



Ethiopia Institute of Architecture, Building Construction and City Development

Low Impact Development (LID) Design Retrofit to Reduce the Impact of
Flooding and Diffused Pollutants from Affecting the Urban Lakes, The Case of
Hawassa City, Ethiopia

For

The partial fulfilment of MSc in Urban Design and Development.

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This thesis is submitted to the Ethiopian Institute of Architecture, Building Construction and City Development/EiABC/ and to the school of graduate studies at Addis Ababa University in partial fulfilment of the requirements for the degree of Master of Science in Urban Design and Development.

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Low Impact Development (LID) Design Retrofit to Reduce the Impact of Flooding and Diffused Pollutants from Affecting the Urban Lakes, The Case of Hawassa City, Ethiopia

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Confirmation

Herewith I state that Yared Dereje has carried out this research work on the topic entitled “*Low Impact Development (LID) Design Retrofit to Reduce the Impact of Flooding and Diffused Pollutants from Affecting the Urban Lakes, The Case of Hawassa City, Ethiopia*” under my supervision and it is sufficient for submission for the partial fulfilment for the award of MSc Degree in Urban Design and Developments.

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Abstract

Rapid urbanization has become a prevalent trend in the twenty-first century, putting development pressures on existing urban areas as a result of socio-economic changes, which has an impact on the natural system, particularly the hydrological system, by increasing flooding and degrading water quality. The recent expansion and densification of Hawassa city contribute greatly to the generation of more pollutants, which are transported to the city's lake through stormwater runoff from built-up areas. The objectives of the study is to see how fast urbanization impacts the city's natural environment, particularly the lake ecology, while also addressing sustainable stormwater management to safeguard the city's lake using the Low Impact Development (LID) site design approaches. The city's natural and man-made land cover were investigated to determine the source of Lake Hawassa's ecological problem, which was connected to an increase in impermeable surfaces. In this regard, the study used a data set that included a Digital Elevation Model (DEM), a high-resolution satellite image, an existing land use map, precipitation data, and water quality samples. Using spatial analysis tools in QGIS 3.6.3 and a simulation model in SWMM 5.1, the quantity and quality of stormwater runoff impacting the lake environment were evaluated. The imperviousness level of 14 sub-catchments that directly flow into the lake, as well as the pollution load from impacted catchments, have all been investigated to determine which sub-watersheds contribute the most pollutants to the lake. The study revealed that between 2013 and 2018, the imperviousness level in catchments that directly drain to the lake increased from 12.20 % to 20.32 %. That shows an increment of 43.4 % of runoff from impervious covers within five years period. COD, TSS, TN, and TP levels in water samples tested from the degraded catchments' lake intake streams were 2307.5, 510.5, 2.09, and 10.4 mg/l, respectively, which are all above the permitted range. The SWMM model's simulation results also show that surface water quality is substantially degraded and exceeds acceptable limits. The study identified various types of LID design features as well as potential retrofitting open spaces in the study catchments. After incorporating the proposed LID retrofits, simulated results reveal a reduction of 16.0 % and 17.4 % in stormwater runoff and peak flows for catchment 10 (C10) and a drop of 66.3 % and 5.0 % for catchment 11 (C11). Regarding to water quality, the COD, TSS, TN, and TP pollutant loads were reduced by 16.5 %, 16.2 %, 16.3 % and 16.3 %, and for C10 and 26.7 %, 13.1 %, 26.6 percent, and 26.2 %, for C11 respectively. Finally, flooding and water quality impairment shows the disruptions in the urban hydrologic cycle resulting from the construction of more impermeable surfaces have contributed to the degradation of Hawassa Lake's water quality. Incorporating effective LID solutions into the city watershed management systems and limiting a significant increase in impervious surfaces in urbanized catchments has the potential to reduce urban flooding, nonpoint source pollution into the lake, and the oncoming environmental crisis.

Keywords

Imperviousness, Urban Hydrology, Urbanization

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Acronyms and Abbreviations

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
C10	Catchment 10
C11	Catchment 11
EMA	Ethiopian Mapping Agency
EMC	Event mean concentration
EEA	European Environment Agency
EPA	Environmental Protection Authority
ESUD	Ecological sensitive urban design
FDRE EPA	Federal Democratic Republic of Ethiopia Environmental Protection Authority
GI	Green Infrastructure
GIS	Geographic information system
HCA	Hawassa City Administration
IC	Impervious Cover
LID	Low Impact Development
LULC	Land Use Land Cover
NMA	National Meteorology Agency
NPSP	Nonpoint source pollution
SMP	Sustainable Management Practices
TSS	Total suspended solids
US EPA	United States Environmental Protection Authority
WEPA	Water Environment Partnership in Asia
WSUD	Water sensitive urban design

CHAPTER ONE: INTRODUCTION

1.1 Background

Under the development pressures and socio-economic changes of cities, urban and urbanizations have become a pervasive trend of our future. As the spaces and environment of cities get into expansive sprawl and densification an environmental challenge to the urban hydrologic and climatic effects on the surrounding natural features. As space is a finite resource, the ever-increasing demand for land in urban uses, such as housing, workplaces, recreation, infrastructure, and transportation networks, intensifies the pressure on the natural ecosystems (Costa, 2015). The sustainable environmental approaches consider cities, that comprehend the built and natural environment in the focus of inclusive, safe, resilient and sustainable cities stated on the new urban agenda (NUA) 2016. The global prominence now given to urbanization is nuanced, drawing both on traditional views that urbanization creates negative externalities such as environmental degradation. This recognition, according to the same document, goes beyond viewing urbanization as a simple demographic phenomenon instead of as a transformative process capable of galvanizing development momentum (UN-Habitat, 2020).



Figure 1.1-1 Flooding in Calgary, Canada.

Source: (Ndubisi, 2014) Photograph from Wikimedia Commons.

Urban flooding runs out of planned drainage lines to public infrastructures which causes enormous impacts on the lives and facilities of the urban environment as shown on (Fig. 1.1-1) (Ndubisi,

2014). Such challenges have been shown in increments and criticality reflected as flooding and pollution through day-to-day experiences of cities (Melaku, et al., 2019). The urbanization trend shows both the sprawl and densification by diverse anthropogenic activities of living, working and transportation systems in cities. Imperviousness is a significant indicator as land cover changes in the urban environment leads to an increment in urban flooding (Schueler, 1994) (US EPA, 2018). Beyond the flooding impacts, urban pollution led to environmental degradation of the water, air and soil of the urban areas. Pollutants from impervious surfaces are defined as nonpoint sources of pollution (Schweitzer, Noblet, 2018). That is also called diffused sources by land covers, activities and behaviour of urban areas (Petrucci, et al., 2014).

For the past decade, Ethiopia has made tremendous strides in its economic growth, poverty reduction and developmental progress yet remains a lot to overcome. However, this developmental focus on the built environment and related infrastructures has diverse impacts on the environment. Harmonizing such divergent interests necessitates the implementation of strategic initiatives aimed at reducing the impact of pollution impacts to water environments, which Ethiopian urban rivers and lakes have currently challenged (Dadi et al., 2018). Beyond the casual flooding of stormwater systems, local reports have shown critical damages by flooding in the different parts of the country on 2020/21 GC. In the case of Hawassa, the urban stormwater is channelized to the lake. Flooding that overflow from the stormwater systems because of sedimentation and the size of channels has been identified as a problem (Adane, 2019). The urbanization and Land Use Land cover change LULC change of Hawassa city has studied by different researches showing significant change though time. Wondrade et al. (2014) and Paulos (2014) have shown the increment of the built-up and cultivated covers that has a critical contribution to flooding, pollutants and sediments to the water environment.



Figure 1.1-2 Areal pictures of Hawassa city in different years.

Source: (Tekalign, 2013) cited (www.hawassaturism.html)

The city Hawassa was founded in 1952 E.C. by Ras Mangesha Siyoum & under the permission of Emperor Haile Selassie. The early settlement was an area called Arab-Sefer. In 1953 E.C four hundred and four pensioned soldiers and their families (not less than 1,000 people) were provided with plots to settle in the eastern part of the town which is now called “404 Sefer”. This is a start to have given an impetus to the growth and development of the town. At this time the total settlement area was around 48 hectares; and by the end of 1958 E.C, the population grew to 5,460 (FUPI, 2006).The town of Hawassa takes its name from "Hawassa hayik," which means large or wide water body and before the establishment of the town, the area was known as "Adare," which means "field of cattle" in the Sidama language (FUPI, 2006). Tabor hill also used to be known as “Title” or “Dime” hill, which in Sidama language means a dish, with which cultural food is served. Before the foundation of Hawassa town, the area where the present town lies and its environs were covered by forest (Fig. 1.1-2), which used to house a variety of wild animals. The first settlers of the area were the pastoral Sidama people. This settlement brought about a sedentary way of life and the increasing importance of farming that put pressure on the immediate natural environment, which is the source of livelihood for the sedentary farmers. Thus, with the ever-increasing population and its increasing demand for new farmland as well as wood as a source of construction material and household energy, the natural forest and the natural habitat of the wildlife had been depleted (FUPI, 2006).

1.2 Problem Statement

The natural land cover change to impervious surfaces has significantly impacted the water environment with increased runoff and degradation of the stream water quality. Changes in a catchment that alters the existing land use have a significant influence on the water environment's quantity and quality features (Arnold & Gibbons, 1996) (Goonetilleke, 2004). And stormwater runoff from steadily increasing impermeable surfaces in cities has emerged as a major concern to water quality (US EPA, 2018).

Hawassa city is a planned and well-developed urban area in the country that is adjacent to the water environment. Recent reports show the challenge of flooding on a seasonal basis. Beyond global climatic factors, the land use land cover change and anthropogenic activities associated with urbanization cause the impact very severe. Yet the level of impact of the urbanization trend has not been identified very well. According to recent studies, the natural environment of the city is being harmed as a result of rapid urbanization, which has caused ecological degradation, the

connectivity of ecological services to be disrupted, resulting in flooding and air pollution (Dinku, 2018). Urbanization has shown significant change to the built environment as the built-up area had increased by 234.5% between 1987 and 2011 (Wondrade, et al., 2014). Likewise, pollution impacts have been exceeding with population and development of cities (Moga, et al, 2021). Pollutants after dilution within the lake measured as BOD test on the lake and the city areas ‘Amora gedel’, ‘Yefikr haik’ and Haile resort area has measured 157.7 mg/L, 136.7 mg/L and 94.5 mg/L (Woldesenbet, 2015). The concentration of BOD at all sites exceeds the EPA's permissible threshold (five milligrams per liter) for aquatic species, indicating that the lake is significantly polluted by organic waste (Woldesenbet, 2015).

Pollutant loads are caused by urban stormwater, agricultural runoff, overgrazing, deforestation, and soil erosion whereas the pollution impact from the urbanized landscape flows to this natural feature (Melaku, et al., 2019). Similarly, Atnafu (2014) describes the pollution impacts of the lake not only by the urban runoff but groundwater flows to the Lake Hawassa. The diffused pollution from the urbanized landscape has been discussed in some literature studies as Desta (2003) states the Lake, river and swamps are in serious ecological problems due to harmful anthropogenic activities. Most studies focus on point source and gross impacts on the lake environment. Whereas the contribution of the urbanized area has a significant impact on the lake environment. The contemporary approaches to stormwater management on urban setting has introduced sustainable ways as low impact development (LID) strategies that has not practice broadly.

1.3 The Objective of the Research

1.3.1 General objective

The general objective of this study is to develop watershed-level retrofitting strategies through incorporates LID design elements as a retrofit.

1.3.2 Specific Objectives

The specific objective of the Research is;

1. To map the sub-watersheds of the urbanized landscape to estimate runoff generated by the impervious surfaces,
2. To identify the water quality level from impacted catchments type and concentration of pollutants originating from the impervious surfaces of the impacted watershed and
3. To identify LID retrofits with ideal site conditions to disconnect the flow of polluted stormwater runoff into the lake.

1.3 Research Question

- How is the natural watershed drain to the lake on the urbanized zone of Hawassa city?
- How much is the imperviousness level of the sub catchments?
- Which sub-catchment is the most impacted due to a higher level of imperviousness?
- What are the major diffused pollutants and levels of concentrations from the impervious surfaces?
- How LID strategies can reduce stormwater runoff and pollutant concentration from the impacted watersheds?

1.4 Scope of the Study

Considering the urbanization trends near the water environments, the geographic scope of the study is specifically on the city and the lake Hawassa. Following the watershed patterns, catchments that directly drain into the lake are the main focus. The thematic scope focuses on the land cover change with stormwater management aspects considering the flooding and diffused pollutants generation.

It focuses on physical parameters of imperviousness level, runoff from impervious surfaces, diffused pollutants from the impervious surface and LID strategies to reduce the negative impact on the lake ecology. It surveys the urbanized sub-watershed zone of the city drain to the lake, the Imperviousness level and its cause of flooding and diffused pollution on the ecological environments has examined with simulation and water quality sample at one rain event.

1.5 Limitation of the Study

The study reviews the built-up factors that have an impact on urban hydrology. It only examines the LULC change specific to the impervious area. Lacking contextual reference data for the specific land uses in the area has limitations on the accuracy of pollutant load on-site. Although the researcher had taken water quality samples to a specific context the specific point source pollutants, seasonal variance and diverse water quality parameters as heavy metals have not been examined because of time and budget constraints.

It focuses on a quantitative assessment of the contribution of the urbanization trend to runoff and diffused pollutants from the urbanized catchments. Other socio-economic and existing drainage system stormwater management have not been covered by this study. Uncovered spatiotemporal factors and the effectiveness of the retrofitting measures has stated for further study.

1.6 Significance of the Study

Sustainability and resilience of cities become the imperative case of urban studies to address the current and future development directions of our environment. And water as a means to live has a direct impact on our daily activity. The use and integration of this resource have an impact from global to regional, national and individual levels impacts reflected recently need means and considerations to the integration of man with nature. Water environments in the rift valley have the potential to develop as an urban environment that have not been explored very well. Whereas urbanization with such natural environment has significant impacts that need critical focus. This study reveals the impact of urbanization on the water environment. As a glimpse to see the trend and possible approaches to stormwater management, the study helps to consider the impact and retrofitting strategies by planners, designers and practitioners in this area.

The findings of this study will contribute to the understanding and improvement of required techniques for sustainable stormwater management in Hawassa city. As the impact of flooding and pollution has shown clear challenges to the city, the study implies factors and methods to reduce the impact of floods and diffused pollutants caused by impervious surfaces, which intensify the deterioration of Lake Hawassa and the lakefront environment.

1.7 Organization of the Paper

The paper is organized into five chapters. The first chapter describes the research brief as the background of the study, problem statement, objective of the research and overall research scheme. In the second and third chapters, literature reviews and the methodology for specified objectives has described and presented. And on the fourth chapter, the results and discussions have described the level and impacts of flooding and pollution on the environment. And on the final chapter conclusions and recommendations have been presented that imply the research finding as a whole.

CHAPTER TWO: LITERATURE REVIEW

2.1 Definition and Context

*Water, the Hub of Life. It is mater and matrix, mother and medium. Water is the most extraordinary substance!
Practically all its properties are anomalous, which enabled life to use it as a building material for its machinery.
Life is water dancing to the tune of solids.*

Albert Szent-Gyorgyi, 1972

2.1.1 Definition of Terms

The general concepts and terms related to stormwater management have covered in this part. Terms as urban and urbanization, watershed, imperviousness, runoff and flooding, and also diffused pollutant load has reviewed as follows;

Urban¹ and urbanization have been defined as:

UNEP (2018) states the urban environment as an area where households are clustered together into coterminous neighborhoods with recognizable socio-physical space that is distinct from the surrounding rural area. For most entities, there are two primary components to a definition of what is urban: *population size* and *population density* (Douglas, 2011). The fundamental character of the urban area has been reviewed as the presence of lots of people, anthropogenic activities on land uses, and altered forms of land cover – which have ramifications on biota, ecosystem processes and social patterns (e.g., sense of community). And the term "urbanization" means an expansion of an existing human population. Specifically, the proportion of total population or area in urban locations or areas (cities and towns). That has shown an exponential rate at which the urban proportion is growing (UNEP, 2008). In this study, urbanization has been measured as land cover change. It focuses on impervious surfaces and diffused pollutants generation.

An *impervious cover (IC)* is a man-made material or structure that slows the rate of precipitation infiltration (either intentionally or, unintentionally (Moore, 2017). Furthermore, those are any materials that prevent water from infiltrating into the soil, and their coverage is a quantifiable land-use indicator that correlates closely with the stormwater discharge (Arnold & Gibbons, 1996). On the contrary, *open spaces* refer specifically to areas left unbuilt, while sectors adjacent to them are developed (Friedman, 2021). An imperviousness has been discussed as an indicator of the stream water quantity and quality of urban watersheds by Schueler (1994).

¹ The Oxford Advanced Learner's Dictionary, 8th edition defines urban as "pertaining to or characteristic of, occurring or taking place in, a city or town."

Precipitation seeps into the earth, refilling the Earth's groundwater. The majority of it runs downhill as *runoff*. Runoff keeps rivers and lakes flowing with water, yet it also causes erosion, which affects the terrain. Uncontrolled factors such as the precipitation and human activities such as urbanization and agriculture change the hydrology of streams, rivers and lakes. Depending on the occurrence and sources runoff² can be categorized differently (UNEP, 2008).

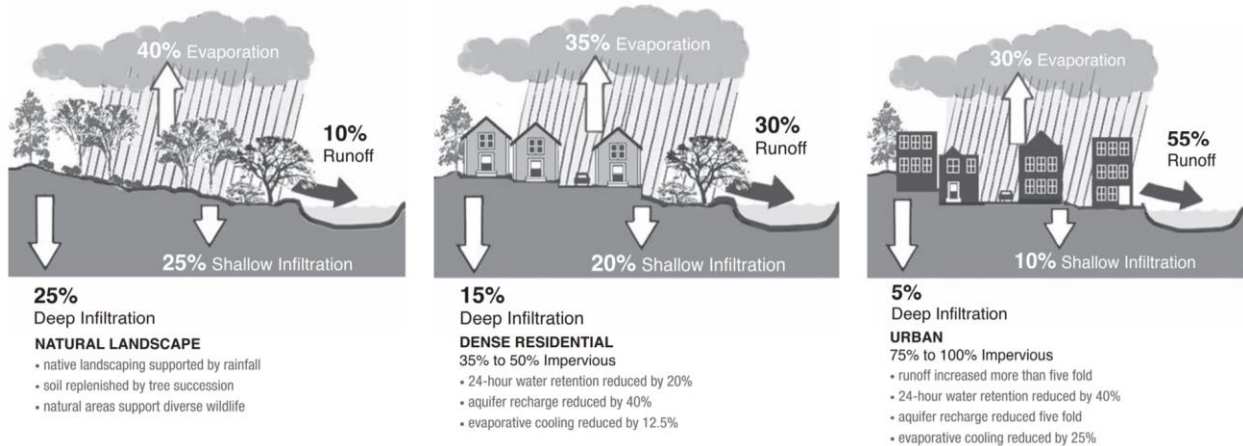


Figure 2.1.1-1 Stormwater runoff, Impervious surfaces and Infiltration factors.

Source: (Watson & Adams, 2011) cited U.S. Department of Agriculture, Soil Conservation Service. Technical Release No. 55, 2nd ed. (Washington, DC: Author, 1986).

Flood is a term described as inundation shortly. And the term "flood inundation" in this study refers to the presence of undesired water in the urban environment as defined by (Moore, 2017). And an urban flood is defined as 'excessive runoff in developed urban areas, where stormwater has nowhere to go due to poor capacity of the drainage system, resulting in inundations' (Vazhuthi, 2020) although stated as 'overland flow' (Cahill, 2012). This definition indicates two components for flood occurrences, which are the *rainfall intensity* and the *drainage area features* (Şen, 2018). It is also defined as inundation by the water of any land area that is not normally covered by water as a result of a relatively rapid change in the level of the particular flow of water (UNEP, 2008). The amount of storm runoff generated from a watershed depends on the *watershed area*, *land uses* *soil types* and *depression losses* on the surfaces. The movement of storm runoff through a watershed is characterized by the waterway's *length*, *slope*, *floodplains*, and *vegetation condition* (Guo, 2017).

² it can be characterized as direct runoff or base runoff based on how quickly it appears after rainfall or melting snow, and as surface runoff, storm interflow, or groundwater runoff based on its source.

Retrofit³ or retrofitting are the primary practice used to restore sub watersheds since they can remove pollutants, promote more natural hydrology and minimize stream channel erosion (CWP, 2007). And the storm water retrofit means a stormwater management practice designed for an existing development site that previously had either no stormwater management practice in place or a practice inadequate to meet the stormwater management requirements of the site.

A natural drainage network collects surface runoff from its *watershed*⁴. Also called “watershed”, “river basin” or “catchment” it can be stated based on the size as referred on (USEPA, 2005) and referred in literature (Table. 2.1-1). It's a geographical feature that may be found on a map by drawing a line between two places peak elevations, usually at the ridge. Vast numbers of smaller drainage basins can be found in large drainage basins (UNEP, 2008). The land region where precipitation flows off into streams, rivers, lakes, or reservoirs is referred to as the catchment area. A watershed is defined by its boundaries along the ridgelines (Guo, 2017). *Catchment* is termed as the catching of water that flows the stormwater cycles. The surface area is drained by a network of stream channels. And the *catchment area* is all areas that contribute surface water to the intake area (Fig. 2.1-2 (C)). These areas are tributary to a lake, stream, sewer, or drain (Fig. 2.1-2).

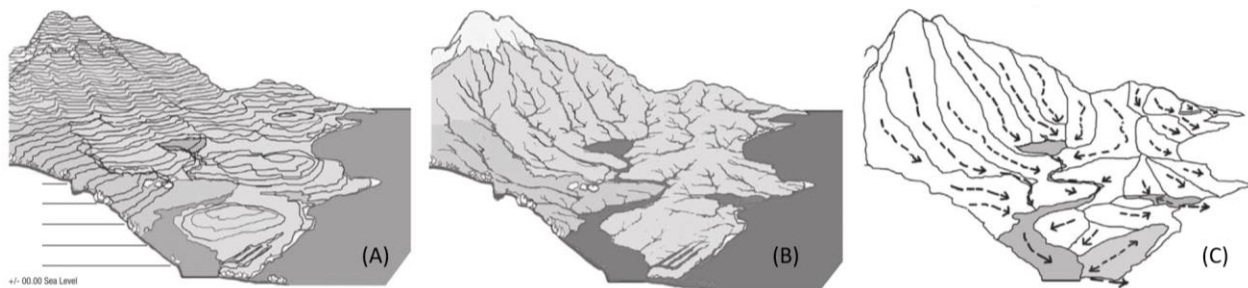


Figure 2.1.1-2 The watershed (A) contour (B) streams and rivers and (C) drainage divides.
Source: (Watson & Adams, 2011)

³ The Oxford Advanced Learner's Dictionary, 8th edition defines as 'to put a new piece of equipment into a machine that did not have it when it was built; to provide a machine with a new part, etc.'.

⁴ The land area that drains water to a particular stream, river, or lake. It's a geographical feature that may be found on a map by following a line between two regions, generally ridges, by topographic divisions that drain a certain stream or river. And Natural or disturbed terrain on which all water that falls (or emerges from springs or melts from snowpacks), pools by gravity, and does not evaporate, courses off through a single exit. All lands are defined on all sides by a continuous hydrologic drainage part and lying upslope from a specific point on a stream; a region or area bounded on all sides by a water parting and eventually draining to a specific watercourse or body of water. Also known as a Water Basin or a Drainage Basin.

Alteration in urbanized catchments impact both water quantity and quality factors of the urban hydrology. And diffused pollutants⁵ are one of the major factors on water quality degradation. Runoff from urban areas, farmland, construction sites, etc., is known as diffused or nonpoint source pollution. Acidic deposition in rainfall and dry fallout also is a nonpoint source of pollution (Boyd, 2015). Diffused or Non-point source (NPS) pollutants that move in association with or attached to particles include total suspended solids (TSS), phosphorus (TP), most organic matter (as estimated by COD), metals, and some herbicides and pesticides (Cahill, 2012).

2.1.2 The global and regional context

There is a long history of building cities on or near rivers to have access to clean drinking water and navigable waterways that provided a means for transportation/ trade and conveyed wastes away from the city. The case of urban expansion in the US has caused an expansion of impermeable surfaces (cement and asphalt through which water does not flow) and a significant loss in naturally vegetated regions after WW II and has accelerated over the previous decades (Sun, et al., 2019). Forman (2014) has described trends of urbanization and stormwaters as no place even mimics the water flows of an urban area. Urban stormwater design that streams are channelized, disappearing into pipes and reappearing "magically" over hard surfaces and through pipes.

The environments in cities have been extremely altered as a change in human lifestyle, consumerism and unsustainability on material productions on urban scenarios (Perini and Sabbion, 2017). Natural land surfaces have been replaced by paved and impervious surfaces in urban environments to allow for more convenient living and working whereas the disturbance to the natural hydrological cycle occurred as shown in (Fig. 2.1.1-1 and 2.1.1-2). Roads, roofs, and pavements reduce the retention and infiltration capacity previously existed by soils or vegetation (Illgen, 2011). On the characterization of a specific catchment, streams that were once natural may now be channeled into artificially modified or constructed channels in urban hydrologic systems, rather than flowing naturally (Fig.2.1.1-2) (Watson & Adams, 2011). Impervious surfaces such as buildings and road networks drain the stormwater via storm drains, pipes, and ditches, resulting in a variety of storm sewer systems (Forman, 2014). As shown below (Fig. 4) the land cover change of a catchment's first-order stream patterns leading disruption to natural hydrological systems.

⁵ Pollution sources which are diffuse and do not have a single point of origin or are not introduced into a receiving stream from a specific outlet (UNEP, 2008).

The primary goal of the urban drainage system is to get the water out of the way as quickly as possible. There was no concern about stream flow rate, volume, frequency, duration, or water quality. For millennia, this meant sizing pipes and drainage systems large enough to carry water away from a place efficiently (Echols, et al., 2015). The stormwater management systems vary to infrastructure development and contextual factors. Conventionally there are two types of sewerage systems. Those are combined and separate systems in which stormwater and wastewater could be managed (Butler, et al., 2018). It includes a combined sewer system (CSS), sanitary sewer system (SSS), and municipal separate stormwater sewer system (MS4) (Sun, et al., 2019).

Urban stormwater management practices in Ethiopia are still in their early stages of development. However, there are a number of initiatives underway to improve stormwater management in the country. One of the most important initiatives is the development of a national stormwater management strategy. This strategy will identify the key challenges and opportunities for stormwater management in Ethiopia, and will outline a plan for addressing these challenges.

Challenges of urban stormwater management in Ethiopia are significant. The country is experiencing rapid urbanization, which is leading to increased impervious cover and decreased infiltration. This is putting a strain on existing stormwater systems and increasing the risk of flooding. However, there are also a number of opportunities for improving stormwater management practices. With the right investments and initiatives, Ethiopia can make significant progress in improving stormwater management. This will help to protect the environment, improve public health, and reduce the risk of flooding.

There are some specific examples of urban stormwater management practices at different scales on public and private developments as the rain gardens, green roofs, porous pavements and stormwater harvesting at different scale. Rain gardens are vegetated areas that are designed to collect and filter stormwater runoff. They are a low-cost and effective way to manage stormwater at the source. Green roofs are vegetated roofs that provide a number of benefits, including stormwater management, improved air quality, and reduced energy consumption. Porous pavement is a type of pavement that allows water to infiltrate into the ground. It is a good alternative to traditional pavement in areas where stormwater management is a concern. Stormwater harvesting is the collection and storage of stormwater for reuse. It is a sustainable way to manage stormwater and reduce the demand for potable water.

As the country continues to urbanize, it is important to continue to invest in stormwater management practices that will help to protect the environment and improve public health.

2.1.3 Flooding, Diffused pollutants with the Water Environment

On the subject of water, two quantity and quality questions always arise. How much and how clean or polluted it is (Forman, 2014). The study arises from the flow of water and its impact between the urban landscape and the lake. The placement and timing of return flow via sewage effluent can have a major impact on water quality and quantity along a stream. The degree of urbanization (Fig. 2.1-3), which increases runoff volume and peak flow rates, is closely associated with increased pollutant concentrations reported in urban runoff (Sun, et al., 2019).

Related to the urban environment and pollutant⁶ generations vary and intermit to the environment in different ways. From different sources of pollution to the surrounding and specifically to the surface water impairments, diffused pollutants are stated. Improperly disposed of junk or rubbish generated by human activity frequently winds up in waterways that are considered *trash*⁷ and *litter*⁸. And other chemicals that have an impact on humans and other organisms are taken as a *toxin*⁹. The lowest concentration at which mortality can be detected is the threshold toxic concentration. The threshold concentration also may be defined as the minimum concentration necessary to cause some response other than death (Boyd, 2015) (see Chapter 2.3.3 for details).

