris and huge impact on the community. Due to the instant flooding which results from imperviousness of the surface the roads, buildings and other impermeable surfaces, the soils or embankments and infrastructures encountered damages. The following figures are taken from previous study by (Addis Ababa urban age task force, 2002).

2.5. Effects of high flood in Addis Ababa

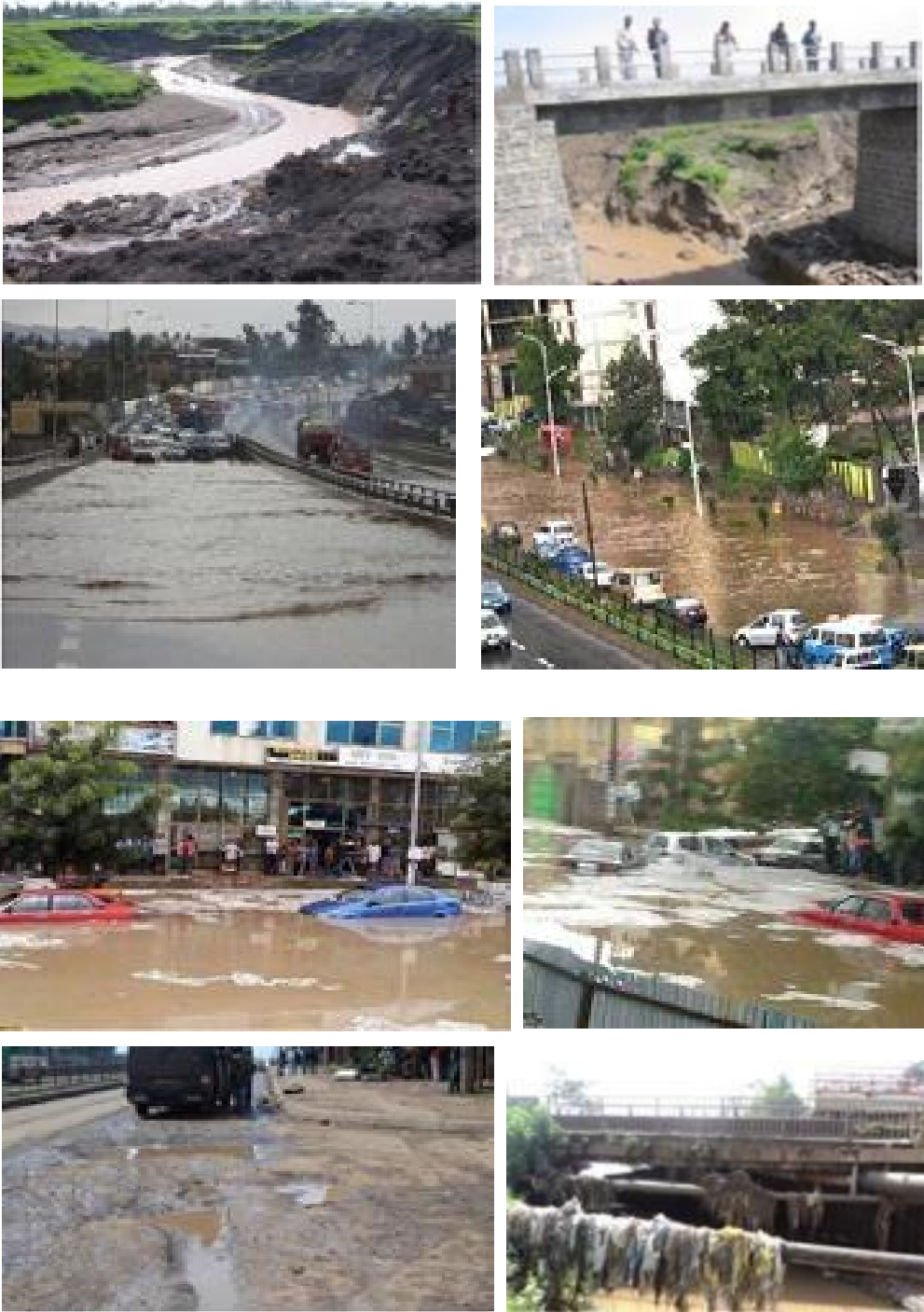


Figure 2. 17: Flood impacts in Addis Ababa

Source: (Technical Report 3.1 |Green and Blue Infrastructure in Addis Ababa), Addis Ababa urban age task force, 2002)

The above figure No.17, shows a Collapsed stream banks and land loss; damage to transport infrastructure (bridge); flooded streets in the middle of the city causing disruption of the transport system; damaged roads as a result of flooding leading to increased maintenance and replacement requirements; flood markers showing bridge over- topped by flood (Worku, 2017).

In addition to the above flood causes the debris, trashes and industrial wastes are directly washed by the flood and entered in to the streams and water reservoir which results in high cost of treatment of water, accumulation of debris, trashes and soils in to Dams thereby shorten the service life of the dams that was planned to serve for its intended design period.

As pollution from industry wastes, garbage and solid wastes thrown in to lands if not trapped or collected in a manner that to safely transported they become a pollution as they can easily washed by the floods and entered in to streams that endangers aquatic animals as well as pollute the water. Hence, the following figure shows some causes of pollution of water in Addis Ababa.



(a) Solid water directly dumped into surface water bodies (left) and combined Impacts of solid waste and informal settlements (right)



(b) Water pollution sources from garages and workshops (left) and domestic wastewater (right)

(Source: Addis Ababa urban age task force, 2002)



(c) Water pollution sources from industries

Figure 2. 18: Causes of water pollution

(Source: Addis Ababa urban age task force, 2002)

McFarland et al., 2019 they studied and found that “Lack of stricter water quality regulations and the associated enforcement of those regulations allow for untreated wastewater effluents to enter the environment and effect public health and quality of life throughout the city. This includes runoff from industries such as dyeing and tanneries with synthetic organics, heavy metals, and carcinogens, as well as urban agriculture with

increased nutrient loading in the runoff. Urban farming is also practiced, which can introduce nutrients as well as pathogens to the storm water runoff.” One of the most vulnerable issues in Addis Ababa is implementing the regulation set by the Government.

And most importantly the cost of GI in Addis Ababa is currently hindering more rapid implementation. This is highly due to the city does not regulate water quality strictly, there is little motivation to use GI for water quality improvement or its many other public benefits. However, water management officials in Addis Ababa acknowledge there would be associated cost savings such as reducing damage to public infrastructure (roads) due to storm water. University scholars and researchers are urging the city to consider GI as a low-cost addition to the urban water management system that can slow flows and provide a contaminant buffer before entering the receiving rivers. Some research-associated GI systems are currently being implemented and monitored, with results intended to strengthen the argument for incorporating further GI throughout the city. Some scholars study and recommendation for storm water management was given by the rain garden can treat runoff before it enters the river, thus reducing overall pollutant loads.

Review by Alok Tiwari,2016 states that “Ethiopia cities at large, are troubled with storm water leading into floods especially during the rainy season due to inadequate installation of desired infrastructure, problem is more critical in cities of highland regions like Addis Ababa, Scholars attempted to examine the role of integration among road and drainage infrastructure in offering solution for urban floods, while the other associated themes were; impact of urban flood on urban infrastructure, PPP in the integration of road and drainage, and impact of delayed provision of such infrastructures”

Gebru, 2023 in his study for areas that usually affected by floods, stated that the institutional plots and urban agriculture are severely affected by recurrent over flooding of the little Akaki River. And proposed an introduction of sediment basin for controlling the surface runoff generated from the compound and in the surrounding residential areas; and retention pond in the available space within Seminaries compounds suggested as a temporary solution. Maintaining the landscape and constructing suitable landscape conditions to retain water with respect to irrigation scheme, the water will be utilized for gardening and urban agriculture.



Figure 2. 19: Storm water run-off in Addis Ababa 2020

Source: (Green infrastructure benefits to value and enhance the built environment: the case of Addis Ababa, Samuel et al., 2020)

According to Addis Ababa city government plan commission Samuel et al., 2020, “the city is losing its green coverage at a devastating speed. In 1986 from the total city area, 32,083 ha was covered by green; in 2003, it becomes 21,538 ha, and in 2016 it reduced to 16,265 ha, almost lost half of the green parts that were in 1986. According to the city government plan commission projection, if this continues like that by the year 2040, the green coverage becomes 2,405 ha (Fig. 2.20).”

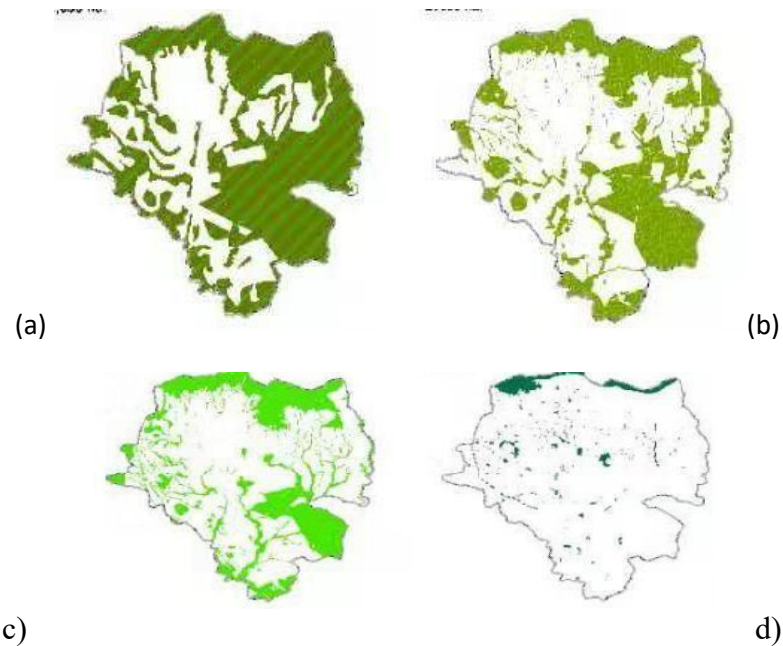


Figure 2. 20: Green coverage map

(a) In 1986; (b) Change from 1986 to 2003; (c) Change from 2003 to 2016; and (d) Expected green cover in 2032. (Source: Addis Ababa City Plan Commission 2019)

Currently there are so many development which includes the strategies of green infrastructure integrated plan has practiced in Addis Ababa, for example the design in Legare in Addis Ababa illustrated a comprehensive storm water management strategy which will be embedded in the street network and public open spaces that infiltrates, filters, and stores storm water for irrigation. Thereby robust streetscape plantings and storm water infrastructure serve critical roles during the rainy season by managing runoff and improving local water quality.

Control and management of surface run-off near the source is now widely encouraged, and it is seen in many nations as an acceptable set of strategies that facilitate natural processes while limiting hydrologic consequences. Such solutions focus on local water runoff treatment, retention, re-use, infiltration, and conveyance in metropolitan areas, and hence more in line with a sustainable development program. Green roofs have been used to boost interception, storm water storage, and evaporation in metropolitan regions where green infrastructure is limited.

2.5 Research Gap

Many studies have been conducted on water conservation and harvesting; however, a significant research gap exists regarding the utilization of green infrastructure as a dual approach for flood control and storm water runoff management solutions. This research will elucidate how valuable green infrastructure contributes to mitigating storm water runoff volume, particularly as initial flooding can inflict environmental damage and exacerbate flood occurrences. Beyond its aesthetic appeal, green infrastructure emerges as a paramount environmental solution, effectively reducing storm water runoff and thereby safeguarding the ecosystem. Moreover, the implementation of green infrastructure fosters enhanced biodiversity, creating habitats that support various species and contribute to ecological resilience. Techniques such as permeable pavements, green roofs, and rain gardens not only facilitate the infiltration of rainwater but also promote healthier urban environments by filtering pollutants and improving air quality.

The integration of these strategies into urban planning can significantly mitigate the adverse effects of urbanization, such as increased surface runoff and the urban heat island effect. By

embracing sustainable practices, municipalities can bolster their capacity to manage excess water during heavy rainfall, thus reducing the likelihood of devastating runoff Volume and their consequential impacts.

Furthermore, the economic benefits of green infrastructure cannot be overlooked. Investing in these innovative solutions can yield long-term savings by reducing the costs associated with traditional storm water management systems, decreasing the need for costly repairs of gray infrastructure, and enhancing property values through improved neighborhood aesthetics and environmental quality.

In conclusion, the strategic incorporation of green infrastructure represents a transformative opportunity for communities seeking to address storm water runoff challenges. By harnessing the potential of nature-based solutions, we can create resilient urban landscapes that prioritize sustainability, environmental health, and the well-being of inhabitants, and this research study can show us how valuable green infrastructure development towards the reduction and control of storm water runoff.

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Description of the Study Area

The research was conducted at the main campus of Addis Ababa University Sidist Kilo. "The study area, Addis Ababa university main campus is situated at the center of Addis Ababa City. The geographical location of the study area is 9°02'24.0"N (9.0400°N), and 38°45'00.0"E (38.7500°E) coordinates. And has a total area of 26.7 ha and the spatial distribution of various settlement, such as buildings, parking lots, roads, green areas and other developments. The geographical location of the study area in relation to the city of Addis Ababa is illustrated in Figure 3.1.

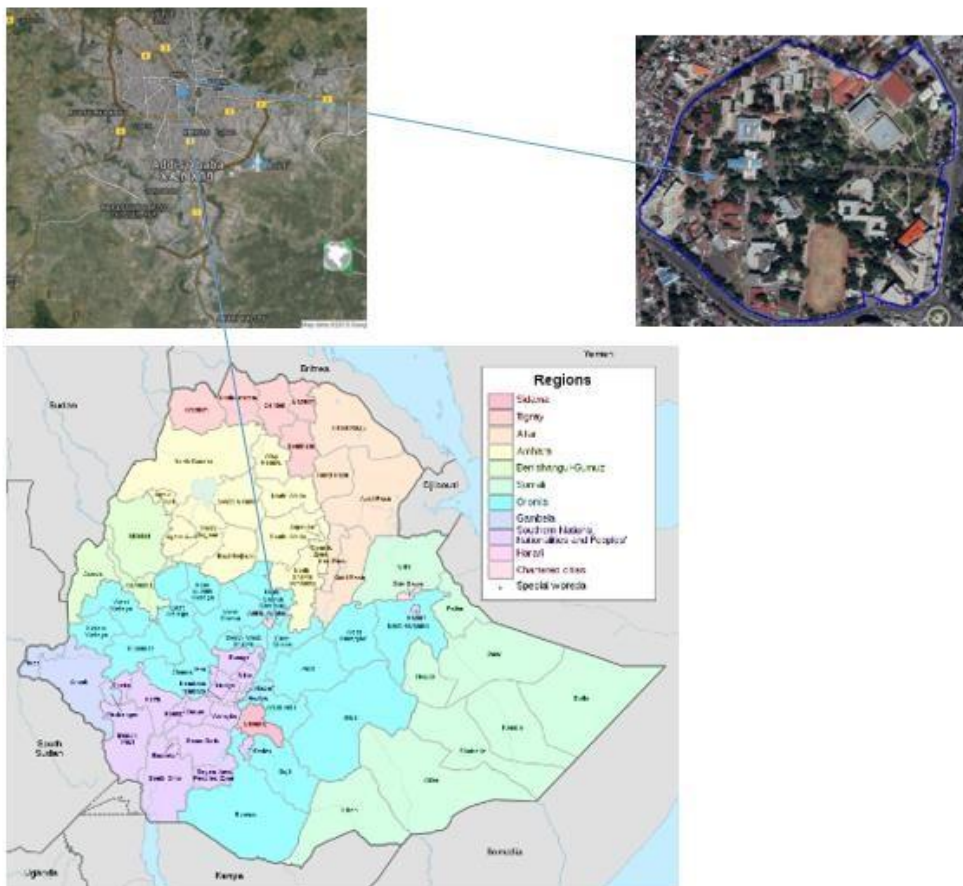


Figure 3. 1: Location map of the study area

3.1.1 Land Potential and Current Land use of the Study Area

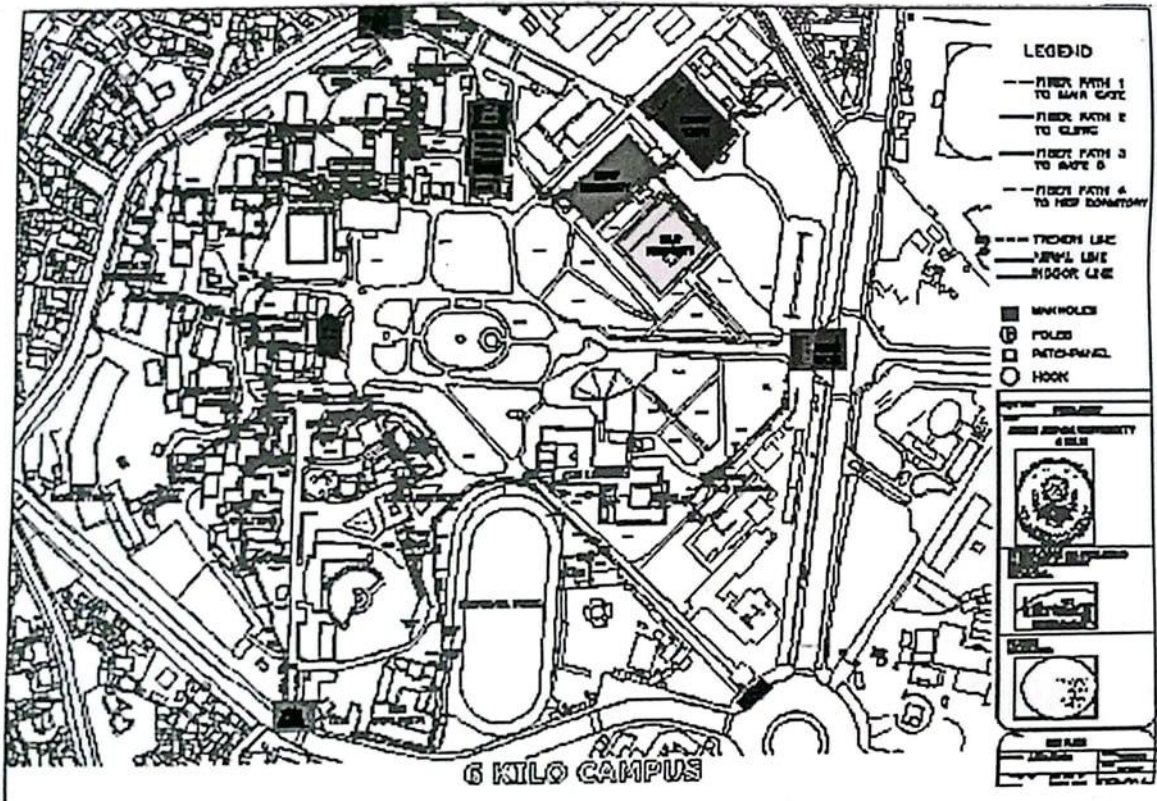


Figure 3. 2: Site layout of main campus

(Source: University construction site consultant, 2021)

3.2 Research Study Area Description

The research encompasses an expanse of 26.7 hectares characterized by diverse land use attributes, including various Buildings, vegetation, grasses, asphalt roads, concrete surfaces, and cobblestones. In accordance with the site's drainage conditions, two locations have been identified as outlet points for storm water runoff from the compound, designated as DP1 and DP2, as illustrated in Figure 3.3 below.