⁶ The National Pollutant Discharge Elimination System (NPDES) defines a pollutant as any sort of industrial, municipal, or agricultural waste discharged into water. Dredged soil, solid waste, incinerator residue, sewage, rubbish, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste are just a few examples. According to the law, sewage from vessels or emissions incidental to the normal operation of an Armed Forces vessel, or certain items pumped into an oil and gas production well, are not a pollutant. (Source: NPDES Permit Basics | US EPA)

⁷ Trash can include cigarette butts, paper, fast food containers, plastic grocery bags, cans, and bottles, used diapers, construction site debris, industrial plastic pellets, old tires, and appliances (CWT, 2021).

⁸ All improperly discarded waste material, including, but not limited to, convenience food, beverage, and other product packages or containers constructed of steel, aluminum, glass, paper, plastic, and other natural and synthetic materials, thrown or deposited on the lands and waters of the state, but not including the properly discarded waste of the primary processing of agriculture, mining, logging, sawmilling, or manufacturing (CWT, 2021).

⁹ There is a large number of potentially toxic chemicals, but the major classes of chemicals are petroleum products, inorganic compounds such as ammonia, heavy metals, and cyanide, pesticides and other agricultural chemicals (CWT, 2021).

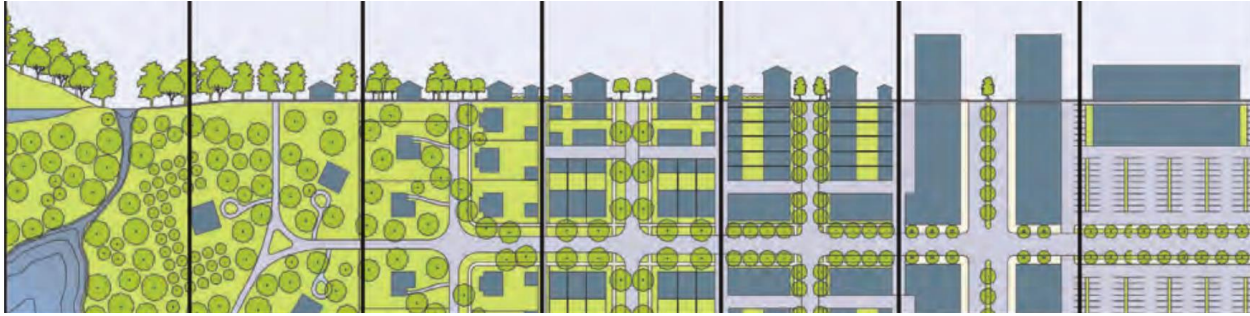


Figure 2.1.3-3 Urbanization and alteration to the natural environments.

Source: (Rouse & Bunster-Ossa, 2013)

2.1.4 Water and Environmental Sustainability

Cohen (2018) defines the “sustainable city,” highlighting several key environmental aspects. He states that the sustainable city uses as few nonrenewable resources as possible, uses energy and water as efficiently as possible, and attempts to reduce and recycle waste, minimizing the impact of waste disposal. Although the emphasis of each definition differs, putting environmental sustainability first is a priority in each case (Friedman, 2021). The water and ecological sensitive urban design principles consider the utilization of water and ecological factors in the urban environments. Since greenspaces and spots of green cover typically have very low runoff percentages, the spatial arrangement of impervious and vegetated surfaces is a key to stormwater flows (Forman, 2014).

Lotic (flowing) ecosystems, such as streams, rivers, and estuaries, are comprised of abiotic and biotic components that work together to perform ecological functions (Sun, et al., 2019). Whereas the urban systems are the configuration of spaces, infrastructures, buildings and activities of consumption, activity and movements of particular urban settlements and cities that have imposed on the natural hydrologic and environmental process of nature (UNEP, 2008). The wetlands are areas with natural depression. (Boyd, 2015)cites Cowardin et al. (1979) for the definition of wetlands indicating shallow water or a water table that is at or near the ground surface. In addition, an area that is periodically or permanently saturated with or covered by water has wet soil that is aerobic and water-loving plants are characteristics of wetland areas (UNEP, 2008).

2.2 Urban Hydrology and Flooding

“The 21st-century urbanization questions the ability to orientate ourselves in a landscape of risk, defined by the impacts of increasing human activity in a complex relationship with nature”

Kuzniecowa Bacchin

“When a city is inundated with water, the water will move in all of the streets. Even pathways that have been made will be used. It doesn’t matter the reason of its making.”

John de Ruiter

Water is constantly in motion. It constantly circulates between the atmosphere, land, and water bodies, and this movement is described by the water cycle—the most basic principle of hydrology (Illgen, 2011). The hydrologic cycle (Fig. 2.2-1) is the flow of water on Earth and the atmosphere. It is a dynamic and integrated system of flows that are influenced by a variety of interacting processes such as precipitation, infiltration and percolation, evapotranspiration, snow accumulation and melt, canopy interception, condensation etc. When the temperature and atmospheric pressure are just right, the gas condenses into a liquid, and precipitation falls in the form of rain, snow, hail, etc. (Sun, et al., 2019).

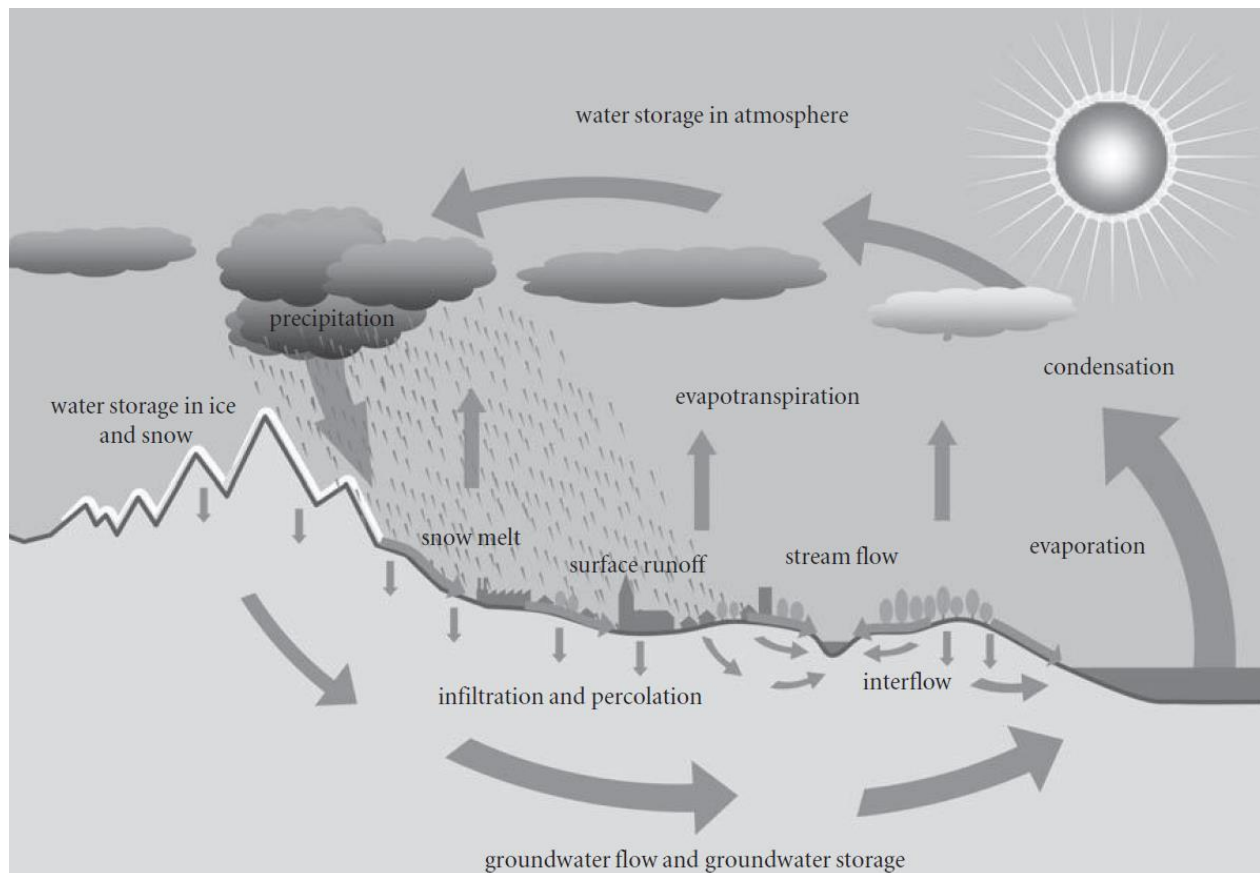


Figure 2.1.4-4 The natural hydrologic cycles
Source: (Illgen, 2011)

Stormwater, however, can be intercepted by vegetation, buildings, and other objects, where it can evaporate or move from these surfaces to the land surface. As water hits the ground surface, it goes through one of three stages (Sun, et al., 2019):

- (1) *Water is temporarily stored in natural depressions*, such as pits and trenches, and is largely lost due to evaporation.
- (2) *It immerses into the soil*, i.e., infiltration. some of the infiltrated water evaporates from the soil or is transpired by plants. These processes are referred to as evapotranspiration when they are combined. Following infiltration, the remaining water moves downward through the soil profile in a process known as percolation and recharges the groundwater, which eventually discharges into streams and returns to the ocean (groundwater flow), where the cycle begins again.
- (3) When the soil's water retention capacity is exceeded, rainwater may *flow over the surface* (surface runoff) and eventually reach the ocean (Sun, et al., 2019).

2.2.1 Cause and Factors on Degradation of Urban Hydrology

Urbanization significantly impacts the water environment with increased runoff and the degradation of water quality (Goonetilleke, 2004). The natural hydrology is modified by the urban surface, with large impermeable areas that encourage rapid runoff and decrease infiltration. The increment in the impervious surface is the major and directly related factor to runoff and flooding stated in different reviews by scholars (Schueler, 1994) (Forman, 2014) (Douglas, 2011). Consequently, the natural hydrologic cycle shifts from infiltration and evapotranspiration-based system to one dominated by surface runoff (Sun, et al., 2019).

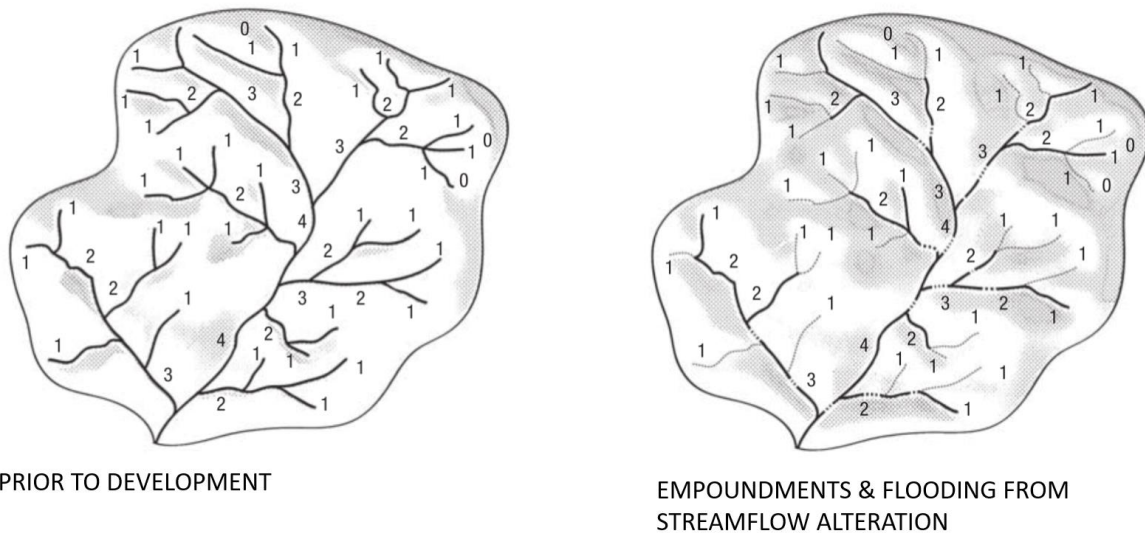


Figure 2.2.1-1 Changes for the urban stream before and after development.

Source: (Watson & Adams, 2011)

Impervious surfaces not only indicate urbanization but also contribute significantly to environmental degradation in both the quality and quantity of the stormwater flows. When natural landscapes have all been paved over, a series of events occur that usually results in degraded water resources. Changes in the hydrologic cycle, which governs how water is transported and stored, start this chain (Arnold & Gibbons, 1996). The majority of precipitation infiltrates into the soil and evaporates into the atmosphere in natural watersheds. The capacity of subsurface water transport also limits infiltration. Water movement within the subsurface is determined by infiltration into the subsurface (Illgen, 2011).

Schueler (1994) categorizes the component and level of imperviousness as follows: the two primary components – *the rooftop* of buildings, and *the transport system* (roads, driveways, and parking lots). And the urban streams have three management categories based on the general relationships between the IC and stream quality:

1. Stressed Streams: (1 to 10% Impervious cover)
2. Impacted Streams:(11 to 25% Impervious cover)
3. Degraded Streams:(26 to 100% Impervious cover)

"Stressed Streams" are the most protected category, with strict zoning, site impervious restrictions, stream buffers, and best management practices used to maintain predevelopment stream quality. And "Impacted Streams" are above the threshold and can be expected to degrade after development. The third stage, "Degraded Streams," recognizes that even when best management practices or retrofits are fully implemented, predevelopment channel stability and biodiversity cannot be fully maintained. In degraded streams, the primary resource goal shifts to protecting downstream water quality by removing urban pollutants (Schueler, 1994).

The general factors related to urban flooding have been identified and classified into two categories: Solvable – Unsolvable by altering the planning guidelines shown (Fig. 2.2-3) (Vazhuthi, 2020). Factors discussed as direct causes are urbanization as alteration of the land cover and the built-up density factors dominantly.

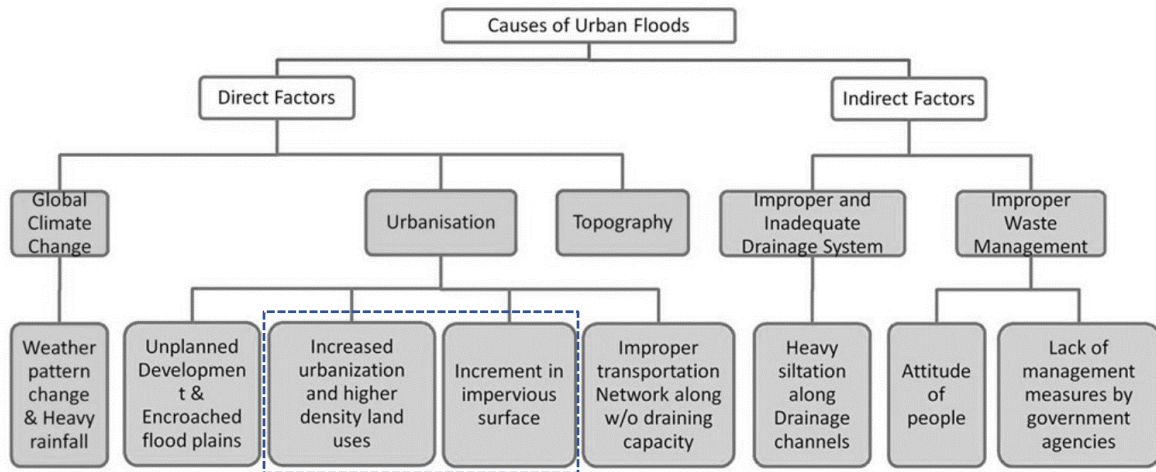


Figure 2.2.1-2 Causes of Urban Flooding

Source: (Vazhuthi, 2020)

According to Watson & Adams (2011) riverine flood conditions change due to three combined factors. Firstly, as *Increased rainfall*, both in intensity and number of events. Rainfall frequency, amount, and extremes are increasing because of global climate change. Second, the *loss of absorptive landscape* by the spread of urbanization and sprawl increases impervious surfaces, which increases stormwater flow rates. And thirdly, *waterways silt up* as a result of increased stormwater discharge across altered landscapes. Runoff restrictions caused by sand, sediment, and debris deposition cause ponding in previously dry areas.

Climatic variables can indirectly affect the number of pollutants stored in the catchment due to a cross-correlation between climate and other factors. This is mostly due to increased temperatures causing more terrestrial and aquatic plant growth, and hence nutrient intake (Lintern, et al., 2018). Hydrologic processes vary both spatial and temporal as a result of intricate interactions between climate, topography, soil, and vegetation. The global hydrologic cycle is less variable than at smaller geographic scales (such as regionally or even in a small watershed) because variations in one region can be offset by opposite variations in another (Sun, et al., 2019). Stormwater flows are concentrated and accelerated by hard or impervious surfaces, as well as a storm-drainage pipe system (Forman, 2014). The land use and surface materials in a catchment have a significant relationship as shown (Fig. 2.2-4) studies in cities in the US from agricultural to urbanized LULC changes alter the stormwater runoff.

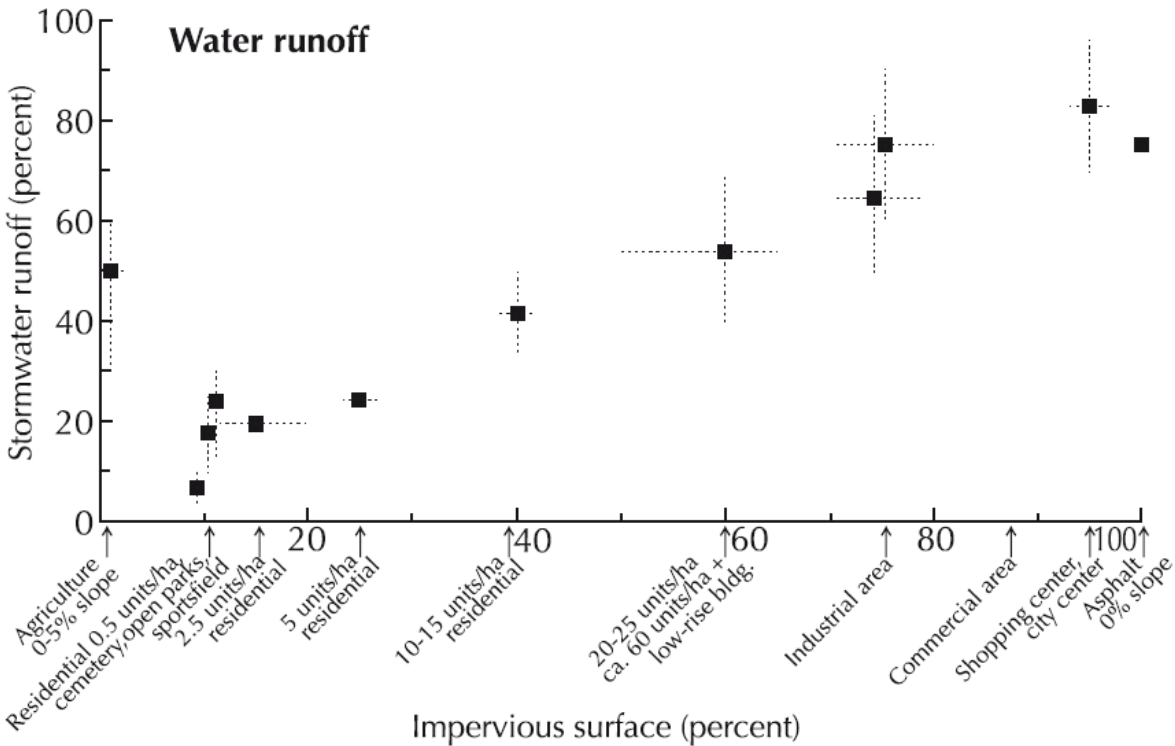


Figure 2.2.1-3 Impervious surface cover and stormwater runoff
 Source: Patterns from urban sites in the USA. (Forman, 2014)

From a hydrological standpoint, the following variables are important in any flash flood calculation *rainfall intensity, duration, topography, soil condition* and *coverage of the terrain* are five major factors (Şen, 2018). These stated factors can be categorized into two major factors as defined by Sun et al. (2019) as *meteorological factors* including precipitation characteristics, air temperature, solar radiation, humidity, wind speed, etc. and *physiographic elements* cover topographic patterns, geological nature that has generated the hydrological properties of surface and subsurface soil layers, and land use and land cover factors. In similar reviews, literature such as (Shaver, et al., 2007), (Lintern, et al., 2018) states different factors such as climatic, surface and subsurface factors (topographical and geological) and land-use variables in detail. It has been reviewed as follows;

Climatic variables are the major factor in the stormwater quantity and quality impacts. Global and regional weather conditions such as wind, temperature, relative humidity and precipitations affect the stormwater condition in general. As stated earlier the rainfall intensity and duration is a major factor in stormwater volumes (Watson & Adams, 2011) (Şen, 2018). And cross correlational factors such as increased temperatures cause more terrestrial and aquatic plant growth, and hence nutrient intake impacts the water quality factors (Lintern, et al., 2018) The mobilization of

sediments and particle nutrients within catchments can be aided by temperature extremes. High temperatures can increase weathering and streambank erosion because the drying of sediments makes them more susceptible to erosion by wind, rain, and animal trampling.

Topographic & geological variables such as altitude/elevation, slope angle, and solar orientation or aspect are topographic (landform) features that influence runoff. These, along with land cover characteristics such as type of vegetation, vegetation cover, paving covers, and so on, constitute an area's physical features (Sun, et al., 2019). Elevation and slope are important factors in determining the direction, travel time, and volume of surface and subsurface runoff. The level of incident radiation that reaches the surface is directly affected by slope orientation, making it crucial to the distribution of soil moisture and plants (Sun, et al., 2019). Vegetation covers contribute to water quantity and quality impacts as shading, conserving and sustaining the water cycle naturally. Canopy cover considerably modifies the surface mass and energy balance in heavily wooded areas through evapotranspiration, canopy shade, and canopy interception. Deep-rooted trees and plants can improve soil structure and infiltration capacity, reducing runoff potential. (Sun, et al., 2019).

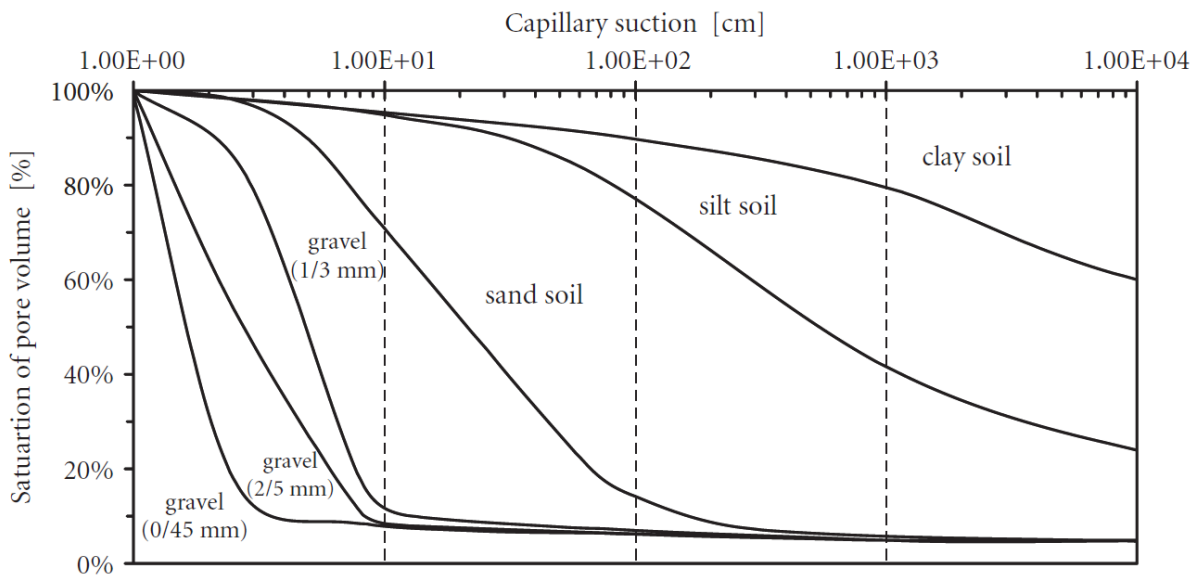


Figure 2.2.1-4 Water retention curves of natural soils and urban construction materials

Source: (Illgen, 2011)

Similarly, the subsurface conditions of soils within a drainage area can play a direct role in determining the volume and rate of runoff from rainfall. Chemical characteristics of soils impact the form and magnitude of nutrients on stormwater quality (Shaver, et al., 2007) (Lintern, et al., 2018). Geology is another important physiographic factor in the hydrological cycle. Clay and sandy soils, for example, have distinct properties that influence the level of precipitation absorbed versus how much flow off the surface. The groundwater's velocity is determined by the

combination of these properties. Water can pass inside coarse-grained sands and gravels at speeds ranging from 50 to 1000 m/day, whereas grained silts and clays have low values in the 0.001–0.1 m/day range (Sun, et al., 2019). Water retention is influenced by a variety of physical soil properties, which differ depending on soil texture. Clay has a much higher matric potential head than silt, sand, or coarse, as shown in (Fig. 8). As a result, sandy soil with specific water content (e.g., 20%) feels wet to the touch, whereas silt feels slightly humid and clay feels completely dry. The highly nonlinear relationships between water content and matric potential can be described using a variety of analytical functions (Illgen, 2011).

Land-use variables and the LULC characteristics are also important in the hydrologic cycle (Sun, et al., 2019). Long-term rainfall patterns have shaped the natural landscape, which comprises vegetation, soils, stream networks, and natural features. As the natural landscape changes, water resources will be altered, and flooding will become more common. Thousands of homes, businesses, roads, and farm properties can exist even within a small urban watershed. Each site that disrupts the water balance adds to the volume of runoff and the risk of flooding, akin to "death by a thousand cuts." (Watson & Adams, 2011). The topography and land cover relationships, for example, steep slopes should theoretically produce more sediment from erosion due to higher runoff velocities, but previous studies have claimed that because of the cross-correlations between catchment topography and land cover, the supply of both particulate and dissolved contaminants is less in steeply sloping areas (Lintern, et al., 2018).

2.2.2 Impacts of Floods on the Urban Environment

Stormwater runoff issues are nothing new to local land-use planners. The basic focus of stormwater management is safety, with the emphasis on quickly and efficiently directing and draining water off of paved surfaces. Stormwater is mainly “out of sight and out of mind” once it is off the road—downstream consequences are dammed (Arnold & Gibbons, 1996). Storm and sewer systems were built to address two persistent issues in cities:

- 1) how to dispose of huge amounts of wastewater and
- 2) how to protect property and lives from flooding, during large storm events (Sun, et al., 2019).

Urbanization has an impact on stream courses and flood plains¹⁰, forcing water to flow more quickly through cities. These urbanization-related hydrological consequences may be divided into four categories (Douglas, 2011) cited (Leopold 1968):

¹⁰ Any land area susceptible to being inundated by water from any source (Watson & Adams, 2011).

1. a rise or in total runoff
2. an alteration in the characteristics of peak flow
3. a decline in the quality of water
4. changes in the hydrological amenities of the stream and their ecology.

The magnitude of these effects on the water cycle is determined by the degree of surface sealing. Stormwater runoff in an urban environment can range from 10% to 50% of total precipitation, with a corresponding reduction in the evapotranspiration ratio (Illgen, 2011). A heavy rainfall event's main feature is flash flooding, and such an event (in any region) could be stated as a natural hazard that causes major floods and severe destruction, often leading to loss of life & property damage (Şen, 2018).

2.2.3 Hydrological modeling on urban flooding

The Storm Water Management Model (SWMM) is a widely used tool for simulating urban stormwater runoff and quality. It is a dynamic rainfall-runoff model that can be used to simulate the movement of water through an urban watershed, from the atmosphere to the ground, through storm sewers and rivers, and ultimately to the ocean (EPA, 2016). There are different aspects to model urban drainage modeling as drainage network models, 2D SWE based models and *hydrogeomorphic* approaches. On this study we will focus to review to hydrogeomorphic approaches with that could be managed with available data with computationally efficient (Guo, et al, 2020). Whereas it does not include the infrastructures of drainage systems that lead uncertainty of empirical data.

Hydrogeomorphic approaches can identify the inundation area directly from the topography. Thus, it requires much less computation time and no time-series data. However, there are still many limitations for the application of these.

- Only approximated inundation area can be obtained. Flow dynamic information (water depth, velocity, et al.) cannot be provided.
- The effects of recent anthropogenic modifications on a floodplain or urban surface features will increase uncertainty in a floodplain maps. There is no effective way to characterize infrastructures and the altered geomorphic signature in highly urbanized areas.
- Empirical data related to flood stage are needed to determine the floodplain flow depth scaling relationship. These data have great uncertainties, such as availability and quality, which directly affect whether to get the accurate floodplain area.

However, flood mapping can be considered as a complement to physically-based hydrodynamic modelling. For example, using an ungauged condition to preliminarily identify inundation areas can provide references for physically representative models.

SWMM is a versatile model that can be used for a variety of purposes, including:

- Designing and evaluating stormwater management systems: SWMM can be used to design and evaluate stormwater management systems, such as detention ponds, infiltration basins, and green infrastructure.
- Predicting the effects of land use change on stormwater runoff: SWMM can be used to predict the effects of land use change on stormwater runoff, such as the impact of a new development on flooding.
- Evaluating the effectiveness of stormwater management practices: SWMM can be used to evaluate the effectiveness of stormwater management practices, such as green roofs and rain gardens.

SWMM is a powerful tool for urban stormwater management, but it is important to note that it is not without its limitations. Some of the limitations of SWMM include: the data requirements as SWMM requires a significant amount of data to run, including rainfall data, land use data, and soil data. Calibration and validation: it can be difficult to calibrate and validate, especially for complex watersheds. Complexity: it is a complex model, and it can be difficult to learn how to use it. Despite its limitations, and it is a valuable tool for urban stormwater management. It is a versatile model that can be used for a variety of purposes, and it is widely used by engineers and planners around the world (EPA, 2016).

2.2.4 Considerations to Retrofit the impacts of Flooding

The general factors and considerations to manage stormwater impacts have been referred to in (Fig. 9). Comprehensive urban planning that balances environmental and economic concerns is required. The major emphasis of efforts to solve the problem of recurring floods should be prevention and recovery measures (Vazhuthi, 2020). Considering the size and IC the watershed management units (Table. 2.2-1) have different categories with their size factors that have shown retrofitting strategies (adapted from Caraco et al., 1998).

Table 2.2-1 Watershed management units.

Watershed Management Unit	Typical Area			Influence of Impervious Cover
	(Square miles)	(Square Kilometers)	~ Ha	
Catchment	0.05 – 0.50	0.12 – 1.29	129.5	Very strong
Sub-watershed	1–10	2.59 – 25.89	2,590	Strong
Watershed	10–100	25.89 – 258.99	25,900	Moderate
Subbasin	100–1,000	258.99 – 2,589.98	259,000	Weak
Basin	1,000–10,000	2,589.98 – 25,899.88	2,589,988	Very weak

Source: (USEPA, 2005)

In the case of newer developments, urban water problems should be studied in conjunction with all planned and unplanned changes in land-use, and the application of planning strategies. Vazhuthi (2020) discusses that watershed management entails de-silting, cleaning, and deepening drainage channels throughout the river basin rather than just in urban areas.

Natural systems of the water flow must be well-maintained and free of encroachment and pollution to keep the flow of water free of impediments.

- Planning guidelines that give adequate weightage to topography, drainage, rainfall, and lithology, as well as an improved stormwater disposal system.
- Keeping track of all water bodies and wetlands at the city and village levels.
- River, lake, and other water channel catchment areas must be designated as protected areas and incorporated into city development regulations.
- Strict land-use control will reduce tangible and intangible losses, particularly in hill towns, coastal towns, and flood plain areas.

Firstly, risk reduction should be to map flood vulnerability. These areas can be identified by analyzing topography and historical data on the extent and duration of inundations.

- The flood pattern for at least the last five years must be studied using hydraulic and hydrological models. The findings lead to guide strategic planning.
- The extent of damage in a vulnerable area is related to the density of development and population. No development zones should be established in flood-prone low-lying areas.
- Flood walls and raised platforms will be built along flood-prone river basins and coastal areas. Town protection works must be implemented with proper monitoring to mitigate floods.

Runoff can be reduced by reducing the area of hard surfaces and providing more green cover, conserving water bodies, and harvesting rainwater from built spaces. Rain gardens, green roofs, bio-retention swales, artificial ponds, and underground storage sumps can also help with percolation and runoff.

- Floods can be diverted through measures such as the construction of embankments, levees, and dams, among others.
- Reforestation and debris removal from catchment areas could help prevent soil erosion, which could further degrade an urban settlement's resources.

Source: (Vazhuthi, 2020)

Figure 2.2.4-1 Watershed management strategies

2.3 Urban Pollution and Diffused Pollutants

'Let's not muddy the water: Somewhere downstream, a pigeon may be drinking, or in a distant wood, a goldfinch may be washing her feathers. Perhaps a dervish has dipped his dry bread in it. The people upstream appreciate the water. They have not muddied it. Let's also keep the water clear.' **Sohrab Sepehri**

Rivers across the globe have shown major water quality declines; over 45% in China, similarly over one-third of rivers in the US have faced stream water quality challenges (Lintern, et al., 2018). In Europe, factors such as diffused pollutants, hydro morphological changes and point source pollutants contribute 38%, 40% and 18% respectively. Many stormwater pollutants, such as sediment, nutrients, bacteria, metals, hydrocarbons, chlorides, and trash/debris, impact the water column and sediments of urban lakes. Given that more than 80% of urban lakes exhibit eutrophication symptoms. (The degradation of water quality due to enrichment by nutrients, primarily nitrogen (N) and phosphorus (P), which results in excessive plant (principally algae) growth and decay. When levels of N:P are about 7:1, algae will thrive. Low dissolved oxygen (DO) in the water is a common consequence. The degree of this condition categorized as Oligotrophic, chlorophyll, mesotrophic and hypereutrophic levels ascendingly.) Nutrients are chemical components of the water quality parameters defined on USEP (2008) as (1) An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others. (2) Animal, vegetable, or mineral substance which sustains individual organisms and ecosystems. And (3) Portion of any element or compound in the soil that can be readily absorbed and assimilated to nourish growing plants, e.g., nitrogen, phosphorus, potassium, iron and suspended sediments have been identified as major sources of water quality degradation (Sun, et al., 2019).

The concentration of sediments, nutrients, and salts in rivers and streams are affected by a combination of terrain variables and landscape heterogeneity can have a big impact on water quality in streams. In addition, other landscape characteristics that impact riverine water quality include atmospheric deposition, climate, geology, soil properties, and catchment hydrology (Lintern, et al., 2018). These factors are leading causes of water quality impairments in rivers & streams; *hydro-modification, habitat alteration, and urban runoff with storm /sewers*, all of which are nonpoint sources leading sources of impairment (UNEP, 2008).

2.3.1 Imperviousness, Flooding and Diffused Pollutants

As a general rule on average, most lakes are extremely sensitive to increases in phosphorus loads caused by watershed IC. Schueler (1994) states imperviousness is a powerful and important

indicator of future stream quality, and that significant degradation occurs at a low development level. Pollutants are washed away by the rapidly flowing stormwater. This effectively cleans the city while polluting the nearby water bodies (Forman, 2014). Stormwater often picks up a variety of pollutants produced by various anthropogenic activities as it flows over impervious surfaces, such as pet waste, pesticides used to control insects and weeds, and petroleum pollutants from parking lots (Sun, et al., 2019). River water loaded with sediment and various pollutants constantly rush through a city, sometimes with floods, washing out accumulated toxins from industrial sites and transporting incorrectly positioned urban structures (Forman, 2014). The first flush effect (FFE) shows the maximum pollutant load that washes off at the first rain event.

These pollutants, along with stormwater runoff, enter storm sewers and nearby bodies of water, contributing to elevated pollutant concentrations in the water. Stormwater contributes significantly to another major source of water pollution: sediment pollution, on a large scale (Sun, et al., 2019). Factors reviewed in the last subchapter¹¹ as climate, topographic and geological and land-use factors impact the type and concentration of pollutants in a catchment.

2.3.2 Water Quality Parameters

In nature, pure water with solely hydrogen and oxygen is uncommon. Rainwater contains dissolved gases and traces of mineral and organic substances originating from gases, dust, and other substances in the atmosphere (USGS, 2018). A water quality variable is any physical, chemical, or biological property that influences the suitability of water for natural ecological systems or human use, and the term water quality refers to the suitability of water for a specific purpose (Boyd, 2015). Basic water quality parameters (physical, chemical, and biological) are categorized by different works of literature (Omer, 2019) flows (Table 2):

Table 2.3-1 Types of water quality parameters

No.	Physical parameters	Chemical parameters	Biological parameters
1	Turbidity	pH	Bacteria
2	Temperature	Acidity	Algae
3	Color	Alkalinity	Viruses
4	Taste and odor	Chloride	Protozoa
5	Solids	Chlorine residual	
6	Electrical conductivity (EC)	Sulfate	
7		Nitrogen	

¹¹ See (Chapter 2.3.1) cause and factors on degradation of urban hydrology.

8	Fluoride
9	Iron and manganese
10	Copper and zinc
11	Hardness
12	Dissolved oxygen
13	Biochemical oxygen demand (BOD)
14	Chemical oxygen demand (COD)
15	Toxic inorganic substances
16	Toxic organic substances
17	Radioactive substances

Source: (Omer, 2019)

Water quality factors on the stormwater has diverse factors and impacts by their source, mobilization and delivery (Lintern, et al., 2018). As of the geological condition, land covers and dispersion/ dilution summary of the level of contaminants described in ranges (David, et al., 1995) by different documents. This review covers water quality impacts on the human and aquatic environment. Although there is a complexity to set common standards for stormwater quality with landcover factor major categories are discussed as follows.

The alkalinity and hardness vary with the level of calcium carbonate level in the water. Alkalinity ranges between 8 to 1273 mg/l as CaCO₃. The hardness level in the stormwater ranges from 12 to 1100 mg/l of CaCO₃. It is appropriate in which to balance the toxicity levels of heavy metals and stormwater in moderate to very hard hardness character. The pH level of stormwater is determined by the level of sulfur dioxide and nitrogen emissions. It is common in the range of 4.5 to 8.7. On Canadian standards for freshwater considering aquatic life has a permissible range of 6.5 to 9.0 (David, et al., 1995).

Oxygen enters from the surroundings and plants within the surface and subsurface of water. Dissolved oxygen (DO) is the basic factor in providing life to the water environment. At a normal salinity and summer temperature, a freshwater DO level reaches 8 mg/l when the oxygen concentrations reach less than 2mg/l (USGS, 2018). When oxygen depilates in the water called hypoxic, living things cannot sustain in the water. As an indicator of life decline level of DO leads to a “dead zone” in the water environment. And other factors such as temperature and nutrients (phosphorus and nitrogen) lead to depilation of subsurface dissolved oxygen (USGS, 2018).

The organic matter comes from dead leaves, garbage, combined sewer overflows, and other sources that could be seen by BOD and COD results. A water quality metric by COD is used to measure the number of organic compounds in a body of water (David, et al., 1995). BOD is a measure of the quantity of oxygen needed to eliminate waste organic matter from water during the breakdown process by aerobic bacteria (bacteria that live only in an environment containing oxygen) (USGS, 2018). The waste organic matter is stabilized by decomposition by living bacterial organisms that require oxygen to function. Organic matters that discharge into the watercourse will break down into less complex organic substances with bacterial reaction to form carbon dioxide and water with aerobic reaction (FDRE EPA, 2003).

Solid matters that are both suspended and settleable are other groups impacting the water quality (Rădulescu et al., 2019). The suspended solids (SSs) content is the solid matter (both organic and inorganic) maintained in suspension, and retained when a sample is filtered (0.45 µm pore size) (Butler, et al., 2018). It is estimated for a water sample by passing a precisely measured volume of water through a pre-weighed filter with particular pore size, then weighing the filter again after drying to eliminate all water (UNEP, 2008).

Nitrogen and phosphorus come from almost all types of the urban area including lawns, transportation, industry and commercial areas (Forman, 2014). Nitrogen exists in stormwater in four main forms organic (in the form of protein) ammonia (ammonium salt), nitrite and nitrate. As a total nitrogen form, it has a considerable range of 0.07 to 16.0 mg/l (David, et al., 1995). A nutrient present in and industrial outflows, and non-point sources ammonia, nitrate or nitrite or elemental such as commercial fertilizers, animal waste, form in water due possibly to diffused pollution (UNEP, 2008). Phosphorus is defined as an element that is necessary for plant growth but contributes to increasing trophic levels in aquatic bodies (Eutrophication). One of the three primary nutrients in a complete fertilizer and the second one listed in the formulation on a fertilizer label: 10-8-6 (nitrogen, phosphorus, potassium) (UNEP, 2008). Phosphorus can occur in both dissolved and particulate forms in stormwater runoff. Dissolved phosphorus can pass through a 0.45-micron filter arbitrarily defined as dissolved phosphorus. Solid or particulate phosphorus, which is defined as that portion of the TSS that is retained by a 0.45-micron filter, can come from grass clippings, leaves, animal waste, or any other solid organic matter (Weiss, et al., 2005). Weiss (2005) refers (USEPA, 1983) according to publications the total and dissolved phosphorus concentrations in urban runoff are expected to be 0.33 mg/L and 0.12 mg/L, respectively.

2.3.3 Types and Sources of Pollutants from the Urbanized Landscape

On surface stream water quality conditions, the oxygenation levels (BOD and COD), nutrients (nitrogen and phosphorus) and acidification (pH and alkalinity) levels, are major water quality indicators to study the impacts considering pollution with aquatic environments (OECD, 2007).

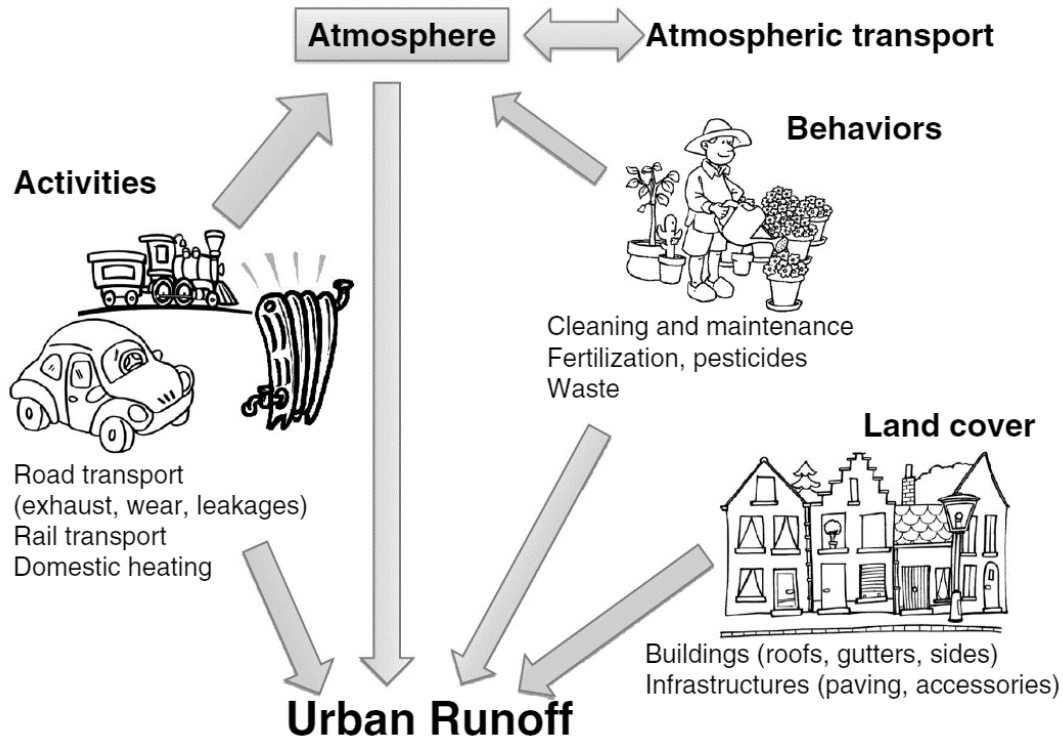


Figure 2.3.3-1 non-point chronic pollutants in urban catchments.

Source: (Petrucci, et al., 2014)

G. Petrucci (2014) categorize diffused pollutants source into three major types: activity-related, land cover-related, and behaviour-related, as well as atmospheric deposition stated as follows (Fig. 9);

- 1) **Activity-related;** Road transport emissions are generally well-documented. This source has considered air pollutants as of their occurrence and size (i.e., diameter <math><10 \mu\text{m}</math>)
- 2) **Land cover-related:** these sources consider constructed structures like buildings. That surface materials change into impervious.
- 3) **Behaviour related:** pollutants are emitted more as a result of individual, collective, or institutional behavior than by land cover or activities. This is true of biocides, pesticides, fertilizers, and other compounds used in urban areas for maintenance (Petrucci, et al., 2014).

2.3.3.1 Types of pollution from the urban environment.

The excess materials, chemicals, and heat carried by runoff come from a variety of sources. Pollutants are emitted by rainwater, dry aerial deposition (including wind-borne material), vehicles (leaks, wear, and exhaust), commercial waste, industrial waste, construction sites, people's garbage, animal waste, and road de-icing, urban agriculture, and lawns and parks. (Forman, 2014). Oil, faecal coliform bacteria, nitrogen and phosphorus from lawn fertilizers and other sources, as well as sediment, road salt, numerous chemicals from leaks and spills, and heat, are all examples of stormwater pollutants. Carparks are typically significant sources of heavy metals and hydrocarbons (Forman, 2014).

Pollutants have a diverse set of characteristics. General categories as stormwater pollution there are two components in their physical forms (Boyd, 2015) and (Forman, 2014):

- 1) Suspended solids that can be filtered or, in still water, settle to the bottom;
Suspended solids are important pollutants consisting of suspended minerals and organic particles. Solids do not settle immediately, and they can create turbidity plumes.
- 2) Dissolved substances that are chemically in solution in the water.

Pollutants detected in urban stormwater could be categorized as their properties and nature of existence. Physical contaminants such as suspended and settleable solids, Heavy metals, Polycyclic aromatic hydrocarbons (PAHs), Nutrients, and Pathogens are sectors to be considered (David, et al., 1995) (Rădulescu et al., 2019). Organic wastes that involve oxygen to decompose are major contaminants in domestic and municipal wastewater, animal feedlot effluents, and food processing and paper manufacturing discharges.

Other types such as oil and grease, non-hazardous wastes and persistent organic pollutants (POP) has described as follows; oil and grease are a composition of diverse organic chemicals with diverse properties and toxicities. It has a range of 0.001 to 110.0 mg/l range in stormwaters (David, et al., 1995). *Nonhazardous* (combustible and non-combustible solid and semi-solid, such as garbage, trash, paper, demolition and parts thereof, as long as they do not contain harmful byproducts (CWT, 2021) and *POPs* are organic molecules that are resistive to a breakdown in the environment have thus been observed remained in the environment. They may travel vast distances, bio-accumulate in human and animal tissue, and may have major effects on human and

wildlife health and well-being (UNEP, 2008). Sediments¹² are built up in reservoirs, rivers, and harbors, obstructing sunlight from reaching aquatic plants and destroying fish and wildlife habitats. Careless agriculture, quarrying, and construction will expose sediment materials, causing them to wash away after rains. Usually applied to the material in suspension in water or recently deposited from suspension. In the plural, the word is applied to all kinds of deposits from the waters of streams, lakes, or seas. The particulate matter settles to the bottom of a liquid (UNEP, 2008).

Pollutant Load from the Urbanized Landscape; the expansion of urbanization has resulted in an increase in impervious surfaces, which has increased pollutants being transported through stormwater runoff and an increased risk of flooding (David, et al., 1995). Based on the types of pollutants generated (Pazwash, 2016) described the sources of pollutants on (Table. 3);

Table 2.3-2 Sources of Pollution

Pollutant	Source
Floatable	Shopping centers, streets, parking lots, parks and recreational areas
Sediment	Construction sites, roads, lawns and gardens
Nitrogen and Phosphorus	Lawn fertilizers, detergents, pet wastes, automobile deposition
Organic Materials	Lawns and gardens, parks, golf courses, leaves and animal wastes
Pesticides and Herbicides	Lawns and gardens, roadside channels, parks, golf courses
Metals	Atmospheric deposition, automobiles, industrial sites, steel bridges corrosion
Oil and Grease	Lawns, roads, septic systems, leaky sanitary sewers, pet wastes, Canadian geese droppings

Source: (Pazwash, 2016)

The general ranges of the stormwater quality on road surfaces and major land use categories have been presented as follows (Table. 2.3-2) and (Table. 2.3-3). Table. 2.3-3 referred to the estimation of pollutant load from different land uses estimated by Median Event Mean Concentration (EMC) variables for Urban Land Uses that have coefficient for using pollutant load computation of Storm Water Management Model SWMM.

Table 2.3-3 The range of concentration in urban stormwater.

Parameter	Low - High	Parameter	Low - High	Parameter	Low - High
BOD ₅	1 – 700 mg/l	Organic N	0.01 – 16 mg/l	Oils	0 – 110 mg/l
TOC	1 – 150 mg/l	Total N	0.01 – 4.5 mg/l	Lead	0 – 1.9 mg/l
COD	5 – 3,100 mg/l	NH ₃ N	0.1 – 2.5 mg/l	Total Coliforms	200 – 150 x 10 ⁶ /100 ml

¹² Soil, sand, and minerals are washed from the land into water, typically after rain.

Suspended Solids	2 – 11,300 mg/l	NO ₃ N	0.01 – 1.5 mg/l	Faecal Coliforms	55 – 110 x 10 ⁶ /100 ml
Settleable Solids	0.5 – 5,400 mg/l	Soluble PO ₄	0.1 – 10 mg/l	Faecal Streptococci	200 – 1.2 x 10 ⁶ /100 ml
		Total PO ₄	0.1 – 125 mg/l		
		Chlorides	2– 25,000 mg/l*		

* With highway de-icing

Source: (Rădulescu et al., 2019) cited a review of several studies.

Developing considerable coefficients of pollutants, the US EPA review document has developed factors for selected major categories.

Table 2.3-4 Pollutant Load from land-use variables reviewed

Pollutant	Units	Residential		Mixed		Commercial		Open/Non-urban	
		Median	COV	Median	COV	Median	COV	Median	COV
BOD	mg/l	10	0.41	7.8	0.52	9.3	0.31	-	-
COD	mg/l	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/l	101	0.96	67	1.14	69	0.85	70	2.92
Total lead	µg/L	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper	µg/L	33	0.99	27	1.32	29	0.81	-	-
Total zinc	µg/L	135	0.84	154	0.78	226	1.07	195	0.66
Total Nitrogen	µg/L	1900	0.73	1288	0.50	1179	0.43	965	1.00
Nitrate + Nitrite	µg/L	736	0.83	558	0.67	572	0.48	543	0.91
Total phosphorus	µg/L	383	0.69	263	0.75	201	0.67	121	1.66
Soluble Phosphorus	µg/L	143	0.46	56	0.75	80	0.71	26	2.11

Source: (Pazwash, 2016) cited (US EPA, 1983)

2.3.4 Impacts of the major pollutants on the environments

Studies for stormwater quality are varied in use and level of degradation by different directives and standards. As a surface water characteristic, stormwater qualities have two major contexts to consider degradation to the aquatic environment and downstream water use (David, et al., 1995). The evaluation of urban stormwater quality is a difficult task. As stormwater passes through the collecting system on its way to the receiving waters, the concentrations of various chemicals will fluctuate. Dilution and dispersion will occur downstream of discharges, lowering pollutant concentrations over time. One of the most efficient stormwater treatments is identifying pollutant sources and regulating or removing them before they enter the collection system (David, et al., 1995).

The surface water quality standards have been reviewed considering the environmental aspects in US and European guidelines and directives as the US EPA clean water act and EEA water

framework directives. In Asian countries, the Water Environment Partnership in Asia (WEPA, 2013) has organized surface water quality standards. Nationally standards concerning the environment have been developed by the environmental protection authority for pollution (FDRE EPA, 2003). The researcher has reviewed American (US EPA), European surface water quality standards Moldova surface water quality standards and Asian (Philippines and Taiwan) and Ethiopian national standards available to consider human and aquatic impacts on stormwater quality. The water quality reviews cover freshwater on the surface as rivers and lakes that has a risk of pollution for properly functioning aquatic ecosystems. Reviewing different sources of literature on global, regional and national water quality standards and limits has compiled as follows:

Table 2.3-5 Global and regional water quality standard limits.

Parameter	US EPA	EEA	WEPA	FDRE EPA	Remark
T (°c)	–	6 – 9	–	1.5 – 3	Pollution impacts are considered by the discharge water and water body temperature.
PH	–	6.5 – 8.5	–	6 – 9	It is negative logarithm of hydrogen ion.
DO (mg/l)	–	5	>6	4	
TSS (mg/l)	–	<25	<60	< 50	Natural and added solids present in water.
COD (mg/l)	1000	7	<400	–	Indicators of the possible presence of pathogenic micro-organisms
BOD₅ (mg/l)	2	3 – 6	1,5	≤5	Excessive amounts of boron can cause nervous problems; danger to crops when present in irrigation water at the 1 – 2 mg/l concentration range.
TKN (mg/l)	1	4	<40	–	
Ammonia (mg/l)	11	< 1	0.2	–	Hazard to infants above 11 mg/l N
Nitrate (as NO₃) mg/l	50	3	<5	50	
Nitrite (as NO₂) mg/l		0.06		0.1	
TN (mg/l)	1	4		1	No direct significance but the parameter is an indication of the overall purity of water.
TP (mg/l)	–	0.2	–	–	
Phosphates PO₄– (mg/l)	–	0.1	–	–	

Sulphate SO ₄ ⁻⁻ (mg/l)	–	–	–	200	In polluted water, it is reduced to sulphide causing noxious odors.
Copper Cu (mg/l)	0.05	–	–	10	Copper is not particularly toxic to humans and medicinal does up to 20 mg/l. however, astringent tastes in water can be caused by levels above 1 mg/l Cu
Lead Pb (mg/l)	0.05	–	–	0.05	Toxic cumulative poison

Source: (OECD, 2007), (FDRE EPA, 2003), (Tsegaye, 2020) cited (EPA,2001) and (WEPA, 2013).

Diversely, the fragmentation and pollutant load cause discontinuities to the ecosystem and biodiversity loss (Perini and Sabbion, 2017). Broader factors and considerations are needed to understand the aquatic impacts of stated pollutants further. The environmental concerns as a causal factor have been reviewed by (Shaver, et al., 2007) as the cause and potential impacts on the aquatic environment.

Table 2.3-6 Flooding and pollution impacts on the natural environment

Environmental concern	Potential Impacts	Cause/ source
<ul style="list-style-type: none"> – Increase in runoff-driven flooding frequency and duration, – Increase in wetland water level fluctuations 	Degradation of aquatic habitat and loss of sensitive species	Increase stormwater runoff volume due to an increase in basin imperviousness
<ul style="list-style-type: none"> – Excessive turbidity – Fine sediment deposition – Sediment contamination 	Degradation of aquatic habitat or loss of sensitive species benthic organisms and behavioural interference	Increase in basin imperviousness and streambank erosion Storm runoff pollutants
<ul style="list-style-type: none"> – Elevated water temperature – Low dissolved oxygen (DO) levels 	Lethal and non-lethal stress to aquatic organisms reduced DO levels	Los of riparian forest shade and direct runoff of high-temperature stormwater from impervious surfaces
<ul style="list-style-type: none"> – Decline in aquatic plant diversity – Decline in invertebrate diversity – Decline in amphibian diversity 	Alteration of natural food web structure and function and Loss of ecologically important spices	Cumulative impacts of urbanization

Source: (Shaver, et al., 2007)

Identifying the level of pollution, the water quality level as good, slightly, moderately and gross polluted levels are stated based on Taiwan Surface Water Quality Standard (Liou, et al., 2004) cited as follows (Table. 8):

Table 2.3-7 Pollution index (Taiwan)

Parameter	Good	Slightly polluted	Moderate polluted	Gross polluted
DO (mg/L)	Above 6.5	4.6–6.5	2.0–4.5	Under 2.0
BOD5 (mg/L)	Under 3.0	3.0–4.9	5.0–15	Above 15
SS (mg/L)	Under 20	20–49	50–100	Above 100
NH3-N (mg/L)	Under 0.5	0.5–0.99	1.0–3.0	Above 3.0
Index Scores (Si)	1	3	6	10

Source: (Liou, et al., 2004)

2.4 LID Controls with the Built Environment

“አጼ ላሊበላ ግን የዓባይን ውኃ ከየመንገዱ አውጥቶ ወደ በረሃ በመስደድ እጅግ የሚያስቸግርና የማይቻል መሆኑን አውቆ ለዓባይ ውኃ ኃይልና ብርታት የሚሰጡትን በዝናብ ጊዜ ብዙ ጎርፍ እየያዙ ወደ ዓባይ የሚገቡትን ከየተራራው የሚወርዱትን ወንዞች ሁሉ ወደ ዓባይ እንዳይገቡ እያቋረጠ ወደ ሌላ ስፍራ ለመስደድ ጀመረ። በዚህም ሁሉ ምክንያት የላሊበላ ስሙ በሙሉ ኢትዮጵያ በውጭም አገር ሁሉ የታወቀ ሆነ። በመሬትም ውስጥ የታነጹትን አብያተ ክርስቲያናት ለማየት የኢትዮጵያ ሕዝብ ከየአውራጃው እየተሰበሰቡ በየአመቱ እየሄዱ እንደ ኢየሩሳሌም አከብረው ይሳለሙታል። ስፍራውም ገዳም ርሐ ወይም ደብረ ርሐ ተብሏል።...”