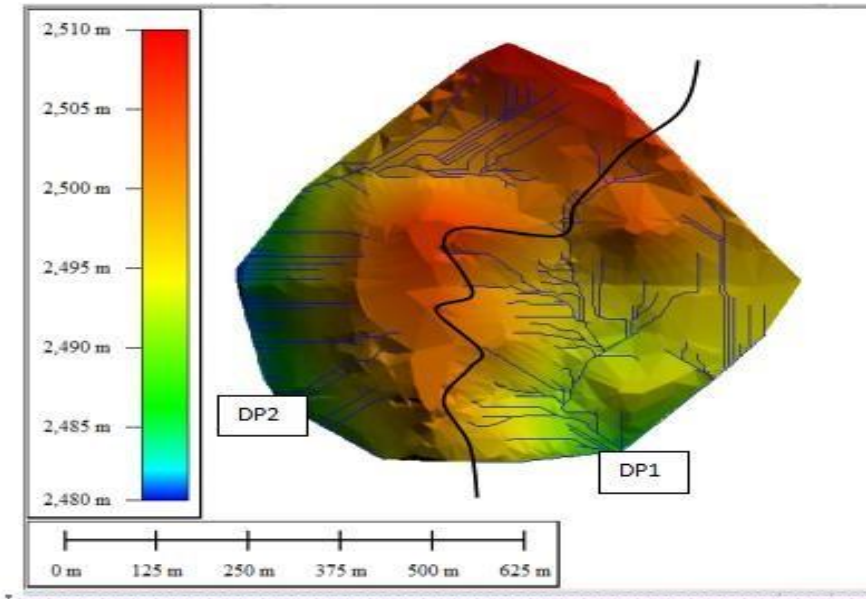


Figure 3. 3: Watershed delineation

The above Figure 3.3. Which is the watershed delineation for the study area illustrates the intricate pathways that stormwater runoff follows as it flows across the landscape. This interconnected network of water movement is intricately shaped by the area's contours, which define the various watershed lines. Each contour line serves as a marker, guiding the flow of water towards its natural destinations, while highlighting the unique features of the area.

As indicated in the attached picture, there are two exit points designated as DP1 and DP2. These points are the only existing drainage outlets located outside the study area. The details of these locations are as follows:

- Pipe culvert (DP1): size 1 meter internal diameter, coordinates: DP1 - 473718.00 E, 999752.00 N
- Pipe culvert (DP2): size 1 meter internal diameter, coordinates: 473198.69 E, 1000009.64 N

The main drainage runoff is managed at these locations based on the delineated watershed areas, which will be discussed in detail in the analysis section. Based on my site

observations and reports from others in the study area, it has been noted that flooding occurs during heavy rain events due to insufficient drainage capacity at the outlet.

3.3 Research Approach

The analysis of storm water runoff employed both quantitative and qualitative methodologies to evaluate the efficacy of green infrastructure development within the designated study area. To substantiate its effectiveness, we harnessed primary data sources, encompassing the identification of green infrastructure initiatives within the study locales, alongside secondary data procured from meteorological agencies. The site conditions and spatial configurations served as the principal inputs for our analytical methods. To facilitate a comparative analysis between the total capacity of the drainage system and the volume of precipitation, meteorological data from the pertinent agency was integrated.

An evaluation was conducted utilizing peak rainfall values extracted from a thirteen year meteorological data set spanning from July to September, covering the period from 2005 to 2018.

3.3.1 Data Collection Method

Global Positioning System (GPS) technology was employed to ascertain the precise geographical coordinates of the drainage outlet. Comprehensive site observations and photographic documentation were meticulously conducted as integral components of the data gathering and collection methodology. Notably, an exhaustive visual assessment of the area was undertaken to establish an initial evaluation of the prevailing site conditions. Advanced tools such as Geographic Information Systems (GIS), an Arc Map, Excel, global mapping software, and hydrologic modeling formulas/applications were utilized for computational analysis.

3.4 Assessment Procedures

The analytical methodology employed for the management of storm water runoff is centered on predictive modeling utilizing a data mining approach, leveraging meteorological rainfall data sourced from the meteorological agency in Addis Ababa. To assess the efficacy of the best management practices for storm water within the designated

study area, a thorough evaluation of green spaces, existing green infrastructure developments, and available spatial areas has been conducted to ascertain how these best management practices contribute to the reduction of flow volume through peak flow attenuation. The analytical strategy adopted for storm water runoff management within the study areas to identify its effectiveness had been verified. Hence the following procedures have been implemented.

To evaluate the development of green infrastructure within the study area for effective storm water runoff management, the following procedures have been implemented:

- Ascertain the arrangement and positioning of various spaces to facilitate the identification of land utilization and coverage through meticulous site observation and photographic documentation.
- Areas characterized by buildings, vegetation, grasslands, roadways, and parking facilities analyzed utilizing GIS software.
- Identification of all exit points of the stormwater runoff from the study areas.
- The total runoff volume will be estimated both with and without green infrastructure by comparing the permeable and impermeable surfaces of the study areas, thereby elucidating the advantages of green infrastructure in mitigating stormwater runoff.
- The management of watershed dynamics within the designated study areas will be illustrated utilizing advanced global mapping software. The analysis will encompass the delineation of contours throughout the study site.
- The total area covered by each spatial category will be calculated, encompassing the land occupied by buildings, asphalt roads, vegetation, grasses and open spaces.
- Data, rainfall metrics, annual precipitation figures, and maximum rainfall volumes necessary for the computation of runoff volumes.
- The role of green infrastructure in reducing storm water runoff will be explored, emphasizing how the expansion of green spaces can capture and retain flow, thus delaying the onset of stormwater movement as a natural trapping mechanism and its benefit for infiltration and ground water level improvement.

Sensitivity Analysis

Following the assessment procedures, a comprehensive data analysis will be conducted to ascertain the efficacy of the implemented green infrastructure. This entails a detailed examination of the relationship between the extent of green cover and corresponding reductions in storm water runoff volumes.

Comparative Study

A comprehensive comparative analysis will be undertaken to set the transformations observed in the study area through aerial photographs from three distinct years: 2003, 2008, and 2013. This investigation aims to clarify the developmental transform and modifications of attributes within the study areas, thereby emphasize how various developmental changes have influenced attribute evolution, utilizing GIS software to meticulously observe the changes over time. Ultimately, recommendations will be provided based on the findings obtained.

3.5. Tools and Technique used

Geographic Information Systems were used for mapping and analyses of green infrastructure. GIS played a crucial role in the detailed mapping and intricate overlay analyses of green infrastructure. By leveraging advanced spatial analysis techniques, GIS allowed for the visualization and examination of various environmental components, such as green areas, trees, grasses, Buildings, street paved areas, bare lands and urban Vegetation's. In addition to this GIS provided insights into the potential growth and the changes that happened through the years. To detect the changes that has been made.

3.6. Assessment Criteria

The following criteria will be utilized to assess the effectiveness of green infrastructure within the designated study areas:

- 1. Check for Runoff:** Reduction due to the existing green areas: This criterion focuses on evaluating how effectively green infrastructure minimizes the volume of stormwater runoff

generated during rainfall events. By incorporating elements such as green areas, to capture and absorb rainwater.

2. Computation of Peak Flow: This aspect measures the ability of green infrastructure to mitigate the peak flow of stormwater. By slowing down and storing water during heavy precipitation, features such as rain gardens and constructed wetlands help to reduce the risk of localized flooding and downstream erosion.

3. Flood Mitigation: This criterion assesses how green infrastructure contributes to overall flood risk reduction within the study areas. By improving water retention and enhancing natural drainage patterns.

3.7. Computation of Storm water Runoff using Rational Formula

John Poullain (2012), The Rational Formula is the most commonly used method of determining peak discharges from small drainage areas. This method is traditionally used to size storm sewers, channels and other storm water structures which handle runoff from drainage areas. The Rational method formula is expressed as:

$$Q = C * I * A \text{ ----- (Eq. 1)}$$

Where:

Q = Peak rate of runoff in cubic meter per second (m³/s)

C = Runoff coefficient, a dimensionless unit

I = Average intensity of rainfall in mm per hour (mm/hr.) A = the watershed area (m²).

The clean water Team guidance compendium for watershed monitoring and assessment state water resources control board 5.1.3 FS-(RC) 2011 give us the value of the runoff coefficient C- computed based on the soil type, gradient, permeability and land use. The values are taken from the table below. The larger values correspond to higher runoff and lower infiltration.

Table 3. 1: Runoff Coefficient C

Land Use	C	Land Use	C
Business: Downtown areas Neighborhood areas	0.70 - 0.95 0.50 - 0.70	Lawns:	
		Sandy soil, flat, 2%	0.05 - 0.10
		Sandy soil, avg., 2-7%	0.10 - 0.15
		Sandy soil, steep, 7%	0.15 - 0.20
		Heavy soil, flat, 2%	0.13 - 0.17
		Heavy soil, avg., 2-7%	0.18 - 0.22
		Heavy soil, steep, 7%	0.25 - 0.35
Residential: Single-family areas Multi units, detached Munti units, attached Suburban	0.30 - 0.50 0.40 - 0.60 0.60 - 0.75 0.25 - 0.40	Agricultural land:	
		<i>Bare packed soil</i>	
		*Smooth	0.30 - 0.60
		*Rough	0.20 - 0.50
		<i>Cultivated rows</i>	
		*Heavy soil, no crop	0.30 - 0.60
		*Heavy soil, with crop	0.20 - 0.50
		*Sandy soil, no crop	0.20 - 0.40
		*Sandy soil, with crop	0.10 - 0.25
		<i>Pasture</i>	
		*Heavy soil	0.15 - 0.45
		*Sandy soil	0.05 - 0.25
Woodlands	0.05 - 0.25		

Industrial: Light areas Heavy areas	0.50 - 0.80 0.60 - 0.90	Streets:	
		Asphaltic	0.70 - 0.95
		Concrete	0.80 - 0.95
		Brick	0.70 - 0.85
Parks, cemeteries	0.10 - 0.25	Unimproved areas	0.10 - 0.30
Playgrounds	0.20 - 0.35	Drives and walks	0.75 - 0.85
Railroad yard areas	0.20 - 0.40	Roofs	0.75 - 0.95

(Source: <http://water.me.vccs.edu/courses/CIV246/table2b.htm> accessed 11/19/09)

The storm water runoff depends on the types of areas that are increase impervious areas will increase the volume of runoff whereas an increasing of green infrastructure will reduce the volume of the storm water runoff.

There are variables that have been used for the analysis of the runoff volume and their effect on the reduction of the runoff depends on the type and nature of the green infrastructure used at the particular areas.

3.7.1 Formula to compute the runoff volume using rational method:

To compute the runoff volume we used the above equations of the rational method Equation Number 1.

Storm water Runoff volume (Q) is a function of, Area of impervious layer (A imp) (buildings, roads, impervious surfaces) and the total green areas (A gr).

$$Q=C1 (A_{imp}) I+C2A_{gr}I..... (2)$$

As the runoff volume depends on the type of green infrastructure the runoff volume is a function of the type and extent of area of green infrastructure, the following relation can be expressed as:

$$Q_{gr}=f(X1, X2, X3.....Xn)..... (3)$$

Where X1 ..., Xn is the type of green infrastructure introduced in the study areas, in addition the volume of reduction depends on the type of the green infrastructure. Hence, the storm water runoff volume can be reduced with the provision of different kinds of green infrastructure. For the computation of the runoff the type and current practice of green infrastructure with in the study area had been studied. The runoff coefficient (C) has been taken from previous study.

Note: Consideration has been made during analysis of the runoff volume as outlet points are only two locations at manhole locations point No.1 and drainage outlet at the back side of the university as the second drainage outlet locations, it indicated in the study area map, DP1 and DP2 respectively.

The size of the pipes is considered one constraint to the flow of water as they are the only drainage points found to be to accommodate the surface water accumulated and discharged from the study area.

Land use/cover classification of the study area was obtained by using Auto Cad maps of the area that dignifies the type and area of special developments. The impervious and pervious surfaces of the study area were further identified by using Google earth pro to determine the land cover types. Houses/buildings, paths, parking lots, campuses, sidewalks, roads, and bare land were classified as impervious surfaces, while pervious surfaces were referred to those areas covered by tree canopies and grasses.

3.7.2. Data Types

Descriptive data types were used to assess the total study area and the type and location of green infrastructure has been determined based on-site observation and drawings and maps. The study used quantitative data types which is gathered from the meteorological data agency, hence, based on the observational data which is collected from the site that photographs of the types of green infrastructure assessed; and the results are derived from available formula in order to get the best results.

3.8. Sources of Data

Primary data source that was used for the assessment of the research was direct observations of the study area. In addition secondary data was used forms, plans, maps, books and other required inputs to assess the extent of the green infrastructure development with in the study areas.

3.9. Data Collection Techniques

Data is predominantly gathered through the visual representation of direct photographs of the study areas, supplemented by secondary data derived from the aerial topography of the study area. This involved employing ArcGIS to identify land use developments for the years 2012, 2017, and 2022, which constitute the only available data within the country implemented to gather qualitative data regarding land use changes.

Furthermore, a comprehensive analytical approach was utilized for storm water runoff management, utilizing data mining techniques alongside secondary sources, specifically meteorological rainfall data obtained from the meteorological agency in Addis Ababa.

Books, brochures, and literary sources constituted the repositories from which information has been meticulously compiled regarding optimal storm water runoff management within the designated study areas.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Mapping and computing the area of the existing GI

4.1.1 Land Use Land Cover Classification of AAU Main Campus at Sidist Kilo

The land use land cover classification of Addis Ababa University's main campus at sidist kilo for the years 2012, 2017, and 2022 reveals significant changes in land cover patterns over the past decade. The analysis, based on Ariel imagery and supervised classification techniques, shows a clear trend of increasing built-up and paved areas at the expense of vegetated land. This indicates continued infrastructural development and urbanization within the campus.

The maps for three different years 2012, 2017, and 2022 have been identified for classification of the land use land cover, and classification of the same have been done by using ArcMap.

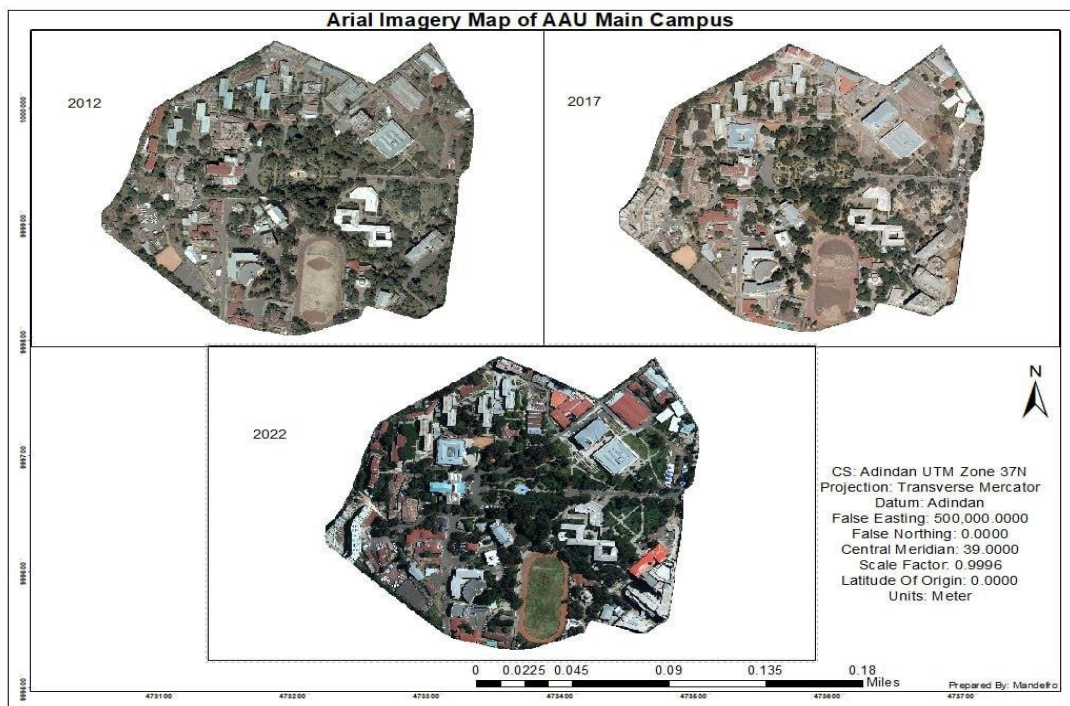


Figure 4. 1: Ariel imagery of study area 2012, 2017 and 2022 G.C.