ጎሩይ ወልደ ሥላሴ (ብላቴን ጌታ) : ዋዜማ : 1921

“(...) the central interest is the fundamental manner in which the entire site is treated as a large-scale landscape, as a kind of tissue and bonding agent that ties all the disparate parts together. Corridors, patches, mosaics, bridges, pathways, landforms, and matrices create a fabric within which the city can grow new roots.”

James Corner (2014)

Historically, the way cities were built was inherently sustainable—without the idea of sustainability is a recognized concept at the time. Early settlements developed for pedestrian access ways with less impervious cover and less ecological disturbance of the environment (Friedman, 2021). Economic developments, urban form and their environmental implications are related to one another. The urban sprawl impact naturally significant areas, wetlands, the farmlands, diverse species, and existing green spaces leading to flooding and ecosystem fragmentation (Friedman, 2021) cited (Johnson 2001). Although rainwater has long been considered a resource in agricultural settings, it has long been considered a waste product in urban areas. Urban rainwater has traditionally been viewed as a problem to be solved, a waste product to be eliminated, or a resource to be managed, with a few exceptions (Echols, et al., 2015).

Avoiding the effect of urbanization can only be achieved through careful site design and implementation of source control and management practices for the aquatic environments (Shaver, et al., 2007). Over the last few decades, management systems have evolved from simple flood control levees to control excess flow rates, and then to infiltration and rainwater harvesting systems designed to reduce runoff volumes and non-point source pollution. (Echols, et al., 2015). The global and regional conditions that impact the city environment sustainable urban development approaches are needed to be considered. Recently, there is great investment and innovation in scientific technologies which can improve environmental sustainability in many ways (Friedman, 2021). The LULC change of natural vegetation can dramatically increase runoff and the volume of water discharged downstream (Watson & Adams, 2011).

Sustainable urban designs need to consider to utilize the use of land, material and energy from environmental degradations as on average 40% of total urban land is impervious covers (Perini and Sabbion, 2017). Asphalt-covered roads channel rainwater runoff to manholes and into the municipal sewer system. Creating bio swells (Fig. 2.4-1) along the sides of highways to filter and collect water is an environmentally viable solution that promotes the growth of native plants, reduces input into the sewer system, and creates a more appealing built environment (Friedman, 2021). The presence of impoundments, lakes, and wetlands in a catchment can lead to lower concentrations of sediments, nutrients, and salts in rivers downstream of these features (Lintern, et al., 2018).



Figure 2.3.44-1 Road Side bio-swell directs rainwater back to nature Hoorn, the Netherlands

Source: (Friedman, 2021)

In a study of rivers in Sweden, it was found that there were lower concentrations of particulate phosphorus in river reaches that had lakes within their catchment. Similarly, wetlands in the US are estimated to retain 14 to 89% of TN from overland runoff. However, in some cases, the presence of these reservoirs and lakes could lead to a reduction in flow and a subsequent increase in the concentration of constituents even if the total load (i.e., mass) of the constituent decreases (Lintern, et al., 2018).

2.4.1 Global Practices

The global scenario has shown urbanization and flooding become urban challenges as 80% of major South Asian cities face flood risk (UN-Habitat, 2020). At the 2016 UN-Habitat conference in Quito, a plan for building cities and promoting sustainable urban development was created with

input from all UN member states and relevant stakeholders called the New Urban Agenda. The framework established a model that promotes sustainability & recognizes the importance of targeting contemporary challenges facing cities today. Some of the main challenges identified were climate change, promoting the sustainable use of water and other natural resources, and promoting environmentally sound waste management, (UN, 2017) cited (Friedman, 2021). Whereas urban drainage systems have shown broader considerations through time from that is from a safety perspective to a resource approach (Butler, et al., 2018).

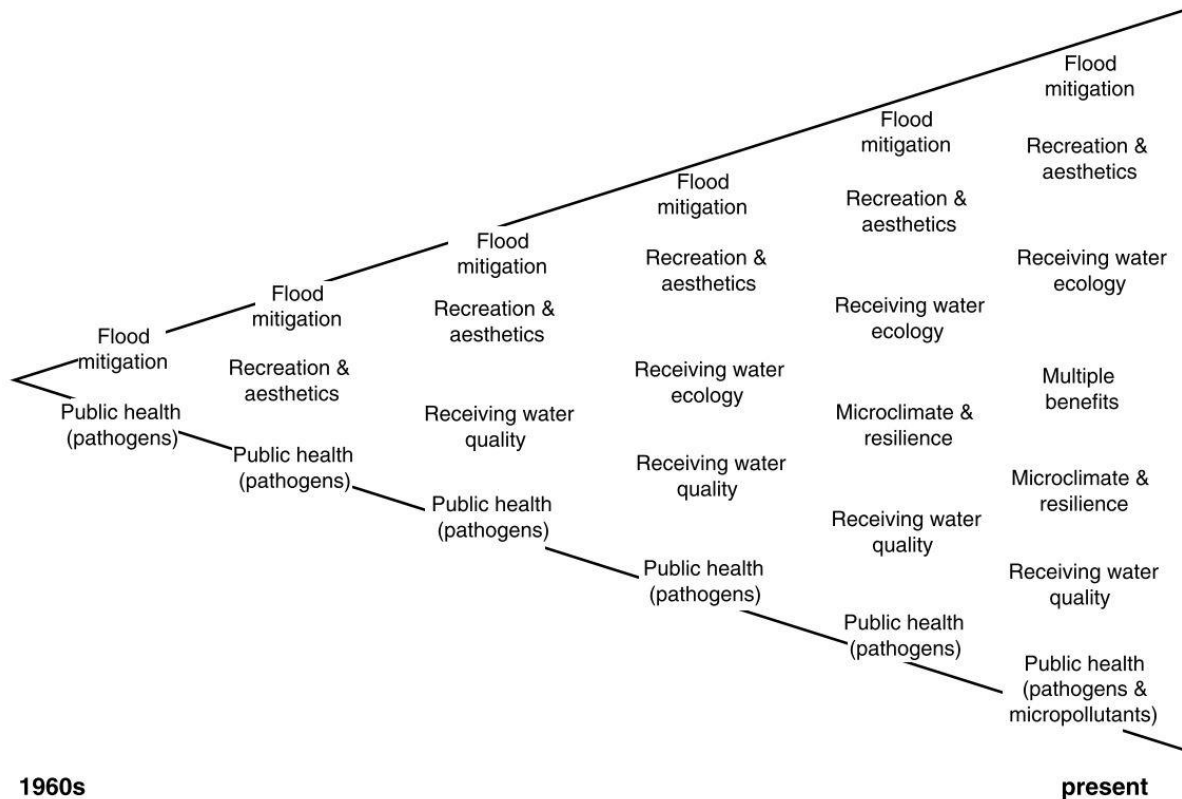


Figure 2.4-2 Urban drainage considerations through time
Source: (Butler, et al., 2018)

On the organization of these systems within implementation areas should consider watershed topography, local hydrology, layout and types of existing impervious covers are significant factors that need to be identified (Fleischmann, 2014). Advancements on these systems lead multifaceted benefits to the urban ecosystem services¹³ considered lead multifaceted benefits in development of such services. In all of this, a sustainable stormwater management commitment has emerged, with each new technique striving to address post-development runoff in ways that approach the

¹³ These services can be divided into four categories as Provisioning, regulating, habitat, and cultural services (Perini and Sabbion, 2017).

predevelopment state. Each human-controlled management technique has flaws that make it less effective than the natural hydrologic cycle (Echols, et al., 2015).

For example, in the case of Los Angeles city, the grey to green infrastructure developments enhances runoff control systems and stream water quality level to address urban challenges related to flooding and diffused pollutants from the urban environment. As shown in (Fig. 13 and 14) green infrastructures that are integrated with the roadways enhance the stormwater management systems and qualities of the urban environment.

(Rouse & Bunster-Ossa, 2013)

The UNEP (2008) document organize four major management practices for major runoff management themes as a guiding document, those are:

- 1) Minimizing the IC and disconnect runoff from IC.
- 2) Promote infiltration.
- 3) Prevent mixing of pollutants with surface runoff.
- 4) Remove pollutants from runoff before allowing it to flow into natural receiving waters.



Figure 2.4-3 Reconstruction of New York Street into Greenways

Source: (NACTO, 2017)

One of the major public spaces in the urban environment is the streets, it covers the highest impervious surface in urban infrastructure developments (Friedman, 2021). The redevelopments and refurbishing of the streets as urban design interventions for stormwater management systems has shown below (Fig. 2.4-3). On the street design and management, NACTO (2017) presents Greenways to Rivers Arterial Stormwater System (GRASS) develops town level integration of green infrastructures to manage the stormwater system on the city level as presented below.

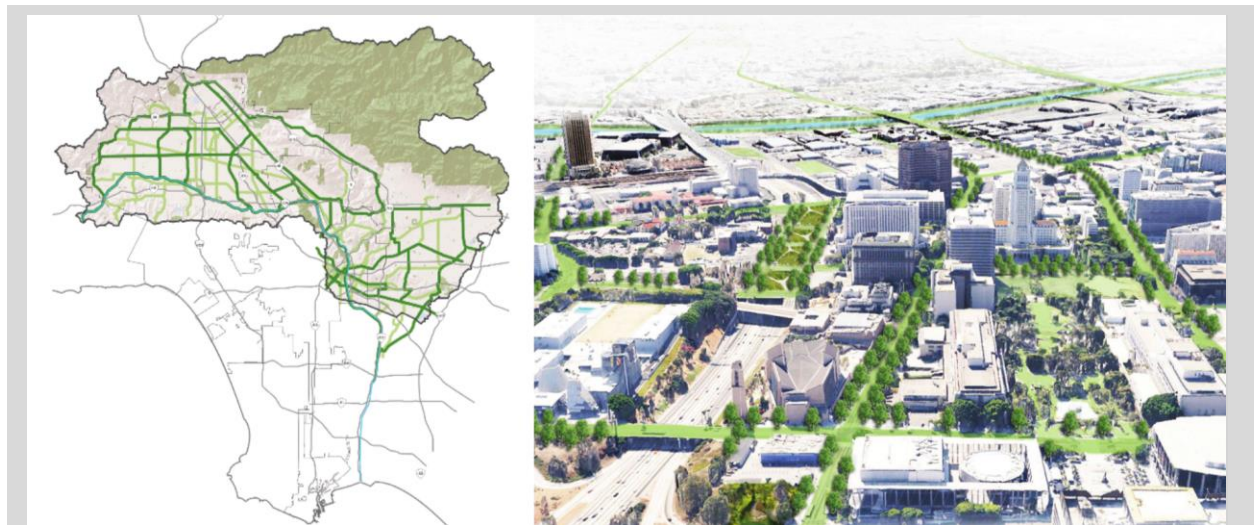


Figure 0-1 Potential greenways for Los Angeles city

Source: (NACTO, 2017)

As shown above the city integrates the need & challenges with possible design solutions on the utilization of stormwater with Greenways to Rivers Arterial Stormwater System (GRASS) to comprehend the expansion the built environment with nature. On potential major arterial roads and rights of way, the need and challenge of water and stormwater challenges (flooding and water quality impairment) have been addressed with curb extensions, filtration systems and vegetative swales. As of the scale of the project, project phasing and prioritizing areas based on their impact has been done. District level intervention in the city of New York as shown in the above figure utilization of streets in the management of sustainable stormwater management systems has been done.

From sustainable stormwater networks', the major points to are runoff volume, water quality improvements and peak flow reduction would be enhanced. Streets are both a significant impediment to natural hydrology and an opportunity for improved stormwater management. City agencies are in charge of public rights-of-way from design, construction, operations, regular maintenance and permitting to the development and management of this facility.

Source: (NACTO, 2017)



Figure 2.4-2 Green infrastructures on the right of way and roadsides

Source: (Echols, et al., 2015), (NACTO, 2017)

Spaces in the institutional environments, the EiABC campus has potential and experiments on landscaping with LID elements (Fig. 2.4-5) for stormwater management systems sustainably that are functional and appealing to the built environment.



Figure 2.4-3 Potential areas in consideration for stormwater management systems at EiABC campus.

Source: Authors observation

2.4.2 Different Approaches for Stormwater Management

Stormwater management systems that are considered sustainable management systems have developed over time. Fletcher et al. (2015) discussed the terms and considerations of this approaches with their origin methods and considerations. The terms are used interchangeably whereas the scale, approaches and contexts vary to the context

In this subchapter, approaches and systems for stormwater management have been reviewed as Green Infrastructure (GI), best management practices (BMPs), and low impact developments (LIDs). On reviewing BMPS, Echols and Pennypacker (2015) refer to Tourbier, a pioneer in sustainable landscapes and author of BMPs for Stormwater, Stormwater management emerged from what was called in legal terms the common enemy rule: draining runoff rashly away from dwellings and backyards. This approach became hazardous as populations rose since one person's backyard poured onto someone else's front yard. The runoff then piled, causing flooding downstream. And BMPs related to the reduction and management of pollutants from the urbanized landscape. Nonpoint source effluents are not confined to a conduit, and conventional treatment techniques cannot generally be applied. The most common means of reducing nonpoint source pollution is through the use of practices that lessen the amounts of pollutants entering runoff (Boyd, 2015).

Low Impact Development (LID)

Fletcher et al. (2015) define GI nomenclature for stormwater control measures (SCMs), also known as best management practices (BMPs) and low impact development (LID). LID is a comprehensive water management strategy that aims to return the natural hydroperiod to its pre-developmental state. LID or the Green Infrastructures (GI)¹⁴ strategies use soils, plants, and rainfall harvesting techniques to conserve, repair, and develop green space (US EPA, 2021).

LID is a land development (or redevelopment) strategy that follows nature to regulate stormwater as close as possible to its source to generate functional and beautiful site drainage, it incorporates methods to preserve and recreate the natural systems, limiting the imperviousness level, and developing practical and attractive site drainage to manage stormwater as a resource rather than a waste product (US EPA, 2021). Stormwater management practices in land development are

¹⁴ refer to the management of wet weather flows that use these processes, and to refer to the patchwork of natural areas that provide habitat, flood protection, cleaner air and cleaner water. It refers to these interconnected actions that work as a system.

conducted to minimize impacts on the natural environment. Systems on stormwater management focus on the reduction of runoff and water quality improvements. And the LID practices help to maintain *the natural hydrological systems with site grading, vegetation, soil and natural processes that absorb and filter stormwater on site* (US EPA, 2021).

Low Impact Development techniques include conserving natural and hydrologic systems by managing rainfall at the source using methods that *infiltrate, filter, store, evaporate, and detain runoff* (CWT, 2021). LID systems integrated both the hard engineering as surface runoff controls and storage systems and soft engineering systems like filtration, infiltration and treatment systems. It is also discussed as a non-structure and structures system of LID. Cahill (2012) defines these systems as Nonstructural measures (limiting imperviousness and site disturbance) whereas structural measures are considered to be retention/detention and infiltration systems (bioremediation as rain gardens).

From the LID measures available as major systems, infiltration of precipitation is an important solution, but this is only one of the three basic methods (infiltration, vegetated systems for evapotranspiration and capture and reuse) that reduce the volume of runoff from land development (Cahill, 2012). On the SWMM model for LID techniques to model the above five Retrofitting measures can be examined to simulate the effect, they could enhance on the environment. Major systems (EPA, 2016) such as retention ponds, vegetative swales, infiltration trenches, rain gardens and rain barrels have been reviewed from different works of literature.

2.4.3 Methods and Techniques in LID system

The stormwater management systems focus on two major systems of infiltration and retention/detention systems as major categories (Weiss, et al., 2005). An *infiltration system* is defined as a system to capture and infiltrate surface runoff into the ground. Techniques that do not discharge runoff to surfaces can be categorized as infiltration practices. The available data on infiltration procedures varies greatly due to numerous aspects such as varying soil conditions, influent water quality, depth to the water table, level of pretreatment, maintenance methods, and so on (Weiss, et al., 2005). Simply described, runoff infiltration is the transfer of surface water into the soil by adsorption (adherence to plants and soil) or absorption (absorption into the soil) (water taken into the plants or soil). And it is another effective way of water purification (Echols, et al., 2015).

Table 2.4-1 Water quality benefits of infiltration

System Component	Mechanism(s)	Contaminants Retained/Reduced
Porous pavement	Filtration and adsorption	Total suspended solids (TSS), heavy metals, hydrocarbons, COD, and deicing salt (less required, more retained) (Note: Maintenance by vacuuming is required!)
Infiltration bed	Filtration, adsorption, settling, microbial biodegradation	TSS, metals, and hydrocarbons, plus total organic carbon, COD, nitrogen
Shallow soil	Filtration, adsorption, ion exchange, microbial biodegradation, conversion, and uptake (only with high plant activity)	Metals and hydrocarbons, including PAHs
Deeper soil	Filtration, adsorption, ion exchange, conversion, and uptake (only with high plant activity)	Metals and hydrocarbons, plus organics and bacteria; very low risk of groundwater contamination

Source: (Cahill, 2012)

The *retention and detention systems* are fundamental storage facilities for stormwater quantity and quality management (EPA, 1986, 1994). Stormwater retention basins became beautiful duck ponds or dry detention basins came to be used as playing fields (Echols, et al., 2015). The dry detention basin stores runoff temporarily. It does not hold a big volume to stagnant water rather it controls the peak flow time within retention and detention systems. The limitation of this system is for retention time that should discharge within 24 to 48 hours. Also, it requires frequent cleaning to reduce re-suspension (Weiss, et al., 2005).

And the wet ponds as natural wetlands or constructed retention systems absorb a volume of runoff and store it until it is partially or completely replaced by the next runoff event. As a result, between runoff episodes, retention systems retain a considerable permanent pool level of water (USEPA, 1999a). Constructed wetlands have more removal mechanisms than detention basins and longer contact durations than retention basins, allowing them to remove more contaminants like nutrients and organics (Weiss, et al., 2005). However, one significant disadvantage of manmade wetland is the vast amount of area they require. Another disadvantage of manmade wetlands (and maybe retention systems) is the inconvenience to birds and insects, as wetlands can serve as breeding sites for mosquitoes and other pests.

LID Control – a low impact development practice that provides detention storage, enhanced infiltration and evapotranspiration of runoff from localized surrounding areas. Examples include

rain gardens, rain barrels, green roofs, vegetative swales, and bio-retention cells (EPA, 2016). These five major LID measures are included in the SWMM application has reviewed as follows;

1. Bio-retention - a stormwater runoff is redirected and held in bioretention systems, which are essentially landscaped depressions. The manicured trees, shrubs, and other plants in the depression help to remove the water through absorption, while the runoff infiltrates into the soil below (Weiss, et al., 2005).
2. Rain Garden - Rain gardens and bioretention cells are vegetated depressions receiving stormwater runoff water from rooftops or other impervious surfaces such as driveways along the flow path (Sun, et al., 2019). Considering the size and placement of this feature, that is appropriate for small areas and volume of runoff.
3. Infiltration Trench - a shallow gravel-lined ditch that collects runoff from upslope impermeable regions and offers additional storage volume and time for collected runoff to permeate into the natural soil (EPA, 2016). That can be thought of as constructed channels filled with filtration media which allows to percolate (Weiss, et al., 2005)
4. Vegetated swales - such as grassed swales and filter strips are designed to convey and treat either shallow flow (swales) or sheet flow (filter strips) runoff (USEPA, 1999a). In sloped applications, vegetated cover slows overland flow, allowing more penetration into the soil and nutrient absorption through the root system (Weiss, et al., 2005).
5. Permeable Pavement - systems consist of permeable pavements or other stabilized surfaces that allow stormwater runoff to infiltrate through the surface and into the groundwater.” (USEPA, 1999a).

From the systems of stormwater management systems and the pollutant removal levels selected cases and pollutant load are as follows;

Table 2.4-2 Pollutant removal on different systems of BMPs

Pollutant	Media Filtration			Detention Basin			Retention basin			Wetland basin		
	In	Out	%	In	Out	%	In	Out	%	In	Out	%
TSS, mg/L	52.7	8.7	-83%	66.8	24.2	-64%	70.7	13.5	-81%	20.4	9.06	-56%
Total P, mg/l	0.18	0.09	-50%	0.28	0.22	-21%	0.30	0.13	-57%	0.13	0.08	-38%
Total N, mg/l	1.06	0.82	-23%	1.40	2.37	69%	1.83	1.28	-30%	1.14	1.19	4%

Source: (Rossman, 2015) cited International Stormwater BMP Database.

Typical ranges of pollutant reduction efficiencies for pervious pavements based on available literature and sampling data are as follows: TSS, 65 to 100%; TP, 80 to 90%; TN, 30 to 65%; and NO₃, 30% (Cahill, 2012). To satisfy the objectives of stormwater treatment performance reduction of 80% for total soluble solids (TSS) and 45% for total phosphorus (TP) and total nitrogen (TN)

in Melbourne. The required wetland size is required to be approximately 2.4% of the contributing impervious area in the catchment (Melbourne Water, 2005).

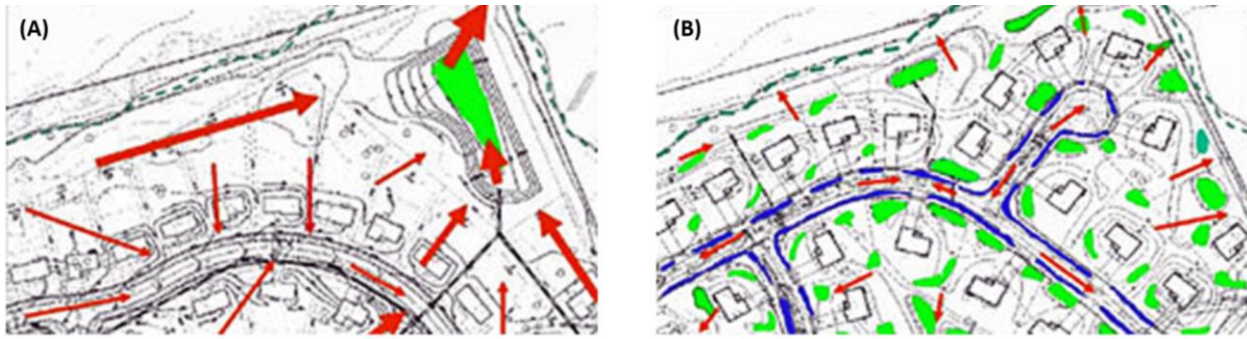


Figure 2.4-6 LID site design approaches (A) Conventional site design and (B) LID site design

Source: (Guillette, 2016)

On LID site design considerations; the LID planning and design process follows an assessment of the context. Cahill (2012) discusses the process of planning and retrofits by LID systems. He has stated five steps understanding the site and watershed, developing a program to conserve, identifying the source and flow of stormwater, designing and detailing the systems and finally reviewing the runoff and water quality factors. Design developments at the site level can be developed as non-piped systems (Fig. 2.4-7) by using permeable pavements, wetlands, retention/detention basins, naturalized swales, tree pits and green roof structures that comprehend (Butler, et al., 2018).

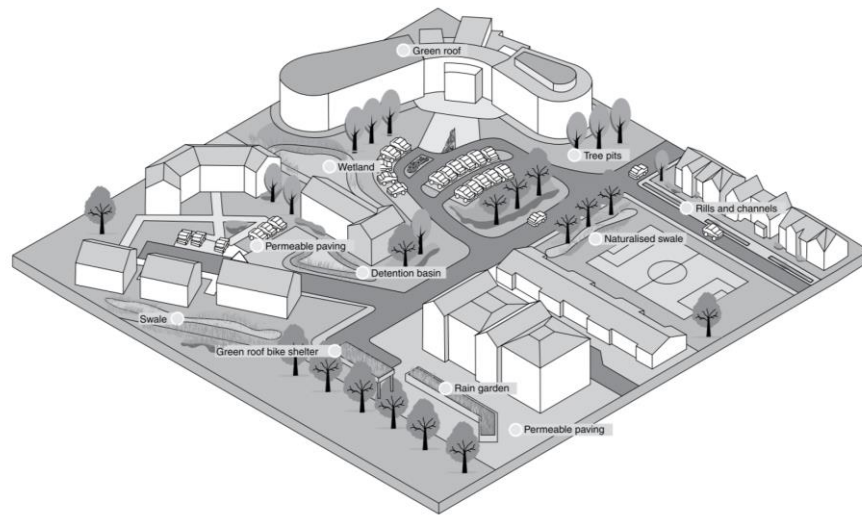


Figure 2.4.3-7 Sustainable stormwater management systems

Source: (Butler, et al., 2018) (Adapted from a graphic on www.susdrain.org.)

2.5 Summary of Literature Review

From the literature review, the researcher has covered specific chapters of the built environment, flooding, Nonpoint source pollutants and retrofitting systems to be considered. Major frameworks have been pointed out as follows:

Table 2.5-1 Major points from literature review.

Topics	Theories	Points from literature
The built environment		
(Holling, 1973), (Douglas, 2011), (US EPA, 2018)	<ul style="list-style-type: none"> Urban, urban hydrology vs the natural system 	<ul style="list-style-type: none"> Urbanization is a pervasive phenomenon, The concept of resilience is the ability of a system to absorb change and disturbance without changing its basic structure and function or shifting into a qualitatively different state.
Imperviousness and Flooding		
(Arnold & Gibbons, 1996), (Goonetilleke, 2004), (Moore, 2017), (Schueler, 1994), (Sun, et al., 2019), (Şen, 2018)	<ul style="list-style-type: none"> Imperviousness Vs Flooding 	<ul style="list-style-type: none"> Imperviousness is directly related to flooding, The lower the catchment area is higher the imperviousness impacts. The extent, relation with the natural system and intensity/density of urban developments are key factors to imperviousness with hydrology.
Urban Pollution and diffused pollutants		
(Petrucci, et al., 2014), (EPA, 2016), (Fleischmann, 2014), (Forman, 2014), (USEPA, 2005)	<ul style="list-style-type: none"> Imperviousness Vs Water Quality ‘Urban stream syndrome’ 	<ul style="list-style-type: none"> Flooding is a transporter of pollutants, The urban environment generates diffused pollutants differently. Water features near the urban environment face the challenge of water quality impairment.
Low impact Developments and Green Infrastructures		
(Douglas, 2011), (Friedman, 2021), (Cahill, 2012), (Fleischmann, 2014), (Fletcher, et al., 2015)	<ul style="list-style-type: none"> Green Infrastructure Low Impact Development 	<ul style="list-style-type: none"> Upcoming urban development focuses on sustainable planning and design to balance human needs with urban ecosystems. LID systems can reduce runoff and diffused pollutants by up to 90%.

Source: (Authors review of literature)

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Study area

The study area is in the southern part of Ethiopia which is in the watershed of the rift valley. It is located in the Sidama region and is the capital city of the regional state. The city is one of the developed and multifaceted urban environments to study cities development beside on water features.

Location

Hawassa city is located adjacent to Lake Hawassa to the east, Cheleleka marshy areas to the east, the river tikur wuha to the north and Alamura mountain to the south. It lies on a relatively flat plain of the rift valley having an average elevation of around 1,690 meters above sea level (m.a.s.l.) with approximate geographical coordinates of about 38°29' East longitude and 07° 03' North latitude (FUPI, 2006).