4.1.2 Classification using Arial map of 2012, LULC

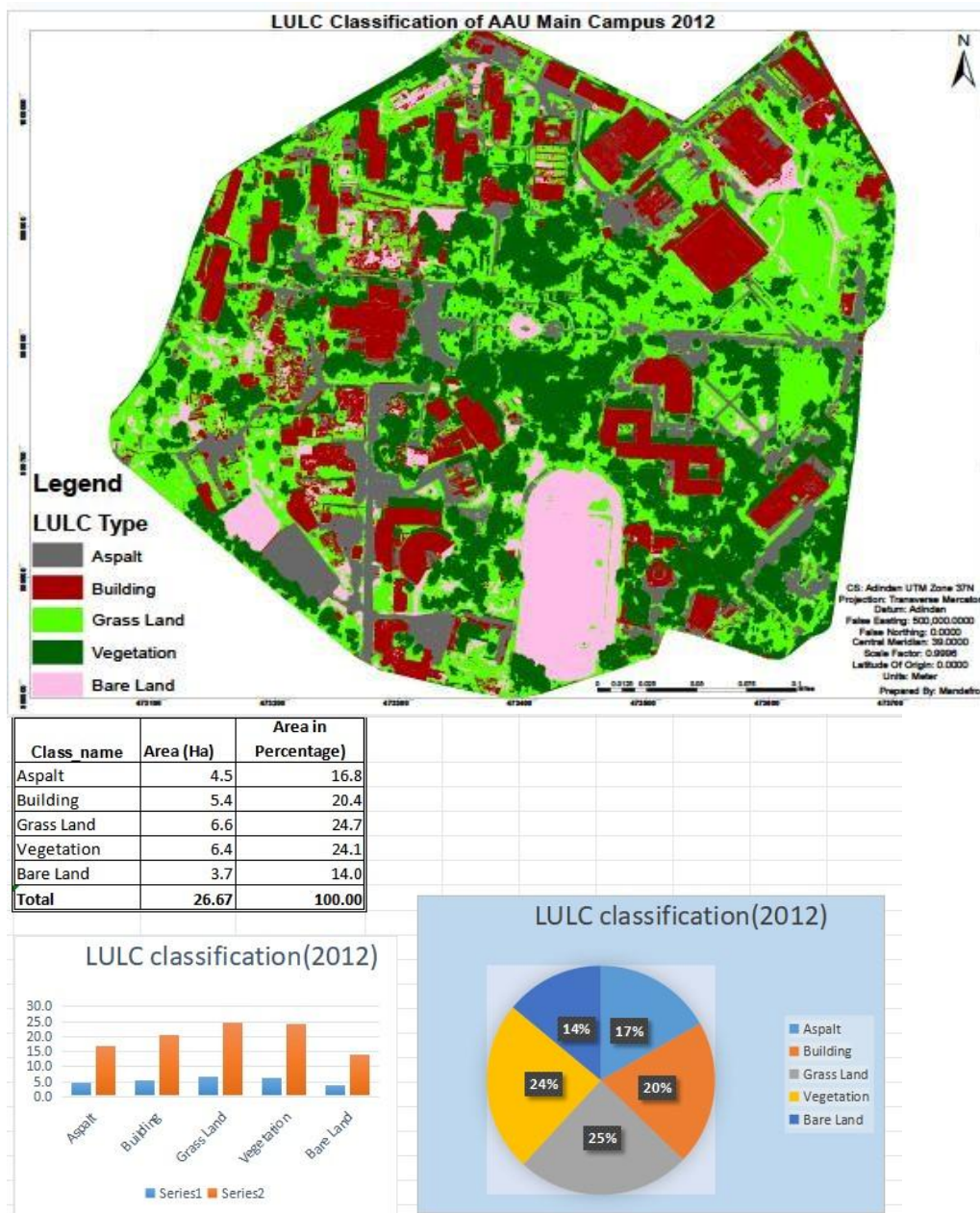


Figure 4. 2: Land use, land cover classification of sidist kilo, 2012

The 2012 land use classification of the study area clearly shows that approximately 45% of the landscape is covered by lush green spaces. In contrast, only 16.8% is occupied by asphalt surfaces, while buildings make up 20.4% of the area. This notable distribution highlights a strong commitment to maintaining vibrant natural environments in the face of urban development.

4.1.3 Classification using Arial map in 2017, LULC

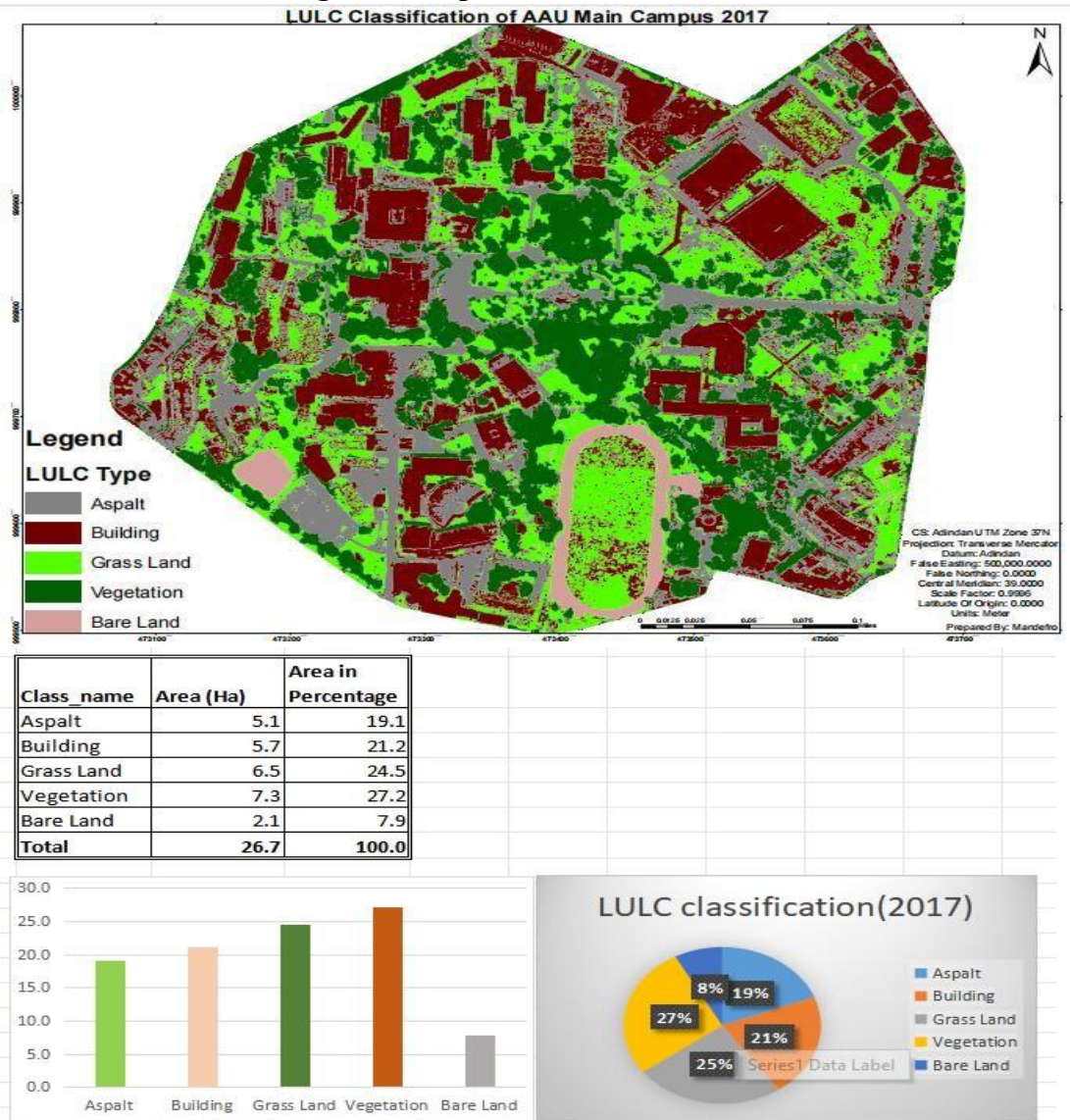


Figure 4. 3: Land use land covers classification of sidist kilo, 2017

The 2017 land use classification of the study area clearly shows that approximately 52.7% of the landscape is covered by lush green spaces. In contrast, only 19 % is occupied by asphalt surfaces, while buildings make up 21 % of the area. This notable distribution highlights a strong commitment to maintaining vibrant natural environments in the face of urban development.

4.1.4. LULC Classification using Arial map of 2022, LULC

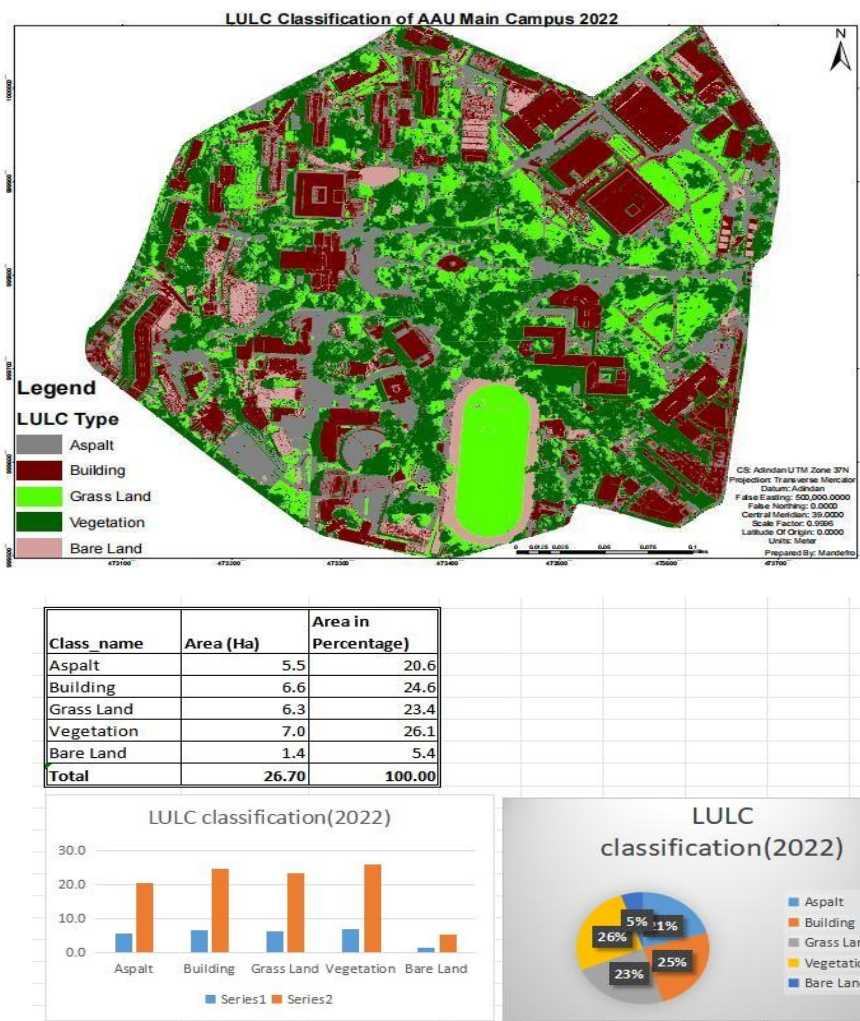


Figure 4. 4: Land use land covers classification of sidist kilo, 2022

The land use land classification of the study area in 2022 shows that 49.5% of the areas is covered by green while 21 % and 25 % of the areas are covered by Asphalt and building respectively which is impermeable layer which allows to increase the runoff volume.

The land use land classification of the study area in 2022 shows that 49% of the areas is covered by green while 21 % and 25 % of the areas are covered by Asphalt and building respectively which is impermeable layer which allows to increase the runoff volume.

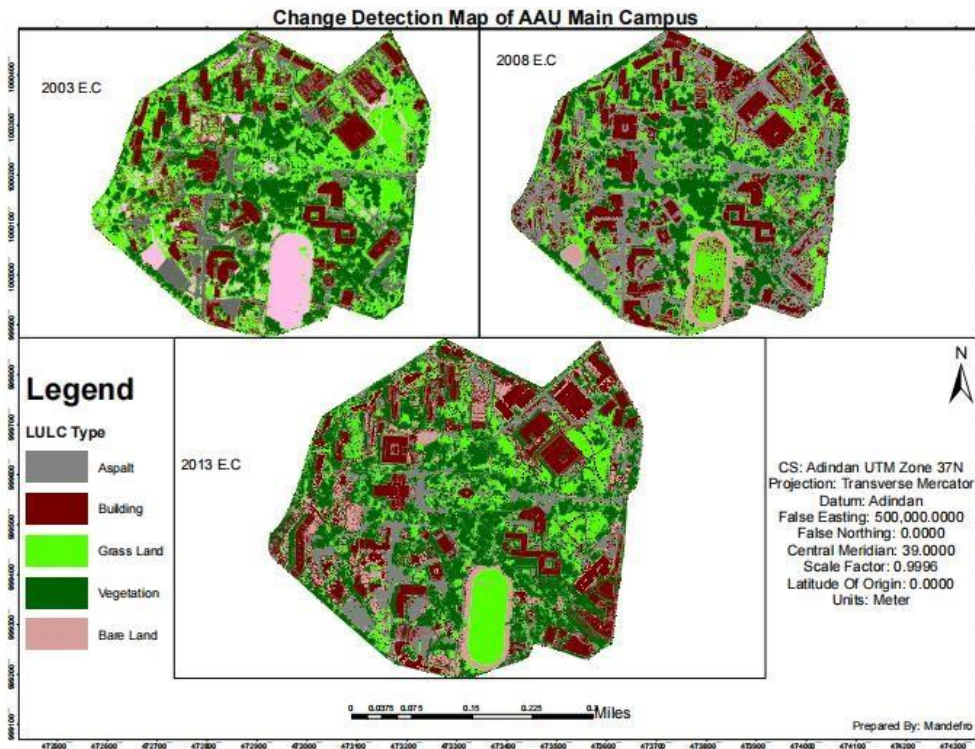


Figure 4. 5: Land use land covers classification of sidist kilo, 2022

Table 4. 1: The existing land use category and their corresponding areas

LULC types	2012		2017		2022	
	Area (ha)	Area (%)	Area(ha)	Area (%)	Area(ha)	Area (%)
Asphalt	4.5	16.8	5.1	19.1	5.5	20.6
Building	5.4	20.4	5.7	21.2	6.6	24.6
Grass Land	6.6	24.7	6.5	24.5	6.3	23.4
Vegetation	6.4	24.1	7.3	27.2	7.0	26.1
Bare Land	3.7	14.0	2.1	7.9	1.4	5.4
Total	26.67	100.0	26.7	100.0	26.70	100.0

Each type of spatial arrangement is meticulously analyzed, and the area is precisely calculated using ArcGIS software to ensure accurate identification of the attributes, as detailed in the table above.

As a result, the total area of the study is determined to be 26,670 m² and the corresponding areas of LULC is summarized as follows by categorizing the types of attributes in to three for the year 2022 for our analysis.

Table 4. 2: The Existing land use category and their corresponding areas

No.	Description	Unit	Coverage Areas(m2)	% from Total
1	Areas Covered by Buildings	M2	66000	24.72%
2	Areas Covered Green	M2	133000	49.81%
3	Areas Covered by Concrete, Paved areas, cobbles tones (parking and roads)	M2	55000	20.59%
4	Bare land	M2	14000	5.24%
Total Areas			267000	100%

The above assessment of the actual condition of the site and coverage of the study area shows 49.81% is covered by green, maximum benefit of GI can be gained by using efficient design and allocation of the GI structures so as to minimize the runoff water.