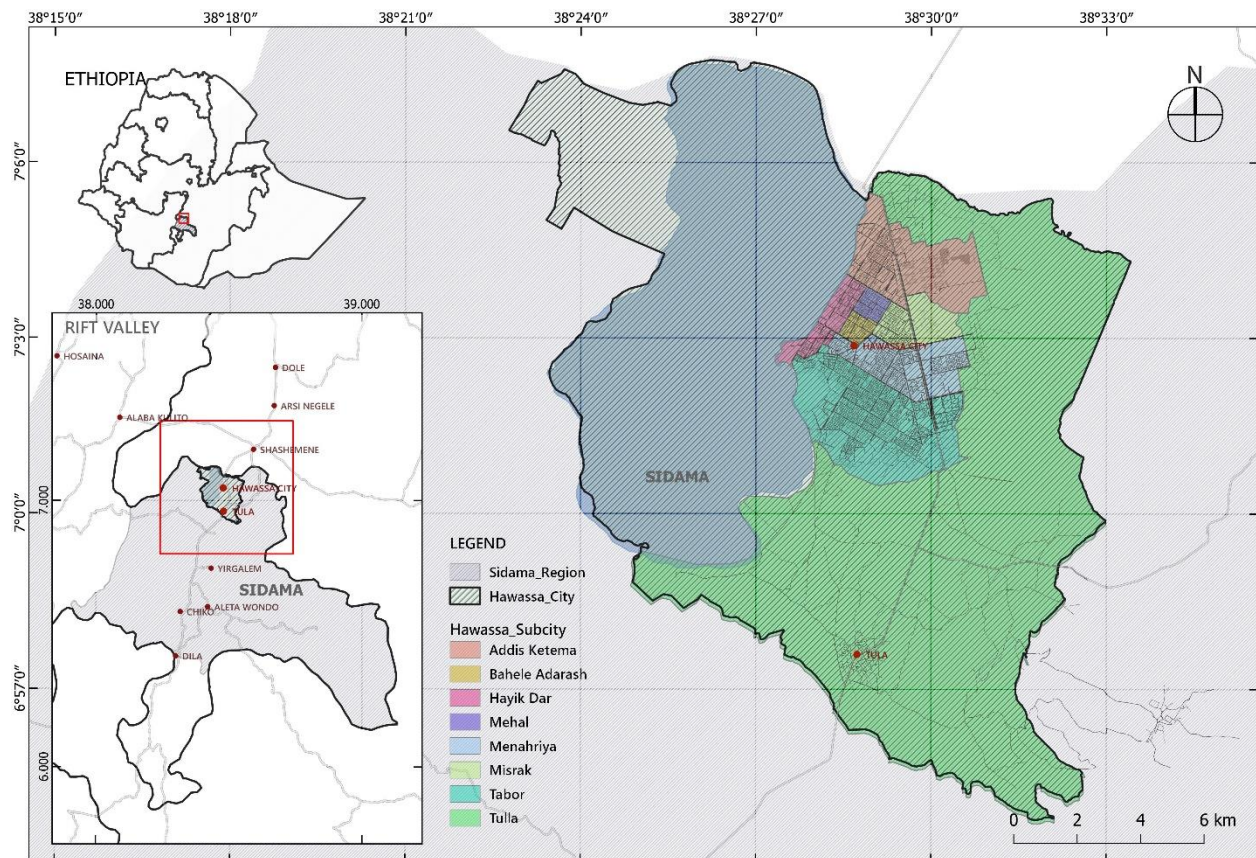


Figure 3.12.4.3-1 Location & Administrative Boundary of Hawassa City

Source: (authors presentation)

It is situated roughly in the center of the depression between the two lakes (Fig. 3.1-1), Shallo in the east and Hawassa to the west. On the east, the town is limited by the Tikurwuha River which connects Lakes Hawassa and Shallo. The town is at an altitude of about 1700 m.a.s.l., though there exist flat-topped hills like Mount Tabor (1800 m.a.s.l.) on the western side, Mount Alamura (2019 m.a.s.l.) and Mount Kika in the South and South-Eastern side, respectively (G.Wahid, 2007).

The city administration covers an area of 157.2 km² (15,720 ha), divided into eight sub-cities and 32 Kebeles. As shown on (Fig. 3.1-2) these eight sub-cities are Hayek Dare, Menehariya, Tabor, Misrak, Bahile Adarash, Addis Ketema, Hawela-Tula and Mehal Ketema. 20 of the kebeles are considered urban (HAC, 2021). Out of the 32 kebeles that form the city of Hawassa, three of the earlier kebeles – Wukro kebele in Misrak sub-city, Addis Ababa kebele in Mehal Ketema sub-city, and Harar Kebele in Bahel Adarash sub-city have maintained their former names. The remaining 29 kebeles have been established recently (FUPI, 2006). This showcases the changing dynamics the city is undergoing.

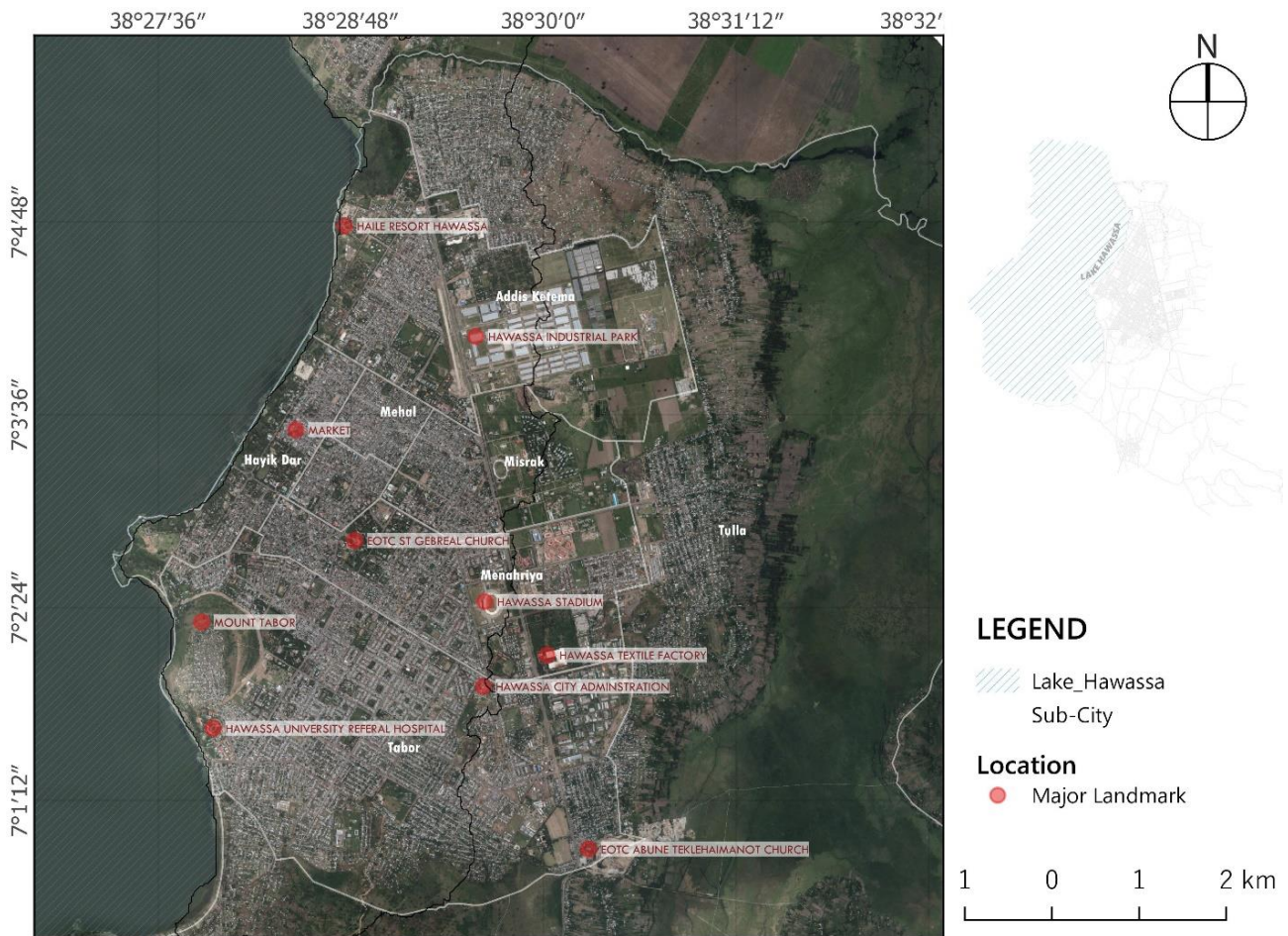


Figure 2.4.3.1-2 The Lake and the City Hawassa

(Source: Authors presentation)

Over the past decades, the urban population of Hawassa grew exponentially and almost doubled every ten years. The population of the city is Hawassa on 2007 to the Central Statistical Agency (CSA) is 281,158 with a forecasting population growth rate of 4.02 the total population for the year 2012/2020 is 436,655 (HAC, 2021). National census reported 36,200 in 1984, 69,200 in 1994 and 157,100 in 2007. The population of the city has shown rapid change through short period of time¹⁵.

3.1.1 The Physical Context

The Land Use Land Cover (LULC) change of the region has shown exponential sprawl as shown on a map of Hawassa city (Fig 3.1-3). Owing to its recent growth the Hawassa town has undergone considerable LULC changes. A few years back the majority of the area in the provided boundary was occupied by state and household farms. However, currently, major land use is being changed to the built-up area (G.Wahid, 2007).

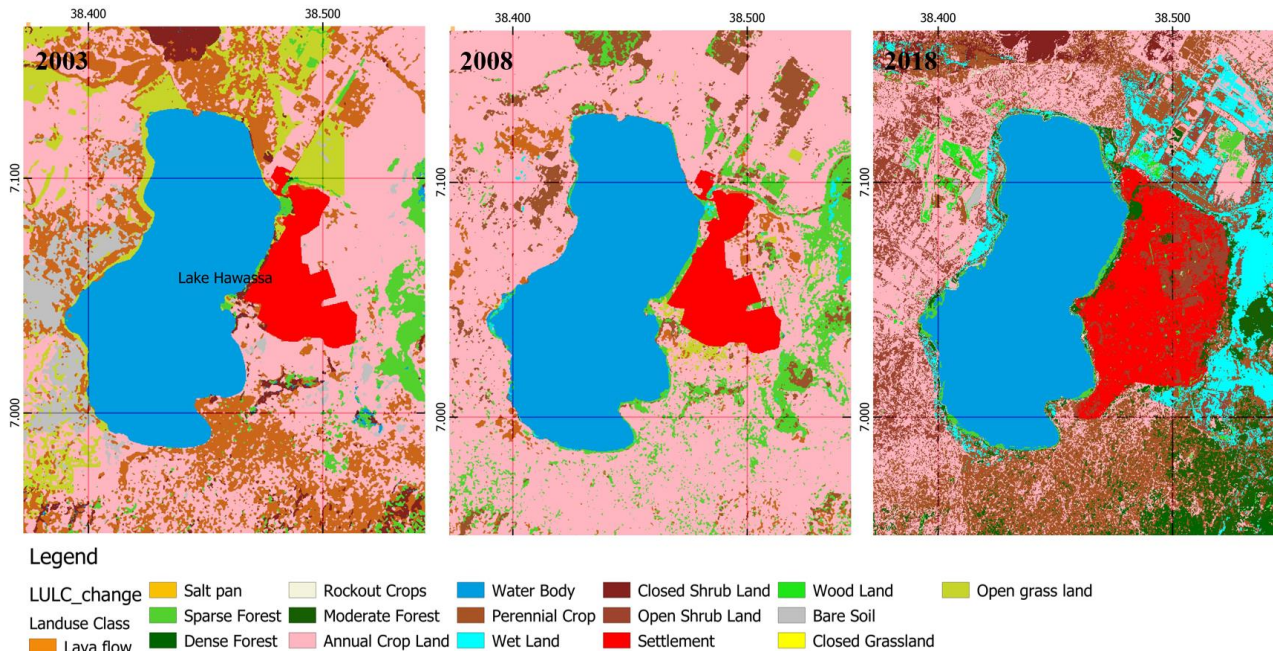


Figure 3.1-3 LULC change 2003,2008 and 2018 respectively.

Source: Map from EMA and graphical presentation by the author.

From the data shown below (Table. 3.1-1) the LULC change for 2003, 2008 and 2018 respectively ~25 km area has been taken and evaluated to examine the change under different periods.

¹⁵ On review of unpublished document of Hawassa Structure Plan (HSP, 2019) the population of the city has forecasted to be 784,522 by 2030 considering annual growth rate of 7%.

Table 3.1-1 LULC change of Hawassa 2003, 2008 and 2018 units in ha.

No.	Land Cover Class	2003	2008	2018
1	Annual Crop Land	35011.96	65252.41	27077.67
2	Bare Soil	5066.254	6.952426	204.39
3	Closed Grassland	-	2.595572	3.6
4	Closed Shrub Land	3489.701	4710.871	1011.42
5	Dense Forest	-	0.648893	9434.88
6	Lava flow	-	-	16.56
7	Moderate Forest	708.944	3.800659	9140.76
8	Open Grass Land	11428.69	-	0.18
9	Open Shrub Land	18817.95	3095.127	9672.75
10	Perennial Crop	-	-	19770.48
11	Rock out Crop	-	-	325.26
12	Salt pan	-	-	0.27
13	Settlement	2015.035	2048.926	3825.81
14	Sparse Forest	12041.12	13534.52	648.99
15	Water Body	9940.498	9487.28	8915.13
16	Wet Land	126.4317	254.6442	8074.35
17	Wood Land	-	-	592.38

Source: EMA (Authors presentation)

Lake Hawassa is a medium-sized lake with a mean depth of about 11 m and a maximum depth of about 22 m. It covers an area of 92 km², a volume of 1.3 x 10⁹ m³ and a total drainage basin of 1020 km², with no surface outlets. It is a topographically closed lake in the Ethiopian Rift Valley. The physical expansion is limited by Lake Hawassa in the west and the Oromia Region in the north. The town and surrounding region (Hawassa ‘zuria’) has estimated to be approximately 1,862.53 and 2,765.19 ha, respectively (FUPI, 2006).

The topographic condition of the catchment is majorly flat to gentle (Dadi, et al., 2017). The natural environs of the area have sustained the lives of the community with the utilization of the wetlands as a livelihood source for irrigation, bathing, recreation and drinking water for domestic uses and wildlife (Desta, 2003). The natural landform of Hawassa city (Fig. 3.1-4: Contour and Slope) has shown an elevation, averagely flat land that has been placed in an enclosed watershed of Hawassa. Elevated zones around the city are mount Tabor and Alamura to the south-west and southern part of the sub-watershed respectively. The natural landform on the urbanized landscape is defined as

ridges of sub-watersheds that directly drain to the major wetland of the catchment that is lake Hawassa and the right part of the city that drains to the 'Tikur wuha' river and Cheleleka wetlands area. The study area is identified based on the watershed pattern of the urbanized environment that has shown in (Fig. 3.1-4 on Stream Order and Blue Spot) in detail.

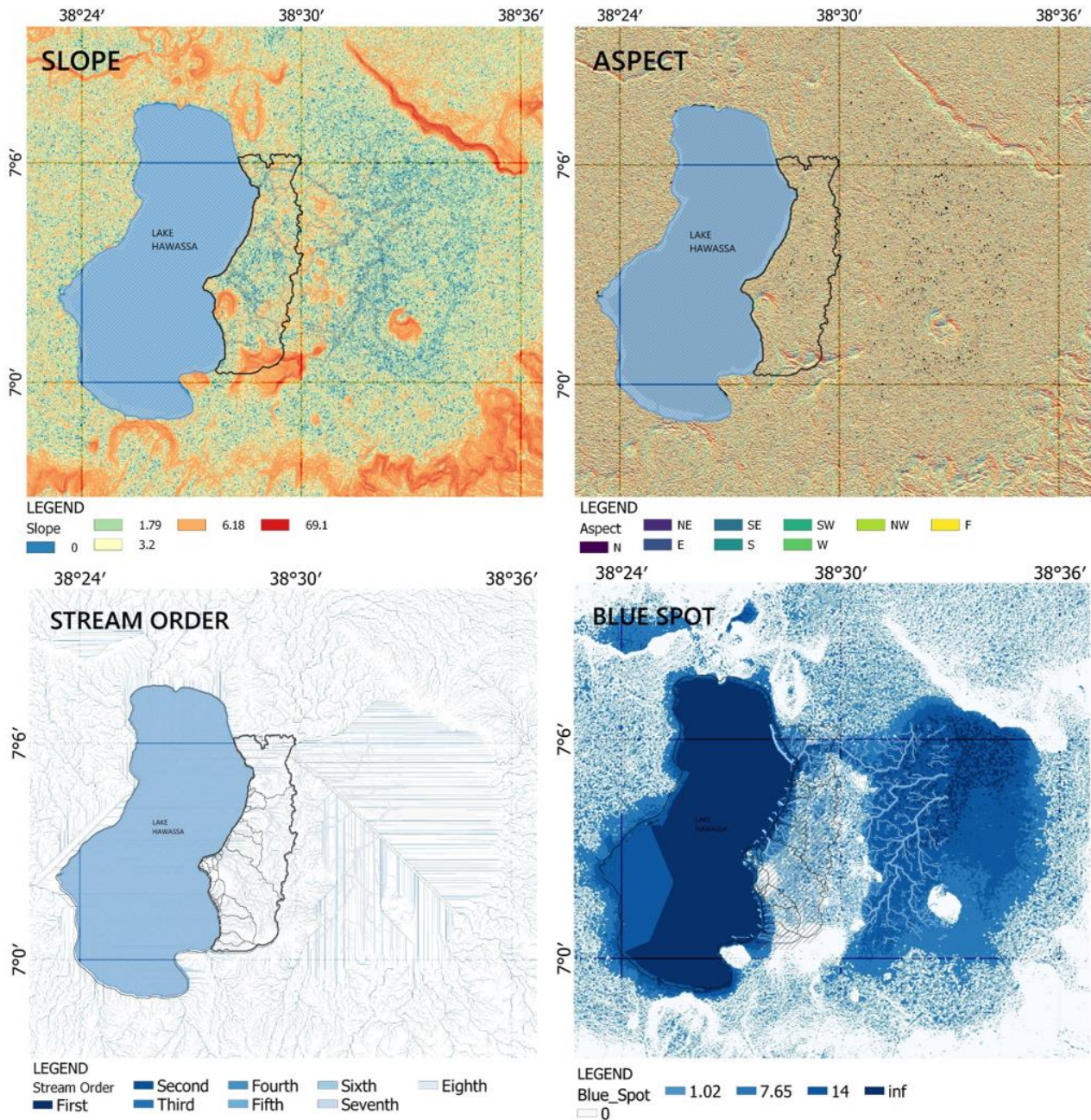


Figure 3.1-4 The natural landform for Lake Hawassa catchment (Source: Map by the author)

The identified sub-watershed covers an area of 3,252.25 ha. Lake Hawassa covers a total perimeter distance of 50.08 km. From the total lake perimeter, the lake and the city cover a marginal perimeter of 13.80 km of distance shown below (Fig. 3.1-5).

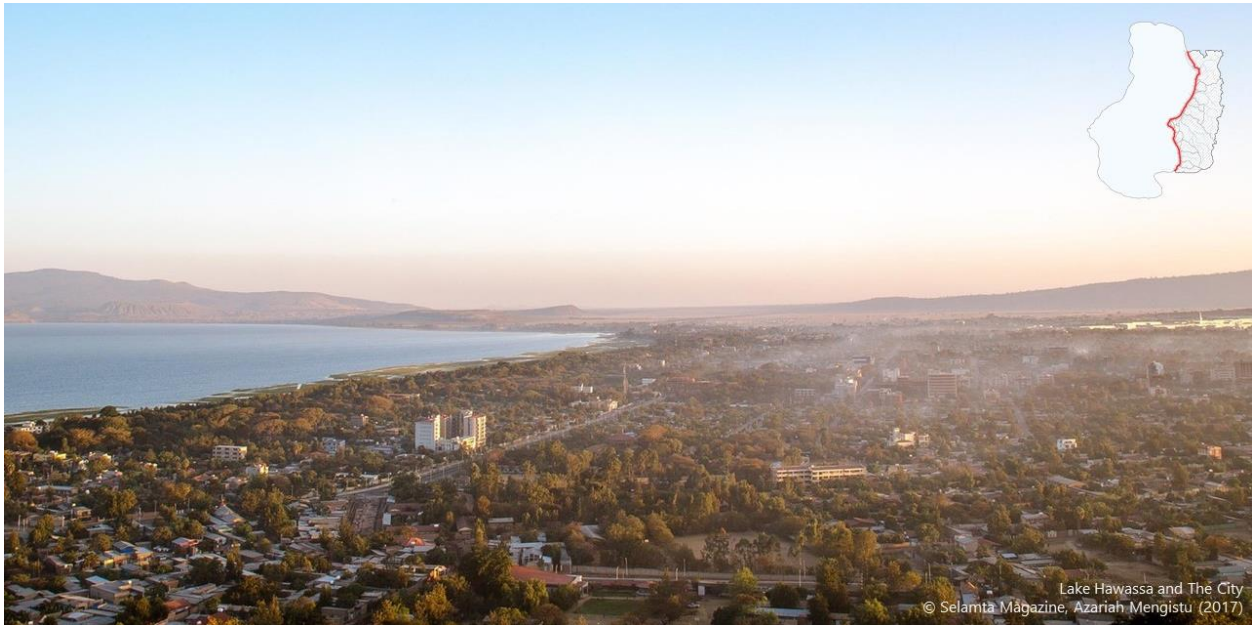


Figure 3.1-5 The Lake and the city

Source: By Azariah Mengistu, from Selamta Magazine (2017)

The stormwater management of the city has been a major challenge and the stormwater drainage system has created flooding problems in various locations immediately after heavy rainfall events (Adane, 2019). In the drainage systems and lower catchment areas of the city, overflows and flooding happens redundantly. The streets and depressed flood plains face the challenge of flooding in such scenarios. (Fig. 3.1-6) show the rainfall in the flood plain area of ‘Hayik dar’ primary school compound. Activities and use of spaces have been disrupted by flooding. In addition, collateral damages happen to flood plain urbanization practices.



Figure 3.1-6 Picture showing how the city faces Stormwater challenges after heavy rainfall events.

Source: Authors' site visit

Based on the causality of rainfall and flooding events NPS pollution to the area impacts and the challenge showed on the streets and lower catchments of the city watershed (Fig. 3.1-7). Although the infrastructure is specifically developed for separate stormwater drainage system, diffused pollutants from the urbanized landscape trapped in the drainage systems shown on figure below.



Figure 3.1-7 Picture showing pollutants on the surface and drainage outlets of the city to the lake.
Source: Authors' site visit

After the heavy rainfall events, the researcher has observed major drainage systems have been blocked (Fig. 3.1-7) with sedimentation and suspended solid wastes from the urban environment. And the municipal does the task of cleaning the channels (Fig. 3.1-8) to manage and control flooding challenges in the city on a seasonal basis.



Figure 3.1-8 Picture showing Cleaning of the drainage channels after heavy rain events.
Source: Authors' site visit

Climate

The climate zone is in an area that ranges from *dry to sub-humid* (Dadi et al., 2018). That is characterized as a "Woina Dega" Agro-climatic zone that has moderate and reliable rainfall that creates rain feed agriculture (FUPI, 2006).

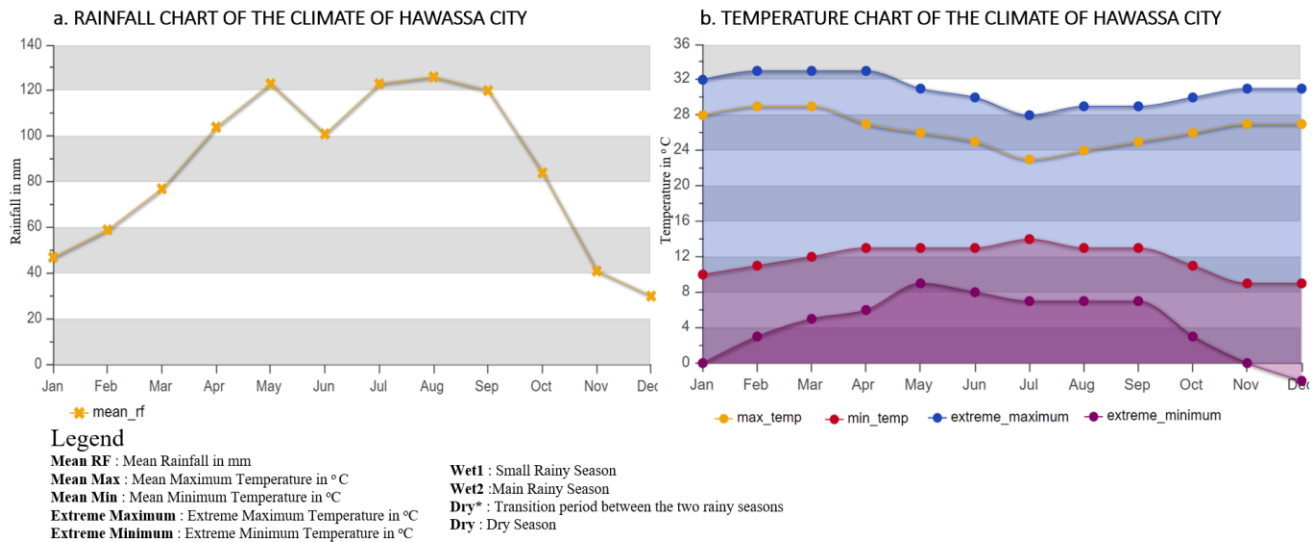


Figure 3.1-9 Climate of the city, Hawassa

Source: NMA, National Meteorology Agency

Rainfall

The major climatic factor for this study is the precipitation data or rainfall character of the city Hawassa. The long term annual average magnitude record at Hawassa weather station is 961mm, which spread as 44% to 50% for Kiremt, 20% for the Bega, and 30% for Belg seasons. That is in the category of "Summer Maxima" and most hinterlands receive "small rain" in spring. (FUPI, 2006). Adane (2019) describes the frequency distribution pattern of rainfall intensities and quantities within 24 hr is by his study reported as 52.75, 68367, 79.20, 92.51, 102.4, and 112.2 mm/hr. for a return period of 2, 5, 10, 25, 50 and 100 years of period respectively. Considering the steady-state water balance for Lake Hawassa precipitation accounted for 56% of the total inputs and 44% of runoff (Gebreegziabher, 2004)cited (Telford 1998, Lamb et al. 2002).

Class-A pan evaporation starting from 1986 has been collected by National Meteorological Service Agency (NMSA). Because it is exposed to air and sun, the pan collects a great amount of energy via radiation and conduction through its base and sides and is located 500m to 1 km east of the lake. Annual lake evaporation is projected to be 1572mm. The average monthly lake evaporation at Hawassa is estimated to be 131mm. Evaporation is as low as 102 mm in July and as high as 156 mm in March, the hottest month of the year (G.Wahid, 2007).

The yearly average precipitation values for (2014-2020) range of seven years has presented as follows below:

Table 3.1-2 Annual Rainfall Data of Hawassa City

Yearly Average (Daily)		
No	Year	Average of Precipitation Hawassa (SUM) (mm)
1	2014	1.899386503
2	2015	1.870921986
3	2016	0.422222222
4	2017	2.816997167
5	2018	0.130645161
6	2019	0.30952381
7	2020	3.080327869
Average yearly precipitation for seven years		2.01704918

Source: NMA (Authors Presentation)

From the NMA data collected from seven years (January 2014- March 2021) range, the average monthly precipitation is presented as follows:

Table 3.1-3 Monthly Rainfall Data of Hawassa City

Monthly Average (Daily)		
No	Month	Average of Precipitation Hawassa (SUM) (mm)
1	January	0.2071
2	February	0.8035
3	March	1.3081
4	April	2.528
5	May	5.2347
6	June	2.9178
7	July	3.0168
8	August	3.5204
9	September	3.4141
10	October	3.4056
11	November	0.2688
12	December	0.1538
Average Monthly precipitation per year		2.0170

Source: NMA (Authors Presentation)

The hinterland of Hawassa is under the influence of easterly and westerly moist air currents that ascend over the relatively higher areas creating a rain effect. The easterly is a dominant type of wind that prevails in the study area during most parts of the year and brings about the autumn rain together with the southwesterly wind which originates from the south-west. The easterly wind also creates small rain in spring (March and April) (FUPI, 2006).

Geological Context

Hawassa town is overlaying volcano lacustrine sediments¹⁶ almost 30 meters thick, though it shows variability laterally and vertically. There are three types of soils in the study area, these are clay soils, sandy silt soils, and silty sand soils (G.Wahid, 2007). The soil map of FAO shows the region of the urbanized landscape of Hawassa city, as shown on the map (Fig 3.1-10 _ Soil map) is FLe ‘Eutric Fluvisols’ soil group. It usually forms ridges and scarp features (ex. Alamura, Tabor hill). These units also outcrop at the eastern, southern and west parts of the Lake Hawassa catchment while around the lake it is underlain by the lacustrine Sediments. It is mostly well joined and its thickness is mostly greater than 200 meters (G.Wahid, 2007) cited (T. Cherenet, 1982).