4.1.5 GI identified with in the study areas presented as follows

1. Assessment of green infrastructure types with in the study area



a) Rain Garden Kennedy library



b) Curbing



c) Road Side ditch garden

Source: Photographs of greenery at study areas taken on 2024



d) Trees with rounded built-ups





e) Cobbles and boulders for infiltration of water that includes rain garden



f) Green fields, grasses

Figure 4. 6: Photographs of greenery at study areas (2024)

Type of Green Infrastructure in the study areas	Picture	Description of	Benefits
Rain Garden		<p>A depressed garden that uses mulch, soil, and deep-rooted native plants to capture, absorb, and infiltrate storm water</p>	<p>Manages storm water and filters pollutant Little maintenance</p>
Tree Planting		<ul style="list-style-type: none"> - Increases infiltration and evapotranspiration of Storm water - Filters pollutants - Requires little maintenance - Provides wildlife habitat 	<ul style="list-style-type: none"> - Increases infiltration and evapotranspiration of storm-water - Filters pollutants - Requires little maintenance - Provides wildlife habitat - Large canopy of native trees




Retention Ponds		<p>A pool of water that collects and releases rainfall and runoff to prevent flooding and erosion.</p>	<p>store excess water from storms and release it slowly to reduce the risk of flooding treat runoff by removing pollutants through sedimentation and biological uptake</p>
Pervious Pavers		<p>- Impervious building materials, such as stone, concrete or brick, laid with space in between to allow for pervious areas (gravel, sand or Vegetation) in driveways, parking areas, or walkways.</p>	<p>-Increases infiltration and groundwater recharge - Reduces volume and rate of runoff</p>
Rain Barrel		<p>A barrel that captures rainwater from a roof and stores it for later use</p>	<p>- Conserves water - Captures and re uses storm water</p>

Figure 4. 7: Types of rain garden identified from the study areas, 2024

The above assessment of the actual condition of the site and coverage of the study area shows 49.81% is covered by green, maximum benefit of GI can be gained by using efficient design and allocation of the GI structures so as to minimize the runoff water. As had been pointed out from different scholars an increase in the area of the green infrastructure can reduce the storm water runoff.

Table No.4.5 below shows us an increase in area of impervious surface affects the volume of the runoff water as computed using the rainfall data and by changing the green space keeping the same data for rainfall.

In our case we have two constraint locations of outlet flow lines, each has their own capacity which we compute the maximum capacity for runoff volume, with their respective watershed areas. This helps us to identify the green values to what extent can hold and reduce the run off volume. There are two basic issues that have to be considered while dealing with green infrastructure:

1. Acting as a retention for accumulation of water there by helps to raise the ground water level, high contribution for evapotranspiration of water
2. Helps to slow the flow and decrease the travel time of the surface water thereby reduce the volume of flood from reaching in to exist.

As seen in figure. 4.9 Water shade layout of the campus of the study area with the total area of 267000 m², the flow of water from the direction indicated towards the manhole no. 5 at gate 5 of the university delineated as DP1. Whereas the other portion of the areas the runoff water accommodated at the back side of the university with the culvert location point of DP2.

4.1.6. Watershed Analysis to define the water path lines

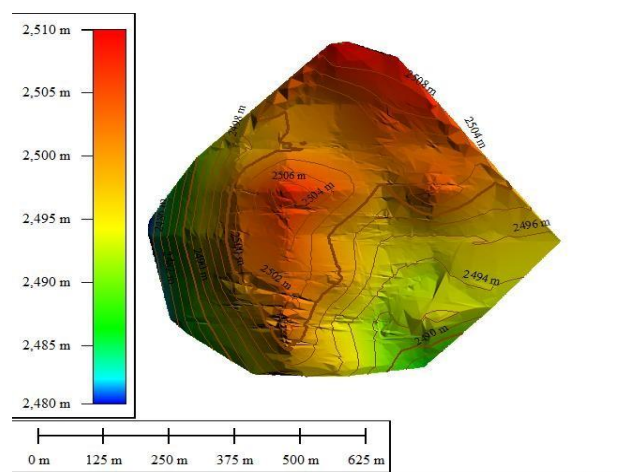


Figure 4. 8: Ground elevation, contours of the study area

4.2 Quantifying the volume of storm water runoff in the study area

4.2.1 Rainfall data at Entoto rain gauge stations

For the computation of runoff volume, the rain fall data from 2005 to 2018, 13 years rainfall data with in the period of June to September of the years from Ethiopian Metrological Agency was used (refer Table 4.7). And the rainfall data for each month has annexed.

Table 4. 3: Maximum Precipitation value

Year	Maximum Precipitation				Peak value
	Month				
	June	July	August	September	
2005	23.4	30.5	46.50	31.30	46.5
2006	13.7	48.9	45.60	18.40	48.9
2007	26.7	33.9	26.90	25.70	33.9
2008	19.8	52.0	31.40	31.50	52.00
2009	25.4	23.2	37.90	36.20	37.90
2010	39.2	33.8	37.40	30.40	39.20
2011	22.3	31.2	46.40	15.10	46.40
2012	28.5	28.7	34.20	28.70	34.20
2013	31.4	30.3	31.90	25.80	31.90
2014	26.7	40.6	31.60	31.60	40.60
2015	27.2	26.5	29.20	24.20	29.20
2016	62.1	28.3	28.00	27.40	62.10
2018	34.2	29.2	30.50	16.10	34.20

4.2.2 Storm water runoff estimation

Table 4.4 : Average Rainfall intensity (13) years data

Annual 24 hours heaviest rainfall series (Entoto station)				
YEAR	Annual Daily heaviest(mm)	Rank	X(mm)	X ²
2005	46.5	62.1	46.5	2162.25
2006	48.9	52.0	48.9	2391.21
2007	33.9	48.9	33.9	1149.21
2008	52.0	46.5	52.0	2704.00
2009	37.9	46.4	37.9	1436.41
2010	39.2	40.6	39.2	1536.64
2011	46.4	39.2	46.4	2152.96
2012	34.2	37.9	34.2	1169.64
2013	31.9	34.2	31.9	1017.61
2014	40.6	33.9	40.6	1648.36
2015	29.2	31.9	29.2	852.64
2016	62.1	30.5	62.1	3856.41
2018	30.5	29.2	30.5	930.25
ΣX^2			533.30	23007.59
Number of records		13	$\sigma_x = \sqrt{\frac{\Sigma x^2 - \frac{1}{n} (\Sigma x)^2}{n - 1}}$ $X_{avg} = \frac{\Sigma x}{n}$	
ΣX^2		23007.59		
Mean daily heaviest rainfall, X_{avg}		41.02308		
	$(\Sigma X)^2$		284408.9	
Standard deviation			9.704	

Table 4. 5: Maximum rainfall Value

Applying Gumbels Extreme Value distribution, design 24 hours rainfall

$$X_T = X_{avg} + K(T, n) * \sigma X$$

Return period(T_r)	Number of years of records, n	$X_{avg}(mm)$	$K(T,n)$	S_x	$X_T(mm)$
5	13	41.02	0.9186	9.704	49.934
25	13	41.02	2.5169	9.704	65.444
50	13	41.02	3.1787	9.704	71.866
100	13	41.02	3.8357	9.704	78.241

Table 4. 6: Depth duration frequency/Intensity duration frequency curve development

Duration (mts)	Duration (hr)	Rainfall Ratio	Depth for given Return periods(mm)				
			5 years	10 years	25 years	50 years	100 years
5	0.08	0.145	7.240	8.234	9.489	10.421	11.345
10	0.17	0.243	12.134	13.799	15.903	17.463	19.013
20	0.33	0.370	18.476	21.011	24.214	26.590	28.949
30	0.50	0.449	22.420	25.497	29.384	32.268	35.130
60	1.00	0.581	29.012	32.993	38.023	41.754	45.458
90	1.50	0.650	32.457	36.911	42.539	46.713	50.857
120	2.00	0.695	34.704	39.466	45.484	49.947	54.378

Rainfall Intensity for given return periods(mm/hr)				
5 years	10 years	25 years	50 years	100 years
86.885	98.808	113.873	125.047	136.140
72.804	82.794	95.417	104.781	114.076
55.427	63.033	72.643	79.771	86.848
44.841	50.994	58.769	64.536	70.261
29.012	32.993	38.023	41.754	45.458
21.638	24.607	28.359	31.142	33.905
17.352	19.733	22.742	24.973	27.189

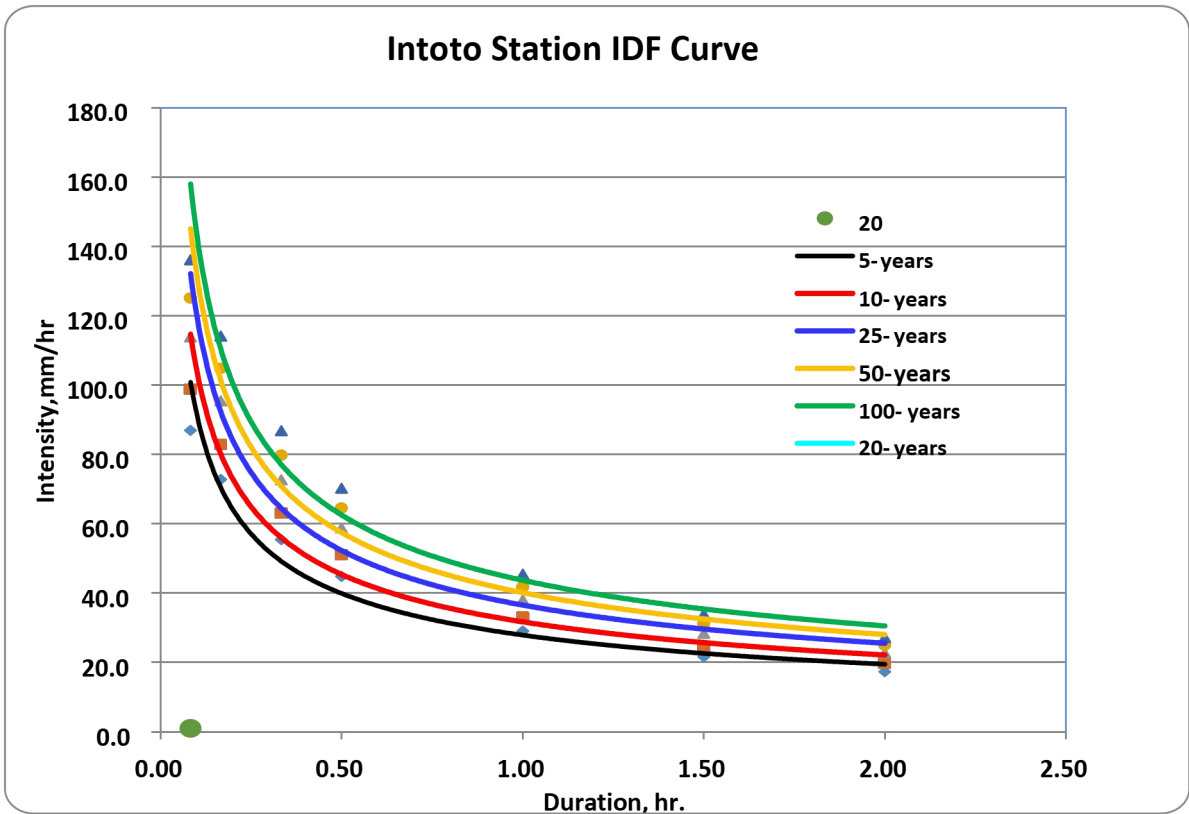


Figure 4. 9: Entoto station IDF curve

Table 4. 7: Entoto station IDF curve Equation

Entoto Station IDF Curve Equation		
Return periods	Equation	R²
5 years	$Y=27.884X^{-0.517}$	0.967
10 years	$Y=31.71X^{-0.517}$	0.967
25 years	$Y=36.545X^{-0.517}$	0.967
50 years	$Y=40.131X^{-0.517}$	0.967
100 years	$Y=43.691X^{-0.517}$	0.967

4.2.3 Computation of Runoff Volume using Rational Method

The main goal is to assess how potential is the green infrastructure helps to manage the storm water runoff within the study area. An increase in green area reduces the volume of runoff water. Computation of runoff volume:

The total area of impervious surface: $66000+55000= 111000\text{m}^2$

Area covered by green= $133,000 \text{ m}^2$

$$Q= C*I*A$$

Where,

Q = maximum rate of runoff ($\text{m}^3 / \text{sec}.$);

I = average rainfall intensity ($\text{mm}/\text{s}.$);

C = runoff coefficient;

A = drainage area (m^2).

Hence, the selection of C values for each part of land covered is used in such a way that similar land covers were selected and determined by their mean values, as shown in Table. 4.1; and for each value of the maximum rain fall data computation of runoff volume shall be executed for each side of the watershed line.

In our case, the delineation of the drainage lines, delineation or area coverage 1 of which the surface water outlet point has been located at DP2, the size of the drainage pipe is 1m.

In order to see how potential is the green infrastructure to reduce the storm water runoff volume we need to compute the total volume of flow considering the area as there is no any development of GI and considering all the area is impervious layer.

Taking the maximum pick flow rainfall intensity 100 years return period and the total volume of flow is computed and comparison has been made with the actual capacity of the two exit drainage outlets DP1 and DP2.

Maximum run off volume computation using rainfall data

$Q = CAI$, $C = 1$ for Impervious layer, $A = 267000 \text{ m}^2$ (total Areas of the study), and $I =$

78.24 mm (Maximum precipitation / rainfall data)

$Q = CAI = 1 * 267000 * .07824 = 20,890.08 \text{ m}^3$

Runoff Volume considering the green area, taking C values from table 3.1 for green areas:

$A_{gr} = 133000 \text{ m}^2$ and $C = 0.2$ (considering the green areas as parks)

The Runoff Volume $Q_{gr} = 0.2 * 133000 \text{ m}^2 * 0.07824 \text{ m} = 2,081.18 \text{ m}^3$,

Hence $0.8 * 133000 * .07824 = 8,324.736 \text{ m}^3$ is retained due to the development of Green Infrastructure. Hence, the total volume of flow contributed to the runoff due to the green infrastructure is only 2,081.18 m^3 ; an increase area of GI infrastructure will result less storm water runoff volume.

4.2.4 Sensitivity Analysis

The Sensitivity analysis based on coverage areas shows that an increase impervious surface results higher flood, changing the arrangement or attributes of the study area will have a direct relationship with the storm water runoff. The following table shows how green infrastructure changes the storm water runoff volume keeping the value of C and I, the discharge / volume of water is computed with the above formula.

Table 4. 8: Computation of Runoff volume for predefined Coefficient & Rainfall Intensity

trials	Coefficient for Green taking as park	Precipitation (m)	Total Area (m ²)	Green Area (m ²)	Areas other than Green (m ²)	Total Volume of rainfall (m ³)	rainfall Volume retained due to GI
1	0.8	0.07824	267000	133000	134000	20890.08	8,324.74
2	0.8	0.07824	267000	138000	129000	20890.08	8,637.70
3	0.8	0.07824	267000	143000	124000	20890.08	8,950.66
4	0.8	0.07824	267000	148000	119000	20890.08	9,263.62

Hence, an increase in areas of green infrastructure and development helps to reduce the runoff volume thereby decreases the storm water runoff as shown in the above sensitivity check.

4.3 Potential strategies to utilize the exiting GI for storm water runoff MGT

The potential strategies which could help to manage storm water runoff in the study area are discussed here under:

- Use of maximum benefits of green infrastructure: the existing green infrastructure shall be properly maintained and preserve, the green spaces shall be kept so that ensure in a healthy situation for the maximization of infiltration capacity.

- Maintain and Improve green infrastructure: It is required regular follow up and maintenance of the green infrastructure swales and other GI structures should be free of debris.
- Recharging the ground water is possible by slowing down the flow rate of the storm water runoff, this requires proper planning and orientation of land use development in efficient way. Hence, the identified Green infrastructure types with in the study areas such as rain garden , detention ponds, swales is required to maximize their storm water management potential.
- From the study we observe that the roads sides and drainage lines are a strategic locations to capture and infiltrate the storm water runoff from impervious layer such as buildings the runoff from roof top shall pass through an infiltrated layer which shall be properly designed and graded with different layers of boulders and rocks so as to allow to infiltrate in to the ground, helps to increase the ground water label.
- Potential locations of Swales are available in the study areas, and hence swales can slow water flow and trap sediments to improve the water quality. Rain gardens have a special soil filter media that can remove pollutants from road runoff. Configure plant and soil filtration systems as garden beds or street tree pits such that they are designed to treat storm water runoff. Hence, designing and implementing swales (shallow, grass-lined channels) to collect and slow down storm water runoff, allowing it to infiltrate gradually, is required and should be implemented. This can help to serve a dual purpose for reducing the runoff volume and generate the quality of water.
- Natural drainage systems are designed to work in harmony with the landscape, relying on the land's inherent features to manage water flow. These systems utilize
- The natural topography, vegetation, and soil characteristics to disperse excess water effectively without the need for extensive artificial structures.
- It is necessary to give lessons and to encourage organizations, companies, and the local residents about the benefit of storm water management using green infrastructure.
- Promoting and use of rain water harvesting has advantageous as it has dual purposes which can reduces the runoff volume and prevents from increase in the run off

volume and also used for water supply. Hence, implementing in harvesting of rainwater helps to control the surface water runoff and contributes in the reduction of instantaneous flood as a result of the rainstorm.

Control and management of surface run-off near the source is now widely encouraged, and it is seen in many nations as an acceptable set of strategies that facilitate natural processes while limiting hydrologic consequences. Such solutions focus on local water runoff treatment, retention, re-use, infiltration, and conveyance in metropolitan areas, and hence more in line with a sustainable development program. Green roofs have been used to boost interception, storm water storage, and evaporation in metropolitan regions where green infrastructure is limited.

To obtain the benefit of Green infrastructure development for storm water management monitoring and evaluation has to be practiced to get the required quantity and quality of storm water, this will save time and cost.

Sidewalks are reorganized to be pedestrian-friendly, there would be opportunities to install bio-swales along both sides of sidewalks, this potentially helps the storm water runoff to concentrate and convey the runoff water by removing debris and pollutants comes from around.

4.4 Discussions

Green infrastructure is increasingly recognized as a sustainable approach to urban storm water management, offering ecological and hydrological benefits through the integration of natural systems into built environments. (Ying, 2022), Green roofs and sustainable buildings can make large and dense cities more attractive. Small rainfall can be handled locally without putting the pipe system under strain, and energy can be saved in the hottest months. Vegetation provides shadow and transpiration from the foliage cools. Buildings with vegetation on the roof and/or on the walls will act as air conditioning with minimal power consumption, only a small pump that distributes the water as needed. If rainfall is collected and used for irrigation, the indoor temperature will improve and the urban heat island effect will be reduced. It is unreasonable that we use energy to cool buildings inside

for high temperatures outside, by sending the heat out of the building to streets that become even hotter, digging can be minimized with innovative stormwater solutions, so that greenhouse gas emissions are reduced (Karamoutsou et.al. 2024).

Unlike conventional “gray” infrastructure, which often channels runoff away quickly through impervious systems, GI solutions slow, filter, and store storm water through natural processes. For large institutional areas such as university campuses, assessing and enhancing green infrastructure is vital for managing storm water sustainably, minimizing flood risk, and promoting environmental stewardship.

The implementation of GI has been found to effectively manage stormwater and reduce flooding risks, particularly in urban areas facing increasing precipitation due to climate change. A study by Fletcher, Shuster, Hunt, Ashley, and Butler (2015) highlights the role of GI in enhancing urban water management systems, noting that it reduces the pressure on conventional drainage systems and minimizes the risk of water pollution. Their findings suggest that GI interventions, such as rain gardens and bioswales, not only capture stormwater but also improve groundwater recharge, promoting water conservation in densely populated urban settings. These benefits make GI an attractive solution for municipalities seeking to comply with environmental regulations and reduce the costs associated with traditional grey infrastructure. The social benefits of GI have also been well-documented, with previous studies emphasizing the positive impact on public health and community well-being. Kondo, 2018 found that access to green spaces through GI initiatives can reduce stress, promote physical activity, and enhance mental health. Their research demonstrates that urban environments with well-maintained green infrastructure foster stronger community engagement and improve social cohesion by providing spaces for recreation and interaction. These findings align with previous work by Wolch et.al., 2014, who argued that GI contributes to environmental justice by improving access to green spaces in underserved communities, thereby addressing inequities in urban planning. Collectively, these studies indicate that GI not only addresses environmental challenges but also delivers considerable social and economic benefits, making it a vital component of sustainable urban development strategies.

Addis Ababa University's sidist kilo campus, situated in a densely urbanized area, experiences frequent localized flooding and surface runoff challenges during the rainy season. As the university expands and surrounding impervious surfaces increase, an assessment of existing green infrastructure and its role in storm water management becomes crucial for both operational resilience and environmental responsibility.

Sidist kilo campus contains a mix of mature trees, gardens, grassy lawns, and seminatural vegetation distributed across its academic, administrative, and residential zones. However, these green spaces are increasingly fragmented by buildings, roads, and paved surfaces. This imbalance between permeable and impermeable surfaces contributes to excessive runoff during rainfall events, which overwhelms existing drainage infrastructure.

A preliminary mapping and spatial analysis of the campus using satellite imagery and GIS tools reveals that green infrastructure covers 50% of the total campus area, leading to limited capacity for natural storm water infiltration. Without intervention with green infrastructure development, this not only exacerbates surface water pooling and erosion but also reduces groundwater recharge and increases pollutant load entering urban drains.

Institutional GI assessments help quantify the performance and potential of existing green assets in mitigating storm water impacts. For sidist kilo campus, such an assessment involves:

- Mapping existing vegetative cover and identifying high-runoff zones.
- Estimating green infrastructure's storm water retention and infiltration capacity.
- Identifying opportunities for green retrofits, such as permeable pavements, rain gardens, bios Wales, and green roofs.

This spatially explicit analysis serves as a baseline for future infrastructure planning and demonstrates the viability of nature-based solutions at the institutional level. It also aligns with sustainable campus development strategies and environmental education goals.

To strengthen the role of green infrastructure in storm water management at sidist kilo, the following measures are recommended: Increase vegetative cover through native tree planting, green corridors, and conversion of unused paved areas into green zones, use

hydrological models to simulate runoff behavior and assess GI effectiveness under different rainfall scenarios, ensure that future development plans prioritize green infrastructure alongside traditional utilities and institutionalize GI planning through campus environmental policies and engage students and staff in green stewardship programs.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

One of the most significant components of urban storm water management strategies, GI is deemed to be a green and sustainable technology for storm water runoff management and water quality enhancement, providing a wide range of hydro-logical and ecological benefits in response to fast urbanization and climate change. .

To undertake a thorough assessment of the existing green infrastructure at the Sidist Kilo campus, we focused on the following key objectives: Mapping and Computing the Area of Existing Land use land cover: by Utilizing advanced Geographic Information Systems (GIS) technology we identified spatial data that allows for precise calculations of the total area occupied by these green spaces.and 50% of the Land Use Land Cover is found to be green areas.

Quantifying the Volume of Storm Water Runoff Under Existing Conditions: the rainfall data gathered from meteorological agency was used to evaluate stormwater runoff generated by various land surfaces on campus during peak rainfall events. the campus's current landscaping and existing green infrastructure reduces the stormwater runoff generated.

The green areas and the green infrastructure at the study areas has an advantages such as improved biodiversity, reduced urban heat island effects, and effective stormwater management, as well as the social benefits of increased engagement and a shared sense of responsibility among students and staff toward fostering a sustainable campus culture. This enriched assessment will aim to deliver actionable insights that guide future developments and initiatives, strengthening the Sidist Kilo campus's commitment to sustainability through effective stewardship of its green infrastructure for stormwater runoff management.

Therefore, our conclusion is that managing the storm water runoff is possible without building further extension of the existing culvert structures thereby building weirs, detention ponds and proper management of the green infrastructure is required so as to serve and retain the storm water more efficient way and for the maximum benefits.

According to the study from different scholars' best management practice building Green infrastructure recovers the natural environment and found in restoring of the ground water level, and for the reduction of the stormwater runoff thereby protecting the environment.

5.2 Recommendation

- ✓ The green area shall be rearranged as a means for holding the storm water to avoid instantaneous flood; and thereby can be used for future development lessons to be implemented in other areas of the country.
- ✓ In order to get high benefit of green infrastructure public participation, awareness and high involvement of government sectors towards the implementation is highly required.
- ✓ Policy makers, city Authority should take awareness and shall pass in to this regulation for the development of green infrastructure in a house hold level, to retain water, thereby slow the flow intensity.
- ✓ Furthermore, initiatives aimed at promoting or impeding the adoption of green infrastructure on campus. This analysis will encompass funding strategies for sustainability projects, educational programs fostering environmental awareness, and the extent of community engagement in green practices.
- ✓ Based on our assessment, recommendation for enhancing the existing green infrastructure on the Sidist Kilo campus, which includes the establishment of new green spaces, the incorporation of rain gardens and permeable pavement solutions, and programs designed to actively involve the campus community in sustainability efforts.

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Annexes

Annex –A1 Metrological Rainfall data Entoto station

Table A1.1: Daily Rainfall precipitation for the Month of June 2005 to 2018

Station	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Entoto	2005	0.0	0.0	2.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	9.8	1.6	3.8
Entoto	2006	7.2	1.3	10.8	0.0	0.0	2.7	4.3	0.5	3.6	5.4	8.0	4.5	7.3	0.0	0.0
Entoto	2007	0.0	0.0	18.5	0.0	0.0	3.7	0.0	0.0	0.0	1.9	6.6	8.2	2.8	23.4	3.2
Entoto	2008	3.2	4.0	14.3	13.0	8.8	0.0	11.2	0.0	19.8	5.8	2.4	2.3	0.0	8.2	0.0
Entoto	2009	0.0	0.0	3.1	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
Entoto	2010	0.0	0.0	0.0	5.4	2.3	3.2	0.0	1.3	2.6	12.3	39.2	14.8	4.0	18.2	2.1
Entoto	2011	0.0	0.0	0.0	0.0	0.0	0.4	0.3	9.4	14.8	8.6	5.4	10.6	4.3	0.2	0.9
Entoto	2012	0.0	0.0	1.9	0.2	0.0	0.0	11.7	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0
Entoto	2013	3.3	0.0	2.8	0.0	0.0	1.5	1.8	0.0	1.4	7.0	5.5	7.2	4.1	0.0	4.7
Entoto	2014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.7	0.1	0.8	0.0	0.0	0.0
Entoto	2015	8.8	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	13.1	0.0
Entoto	2016	0.0	0.0	0.0	0.2	0.1	0.0	0.4	1.3	0.0	0.0	0.0	0.7	1.5	4.9	3.6
Entoto	2018	2.8	22.3	11.7	2.0	10.2	30.4	13.6	7.2	8.0	28.1	32.4	14.6	9.7	17.6	4.9
	Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Entoto	2005	2.0	0.0	2.5	2.3	3.9	4.4	9.9	6.1	4.1	2.6	2.3	23.4	12.7	6.6	4.4
Entoto	2006	0.0	1.6	1.6	7.9	4.5	5.3	0.2	2.2	12.7	0.9	13.7	3.2	5.1	7.9	9.1
Entoto	2007	0.4	18.0	24.1	0.4	26.7	17.9	6.7	17.5	19.0	0.2	19.2	3.3	0.4	16.2	8.4
Entoto	2008	6.5	5.4	2.7	8.4	2.0	0.0	0.0	0.0	2.5	13.6	2.5	2.8	0.0	2.4	0.7
Entoto	2009	9.2	3.6	8.6	0.2	8.0	0.0	0.0	1.8	3.5	2.6	11.8	12.5	22.3	25.4	7.0
Entoto	2010	2.4	9.2	9.3	7.6	22.3	4.2	2.6	0.4	19.9	6.3	9.5	12.3	11.5	11.3	1.0
Entoto	2011	22.3	0.0	0.0	0.0	0.0	3.5	0.0	0.0	11.2	9.9	9.0	5.3	0.9	13.7	12.5
Entoto	2012	0.0	6.0	6.9	28.0	2.6	11.5	4.6	0.0	0.4	0.2	9.6	28.5	0.0	12.2	4.4
Entoto	2013	14.2	1.3	2.4	9.3	6.4	1.8	12.0	4.3	0.4	4.5	0.9	9.4	0.0	27.0	31.4
Entoto	2014	0.0	0.0	0.0	0.0	0.8	3.9	9.7	0.9	26.7	9.6	5.7	9.2	9.1	0.0	0.0
Entoto	2015	0.0	0.3	5.0	4.8	27.2	11.4	0.8	1.6	5.2	22.7	15.3	1.7	21.0	14.0	4.2
Entoto	2016	4.8	5.1	6.7	4.2	0.9	2.4	2.5	6.2	4.8	10.2	9.9	7.6	14.3	62.1	23.0
Entoto	2018	9.2	14.7	6.8	7.9	22.4	17.9	11.7	26.8	34.2	15.1	9.4	13.6	20.3	7.4	16.0

Table A1.2: Daily Rainfall precipitation for the Month of July 2005 to 2018

Station	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Entoto	2005	3.4	3.3	3.8	10.0	10.1	0.0	0.0	6.2	2.8	16.3	7.1	6.3	1.1	15.2	4.7
Entoto	2006	17.3	1.7	4.3	0.6	25.8	3.9	3.3	2.1	18.5	18.8	10.1	5.4	3.6	14.9	15.7
Entoto	2007	0.2	6.4	10.5	6.6	6.1	33.6	5.3	33.5	9.9	0.4	9.3	0.4	8.8	8.4	0.8
Entoto	2008	9.4	2.8	17.5	1.3	52.0	13.0	13.8	0.3	15.8	0.0	12.7	7.0	11.1	5.3	10.9
Entoto	2009	3.0	18.2	10.4	0.0	11.8	15.7	14.3	6.0	4.8	3.6	4.9	4.1	7.2	7.6	14.8
Entoto	2010	5.4	1.7	0.0	13.5	6.7	0.9	33.8	13.7	33.2	2.2	23.1	3.2	33.7	12.3	0.4
Entoto	2011	6.0	5.3	1.7	4.8	4.6	5.9	15.4	14.0	4.5	18.1	11.5	11.3	10.8	1.0	31.2
Entoto	2012	12.6	11.4	1.2	8.5	23.4	4.6	9.2	1.8	18.5	18.9	8.4	8.9	26.3	7.6	22.3
Entoto	2013	20.0	16.6	1.4	18.6	20.0	3.8	0.6	23.1	14.7	9.1	17.6	22.0	0.9	7.1	0.6
Entoto	2014	0.6	0.2	0.8	11.4	20.5	35.9	26.4	20.2	18.7	40.6	0.0	12.1	15.3	5.0	5.1
Entoto	2015	5.7	20.4	17.8	5.9	11.8	13.2	15.7	5.9	0.6	5.3	3.8	1.5	7.2	12.3	9.7
Entoto	2016	20.7	4.9	2.8	14.6	4.7	9.6	16.2	3.7	2.5	28.3	16.8	3.2	7.3	18.9	9.5
Entoto	2018	9.7	27.5	14.0	5.3	13.5	10.3	6.9	7.4	20.1	16.8	27.4	9.3	5.7	17.2	25.4
	Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Entoto	2005	3.6	30.5	4.5	0.0	1.1	21.1	2.5	1.0	21.2	0.6	10.9	0.2	14.4	19.1	12.2
Entoto	2006	4.3	5.4	10.9	1.8	5.7	12.6	22.1	48.9	44.8	2.9	5.8	13.5	26.4	1.6	14.3
Entoto	2007	6.0	0.0	0.2	9.3	5.7	1.8	22.3	0.6	6.4	2.2	14.5	9.9	33.9	0.4	3.8
Entoto	2008	15.7	22.6	12.7	40.2	9.7	5.8	4.9	15.0	1.2	19.8	9.1	13.8	23.3	20.8	11.0
Entoto	2009	3.7	10.0	17.0	4.6	0.8	4.7	13.2	12.8	14.8	0.5	17.6	23.2	20.3	13.7	3.0
Entoto	2010	4.5	13.0	0.0	19.3	7.5	13.7	11.3	32.5	9.2	12.7	22.4	11.5	0.9	1.4	11.3
Entoto	2011	4.1	4.0	7.6	3.9	13.2	15.3	17.5	11.4	10.8	1.2	3.1	5.5	3.3	11.2	11.4
Entoto	2012	22.2	8.9	2.1	18.2	15.0	12.7	2.0	0.8	5.7	18.4	28.7	9.4	8.2	10.0	5.3
Entoto	2013	3.7	6.2	1.8	26.5	8.9	13.7	30.3	0.9	3.7	0.0	14.2	25.3	17.9	12.4	0.0
Entoto	2014	13.6	12.6	5.9	15.2	1.0	12.6	0.0	0.8	0.0	0.4	18.4	4.9	10.3	5.2	0.4
Entoto	2015	8.3	11.8	26.5	23.8	25.9	20.4	5.9	11.2	8.6	15.4	7.4	4.9	20.2	5.5	11.3
Entoto	2016	17.3	5.4	13.1	19.6	13.3	11.0	5.5	0.3	5.8	2.5	7.9	20.1	5.8	1.0	7.9
	2018	18.4	9.2	17.4	22.6	15.0	15.9	11.6	23.8	5.4	14.1	29.2	11.2	8.6	15.0	8.9