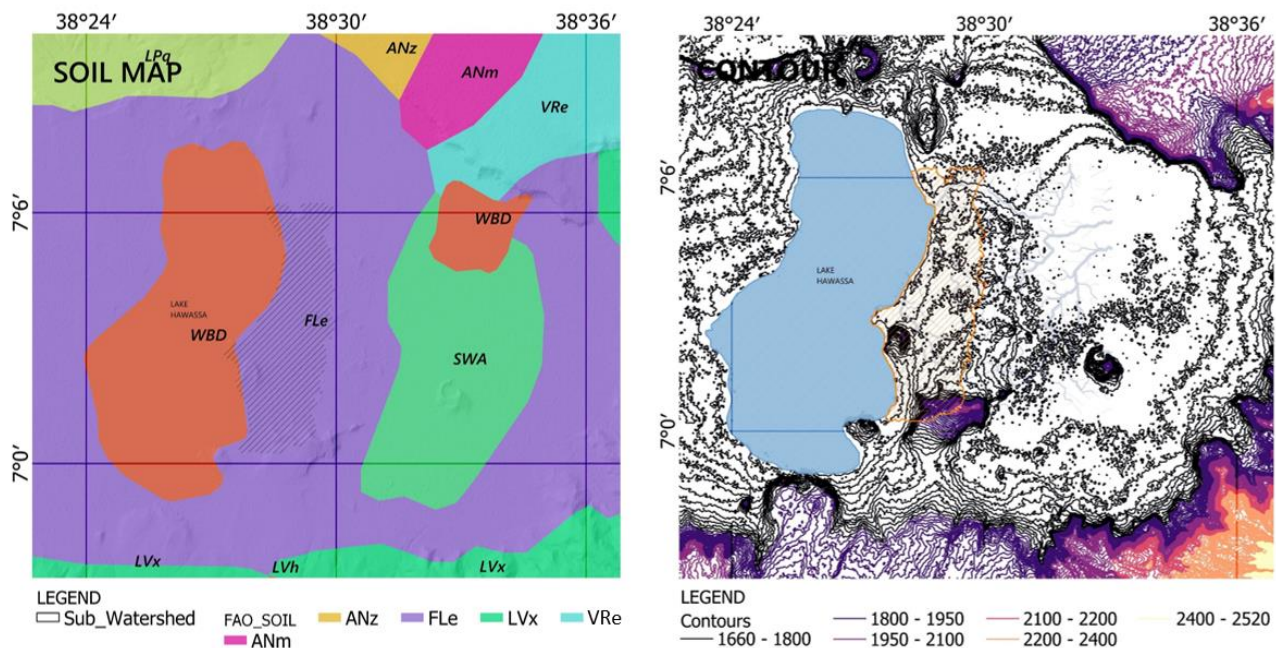


Figure 3.1-10 Soil and contour map of the region

From other literature reviews on the soil texture of Hawassa city, *clay loam soil* is the dominant texture of the soil in the area. Adane (2019) and Gebreegziabher (1994) refer to (W.W.D.S.E,

¹⁶ Lacustrine deposits are sedimentary rock formations which formed in the bottom of ancient lakes. A common characteristic of lacustrine deposits is that a river or stream channel has carried sediment into the basin. They share similar sedimentary deposits which are mainly composed of low-energy particle sizes.

2001), that clay loam soil is the dominant soil texture. The hydraulic conductivity¹⁷ of the soil is Sandy loam soil. Water transmission through the soil is restricted in this situation, which is classified as Group C. It contains loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures and normally contains between 20% and 40% clay and less than 50% of sand (Rossman, 2015).

The existing built-up area of the town and its proposed future expansion zone is almost entirely covered by these lacustrine sediments. These types of soils cover the central, eastern and southeastern parts of the town occupying relatively elevated areas. Their thickness varies between the ranges of 0.85 - 3.5m as Sandy silt soils, And Silty sand, especially at the depth range of 1.5-3.5. However, along the lakeside these soils become dominant. Usually, this unit is found at a depth below 1.5 m (G.Wahid, 2007). Depth of groundwater generally decreases as one goes away from the lake. In the direction of the south and southwestern, the groundwater level increases from zero to 82 meters with an average of 32 meters (G.Wahid, 2007) cited (Lamore 2006). While the eastern and southeastern part of the drainage area has a relatively dense drainage pattern and all the runoff from these catchments feeds Lake Shallo (Cheleleka) and the adjacent swampy area, overflow from lake Shallo flows to Hawassa lake through Tikurwuha river (G.Wahid, 2007) (Zemenu, 2000).

3.1.2 The Sub - Basin and drainage pattern of the region

From the landform of the county of Ethiopia, Lake Hawassa is placed in the middle of the rift valley basin (Fig 3.1-11). And from the watersheds of the rift valley, the lake Hawassa watershed is at an enclosed sub-catchment in the valley (Gebreegziabher, 2004).

Wetlands provide valuable natural resources and benefits to humans. They provide food, recreation, cultural space, flood control, and better water quality. They are also important to biodiversity and wildlife conservation. The lake is the most famous and attractive feature of Hawassa (Desta, 2003). This wetland is one of the country's most well-known tourism destinations, thanks to the stunning views of the lake from resort hotels and the abundance of rare water birds.

¹⁷ Hydraulic conductivity of the material can be defined as the ability of the fluid to pass through the pores and fractured rocks. The conductivity depends on the type of the soils that are found in the region. It is dependent on factors such as *soil texture, particle size distribution, roughness, tortuosity, shape, & degree of interconnection of water-conducting pores.*

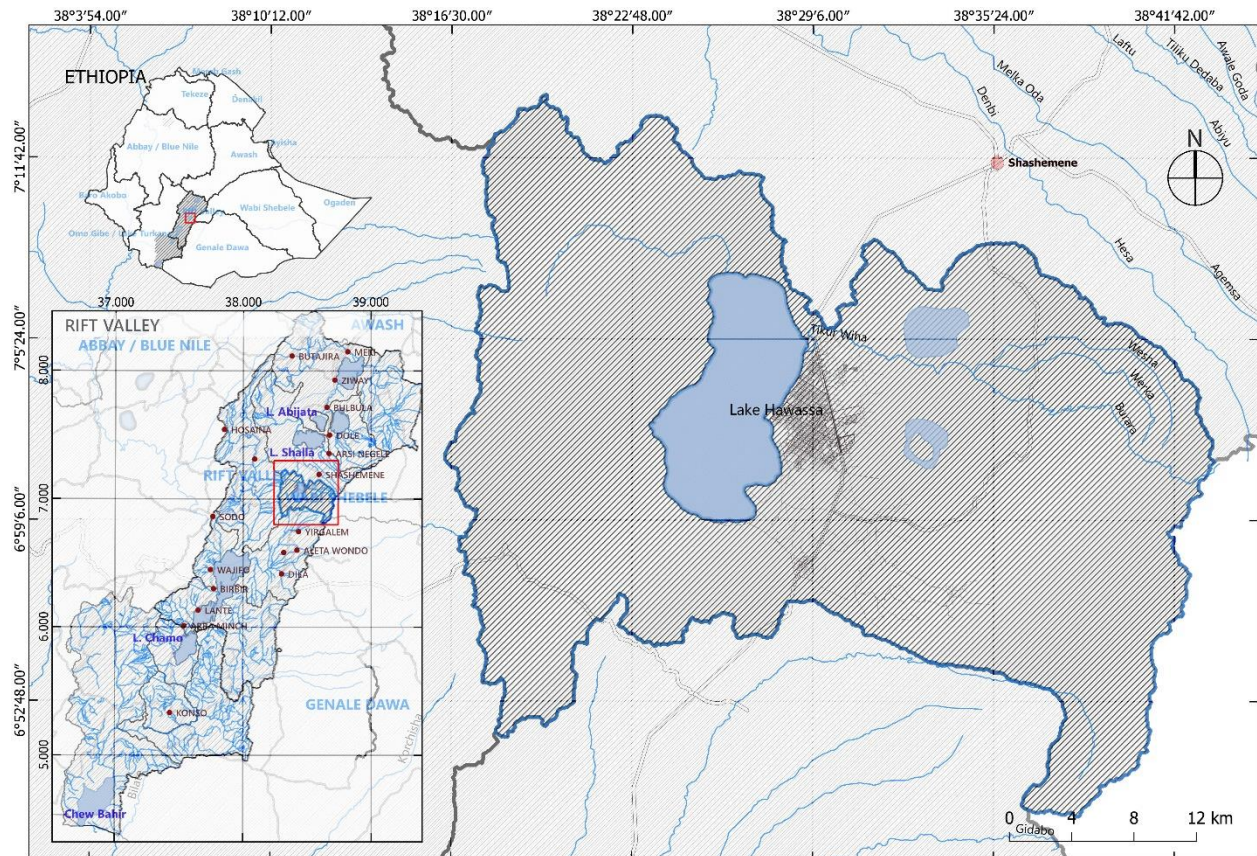


Figure 3.1-11 Regional and the city watershed boundaries.

Source: HCA (Hawassa infrastructure bureau) (authors presentation)

The Lake have bio diversities as Marabou storks in a large population and local and Palearctic migrants. And other wildlife species such as hippopotamus, otters, monitor lizards, vervet and colobus monkeys are found in and around the lake (Desta, 2003) cites (Tilahun et al, 1996). The watershed's geographical location covers 6°45' to 7°15' North and 38°15' to 38°45' East latitude and longitude, respectively (Dadi, et al., 2017), which spans an area of 1436.5 km², is part of north eastern rift valley basin. Dorebafena-Shamena, Wedesa-Kerama, Tikur Wuha, Lalima-Wendo Kosha, and Shashemene-Toga are its five sub-watersheds (Fig. 3.1-12 left).

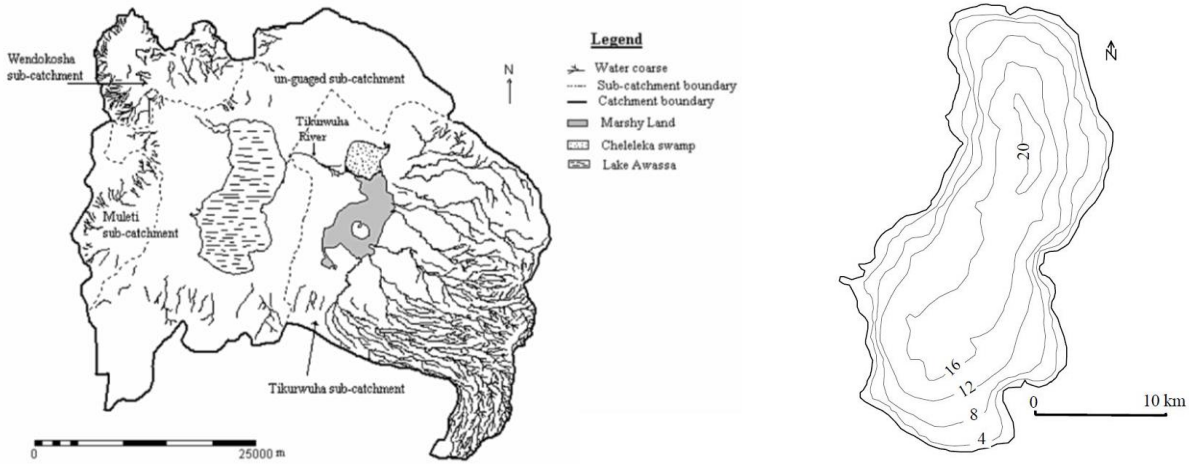


Figure 3.1-12 Drainage System of Lake Hawassa Basin and *Bathymetry pattern of Lake Hawassa*
 Source: left (Gebreegziabher, 2004) right (Atnafu, 2014)

As shown in (Fig. 3.1-12) the watershed pattern of lake Hawassa is enclosed and the two major wetlands flow from Cheleleka to lake Hawassa based on the altitude of the landform. The urban environment of the city has been covered by an elevated plane between the two wetland areas. And the urban area is delineated by sub-watershed surfaces that directly drained to the lake Hawassa and surfaces drain toward Cheleleka wetland and Tikur wuha river, which has shown on with dotted lines (Fig. 3.1-12) sub-watershed boundary. Consequently, the balance between rainfall and evaporation regulates the water level, and the shoreline recedes 100-300m during the dry season (FUPI, 2006). In addition, the lake storage capacity has been reduced by 4% due to sedimentations from both rural and urban environmental challenges to watershed management (Gebreegziabher, 2004).

3.2 Research design

The research follows a causal design that is organized to break down the objectives into flows of tasks. The major two objectives as shown on (Fig. 3.2-1) the impact of urbanization (Imperviousness Module) and pollutant loads from anthropogenic activities (NPSP module) factors had organized into two modules. The first module covers the imperviousness factors on the surface and climatic variables processed. And secondly, the non-point source pollutant factors have been used on sample water quality tests on catchments pour point and land-use factors from US EPA standards and SWMM simulation model has examined. Third, the LID retrofitting strategies had reviewed to recommend optional retrofitting measures and compare the simulated results.

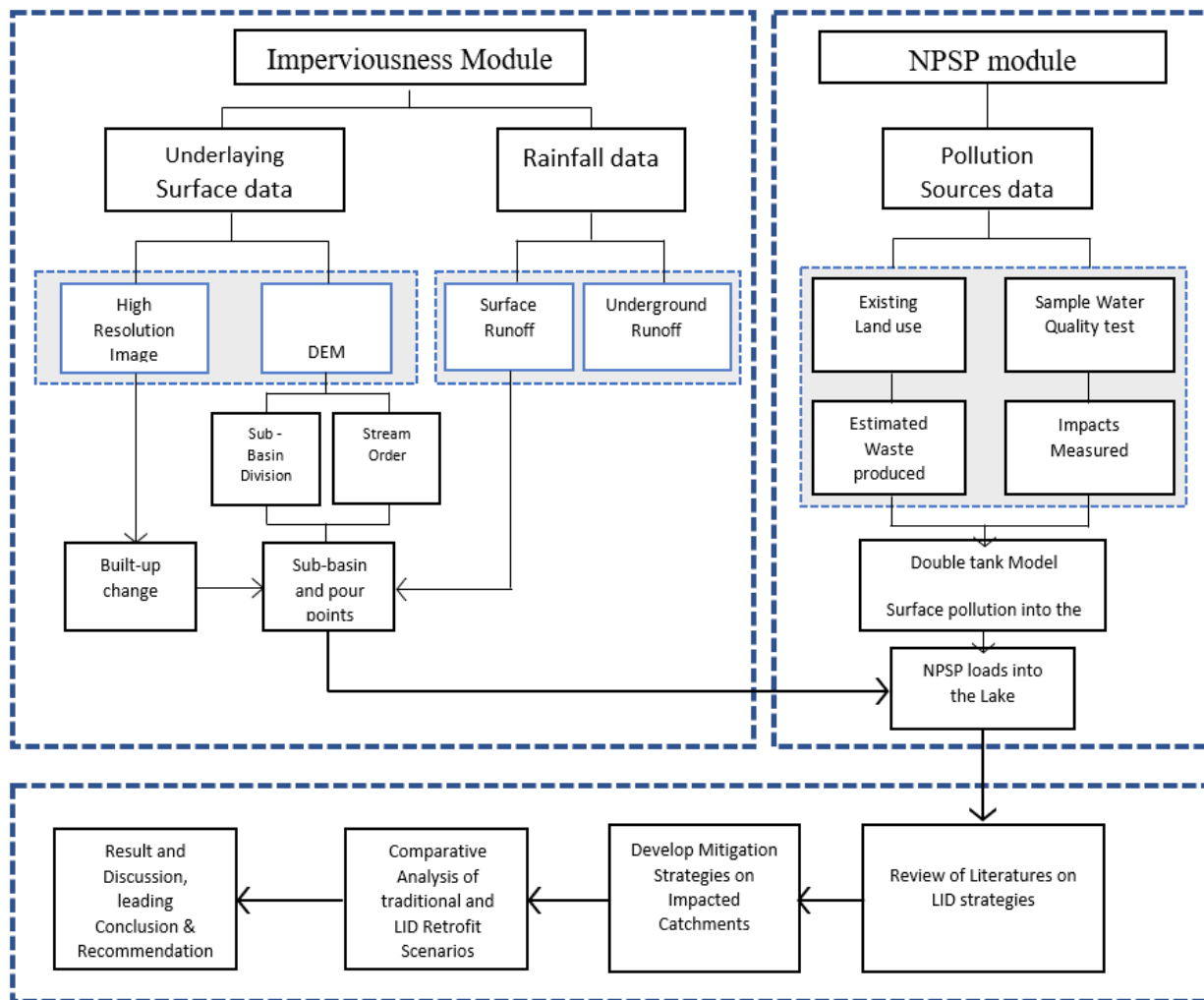


Figure 3.2-1 Flow chart.

Source: Adapted from A Combination Model for Quantifying Non-Point Source Pollution Based on Land Use Type in a Typical Urbanized Area (Authors presentation).

3.3 Sources of data

Both primary and secondary data sources have used by this study. The study uses a data set that included a Digital Elevation Model (DEM), a high-resolution satellite image, an existing land use map, precipitation data, and water quality samples. The data source and type with method has presented as follows;

Table 3.3-1 Objective, Data and Method

Objective	Data Source	Data Type	Method
1. To delineate the sub-watershed of the urbanized landscape. And to show the imperviousness level of the area and identify the impacted sub-watershed.	Primary and Secondary data	<ul style="list-style-type: none"> – DEM – Satellite images – Institutional data 	Processing and mapping specified demarcation of the sub-watersheds. Quantitative measurement for imperviousness level of the city and characterization required.
2. Identify the NPS pollution from impacted urbanized watersheds.	Primary and Secondary data	<ul style="list-style-type: none"> – Sample tests on site – Existing Land use Site observation 	Quantitative measurement for pollutants by water quality samples and simulation resulting in the existing land use.
3. To develop LID strategies to enhance the sustainable stormwater management system.	Secondary data	<ul style="list-style-type: none"> – Literature studies – Case study 	Qualitative and Quantitative impact assessments

Addressing objectives 1 & 2, data sources from open-source materials such as DEM and institutional data sources are used. Primary data from satellites and water quality samples have been collected. Secondary data sources such as literature studies, land use and precipitation have been collected from institutions related. Other data types have been processed from satellite images by digitalization and analysis.

Table 3.3-2 Data and Available Sources.

Data Type	Scale	Data Description	Data Source
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Metrological data	Daily	Precipitation	Ethiopian National Metrology Agency (Appendixes 2)
Land use types	1:50,000	Vector data	Local Government departments
Soil properties	1:1,000,000	Raster data	FAO Ethiopian soil Character
Watershed data	-	Regional watersheds from Government Institutions and Vector data, generated from DEM data and high-resolution images	Local Government departments & ASTAR Global DEM (GDEM) data
Pollution Source	-	Sample Test and Land-use type	On-site and desk study (Literature)
Socioeconomic data	-	Population, industrial structure,	Statistical review (Literature)

Source: Modified from literature (A Combination Model for Quantifying Non-Point Source Pollution Based on Land Use Type in a Typical Urbanized Area.)

3.4 Sampling design

Considering the urbanization and level of impacts on the natural environment, purposive sampling on identified streamline identified to test. Samples from the spots were collected to identify the watershed impacts.

Modelling and Estimation of NPS Pollution

From modelling software like Soil and Water Assessment Tool (SWAT), Storm Water Management Model (SWMM) etc. SWMM has been used to model NPS pollution. It is an open access simulation platform that evaluates the runoff volume and NPSP pollutants.

Table 3.4-1 Simulation Model for Runoff and Pollutant Load level

Model	Name	Applicability	Advantage	Disadvantage
HSPF	Hydrological simulation program-Fortran	Rainstorm events and continuous monitoring for watershed and urban areas	Better capture the detailed runoff and water quality process	Lacking detailed spatial descriptions; limitations in urban areas
SWAT	Soil and water assessment tool	Continuous monitoring for watersheds	Master the long-term effects of land management measures on water, sediment and pollution; low data requirements	Not applicable to simulations finer than daily scale; parameters need to be adjusted in different regions

SWMM	Stormwater management model	Rainstorm events and continuous monitoring for urban areas and watersheds	Complete module and good applicability; suitable for pipe network simulations	Highly demanding parameters; limitations in watersheds
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Source: A Combination Model for Quantifying Non-Point Source Pollution Based on Land Use Type in a Typical Urbanized Area.

Based on the available data for soil types in specific scenarios, the infiltration method has been taken as Modified Horton¹⁸ which is exponential to decrease in time.

3.5 Sample collection

Identifying the sub watershed that directly drain to the lake, the build-up changes between 2013 and 2018 has digitalized from high resolution satellite image. Collecting secondary and primary data sets for objective two, the existing land use factor for 2018 and storm water runoff has collected on selected four sub catchment outlets that directly drain to the lake.

3.6 Lab analysis

Based on the imperviousness level and runoff volumes with in a catchment, water quality samples have taken on sub-catchment outlets that directly drain to the lake. Water quality analysis of the physical and chemical properties of stormwater has analyzed. Purposive sampling of the stormwater runoff on the third rain event on June 22, 2021 has taken and Hawassa university, department of water supply and environmental engineering laboratory has examined the laboratory test. Seven major water quality parameters as turbidity, electrical conductivity, DO, BOD, COD, TP, TN that is attached here in (Appendixes 3).

3.7 Methods of data collection

The study trails collecting and reviewing secondary data from publications and reports to assess the general aspects on the case. Following formulations to the research objectives and questions specific data sets has collected and reviewed on sources and methods listed above (Table 3.3-1).

¹⁸ This method is based on empirical observations showing that infiltration decreases exponentially from an initial maximum rate to some minimum rate over the course of a long rainfall event. Input parameters required by this method include the maximum and minimum infiltration rates, a decay coefficient that describes how fast the rate decreases over time, and a time it takes a fully saturated soil to completely dry (EPA, 2016).

Based on the first objective, the city's natural and man-made land cover were required for spatial information to the case. In this regard, the researcher has collected a data set that included Digital Elevation Model (DEM), a high-resolution satellite image, an existing land use map, precipitation data, and water quality samples. A detailed GIS database to map the watershed pattern, impervious surfaces, land cover types, and drainage networks. In relation with the built-up structures and land use factors on identified catchments directly drain to the lake. Utilize high-resolution satellite imagery to identify and quantify impervious surfaces within the study area. This data has obtained from the municipality of Hawassa city.

On the second objective, required data on water quality aspects has to understand and quantify factors with the specific case secondary data and the actual water quality sample to the case area has taken. Collect water samples from stormwater runoff before diluted to the lake Hawassa. Analyze the samples for various water quality parameters such as pH, turbidity, total suspended solids (TSS), and nutrients (nitrogen, phosphorus). On the third objective of the study global and regional studies has reviewed on studies and projects related with low impact development strategies at different scale.

3.8 Methods of data analysis

The study integrates mixed research methods. Those are descriptive and correlational research methods using quantitative data collected. Based on the objectives stated, mapping, quantifying and simulating the spatial analysis of the sub watershed and level of imperviousness has done firstly. Considering the natural landform (slope, watershed pattern and stream orders) the built-up factors as percentage of imperviousness and the precipitation data, stormwater flows has simulated as total runoff, impervious runoff and peak flow using SWMM model. Major data sets are used to simulate the runoff volume as total runoff and peak flow with major variables of the precipitation data, percentage of imperviousness and infiltration type as Horton (EPA, 2016).

$$f_t = f_c + (f_0 - f_c) e^{-k \cdot t}$$

where f_t is the infiltration rate (in mm/h) at time t , f_c is the stable infiltration rate (i.e., the minimum infiltration rate) in mm/h, f_0 is the initial infiltration rate (i.e., the maximum infiltration rate) in mm/h, k is the attenuation coefficient related to the physical properties of soil (in h^{-1}) and t is time (in h).

In case of the pollutant load modeling the EMC (event mean concentration) coefficients has used with major computed land use characters stated on EPA.

3.9 Methods of data presentation

The spatial data form satellite image and digital elevation models has mapped and presented following the specific objectives. Collected and analyzed data has presented on figures as maps, charts and diagrams. On quantitative data as land cover change, level of imperviousness, simulated results of water quantity and quality results has presented in tabulation. And statistical results as percentile and mean values have quantified and presented as follows.

3.9.1 Map of sub catchments, level of imperviousness and runoff.

Understanding the natural landform and built-up factors of the area is significant to developing the method and data for the objective. The natural and built-up structures have mapped as follows (Fig 3.1-12). Identifying the sub-watershed that directly drains to the lake and developing the watershed pattern is the first method that has shown on (Fig 3.9-1 C and D) below. On the built environment

of the sub-watershed, (Fig 3.9-1, (f), (g) and (h)) that is the built-up area, road networks and land use has identified on the map.

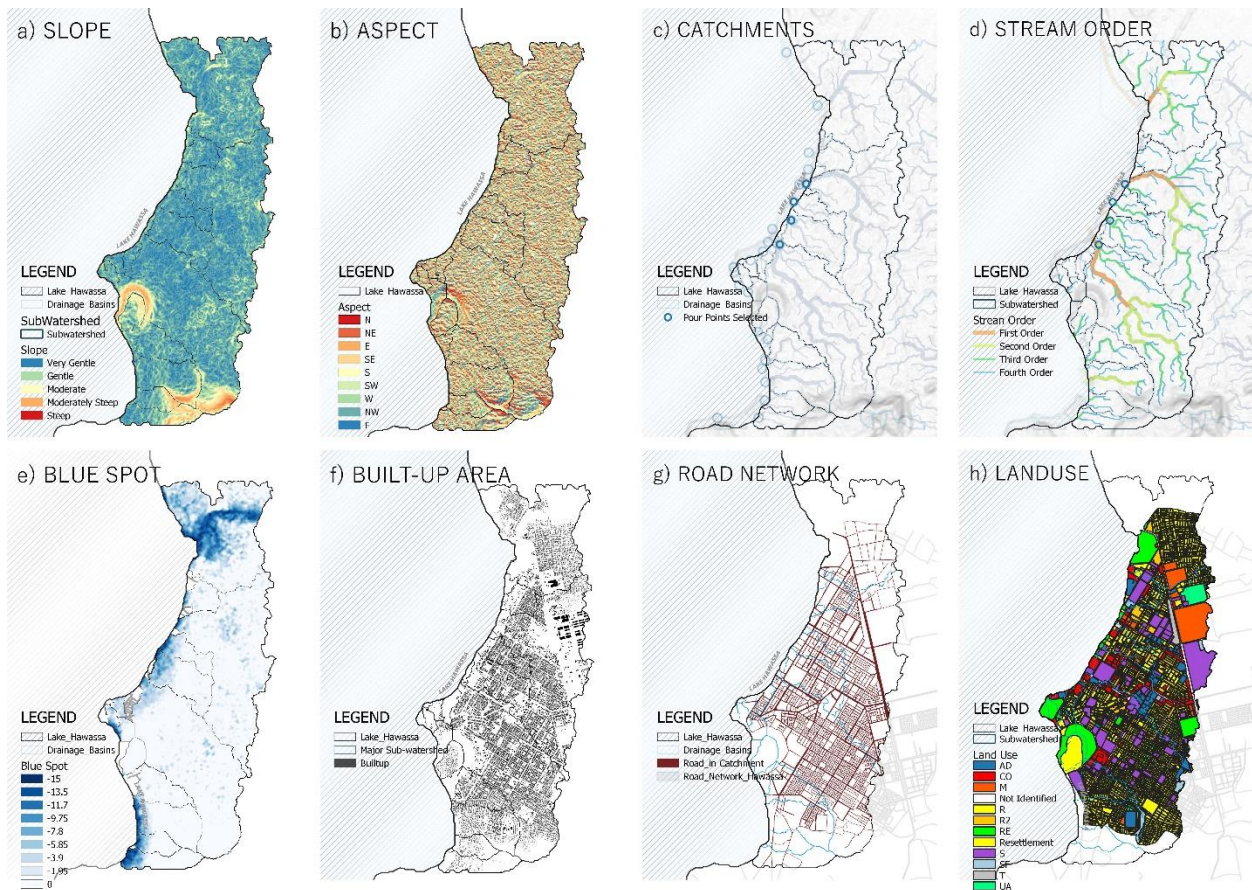


Figure 3.9-1 Map of the natural and built-up factors for sub-watershed that directly drain to the Lake. (Source: Authors presentation)

3.4.1.1 Delineation of catchments that directly drain into the lake.

For delineation of catchments and generating spatial analysis of the natural landform, 12.5 m DEM has been used. Covering the urbanized area of the catchment (10 km²) is delineated to cover the urbanized landscape and the lake has shown the natural watershed pattern that directly drains to the lake and remaining catchments that drain to ‘Tikur wuha’ river. The sub-watershed directly drains into the lake cover an area of 3,137.7 ha. As reviewed above (Fig 3.9-1) the spatial characteristics of the area both natural and built environments have been presented that show the context of the study area. Identifying the watershed pattern, stream orders and natural depressions (blue spots) within the subwatershed (Fig 3.9-1 6 (c), (d) and (e)), major catchments that cover more than 1 ha area has selected, (Fig 3.9-2) below shows 14 major catchments identified.