Table A1.3: Daily Rainfall precipitation for the Month of August 2005 to 2018

Station	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Entoto	2005	6.0	24.6	22.2	36.5	11.3	2.6	33.4	17.4	4.7	0.0	5.9	0.0	21.2	11.3	0.9
Entoto	2006	18.2	45.6	1.8	22.3	5.5	1.2	5.6	41.2	19.2	7.4	6.3	0.5	9.0	6.8	12.4
Entoto	2007	13.6	3.9	26.7	0.8	16.7	26.9	9.4	8.0	16.9	5.7	6.4	4.7	11.5	11.8	0.9
Entoto	2008	19.3	12.4	12.0	13.2	7.0	6.1	5.7	10.9	4.8	6.3	5.8	11.7	11.3	14.8	31.4
Entoto	2009	4.4	19.1	8.6	14.3	8.2	24.3	15.6	0.9	10.7	9.3	4.1	4.9	0.4	9.1	0.4
Entoto	2010	0.0	37.4	0.1	18.6	7.4	2.5	11.7	6.9	6.8	11.0	8.6	7.4	1.5	7.1	4.4
Entoto	2011	46.4	5.3	4.0	2.4	8.5	9.4	20.7	7.3	1.5	10.4	6.9	3.3	13.2	3.3	21.0
Entoto	2012	6.2	12.6	7.0	13.5	8.2	1.1	13.7	0.3	11.8	10.9	10.7	23.4	13.1	17.7	29.5
Entoto	2013	27.2	17.8	0.1	12.5	22.7	9.6	25.4	0.9	15.7	3.2	23.0	13.2	12.0	5.8	16.8
Entoto	2014	1.2	5.4	0.7	1.9	0.5	3.7	28.2	5.3	9.8	0.0	28.6	18.4	19.9	0.0	8.3
Entoto	2015	2.7	5.4	10.9	4.3	5.7	13.9	4.5	24.2	32.3	20.4	0.0	0.6	1.7	4.8	18.6
Entoto	2016	1.9	2.7	1.4	9.0	17.2	20.8	3.9	6.4	19.7	0.8	10.5	9.0	1.7	20.3	6.5
Entoto	2018	10.3	4.7	0.0	0.9	0.0	11.2	0.0	17.8	28.2	20.7	16.3	9.1	21.4	12.7	24.0
	Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Entoto	2005	12.4	15.2	2.3	2.9	0.8	0.0	20.7	0.0	0.0	10.8	3.7	1.3	46.5	9.4	14.2
Entoto	2006	5.9	0.3	11.6	1.6	1.0	15.2	17.0	2.9	11.4	4.9	2.7	11.6	0.1	13.3	0.7
Entoto	2007	2.4	14.3	0.0	18.5	25.3	4.6	14.9	8.7	20.8	2.6	0.9	7.4	12.5	4.6	19.4
Entoto	2008	12.2	14.0	14.4	14.6	6.1	16.4	6.2	20.5	4.0	5.5	10.4	6.8	16.1	16.7	6.4
Entoto	2009	3.7	30.4	17.4	13.2	17.8	3.2	3.5	0.8	13.7	14.1	3.8	10.7	3.6	37.9	18.0
Entoto	2010	6.1	8.8	0.4	5.0	9.3	21.1	15.2	1.1	12.3	2.4	31.8	1.3	7.5	10.3	20.2
Entoto	2011	20.8	8.3	12.2	15.2	17.5	8.3	3.5	8.4	3.7	18.0	14.7	5.8	50.1	2.5	3.4
Entoto	2012	34.2	4.9	3.6	4.9	2.7	14.6	14.0	14.2	14.4	9.9	4.1	3.9	0.8	24.3	8.7
Entoto	2013	7.5	19.7	5.8	13.9	0.0	10.8	13.5	25.7	23.9	28.4	31.9	27.3	10.7	21.4	0.8
Entoto	2014	3.6	0.0	10.2	17.0	12.9	5.0	20.7	4.5	5.8	25.4	5.9	4.6	2.3	18.7	8.3
Entoto	2015	9.9	14.3	8.2	38.3	29.2	5.0	1.1	9.2	6.5	9.1	6.8	0.5	9.2	11.7	6.1
Entoto	2016	0.7	4.3	29.6	25.3	9.4	14.3	9.4	2.7	1.5	28.0	12.7	14.4	6.2	2.8	3.5
	2018	27.6	10.5	15.0	1.9	1.7	20.3	10.9	30.5	26.2	4.0	2.2	4.9	4.1	10.0	19.7

Table A1.4: Daily Rainfall precipitation for the Month of September 2005 to 2018

Station	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Entoto	2005	0.0	2.6	1.2	3.6	3.2	3.8	31.3	3.2	17.4	7.2	4.5	16.1	8.6	8.5	2.6
Entoto	2006	11.1	18.4	1.0	4.8	0.0	5.0	2.1	0.6	5.2	2.4	6.1	12.1	5.3	11.7	2.6
Entoto	2007	0.9	0.4	25.7	1.1	0.3	3.3	0.0	2.7	0.0	0.7	0.2	6.1	1.8	5.4	7.9
Entoto	2008	17.5	12.8	8.6	7.0	2.9	17.0	7.5	7.6	1.7	0.0	4.5	4.7	11.3	13.1	0.0
Entoto	2009	10.1	3.0	13.5	15.2	11.9	36.2	14.7	12.3	15.6	7.5	0.0	0.0	0.0	0.0	0.0
Entoto	2010	8.3	0.0	4.9	0.3	10.2	30.4	1.0	18.2	0.0	15.5	15.3	12.0	5.3	8.4	6.2
Entoto	2011	15.1	9.8	1.4	0.3	1.2	0.1	2.1	3.8	14.3	5.7	2.4	0.9	3.8	4.0	0.8
Entoto	2012	21.4	8.9	2.8	10.0	28.7	12.8	5.0	15.6	5.8	18.6	5.9	9.2	4.7	1.6	27.5
Entoto	2013	10.7	20.4	20.5	10.9	9.6	5.1	2.2	7.5	18.5	0.0	0.0	2.7	5.0	9.5	25.8
Entoto	2014	1.8	0.4	0.0	18.6	5.5	0.3	15.3	5.4	9.5	10.4	31.6	17.8	0.9	4.7	0.6
Entoto	2015	1.2	0.7	0.4	24.2	1.8	4.2	8.7	4.5	17.3	8.9	0.0	0.8	2.9	3.3	0.0
Entoto	2016	9.0	3.6	2.4	6.2	0.0	0.0	12.1	2.7	10.2	0.0	7.0	5.7	0.9	0.4	0.0
Entoto	2018	14.7	9.9	8.7	4.9	0.0	4.2	0.7	0.0	0.1	0.0	0.0	7.0	16.1	0.3	0.1
	Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Entoto	2005	7.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0	8.6	0.0	0.0	3.4	0.0	0.0	0.0
Entoto	2006	10.1	3.0	10.4	1.7	0.0	9.0	4.9	0.2	0.0	0.8	0.2	0.0	0.0	0.0	0.0
Entoto	2007	0.4	13.7	0.0	3.4	0.4	0.0	0.1	0.0	7.3	0.0	1.7	0.6	0.4	1.3	1.2
Entoto	2008	2.6	0.8	22.0	0.0	0.0	0.0	1.3	0.0	16.0	31.5	0.0	0.0	0.0	0.0	0.2
Entoto	2009	6.5	6.3	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Entoto	2010	10.8	8.5	5.5	3.7	5.3	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	1.1
Entoto	2011	2.5	4.8	1.6	0.4	0.2	0.6	11.9	0.0	1.8	12.5	10.7	0.9	0.0	0.0	0.0
Entoto	2012	1.7	18.4	10.8	1.9	6.4	8.1	1.7	0.0	8.4	0.0	0.0	0.0	0.0	0.0	6.8
Entoto	2013	14.5	0.8	0.3	11.6	0.0	0.0	0.8	0.4	1.3	0.0	0.0	0.0	0.0	7.2	12.8
Entoto	2014	2.8	0.0	3.0	10.3	0.8	0.3	0.0	0.7	9.2	0.5	0.2	5.0	0.3	0.6	2.7
Entoto	2015	1.9	3.5	0.0	0.0	0.0	0.0	0.0	0.9	0.7	0.4	0.0	0.0	0.0	0.0	0.0
Entoto	2016	0.2	5.5	4.5	4.3	0.0	2.5	0.9	0.4	1.8	0.0	0.9	0.5	2.4	2.1	27.4
Entoto	2018	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Annex – A2 Publishable Manuscript

Assessment of the volume of storm water runoff reduced due to the existing Green Infrastructure at
sidist kilo campus

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Abstract

The rising population the need for living facilities, prompting the development of essential infrastructure such as roads, buildings, parking areas that increases the imperviousness of the surfaces. Increase impervious surfaces and the presence of inefficient drainage systems significantly intensify the volume of storm water runoff, leading to frequent flooding and limit the ability of stormwater to infiltrate the ground. This situation not only heightens the risk of flooding but also exacerbates water pollution. In response, Green Infrastructure (GI) has become a sustainable and effective approach for managing urban storm water by reducing runoff flow rates, retaining excess water, and enhancing groundwater recharge. The study areas have encountered problems of aging of infrastructure and inadequacy of drainage line outlet points. This thesis aims to constructively explore the spatial distribution of areas within the study areas of Addis Ababa university sidist kilo main campus and assess the potential of green infrastructure to mitigate stormwater runoff volume. Descriptive analysis method was used by leveraging both quantitative and qualitative methods, assessed the potentials of green infrastructure for stormwater runoff management. Graphs, maps, and tables were used to show the extent of development and the special arrangements. Using the rainfall data acquired from metrological agency for the maximum rainfall intensity and obtain the total runoff volume for the maximum generation of stormwater runoff with in the study areas. The green infrastructure covers approximately 49.81% of the total land use in the study area, demonstrating a significant contribution to stormwater runoff conservation and reduction. The development of infrastructure and the changes made at three different years 2012, 2017 and 2022 G.C shows the changes in land use land cover and GIS software were used for classification. The result depicts that the implementation of green infrastructure with in the study areas have positively impacted for the reduction of the volume of stormwater runoff; and has enhanced the capacity of existing stormwater drainage points, ensuring their adequacy. In conclusion, the proactive development of green infrastructure has demonstrated significant effectiveness in reducing stormwater runoff volume. This initiative not only contributes to improved drainage and flood prevention but also fosters a healthier environment, highlighting the importance of sustainable practices in urban planning.

Keywords: Green infrastructure; stormwater management, stormwater runoff, impervious surfaces, Addis Ababa University

1. Introduction

Water is the natural resource which is irreplaceable and requires proper management and conservation. The scarcity and unavailability of potable water are most common in Addis Ababa city, and it becomes an important issue of all time due to the widespread of the town and an increase in population. This leads to high cost of water treatment due to demand of importation of chemicals to treat the polluted water in a reservoir as a result of urbanization.

Storm water runoff has affected the environment it takes all debris, soils, and eroded the surfaces if not properly conserve and manage. This and other factor coupled with the demand requires efficient management of the storm water runoff. Therefore, Green infrastructure helps to reduce the volume of water which can run in to the drainage lines thereby increase the time of concentration which helps to avoid damages that results from flood. More importantly, it can help to raise the ground water table as well as serving as a trapping mechanism for debris and deleterious materials which can be washed by the storm water runoff in to streams and rivers.

Many countries in the world have now working for the development of Green Infrastructure as a means for the storm water runoff management. The Green Infrastructure has many advantages unlike the grey infrastructure, it serves as beautification, creating livable environment, aesthetics, avoid destruction that results from flooding, increase the time of concentration, quality and quantity of water, and helps to increase for the ground water table. There is different naming used for green infrastructure development, In USA it's called the low impact development, in Australia its sustainable urban development, in China its sponge city.

The purpose of the study is to show how green infrastructure benefits to the storm water runoff management and to show the international practice of the green infrastructure that are used for as a solution for conservation and reduction of the volume of storm water runoff. In order to reduce the volume of runoff and its efficiency the developed world has now aware of the solutions; In developed countries like USA , low impact development has been practiced since 1900 and proved to be effective in the management of the storm water runoff, In contrast, the urban landscape green space system plays a significant role in storm water management, and there has been a shift from gray water management to green storm water management thinking in urban watershed management (Novotny and Brown, 2007).

Many countries have integrated storm water treatment into landscape eco-planning and storm water management in order to maintain urban natural hydrological cycling and enhance the urban eco-process safety, and some noticeable practices include Best Management Practice, Low Impact Development, Smart Growth, Sustainable Urban Drainage Systems, and Water Sensitive Urban Design (Van Room et al., 2009).

2. Objectives

2.1 General Objective

The General objective of the study is to assess the potential of green infrastructure to manage storm water runoff: The case of Addis Ababa University, sidist kilo campus.

2.2 Specific Objectives

The specific objectives of the study include:

1. To map and compute the area of the existing green Infrastructure at sidist kilo campus.
2. To quantify the volume of storm water runoff to be reduced (or managed) due to the existing green infrastructure at sidist kilo campus.
3. To develop potential strategy to utilize the exiting green infrastructure for storm water management.

3. Research Methodology

The research was conducted at the main campus of Addis Ababa University sidist kilo. The geographical location of the study area in relation to the city of Addis Ababa is illustrated in figure 3.1.

The sidist kilo main campus of Addis Ababa University is centrally located in Addis Ababa, Ethiopia. Based on available geospatial data, the approximate coordinates and elevation are as follows:

Latitude: 9.04667° N and Longitude: 38.75917° E

Elevation: Approximately 2,499 meters (8,199 feet) above sea level

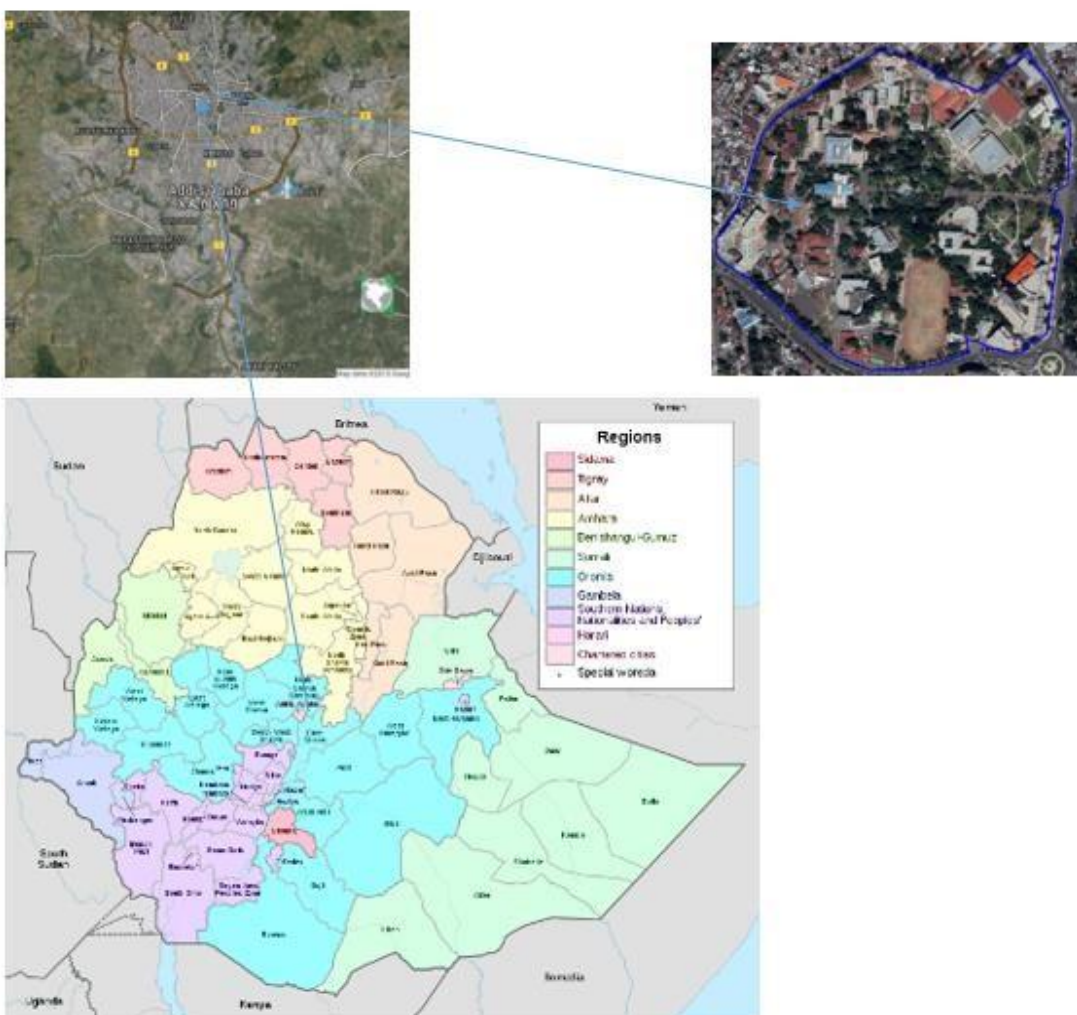


Figure 3.1: Location map of the study area

3.1 Research Approach

Analysis of storm water runoff employed both quantitative and qualitative methodologies to evaluate the efficacy of green infrastructure development within the designated study area. To substantiate its effectiveness, we harnessed primary data sources, encompassing the identification of green infrastructure initiatives within the study locales, alongside secondary data procured from meteorological agencies. The site conditions and spatial configurations served as the principal inputs for our analytical methods. To facilitate a comparative analysis between the changes in spatial arrangements the volume of precipitation, meteorological data from the pertinent agency was integrated.

An evaluation was conducted utilizing peak rainfall values extracted from a thirteen year meteorological data set spanning from July to September, covering the period from 2005 to 2018.

Global Positioning System technology was employed to ascertain the precise geographical coordinates of the drainage outlet. Comprehensive site observations and photographic documentation were meticulously conducted as integral components of the data gathering and collection methodology. Notably, an exhaustive visual assessment of the area was undertaken to establish an initial evaluation of the prevailing site conditions. Advanced tools such as Geographic positioning System, Geographic Information Systems, an Arc map, Excel, global mapping software, and hydrologic modeling formulas/applications were utilized as instruments for computational analysis.

3.1.1 Assessment Procedures

Data is predominantly gathered through the visual representation of direct photographs of the study areas, supplemented by secondary data derived from the aerial topography of the study area. This involved employing ArcGIS to identify land use developments for the years 2012, 2017, and 2022, which constitute the only available data within the country implemented to gather qualitative data regarding land use changes.

Furthermore, a comprehensive analytical approach was utilized for storm water runoff management, utilizing data mining techniques alongside secondary sources, specifically meteorological rainfall data obtained from the meteorological agency in Addis Ababa. Books, brochures, and literary sources constituted the repositories from which information has been meticulously compiled regarding optimal storm water runoff management within the designated study areas.

The analytical methodology employed for the management of storm water runoff is centered on predictive modeling utilizing a data mining approach, leveraging meteorological rainfall data sourced from the meteorological agency in Addis Ababa.

To assess the efficacy of the best management practices for storm water within the designated study area, a thorough evaluation of green spaces, existing green infrastructure developments, and available spatial areas has been conducted to ascertain how these best management practices contribute to the reduction of flow volume through peak flow attenuation. The analytical strategy adopted for storm water runoff management within the study areas to identify its effectiveness had been verified. Hence the following procedures have been implemented.

To evaluate the development of green infrastructure within the study area for effective storm water runoff management, the following procedures have been implemented:

As certain the arrangement and positioning of various spaces to facilitate the identification of land utilization and coverage through meticulous site observation and photographic documentation.