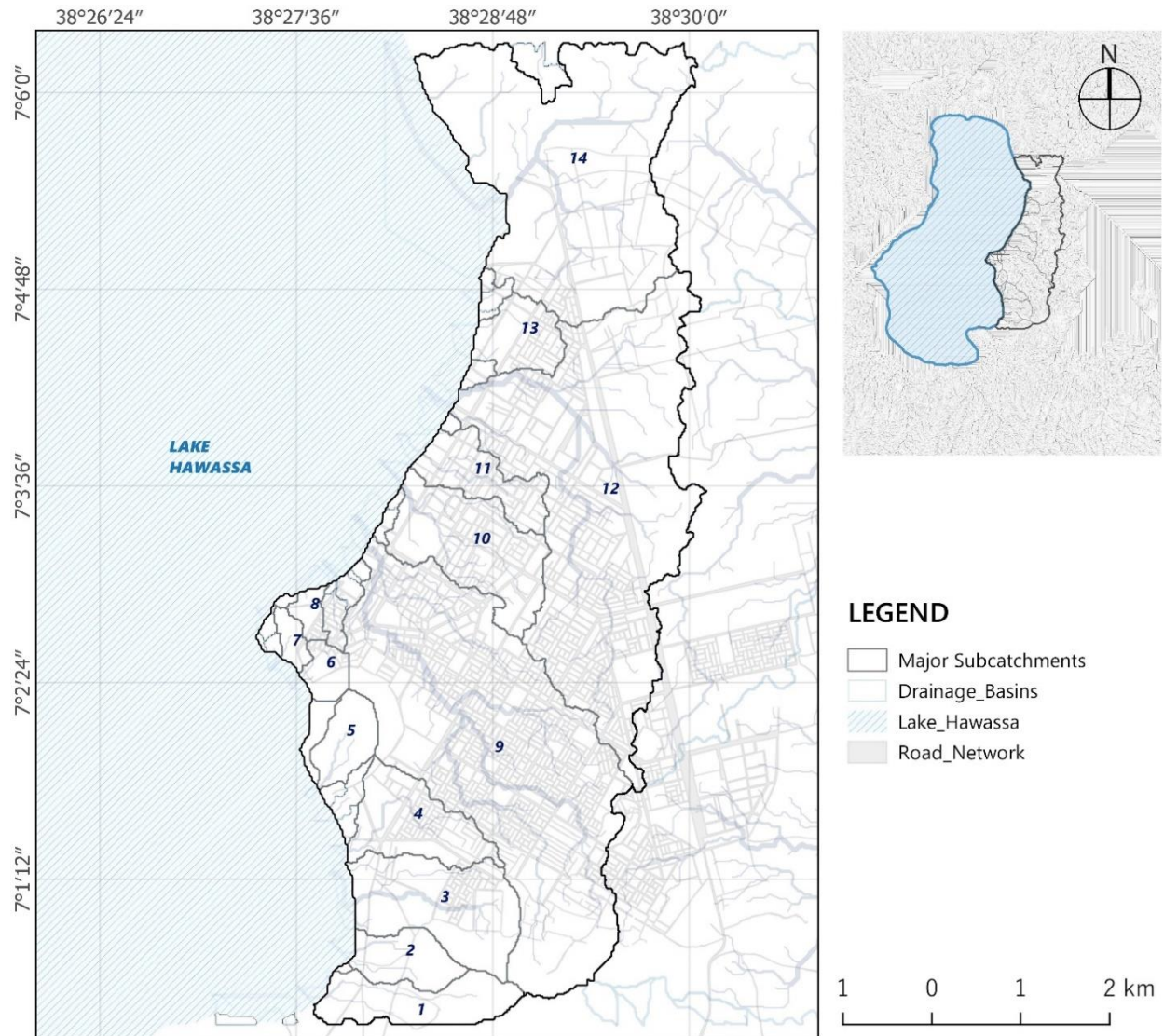


Figure 3.9-2 Map of the watershed and sub-catchments that directly drains to the Lake Hawassa.
 Source: (Authors presentation)

3.4.1.2 Imperviousness level within identified catchments.

As Schueler (1994) definition of the imperviousness within the built environment the built-up change in the urban area of Hawassa city has been identified based on 2013 built-up structures (data collected from Hawassa municipality) and digitizing the built-up structures from a high-resolution real-time image of Hawassa city by the author for the year 2018 has presented on (Map. 8). This data shows the built-up change in the area within five years period. The transport infrastructure as a significant impervious cover and potential to manage stormwater has identified on (Fig. 3.9-4) respectively, which has the potential to develop retrofit systems. The built-up change and runoff generated from the impervious cover have been simulated by the SWMM model considering the watershed area and impervious cover in a catchment. And the comparison between

the built-up change runoff and peak flows between the stated years has been summarized in (Table. 19) in detail.

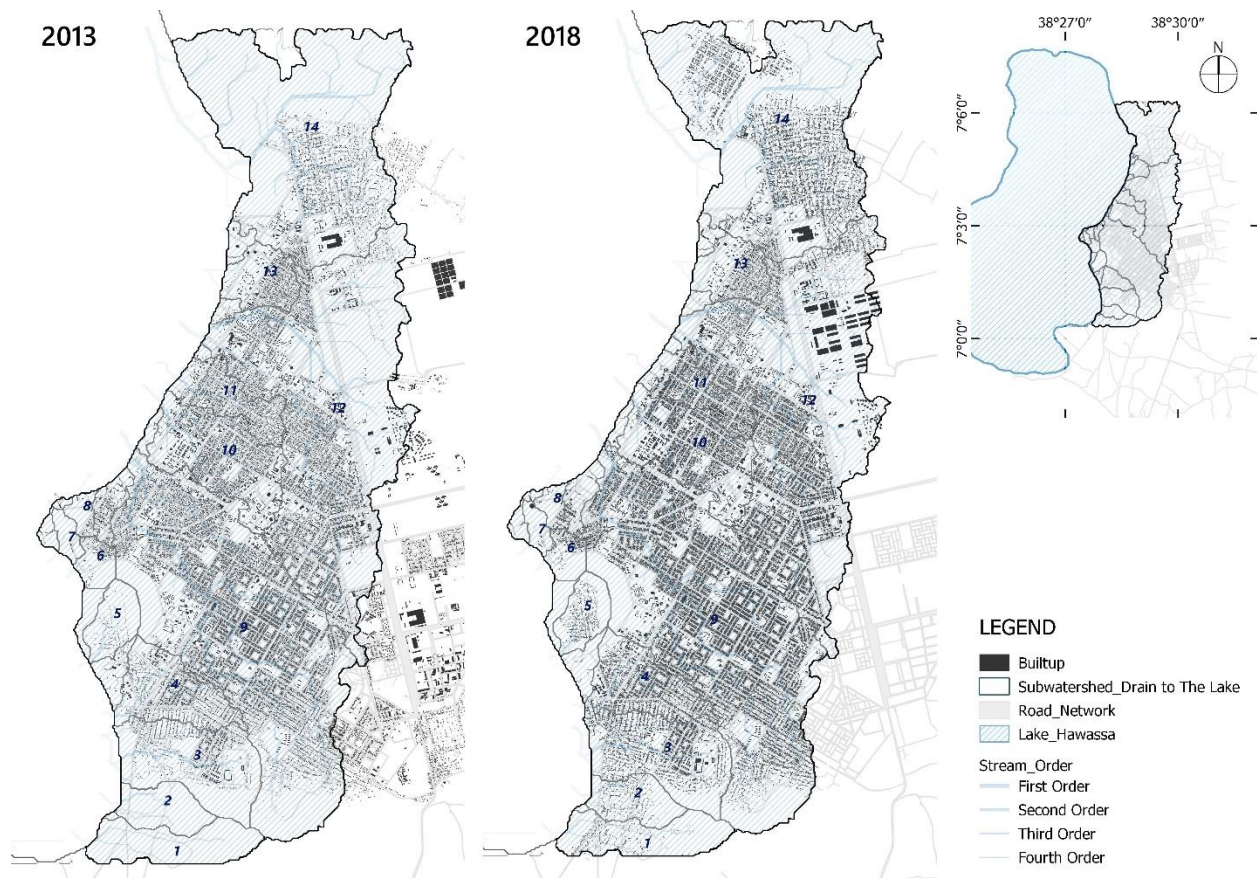


Figure 3.9-3 Built-up area for sub-catchments that directly drain to the lake, the years 2013 and 2018.

Source: (Authors presentation)

Major catchments that cover above one ha. in the sub-watershed have been identified and the area, percentage and runoff generated from the built-up structures in 2013 and 2018 has computed by quantum GIS 3.6.3 and SWMM5.1 modelling that cover the sub-watershed of the city that directly drains to the lake Hawassa has presented on (Fig. 3.9-6) and (Table. 3.9-2).

Similarly, another major built-up structure is transportation systems or roads that are organized on activities, size and material for different purposes. The road networks in the sub-watershed have presented considering the materiality as asphalt, cobblestone, red ash and earthen surfaces (Fig. 3.9-4) and (Table. 3.9-1) as follows;

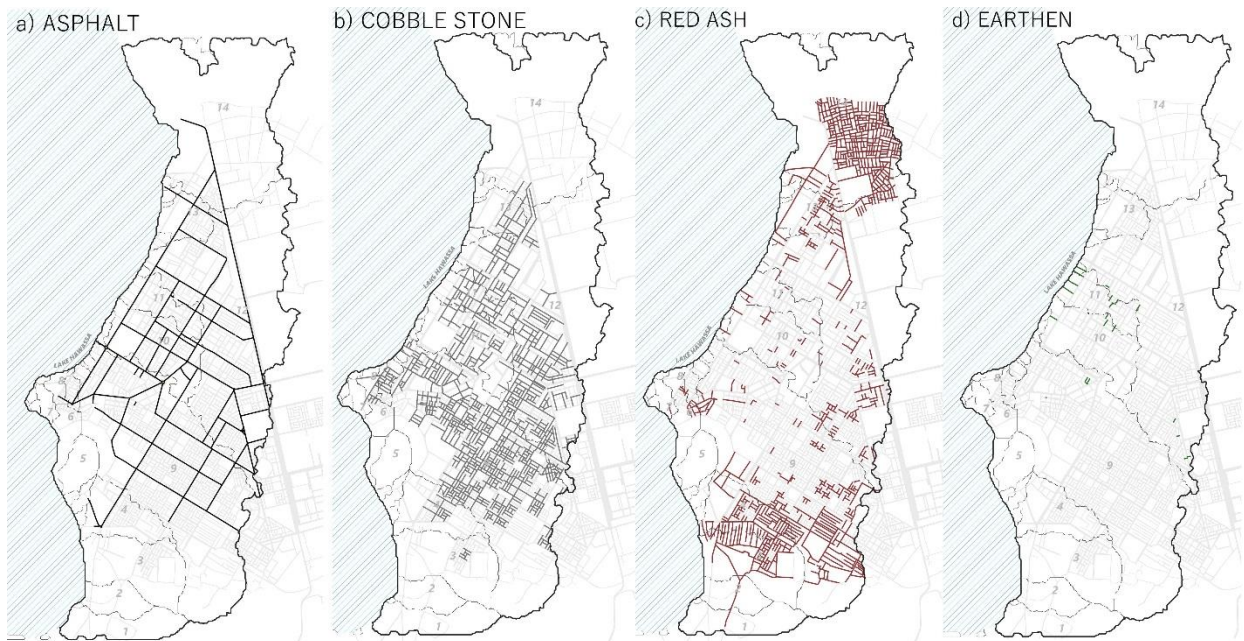


Figure 3.9-4 Road networks in the sub-watershed directly drain into the lake

Source: (Authors presentation)

Table 3.9-1 Road networks in the sub-watershed directly drain into the lake

Type	Estimated Area (ha.)	Remark
Asphalt	66.5	It is considered a two-way lane with an average width of 12 m
Cobblestone	119.1	Collector streets and linkage streets in city centers,
Red ash	107.3	on peripheral zones of the city,
Earthen	1.8	Areas remained undeveloped within city centers and waterfronts.

Source: (Authors Computation) from HCA, bureau of infrastructure.

NB. The above computation has taken road length with an average standard road width of 12 m for asphalt surfaces and 8 meters for cobblestone, red ash and earthen surfaces.

Table 3.9-2 Comparison of the built-up and runoff change for the years 2013 and 2018 respectively

No.	Sub-catchment Area (ha.)	For the year 2013				For the year 2018					
		Built-up 2013 (sq. m)	% Of Built-up area	Impervious Runoff (mm)	Total Runoff (10 ⁶ ltr.)	Peak flow (CMS)	Built-up 2018 (sq. m)	% Of Built-up area	Impervious Runoff (mm)	Total Runoff (10 ⁶ ltr.)	Peak flow (CMS)
1	103.88	-	-	-	34.69	0.63	33,788.29	3.25	3.03	37.19	0.86
2	63.52	355.4	0.05	0.05	25.88	0.61	40,082.69	6.31	5.88	28.52	0.88
3	180.9	155,484.43	8.59	8.00	75.37	2.30	313,575.4	17.33	16.1	86.44	3.34
4	116.67	177,923.1	15.25	14.18	57.09	2.17	311,603.6	26.41	24.54	65.57	3.00
5	52.54	13,290.58	2.53	2.37	23.29	0.66	45043.95	8.57	7.99	25.31	0.87
6	28.44	18,761.41	6.59	6.16	15.56	0.64	30,880.42	10.85	10.12	16.21	0.72
7	17.67	1,412.359	0.79	0.74	10.25	0.50	7,522.09	4.25	3.98	10.54	0.54
8	17.60	10,258.99	5.82	5.44	9.71	0.41	19,942.21	11.32	10.56	10.21	0.47
9	814.93	1,430,048	17.54	16.28	299.66	10.17	2,092,605	26.67	24.73	357.14	12.68
10	175.6	343,583.4	19.56	18.18	83.99	3.34	461,359.7	26.46	24.58	92.47	4.04
11	82.41	177,430.8	21.52	20.00	43.22	1.83	274,088.1	33.25	30.88	49.47	2.40
12	775.5	976,539	12.59	11.70	301.88	9.97	1,662,293	21.43	19.90	351.80	13.89
13	67.67	105,351.3	15.56	14.49	36.73	1.54	162,352.2	23.98	22.30	40.06	1.91
14	640.23	305,273.1	5.58	5.20	203.47	5.30	728,927	13.32	12.38	234.40	8.12
Total	3,137.7	3,715,711	12.20	122.79			6,187,587	20.32	216.97		

Source: Computations from GIS and SWMM modelling (Authors presentation)

3.9.1.3 Runoff generated from the urbanized landscape.

The computed results for catchment runoff (Table. 3.9-2) have shown the trend and existing scenario with runoff and peak flow imply the level of impacts by the impervious surfaces.

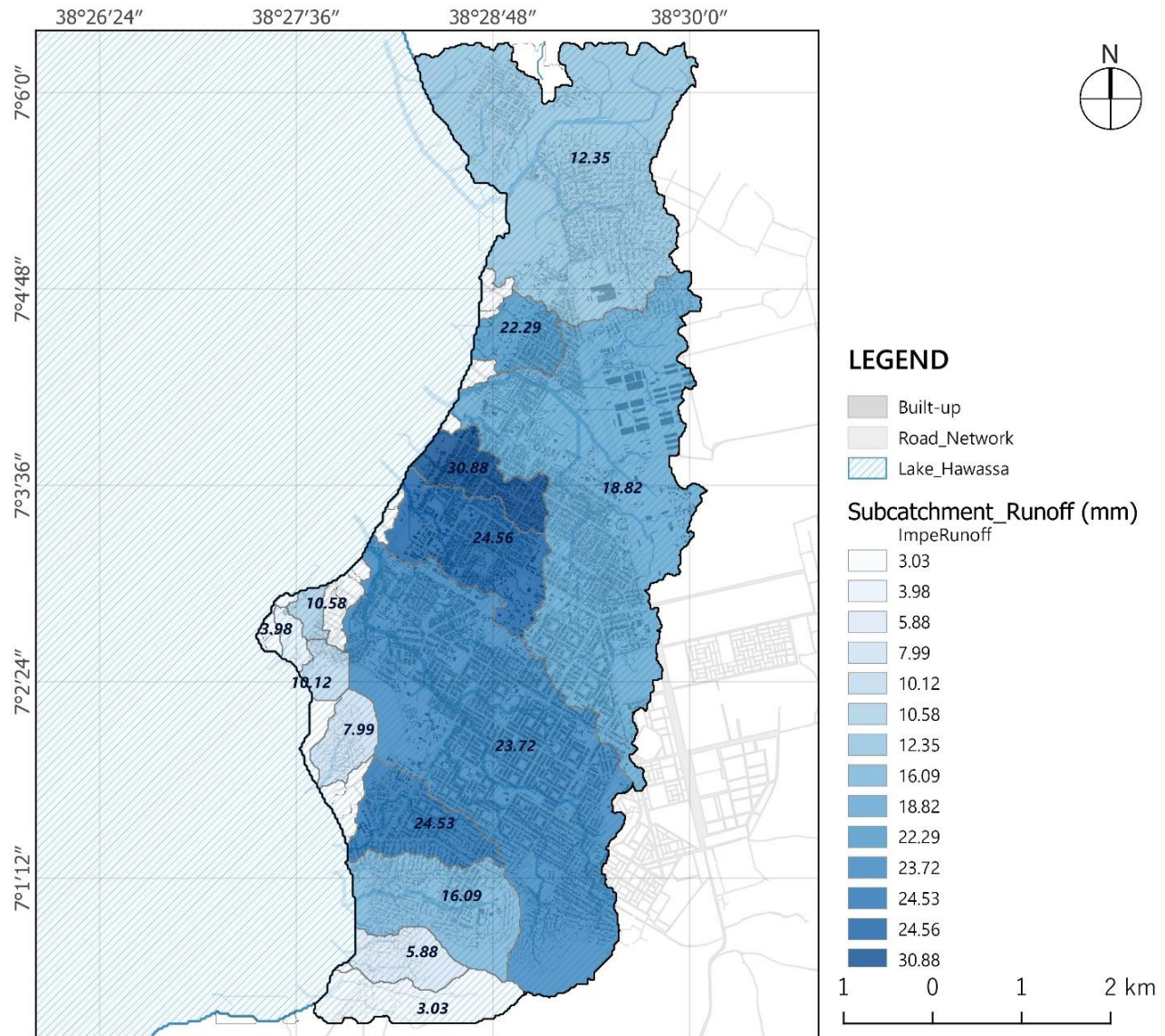


Figure 3.9-5 Impervious runoff from the identified catchment of the urbanized landscape.
Source: (Authors presentation)

As shown in the above (Fig. 3.9-5) contribution of the impervious cover to catchment runoff that is directly drained into the lake has been presented. It shows the level of a runoff (from deep blue to light blue gradient) between catchments. Considering the extracted data of watershed and imperviousness purposive sampling has been applied to identify impacted catchments and take the pollutant load test. Analysis and detailed characterization have followed further objectives. Considering other criteria, the pollutant loads from major land use and water quality samples to identify the level of impact have presented below.

3.9.2 Water quality assessment from simulation and samples taken.

The impact of imperviousness on stream water quality has been examined on two major methods. That are SWMM model simulation results from catchment land use characters and water quality test reviews as follows. Considering the two results the level of impact has been shown which can imply the context

3.9.2.1. Simulation model from land-use characters in a catchment,

Based on the land use coefficient factors by US EPA and the water quality model with SWMM (Fig. 27). An event mean concentrations (EMCs) function has been used with a coefficient of variation from literature standards (EPA, 2016) referred to (Table. 3.9-2). The model identifies catchment characters with size, imperviousness level and the sum of the land use character. Considering the contextual variance and simulation factors water quality samples has reviewed and the pollutant load has been calculated for the month that has taken for water quality samples results that have been compared to see the difference between similar time intervals.

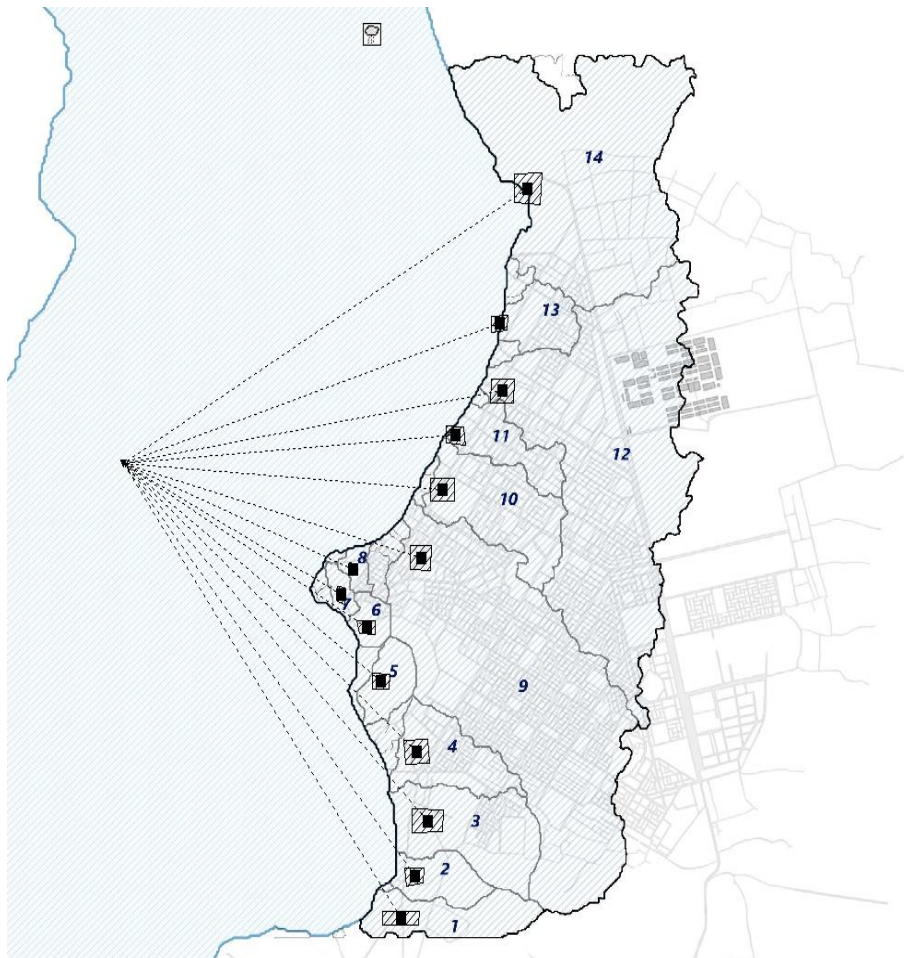


Figure 3.9-6 SWMM model for sub-watershed directly drain to the lake.

Characterizing and computing land-use types from institutional data acquired (Fig 3.9-7 6 (h)) for the existing land use of Hawassa city, the specific sub-watershed impacts have been selected to examine pollutant loads from land-use variables specified. The general estimation of pollutants for 14 catchments has assessed (Table. 3.9-3). Considering overviewed pollutant load and impervious cover percentage purposive selection of impacted catchments has applied. In addition to the land-use factors and pollutant loads from these areas, the statistical values on area coverage, total built-up and average sizes of each major land use (Table. 3.9-4) help to identify methods and approaches that are appropriate for stormwater design retrofits that could be developed. The available space within selected land uses and built-up area has quantified numerically.

Table 3.9-3 Pollutant Load from catchments directly drain to the lake.

No.	Catchment Area (ha.)	Built-up area (sq. m)	Pollutants				
			BOD (kg)	COD (kg)	TSS (kg)	TN (kg)	TP (kg)
1	103.88	33,788	223.16	483.52	185.97	31.61	6.32
2	63.52	40,082	171.13	370.78	142.61	24.21	4.84
3	180.9	313,575	518.62	1123.67	432.18	73.47	14.69
4	116.67	311,603	393.4	852.36	327.83	55.73	11.14
5	52.54	45043	151.85	329.01	126.54	21.51	4.3
6	28.44	30,880	97.23	210.67	81.03	13.77	2.75
7	17.67	7,522	63.21	136.78	52.68	8.95	1.79
8	17.60	19,942	61.28	132.78	51.07	8.68	1.73
9	814.93	2,092,605	2142.83	4642.81	1785.69	303.56	60.71
10	175.6	461,359	554.8	1202.08	462.34	78.59	15.72
11	82.41	274,088	296.8	643.04	247.32	42.04	8.40
12	775.5	1,662,293	2110.81	4573.42	1759.0	299.03	59.80
13	67.67	162,352	240.37	520.71	200.31	34.05	6.81
14	640.23	728,927	1406.40	3047.2	1172.0	199.24	39.84
Total	3,137.7	6,184,063	16,950.09	36,725.2	14,125.07	2401.26	480.25

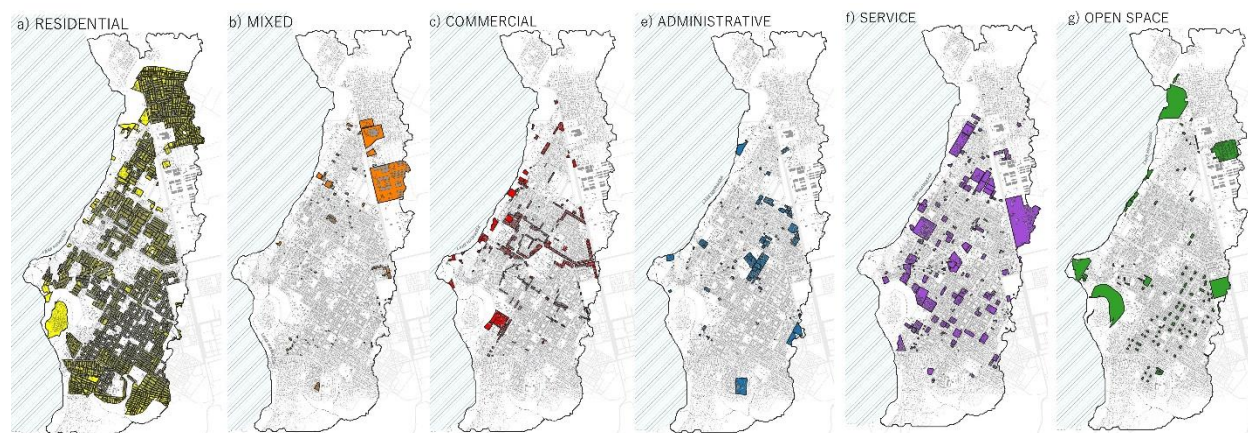


Figure 3.9-7 Land use and Built-up area in sub-watershed directly drain to the lake.

Source: HCA (authors presentation)

Table 3.9-4 Land use to built-up proportion

Major Land Uses	Land use area (ha.)	Built-up area (ha.)	% For built-up area	Number of units	The average area for each unit (Sq.m) (block level)
Residential (low)	916.1	315.6	34.4		
Residential (medium)	149.5	66.4	44.4		
Commercial	149.6	47.7	31.8	8,486	56.4
Mixed	150.8	35.2	23.3	1,549	226.9
Service	344.5	46.1	13.4	3628	127.1
Administrative	101.8	18.04	17.7	1620	111.4
Open space	209.6	3.2	1.52	768	41.6

Based on the imperviousness results and simulated pollutant load by the major categories of land uses purposive samples has taken for water quality tests on catchments 9, 10, 11 and 12 as shown (Fig. 3.9-8). Other considerations as the proximity to the urban center and the lake had taken.

2. Water quality samples have been taken from the selected catchment outlets.

Based on the IC and pollutant loads assessed on chapters 3.9.1 selected catchments has identified to sample the water quality levels on site.

Table 3.9-5 Sample test result for selected Catchment pour points

No.	Parameters	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5*
1	Temperature (°C)	25	25	25	25	21
2	pH	8.1	7.9	8.5	8.4	6.37
3	Electric Conductivity EC (µS/cm)	190	284	154	156	284
4	TURBIDITY TUR (NTU)	128	121	33.6	93.8	1.45
5	Dissolved Oxygen DO (mg/L)	3	2.5	3	3.5	7.2
6	Biochemical Oxygen Demand BOD (mg/L)	403.33	1073	663.33	936.66	14.8
7	Chemical Oxygen Demand COD (mg/L)	1210	3220	1990	2810	178
8	Total Dissolved Solid TDS (mg/L)	90	114	77	88	142
9	Total Suspended Solids TSS (mg/L)	622	726	592	102	2.5
10	Sulfate SO ₄ 2- (mg/L)	25	20	2	13	0.1
11	Nitrate NO ₃ - -N (mg/L)	22	21.4	22	20	2.4
12	Nitrite NO ₂ - -N (mg/L)	1.8	1.4	3.1	3.6	0.05
13	Ammonia NH ₃ (mg/L)	12.48	3.6	1.92	2.54	0.715
14	Phosphate PO ₄ 3--P (mg/L)	16.5	9	8.7	7.4	0.13

NB. * – Sample 5 is a control variable for stormwater that has collected directly from storm drops from the air (not in contact with the physical built environment). The water quality results have taken on the date June 22, which was a rain event the researcher took a sample for laboratory tests.

Figure 3.9-8 and 3.9-9 shows the selected catchments spotted before the watershed pattern has drained to the lake, the water quality samples have been taken and examined and the result has shown as follows (Table. 16). The samples were taken in June, which is an averagely higher precipitation period in the area (Appendix. 1) before the summer season.