Areas characterized by buildings, vegetation, grasslands, roadways, and parking facilities was analyzed utilizing GIS software Arc map.

An examination of the existing drainage system was conducted, alongside the identification of all exit points of the storm water runoff from the study areas.

The total runoff volume was estimated both with and without green infrastructure by comparing the permeable and impermeable surfaces of the study areas, thereby elucidating the advantages of green infrastructure in mitigating storm water runoff.

The management of watershed dynamics within the designated study areas was illustrated by utilizing advanced global mapping software. The analysis will encompass the delineation of contours throughout the study site.

The total area covered by each spatial category will be calculated, encompassing the land occupied by buildings, Asphalt roads, vegetation, grasses and open spaces.

Although an investigation into soil types is required this study will not encompass an analysis of soil types due to its limited scope.

Data collection of rainfall metrics, computation of annual precipitation figures, and maximum rainfall intensity necessary for the computation of runoff volumes was incorporated.

The role of green infrastructure in reducing storm water runoff will be explored, emphasizing how the expansion of green spaces can capture and retain flow, thus delaying the onset of storm water movement as a natural trapping mechanism and its benefit

3.1.2 Sensitivity Analysis

Following the assessment procedures, a comprehensive data analysis will be conducted to ascertain the efficacy of the implemented green infrastructure. This entails a detailed examination of the relationship between the extent of green cover and corresponding reductions in storm water runoff volumes.

3.1.3 Comparative Study

A comprehensive comparative analysis undertaken to set the transformations observed in the study area through aerial photographs from three distinct years: 2012, 2017, and 2022. This investigation aims to clarify the developmental transform and modifications of attributes within the study areas, thereby emphasize how various developmental changes have influenced attribute evolution, utilizing GIS software to meticulously observe the changes over time. Ultimately, recommendations will be provided based on the findings obtained.

3.2 Computation of Storm water Runoff using Rational Formula

John Poullain (2012), the formula is the most commonly used method of determining peak discharges from small drainage areas. This method is traditionally used to size storm sewers, channels and other storm water structures which handle runoff from drainage areas. The Rational method formula is expressed as

$Q = C * I * A$ ----- (Eq. 1)

Where:

Q = Peak rate of runoff in cubic meter per second (m3/s)

C = Runoff coefficient, a dimensionless unit

I = Average intensity of rainfall in mm per hour (mm/hr.) A = the watershed area (m2).

The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment State Water Resources Control Board 5.1.3 FS-(RC) 2011 give us the value of the runoff coefficient C-computed based on the soil type, gradient, permeability and land use. The larger values correspond to higher runoff and lower infiltration.

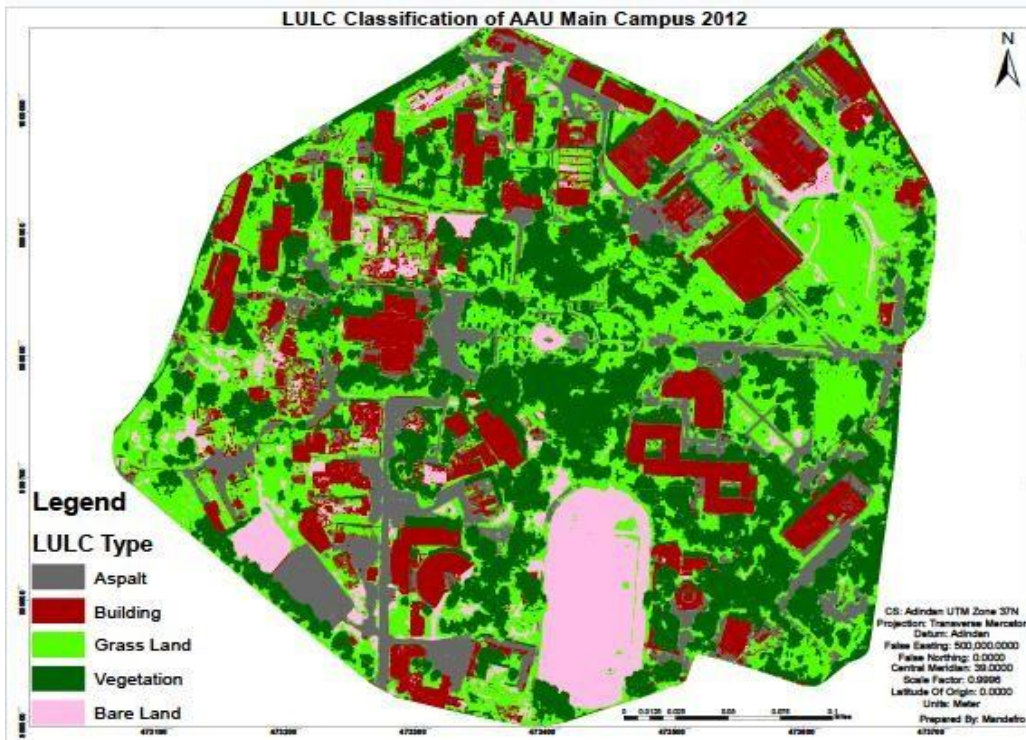
4. Results and Discussions

4.1 Results

1. Mapping and computing the area of existing green infrastructure at sidist kilo campus

The study had assessed, mapped, and quantified the extent of green infrastructure within the sidist Kilo Campus of Addis Ababa University. Green infrastructure includes natural and semi-natural elements such as trees, shrubs, grasslands, gardens, and other vegetated spaces that contribute to the ecological, aesthetic, and climatic value of the campus environment.

LULC for three different years has been taken for comparison of the change in spatial areas through time.



Class name	Area (Ha)	Area in Percentage
Asphalt	4.5	16.8
Building	5.4	20.4
Grass Land	6.6	24.7
Vegetation	6.4	24.1
Bare Land	3.7	14.0
Total	26.67	100.00

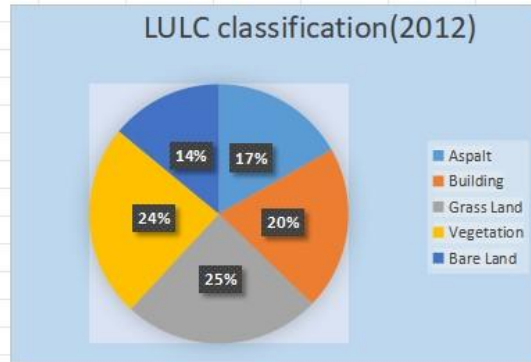
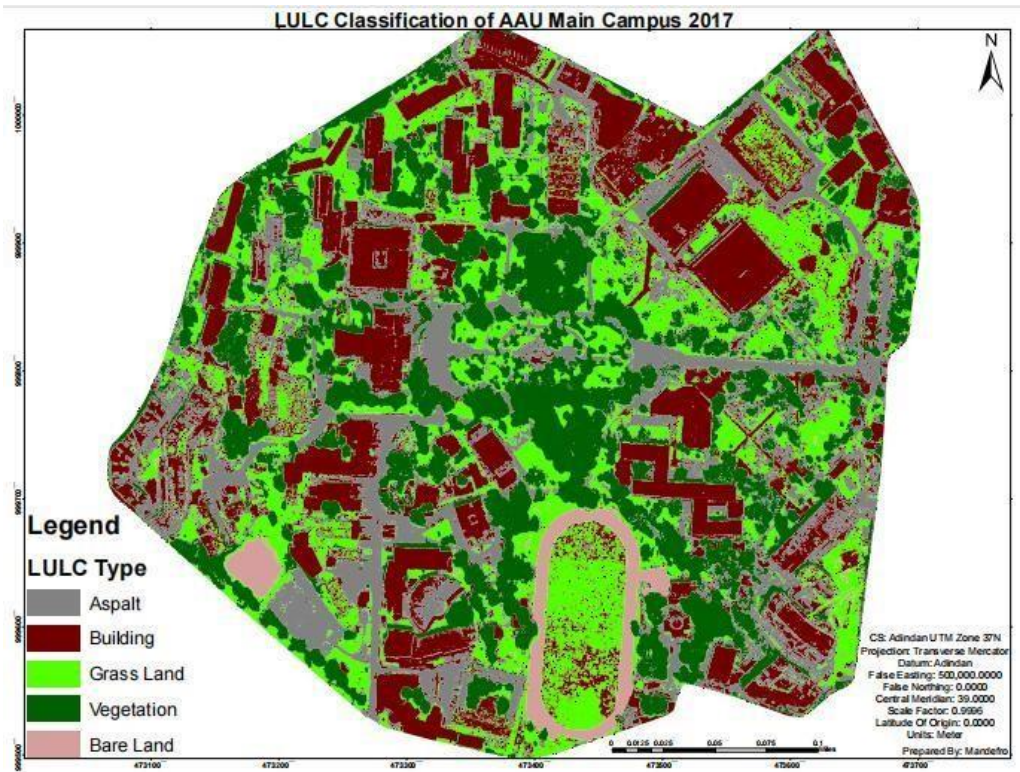


Figure 4.1. Land use land cover classification of sidist kilo, 2012

The 2012 land use classification of the study area clearly shows that approximately 45% of the landscape is covered by lush green spaces. In contrast, only 16.8% is occupied by asphalt surfaces, while buildings make up 20.4% of the area. This notable distribution highlights a strong commitment to maintaining vibrant natural environments in the face of urban development.



Class_name	Area (Ha)	Area in Percentage
Asphalt	5.1	19.1
Building	5.7	21.2
Grass Land	6.5	24.5
Vegetation	7.3	27.2
Bare Land	2.1	7.9
Total	26.7	100.0

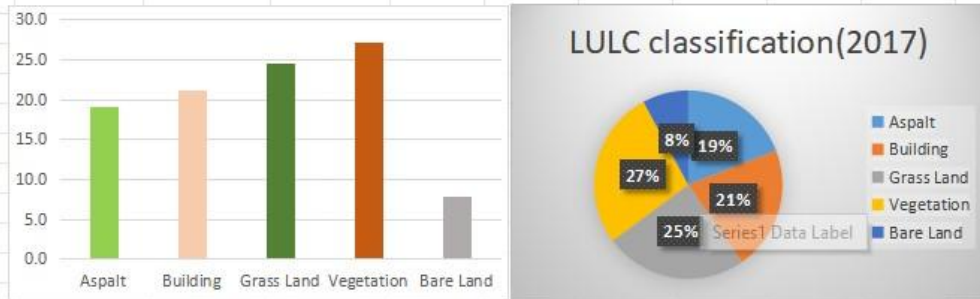
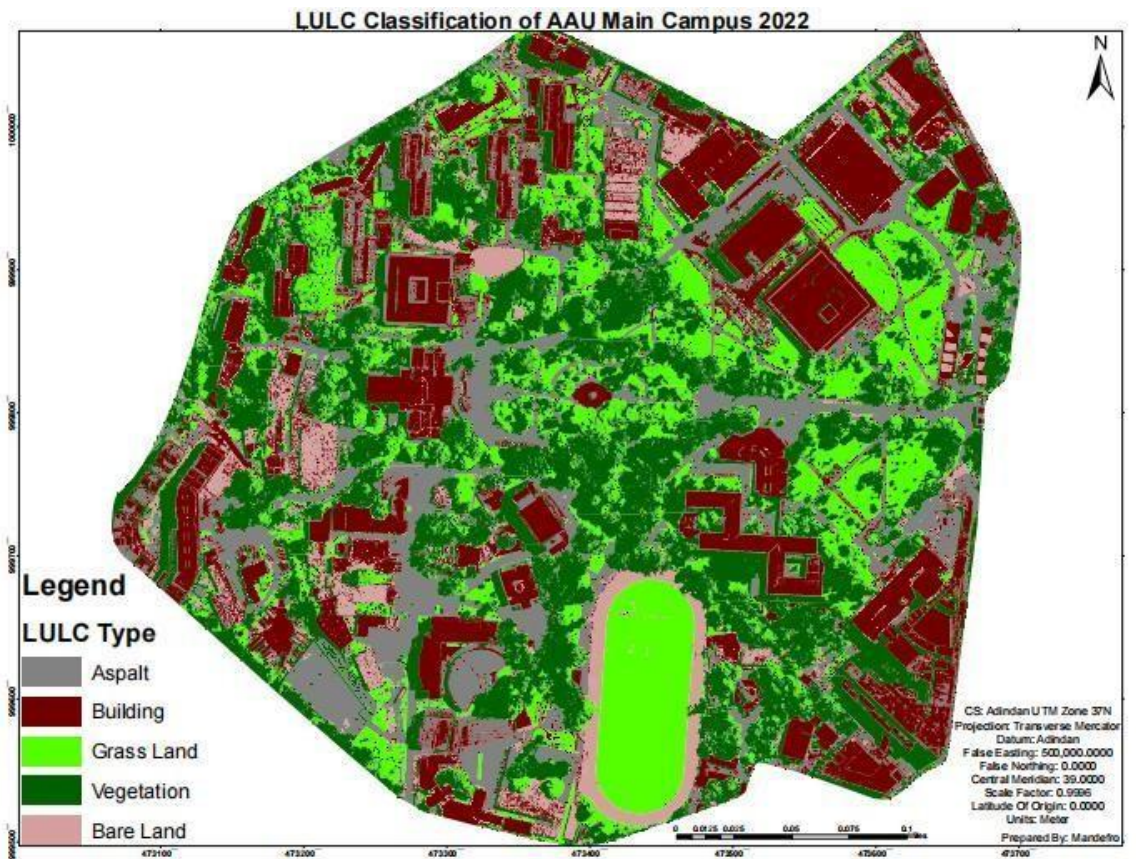


Figure 4.2: Land use land cover classification of sidist kilo, 2017

The 2017 land use classification of the study area clearly shows that approximately 52.7% of the landscape is covered by lush green spaces. In contrast, only 19 % is occupied by asphalt surfaces, while buildings make up 21 % of the area. This notable distribution highlights a strong commitment to maintaining vibrant natural environments in the face of urban development.



Class_name	Area (Ha)	Area in Percentage
Aspalt	5.5	20.6
Building	6.6	24.6
Grass Land	6.3	23.4
Vegetation	7.0	26.1
Bare Land	1.4	5.4
Total	26.70	100.00

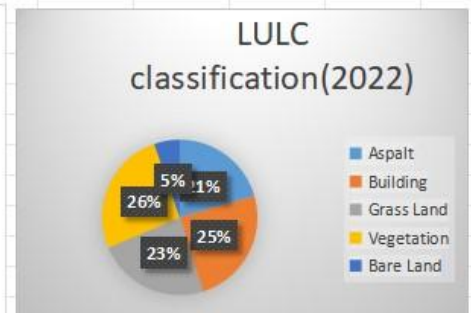
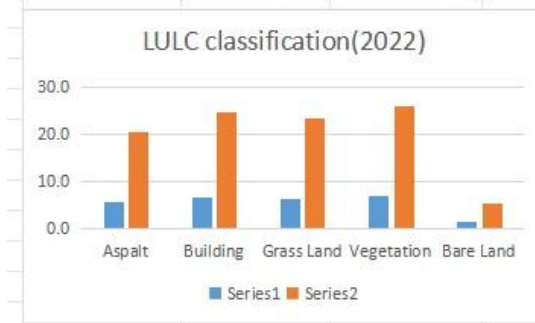


Figure 4.3. Land use land cover classification of sidist kilo, 2022

The land use land classification of the study area in 2022 shows that 49.5% of the areas is covered by green while 21 % and 25 % of the areas are covered by Asphalt and building respectively which is impermeable layer which allows to increase the runoff volume.

Table: 4.1. Computing change detection and statistics

LULC Types	2012		2017		2022	
	Area(ha)	Area (%)	Area(ha)	Area (%)	Area(ha)	Area (%)
Asphalt	4.5	16.8	5.1	19.1	5.5	20.6
Building	5.4	20.4	5.7	21.2	6.6	24.6
Grass Land	6.6	24.7	6.5	24.5	6.3	23.4
Vegetation	6.4	24.1	7.3	27.2	7.0	26.1
Bare Land	3.7	14.0	2.1	7.9	1.4	5.4
Total	26.67	100.0	26.7	100.0	26.70	100.0

Each type of spatial arrangement is meticulously analyzed, and the area is precisely calculated using ArcGIS software to ensure accurate identification of the attributes, as detailed in the table above. In three different years, 2012, 2017 and 2022 the total areas of green space / cover 45% and 52.5 and 49.5% respectively. As we can referred from the result there is a little change in the areas of the three different years, and recently the inclusion of Green infrastructure for storm water management as identified in the study areas found more effective in reducing the storm water runoff as rain garden, detention ponds and different kind of GI are introduced.

As a result, the total area of the study is determined to be 26700 m² and the corresponding areas of LULC is summarized as follows by categorizing the types of attributes in to four for the year 2022 for our analysis.

Table 4. 2 The Existing land use category and their corresponding areas

No.	Description	Unit	Coverage Areas(m2)	% from Total
1	Areas Covered by Buildings	M2	66,000.00	24.72%
2	Areas Covered Green	M2	133,000.00	49.50%
3	Areas Covered by Concrete, Paved areas, cobbles tones (parking and roads)	M2	55,000.00	20.59%
4	Bare land	M2	14,000.00	5.24%
Total Areas			267,000.00	100%

The above assessment of the actual condition of the site and coverage of the study area shows 49.81% is covered by green, maximum benefit of GI can be gained by using efficient design and allocation of the GI structures so as to minimize the runoff water.

As had been pointed out and assessed by different scholars an increase in the area of the green infrastructure found to be effective in the reduction of the storm water runoff.

Based on the data derived from the study increase in area of impervious surface affects the volume of the runoff water as computed using the rainfall data and by changing the green space keeping the same data for rainfall.

In our case we have two constraint locations of outlet flow lines, each has their own capacity which we compute the maximum capacity for runoff volume, with their respective watershed areas. This helps us to identify the green values to what extent can hold and reduce the run off volume.

There are two basic issues that have to be considered while dealing with green infrastructure:

Acting as retention for accumulation of water there by helps to raise the ground water level, high contribution for evapotranspiration of water

Helps to slow the flow and decrease the travel time of the surface water thereby reduce the volume of flood from reaching in to exist.

As seen in figure. 4.5 Water shade layout of the campus of the study area with the total area of 267000 m², the flow of water from the direction indicated towards the manhole no. 5 at gate 5 of the university delineated as DP1. Whereas the other portion of the areas the runoff water accommodated at the back side of the university with the culvert location point of DP2.

4.1.2 Watershed Analysis to define the water path lines

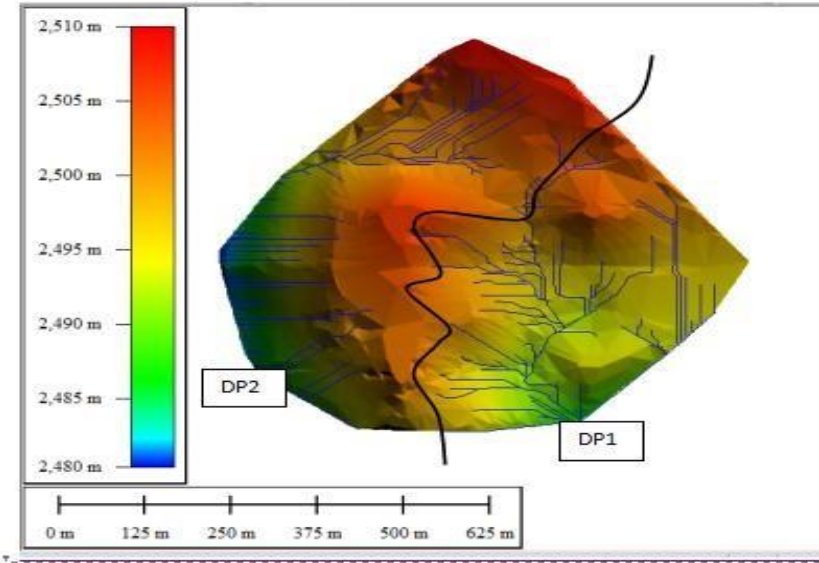


Figure 4.4: Watershed areas

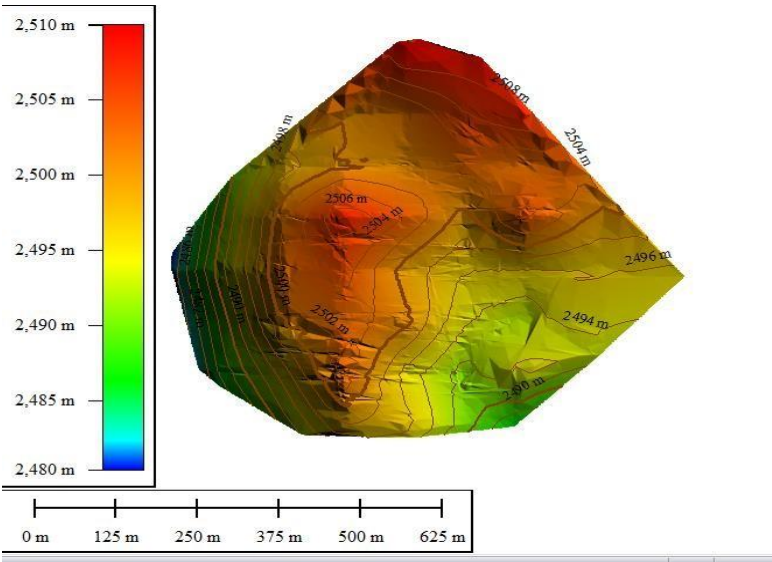


Figure 4.5. Contour Elevation of the study Areas

4.1.3 Rainfall data at Entoto rain gauge stations

For the computation of runoff volume, the rain fall data from 2005 to 2018 G.C, 13 years rainfall data with in the period of June to September of the years from Ethiopian Meteorological Agency was used.

Table 4.3: Summary of the Maximum precipitation value

Year	Maximum Precipitation				Peak value
	Month				
	June	July	August	September	
2005	23.4	30.5	46.50	31.30	46.5
2006	13.7	48.9	45.60	18.40	48.9
2007	26.7	33.9	26.90	25.70	33.9
2008	19.8	52.0	31.40	31.50	52.00
2009	25.4	23.2	37.90	36.20	37.90
2010	39.2	33.8	37.40	30.40	39.20
2011	22.3	31.2	46.40	15.10	46.40
2012	28.5	28.7	34.20	28.70	34.20
2013	31.4	30.3	31.90	25.80	31.90
2014	26.7	40.6	31.60	31.60	40.60
2015	27.2	26.5	29.20	24.20	29.20
2016	62.1	28.3	28.00	27.40	62.10
2018	34.2	29.2	30.50	16.10	30.50

Gumble's storm water runoff estimation, extreme value computation of IDF

Table 4-4: Gumbel Extreme Value determination of rainfall intensity

Gumbel Extreme Value determination of rainfall intensity				
Annual 24 hours heaviest rainfall series (Entoto station)				
YEAR	Annual heaviest(mm)	Dail Rank	X(mm)	X²
2005	46.5	62.1	46.5	2162.25
2006	48.9	52.0	48.9	2391.21
2007	33.9	48.9	33.9	1149.21
2008	52.0	46.5	52.0	2704.00
2009	37.9	46.4	37.9	1436.41
2010	39.2	40.6	39.2	1536.64
2011	46.4	39.2	46.4	2152.96
2012	34.2	37.9	34.2	1169.64
2013	31.9	34.2	31.9	1017.61
2014	40.6	33.9	40.6	1648.36
2015	29.2	31.9	29.2	852.64
2016	62.1	30.5	62.1	3856.41
2018	30.5	29.2	30.5	930.25
ΣX^2			533.30	23007.59
Number of records		13		

Mean daily rainfall, X_{avg}	heaviest	41.02308	
	ΣX^2		23007.59
	$(\Sigma X)^2$		284408.9
Standard deviation		9.704	

$$\sigma_x = \sqrt{\frac{\Sigma x^2 - \frac{1}{n}(\Sigma x)^2}{n-1}}$$

$$X_{avg} = \frac{\Sigma x}{n}$$

Return period(T_r)	Number of years of records,n	$X_{avg}(mm)$	K(T,n)	S_x	$X_T(mm)$
5	13	41.02	0.9186	9.704	49.934
25	13	41.02	2.5169	9.704	65.444
50	13	41.02	3.1787	9.704	71.866
100	13	41.02	3.8357	9.704	78.241

4.1.4 Computation of Runoff Volume using rational Method

The main goal is to assess how potential is the green infrastructure helps to manage the storm water runoff within the study area. An increase in green area reduces the volume of runoff water.

Computation of runoff volume:

The total area of impervious surface: $66000+55000= 111000\text{m}^2$

Area covered by green= $133,000 \text{ m}^2$

$$Q= C*I*A$$

Where

Q = maximum rate of runoff ($\text{m}^3 / \text{sec}.$);

I = average rainfall intensity ($\text{mm}/\text{s}.$);

C = runoff coefficient;

A = drainage area (m^2).

Hence, the selection of C values for each part of land covered is used in such a way that similar land covers were selected and determined by their mean values, as shown in table. 4.4; and for each value of the maximum rain fall data computation of runoff volume shall be executed for each side of the watershed line.

In our case, the delineation of the drainage lines, delineation or area coverage 1 of which the surface water outlet point has been located at DP2, the size of the drainage pipe is 1m. In order to see how potential is the green infrastructure to reduce the storm water runoff volume we need to compute the total volume of flow considering the area as there is no any development of GI and considering all the area is impervious layer.

Taking the maximum pick flow rainfall intensity 100 years return period and the total volume of flow is computed and comparison has been made with the actual capacity of the two exit drainage outlets DP1 and DP2.

Maximum run off volume computation using rainfall data

$Q = CAI$, $C = 1$ for Impervious layer, $A = 267000 \text{ m}^2$ (total Areas of the study), and $I =$

78.24 mm (Maximum precipitation / rainfall data)

$$Q = CAI = 1 * 267000 * 0.07824 = 20,890.08 \text{ m}^3$$

Runoff Volume considering the green area, taking C values from table 3.1 for green areas:

$A_{gr} = 133000 \text{ m}^2$ and $C = 0.2$ (considering the green areas as parks)

The Runoff Volume $Q_{gr} = 0.2 * 133000 \text{ m}^2 * 0.07824 \text{ m} = 2,081.18 \text{ m}^3$,

Hence $0.8 * 133000 * 0.07824 = 8,324.736 \text{ m}^3$ is retained due to the development of Green Infrastructure.

Hence, the total volume of flow contributed to the runoff due to the green infrastructure is only 2,081.18 m³; an increase area of GI infrastructure will result less storm water runoff volume.

4.1.5 Sensitivity Analysis

The Sensitivity analysis based on coverage areas shows that an increase impervious surface results higher flood, changing the arrangement or attributes of the study area will have a direct relationship with the storm water runoff. The following table shows how green infrastructure changes the storm water runoff volume keeping the Value of C and I, the discharge / volume of water is computed with the above formula.

Table 4.5: Computation of runoff volume for predefined coefficient and rainfall intensity

Trial No.	Coefficient for Green Areas value of (C)	Precipitation (m)	Total Area (m ²)	Green Area (m ²)	Areas other than Green (m ²)	Total Volume of rainfall (m ³)	rainfall Volume retained due to GI
1	0.8	0.07824	267000	133000	134000	20890.08	8,324.74
2	0.8	0.07824	267000	138000	129000	20890.08	8,637.70
3	0.8	0.07824	267000	143000	124000	20890.08	8,950.66
4	0.8	0.07824	267000	148000	119000	20890.08	9,263.62

Hence, an increase in areas of green infrastructure and development helps to reduce the runoff volume thereby decreases the storm water runoff as shown in the above sensitivity check.

4.2 Potential strategies to utilize the exiting GI for storm water runoff management

The potential strategies which could help to manage storm water runoff in the study area are discussed here under: Use of maximum benefits of green infrastructure: the existing green infrastructure shall be properly maintained and preserve, the green spaces shall be kept so that ensure in a healthy situation for the maximization of infiltration capacity.

Maintain and Improve green infrastructure: It is required regular follow-up and maintenance of the green infrastructure swales and other GI structures should be free of debris. Recharging the ground water is possible by slowing down the flow rate of the storm water runoff, this requires proper planning and orientation of land use development in efficient way. Hence, the identified Green infrastructure types with in the study areas such as rain garden , detention ponds, swales is required to maximize their storm water management potential.

From the study we observe that the roads sides and drainage lines are a strategic locations to capture and infiltrate the storm water runoff from impervious layer such as buildings the runoff from roof top shall pass through an infiltrated layer which shall be properly designed and graded with different layers of boulders and rocks so as to allow to infiltrate in to the ground, helps to increase the ground water label.

Potential locations of swales are available in the study areas, and hence swales can slow water flow and trap sediments to improve the water quality. Rain gardens have a special soil filter media that can remove pollutants from road runoff. Configure plant and soil filtration systems as garden beds or street tree pits such that they are designed to treat storm water runoff. Hence, designing and implementing swales (shallow, grass-lined channels) to collect and slow down storm water runoff, allowing it to infiltrate gradually, is required and should be implemented. This can help to serve a dual purpose for reducing the runoff volume and generate the quality of water.

Natural drainage systems are designed to work in harmony with the landscape, relying on the land's inherent features to manage water flow. These systems utilize the natural topography, vegetation, and soil characteristics to disperse excess water effectively without the need for extensive artificial structures. It is necessary to give lessons and to encourage organizations, companies, and the local residents about the benefit of storm water management using green infrastructure.

Promoting and use of rain water harvesting has advantageous as it has dual purposes which can reduces the runoff volume and prevents from increase in the run off volume and also used for water

supply. Hence, implementing in harvesting of rainwater helps to control the surface water runoff and contributes in the reduction of instantaneous flood as a result of the rainstorm.

Control and management of surface run-off near the source is now widely encouraged, and it is seen in many nations as an acceptable set of strategies that facilitate natural processes while limiting hydrologic consequences. Such solutions focus on local water runoff treatment, retention, re-use, infiltration, and conveyance in metropolitan areas, and hence more in line with a sustainable development program. Green roofs have been used to boost interception, storm water storage, and evaporation in metropolitan regions where green infrastructure is limited.

To obtain the benefit of Green infrastructure development for storm water management monitoring and evaluation has to be practiced to get the required quantity and quality of storm water, this will save time and cost. Sidewalks are reorganized to be pedestrian friendly, there would be opportunities to install bio-swales along both sides of sidewalks, this potentially helps the storm water runoff to concentrate and convey the runoff water by removing debris and pollutants comes from around.

4.3 Discussions

Green infrastructure is increasingly recognized as a sustainable approach to urban storm water management, offering ecological and hydrological benefits through the integration of natural systems into built environments. Unlike conventional “gray” infrastructure, which often channels runoff away quickly through impervious systems, GI solutions slow, filter, and store storm water through natural processes. For large institutional areas such as university campuses, assessing and enhancing green infrastructure is vital for managing storm water sustainably, minimizing flood risk, and promoting environmental stewardship.

Addis Ababa University’s sidist kilo campus, situated in a densely urbanized area, experiences frequent localized flooding and surface runoff challenges during the rainy season. As the university expands and surrounding impervious surfaces increase, an assessment of existing green infrastructure and its role in storm water management becomes crucial for both operational resilience and environmental responsibility.

Sidist kilo campus contains a mix of mature trees, gardens, grassy lawns, and semi natural vegetation distributed across its academic, administrative, and residential zones. However, these green spaces are increasingly fragmented by buildings, roads, and paved surfaces. This imbalance between permeable and impermeable surfaces contributes to excessive runoff during rainfall events, which overwhelms existing drainage infrastructure.

A preliminary mapping and spatial analysis of the campus using satellite imagery and GIS tools reveals that green infrastructure covers 50% of the total campus area, leading to limited capacity for natural storm water infiltration. Without intervention with green infrastructure development, this not only exacerbates surface water pooling and erosion but also reduces groundwater recharge and increases pollutant load entering urban drains.

Institutional GI assessments help quantify the performance and potential of existing green assets in mitigating storm water impacts. For sidist kilo campus, such an assessment involves:

- ✓ Mapping existing vegetative cover and identifying high-runoff zones.
 - ✓ Estimating green infrastructure's storm water retention and infiltration capacity.
- Identifying opportunities for green retrofits, such as permeable pavements, rain gardens, bios wales, and green roofs.

This spatially explicit analysis serves as a baseline for future infrastructure planning and demonstrates the viability of nature-based solutions at the institutional level. It also aligns with sustainable campus development strategies and environmental education goals.

To strengthen the role of green infrastructure in storm water management at sidist kilo, the following measures are recommended:

Green Infrastructure Expansion: Increase vegetative cover through native tree planting, green corridors, and conversion of unused paved areas into green zones.

Storm water Modeling and Monitoring: Use hydrological models to simulate runoff behavior and assess GI effectiveness under different rainfall scenarios.

Integration into Campus Planning: Ensure that future development plans prioritize green infrastructure alongside traditional utilities.

Policy and Engagement: Institutionalize GI planning through campus environmental policies and engage students and staff in green stewardship programs.

5. Conclusion

One of the most significant components of urban storm water management strategies, GI is deemed to be a green and sustainable technology for storm water runoff management and water quality enhancement, providing a wide range of hydro-logical and ecological benefits in response to fast urbanization and climate change.

The types of green infrastructure developed in the study area retention ponds, grasses, rain gardens are among the many GI types that contributed the slow rate of flow there by avoid instantaneous flood occurred. To estimate the maximum runoff generated from the study area we used the Gumbel's method, the data obtained from the meteorological agency data; and the result from the study depicts an increase in areas of green space reduces the rate of flow and the volume of storm water runoff.

Therefore, our conclusion is that managing the storm water runoff is possible without building further extension of the existing culvert structures thereby building weirs, detention ponds and proper management of the green infrastructure is required so as to serve and retain the storm water more efficient way and for the maximum benefits. From the result, increase the area of green infrastructure decreases the storm water runoff.

According to the study from different scholars' best management practice building Green infrastructure recovers the natural environment. Hence an argument is reached that the green infrastructure helps to reduce the storm water runoff.

Acknowledgment

I would like to express my heartfelt appreciation for the invaluable support and guidance provided by my advisor, Dr. Dagnachewu Adugna. His unwavering dedication to his students, demonstrated through his comprehensive knowledge in our field, was pivotal to my academic journey. Throughout the process of developing my thesis, Dagnachewu Adugna (Dr.) offered insightful feedback that challenged my thinking and refined my arguments, significantly shaping the direction of my research. I am particularly grateful for the countless hours he devoted to meticulously reviewing my drafts, offering constructive criticism that not only improved the clarity and depth of my work but also enhanced my overall understanding of the subject matter. His encouragement and mentorship fostered an environment in which I could explore complex ideas and grow as a researcher. The experience of working closely with him has been invaluable, and I am truly thankful for the profound impact he has had on my academic development.

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