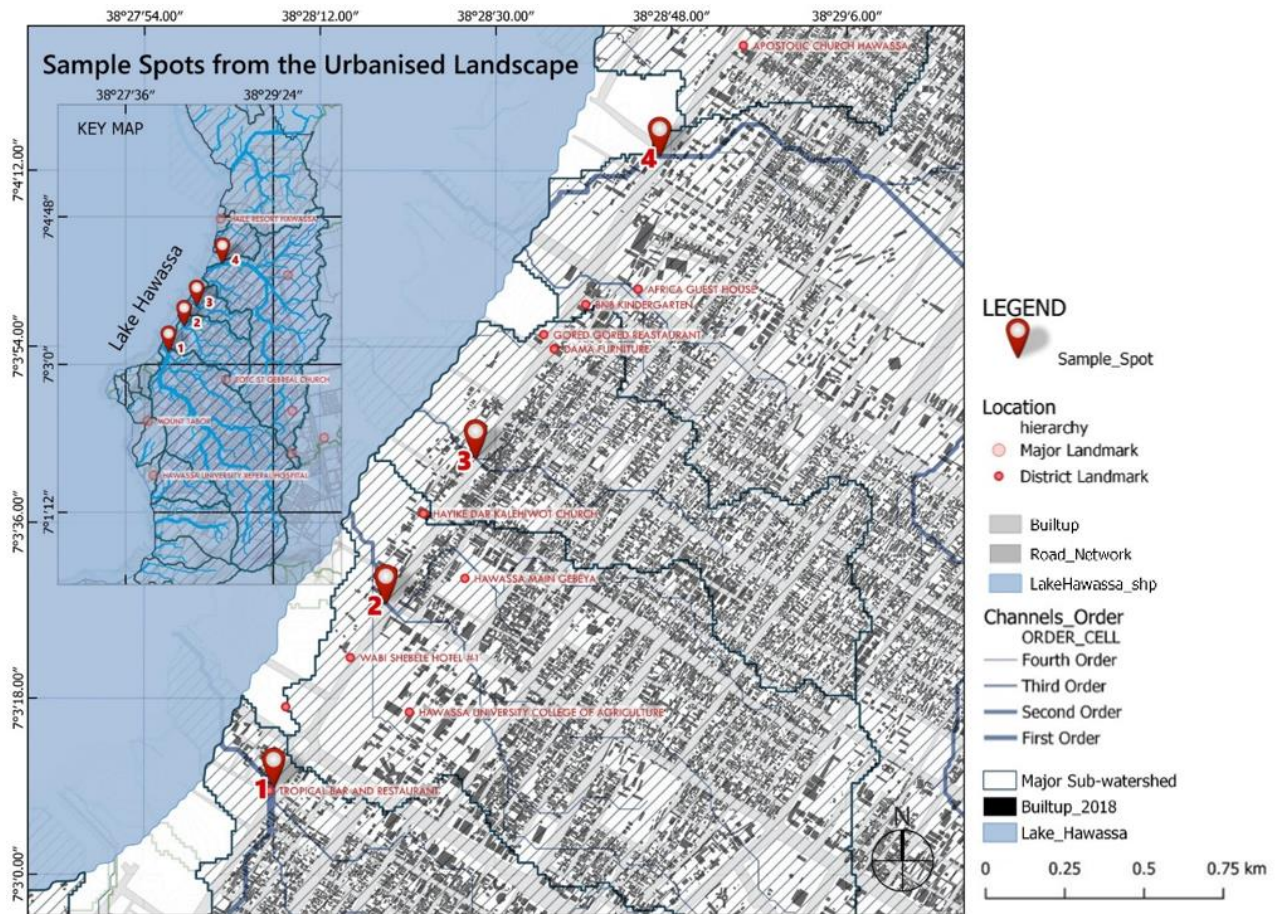


Figure 3.9-8 Pour points to take selected urbanized sub-catchment for water quality samples.



Figure 3.9-9 Pictures from Sample spots taken from areas
Source: Authors' site visits.

The existing sample results for water quality impairment (Table. 3.9-6) physical and chemical parameters have been examined that show the level of the urban stream water quality impairment with contextual factors such as activity, seasonal and environmental outputs. Identifying the impact level of imperviousness and pollutant load on different catchments of the urbanized

landscape, the detailed characterization of impervious surfaces and potential areas identified as follows:

Table 3.9-6 Comparison of Water quality test Results

Catchment	Imperv.		Pollutant Load						
	Year	Runoff	TSS	BOD	COD	NO ₃ Nitrate	NO ₂ Nitrite	NH ₃ Ammonia	PO ₄ ³ Phosphate
9	26.67	23.72	622	403.33	1210	22	1.8	12.48	16.5
10	26.46	24.56	726	1073	3220	21.4	1.4	3.6	9
11	33.25	30.88	592	663.33	1990	22	3.1	1.92	8.7
12	21.43	18.82	102	936.66	2810	20	3.6	2.54	7.4

Comparing the above two results and identifying factors on diffused pollutant loads, selected catchments have been characterized as follows to select retrofitting strategies for the impacted catchments and specified cases will follow on LID measures in the next subchapter 3.4.4. From the selected watershed examined on the imperviousness level and pollutant load level, the selected catchments 10 and 11 have been selected and characterized in detail purposively.

3.9.3 Impacted Catchments

Finding and results from objective one and two has shown the highly impacted catchments that are categorized in degraded stream water quality level (catchment 11, 9 and 10 respectively) and highest NPS pollutant load results (catchment 10). By sorting and characterizing highly impacted catchments, factors that impact the level of urbanization in the lake. The natural landform that has changed by the urbanization trend and quantified results of imperviousness.

Catchments identified above, has developed an assessment of the natural and built environments in detail. By these assessments characteristics to the natural landforms (as stream and wetlands) and the built-up factors (as the imperviousness level, major land uses) has reviewed to develop stormwater retrofit strategies for each catchment characters.

Catchment 10(C10)



Figure 3.9-10 Location and the built environment for Catchment 10 (C10).

Based on the results of the imperviousness level and pollutant load generated characterization of this catchment has proceeded. (Fig 3.9-10) has shown catchment 10 that has taken as the case I as a result of the stated factors imperviousness (26.46%) and pollutant load as presented earlier.

The total catchment area covers 175.6 ha. It is located in the central part of the city, on both the geographic and activities it accommodates both institutional and commercial zones that have dominant land use characteristics in the area. In identifying the characteristics of catchment 10 that is the case I, major factors have been presented as follows; The natural and the built environment of catchment 10 has been discussed as follows (Table. 3.9-7 and 3.9-8):

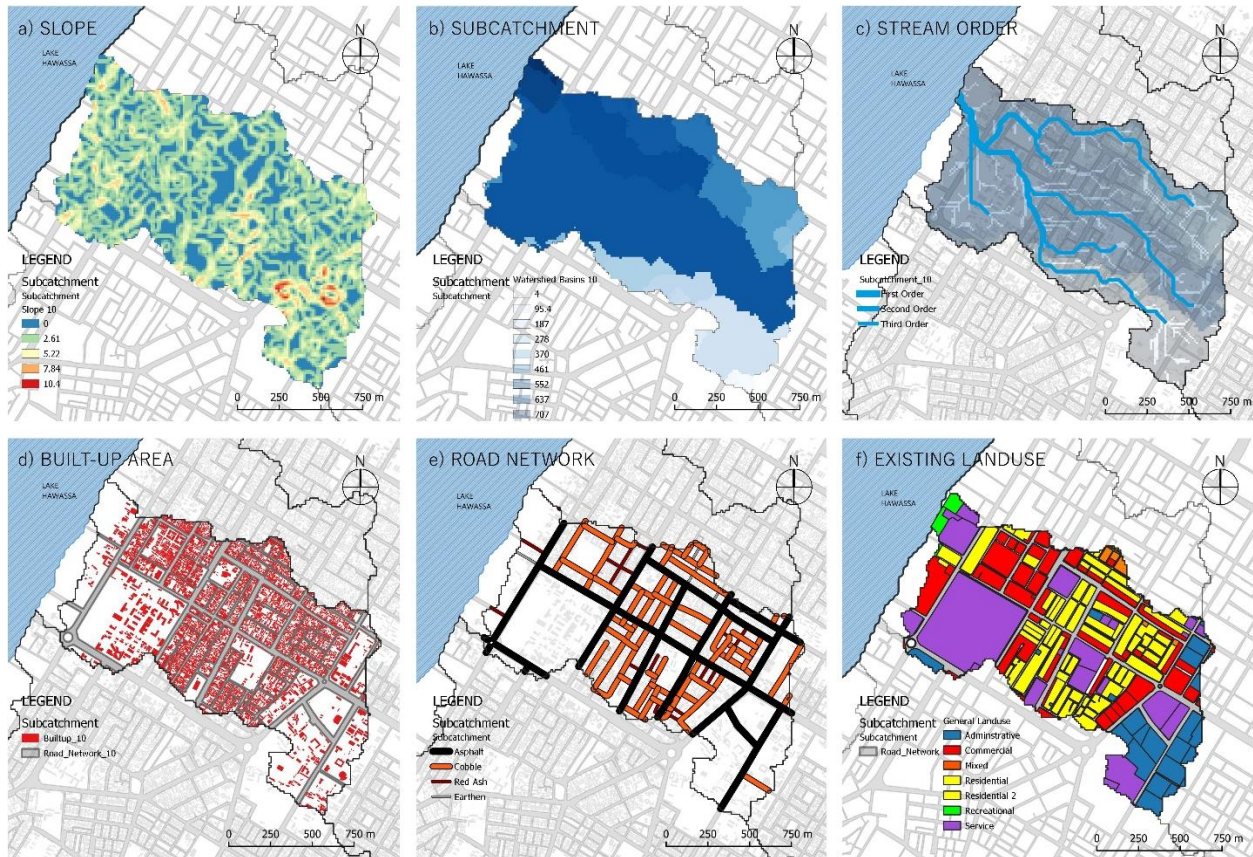


Figure 3.9-11 Maps for the natural and built-up characteristics for C-10.

Table 3.9-7 The Natural factors for Catchment 10(C10)

SUB CATCHMENT 10 _ NATURAL FORMS			
Slope	Area (sq. m)	Percentage %	Description
- < 2	775,937	44.19	From the total area of the catchment, 95.04 % is below 5% of the slope that is almost flat.
- 2.1 - 5	892,812	50.85	
- 5.1 - 8	82,187	4.68	The average slope for catchment 10 is 2.07 %.
- 8.1 - 12	4,843	0.28	
- >12	156	0.01	

Sub catchments	Area (sq. m)	Imperviousness %	Description
1	132,144	7.51	There are 9 identified sub-catchments majorly that cover an area range of 4.72 ha to 90.5 ha. From the identified sub-catchments in (Fig. 32 (b)), the runoff volume reaches
2	68,650	3.9	
3	47,205	2.68	
4	73,830	4.19	
5	194,842	11.08	
6	51,981	2.95	
7	172,468	9.80	
8	112,501	6.39	
9	905,030	50.46	

In the description of the built environment the built-up structures, road networks and land-use factors are discussed as follows (Table. 3.9-8):

Table 3.9-8 The Built-up factors for Catchment (C10)

THE BUILT ENVIRONMENT			
	Area (sq. m)	Description	
BUILDING	461,359.78	From the total catchment area, the built-up structures cover 26.46%. that is on a degraded level of imperviousness to the environment.	
ROAD NETWORK	Area (sq. m)		
Asphalt	173,640.6	The road infrastructure covers a total area of 313,312 sq. m. or 31.33 ha. That is 55.42 % of the asphalt surface and 37.49 % of cobble store surfaces majorly. The road networks have aligned with the lake peripheral path that is parallel to the lakefront. As for the width and span of the streets the major asphalt streets have a higher coverage area. The red ash and earthen surfaces of the road have covered the linkage networks near the lakefronts.	
Cobble stone	118,477.1		
Red Ash	16,998.68		
Earthen	4,196.4		
LAND USE	Area (sq. m)		
Administrative	328,920.9	Land use of the area has dominantly occupied with 0.34, 0.27 and 0.26 % as Service and Commercial and Residences respectively.	
Commercial	460,223.3		
Mixed	32,761.99		
Residential	R1- 267954.1		– 0.34 % Service
	R2 - 167282.9		– 0.27 % Commercial
Service	573,071.9	– 0.26 % residential	

Major factors from the built environment have identified majorly the impervious surfaces of the buildings and road networks and the land-use factors. The above factors have direct impact to quality and quality of stormwater runoff from the urban environments. Quantified areas and general description of the factors has extracted to show the catchment character in detail.

Catchment 11 (C11)

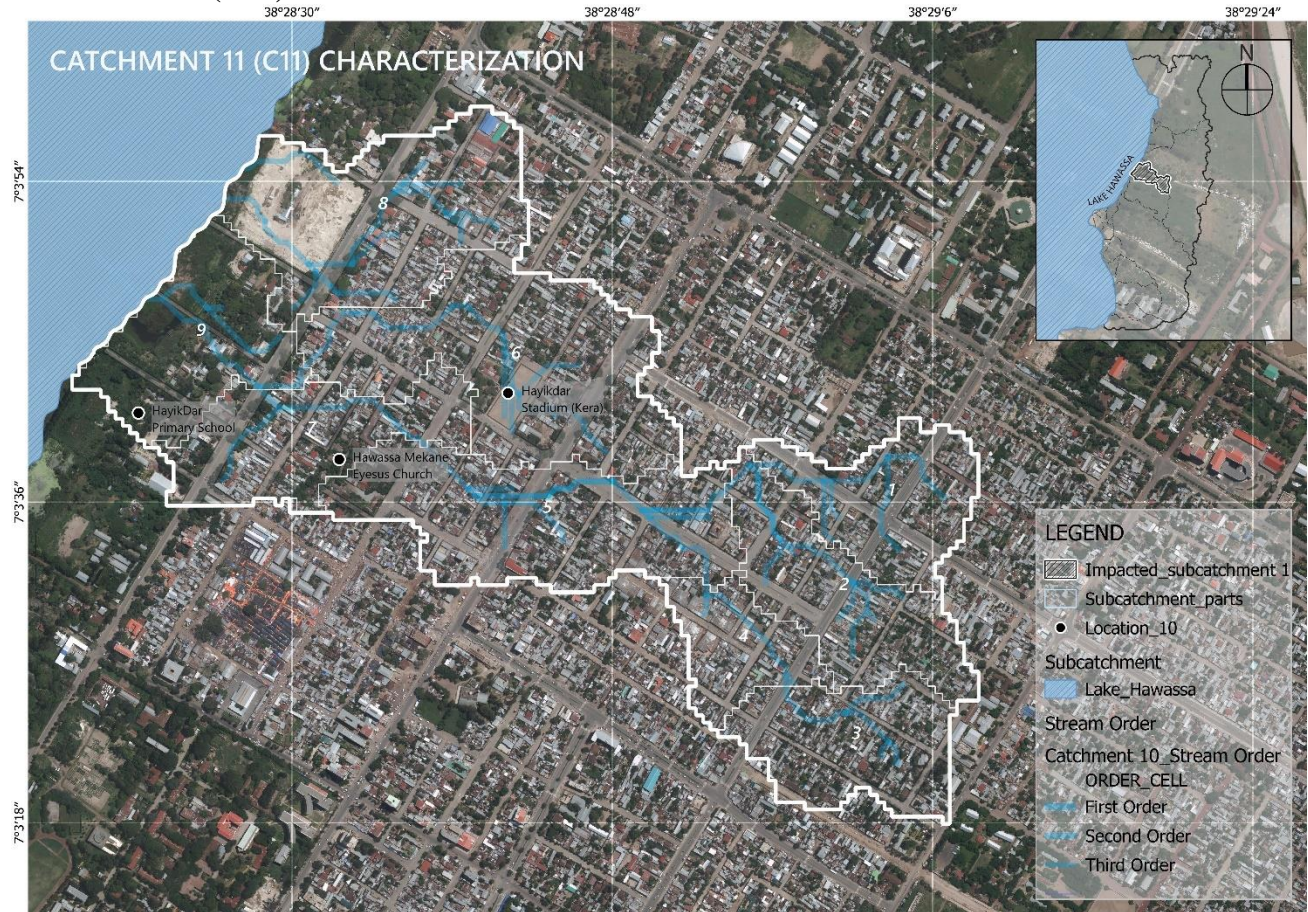


Figure 3.9-12 Location and sub-catchment character for Catchment 11(C11).

Similar to catchment 10(C10), catchment 11(C11) has similar landform characteristics. Whereas the use, activity and infrastructure have variance. That helps to see factors of the built environments differently the land use and road networks has significant variance implying the causality of results differently. The catchment area covers total area of 82.4 ha.

C11 has shown the highest imperviousness level (33.25 %) of all catchments that drain directly to the lake. A major characteristic of choosing the catchment is that it is dominantly covered by residential land use (68.5% on both low and medium density). The road infrastructure is dominantly covered by cobblestone surfaces (66.1 %) that could be taken as LID system (permeable pavement surface) with low modification costs.

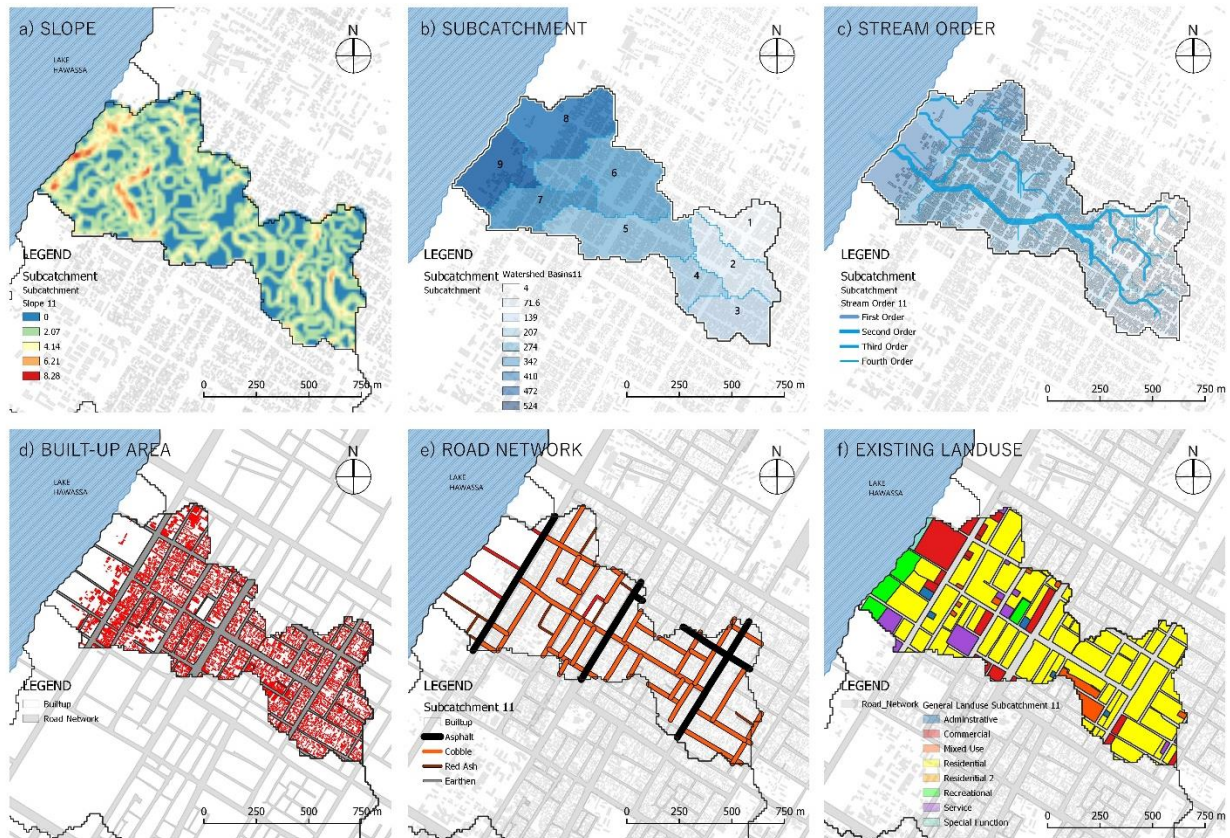


Figure 3.9-13 Maps for the natural and built-up characteristics for C-11.

The natural and man-made features of this catchment have presented as follows;

Table 3.9-9 The Natural factors for Catchment 11

The Natural Environment			
Slope	Area (sq. m)	Percentage	Description
– < 2	387,500	47.0	As the landform of the city has been placed on a flat surface in general, the slope, aspect, hill shade effects are dominantly similar. The average slope for catchment 11 is 2.18%.
– 2.1 - 5	410,937.5	49.83	
– 5.1 - 8	25,937.5	3.14	
– >8	156.25	0.01	
Sub Catchments	Area (sq. m)	Imperviousness %	
1	64,890	32.53	With a similar approach to merge fragmented patterns of sub-catchments major 9 sub-catchment zones have been identified. From the delineated sub-catchment areas sub catchment 6 is the largest and catchment 4 is the lowest.
2	79,432	40.85	
3	72,396	39.38	
4	41,749	47.95	
5	128,686	37.90	
6	149,761	56.77	
7	77,399	45.21	
8	127,187	32.93	
9	83,966	14.86	

Table 3.9-10 The Built-up factors for Catchment 11

The Built Environment		
	Area (sq. m)	Description
Built Structures	274,088	This catchment zone is the highest impervious area of all the catchments covers 33.25 % of the total area.
Road network		It covers a total area of 148,079.28 sq m ~ 14.8 ha.
– Asphalt	37,429	In this sub-catchment, the dominant road network surface is cobblestone surface area which covers 66.1 %. Whereas the alignment of the roads majorly asphalts roads directly aligned to the lakefront path (perpendicular to the stream networks of the catchment)
– Cobble stone	94,970.47	
– Red Ash	8,065.27	
– Earthen	7,614.54	
Land use		
– Administrative	8,030.9	From the total area of 952,392 sq, m (95.23 ha) in the dominant land use is a residential zone that covers 68.5 % of the total catchment area. That covers 64.01 % of low-density residences and 36 % of medium density residences.
– Commercial	109,549.6	
– Mixed	34,459.15	
– Residential (low)	301,335.8	
– Residential (medium)	167,918.1	
– Recreational	49,468.39	
– Services	85,775.81	
– Special Function	12,562.82	

Table 3.9-11 Comparison between impacted catchments

Major factors	Catchment 10	Catchment 11	Remark
Average slope	2.07 %	2.18 %	Similar zone
Soil type (top soil)	Eutric Fluvisols	Eutric Fluvisols	Similar zone, data from soil map data of FAO, other studies describe the context of Hawassa in detail.
Built-up area	26.46 %	33.25 %	-
Asphalt surface (%)	55.42 %	25.27 %	-
Cobble Stone (%)	37.5 %	66.1 %	-
Dominant Land use	- Service - Administrative	- Residential (low density) - Residential (medium density)	-

NB: The physical factors for the area have similar characteristics because of the placement of catchments. In the built environment dominant land use, infrastructure and built-up areas have characterized showing distinctive impacts on the stated problems.

3.9.4 LID retrofitting sites to disconnect the impacts.

Based on the results of the objectives, one and two, the impacted catchments have been identified with detailed characterizations developed. In this part, strategies for the integration of LID systems have been developed. From the reviews of literature and contextual studies in the impacted catchments, scales and systems of sustainable stormwater management systems have been recommended. The first level to address the stormwater management system is to reduce runoff and peak flow with source control infiltration and retention systems are a major one. Secondly, remedies for the reduction of pollutants with retention ponds, vegetative swales and infiltration trenches are required.

From literature reviews on the sustainable stormwater management systems and LID manuals (Rossman, 2015), (EPA, 2016) and that mitigate the flooding and pollutant loads to stream water quality both infiltration and retention/detentions systems have been organized by the scale and land-use factors. Cases and approaches as different scales have been categorized as follows (Table. 3.9-12). Since the impact levels and potential areas to mitigate are identified, the LID systems that meet the contextual factors of both the natural and built environment have been reviewed and identified as follows below.

Table 3.9-12 Selected LID measures as Green Infrastructure for different scale and Land uses

Watershed scale	Sub-Watershed	Catchment	Sub catchment
Urban scale	District	District Neighborhood	Neighborhood House Hold
Retrofitting systems	– Bio retention pond – Vegetative Swale	– Infiltration Trench – Permeable Pavements – Vegetative Swales	– Rain Barrel – Rain garden

NB: 1. The retrofitting techniques considered to incorporate in a simulation model SWMM as LID strategies are selected to simulate the results are; Rain barrel, Rain Garden, Infiltration Trench, Vegetative Swale, and Bio-Retentions 2. Design strategies to identify potential sites and incorporate mechanisms has included in the design recommendations (Appendixes. 4).

The design consideration focuses to identifies potential spatial planning factors to mitigate the impact of flooding and diffused pollutants with combined LID systems. Based on the factors of watershed form, scale and placement; the LID systems (Table. 3.9-12) have shown potential areas to intervein. Of different LID systems, five of it has been selected as bio-retention, vegetative swale, infiltration trench, rain garden and rain barrel has taken as combined LID systems within potential sites.

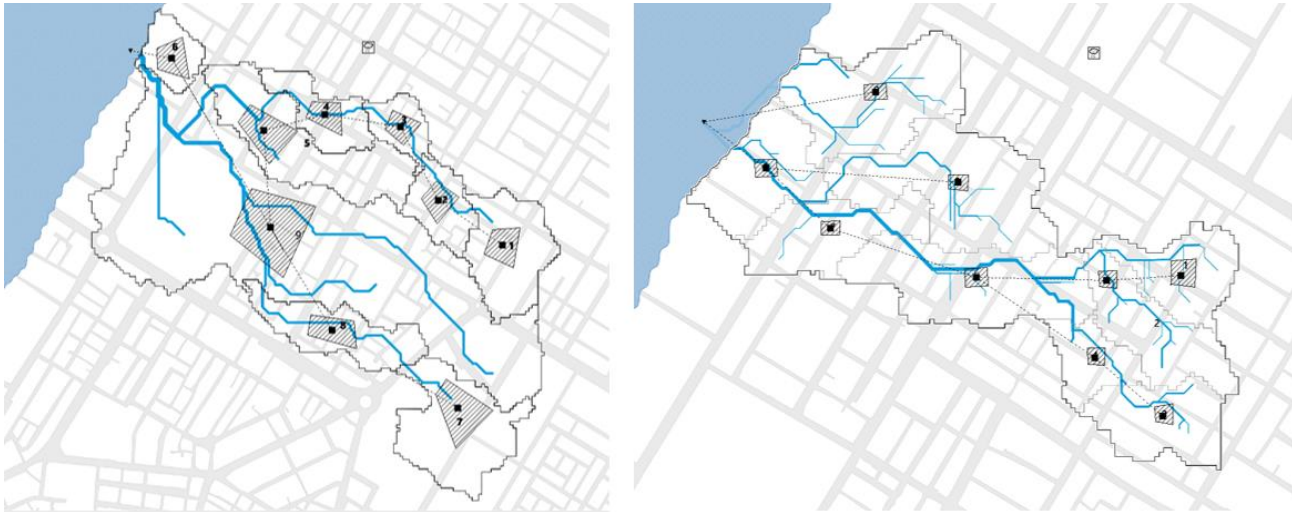


Figure 3.9-14 SWMM modelling for selected catchment areas (C10 and C11)

Selecting and identifying the potential sites for LID systems and measuring the impact with the SWMM simulation model has developed (Fig. 3.9-13), (Table. 3.9-13) shows efficient systems and effective areas have been described with the LID technique that could get incorporated.

Table 3.9-13 Retrofitting Strategies and potential areas with potential areas.

	Potential Land uses	LID technique	Potential areas (sq. M.)	Remark
Catchment 10	<ul style="list-style-type: none"> The right of Way 	<ul style="list-style-type: none"> Infiltration trench Vegetative swale 	- 378,258	<ul style="list-style-type: none"> Considering 10% area from the right of way and 15 % from service and administrative land use,
	<ul style="list-style-type: none"> Service areas 	<ul style="list-style-type: none"> Bio-retention Pond Infiltration Trench Vegetative swale 	- 538,998.3	
	<ul style="list-style-type: none"> Administrative areas 	<ul style="list-style-type: none"> Bio-retention Pond Infiltration trench Vegetative swale 	- 292,676	
Catchment 11	<ul style="list-style-type: none"> The right of Way 	<ul style="list-style-type: none"> Infiltration trench Vegetative swale 	- 188,344	<ul style="list-style-type: none"> In case Two consider 15% from the right of way and 15% and 10 % of open spaces from the low and medium residential land uses. The built-up in the low-density residential area covers 13.3 ha and in the medium-density covers 8.2 ha.
	<ul style="list-style-type: none"> Residential (Low Density) 	<ul style="list-style-type: none"> Rain barrel (From built-up) Rain Gardens (Total area) 	- 417,739	
	<ul style="list-style-type: none"> Residential (Medium density) 	<ul style="list-style-type: none"> Rain barrel (From built-up) Rain Gardens (Total area) 	- 167,918.2	

3.10 Validation

Data validation is a critical step in ensuring the accuracy and reliability of the data and process to meet the specified objectives of mapping watershed patterns, imperviousness changes, and stormwater quality tests from urbanized catchments.

Firstly, the researcher has identified the relevant data sources for watershed patterns, imperviousness changes, and stormwater quality tests. Those include satellite imagery, GIS data, field observations, and list of laboratory tests required to test. With required data to look for including the spatial resolution, temporal coverage, attribute fields, and any specific quality control criteria. Based on the thematic and spatial scope of the research that is urbanized catchments of Hawassa and the impact of urbanization to the lake, representative sample of locations within the urbanized catchments have been conducted. These catchments have covered various land use types and surface hydrological factors. Cross checking the results on maps, site condition and other secondary data has applied to ensure data quality and reliability. It also involves examining metadata, assessing data completeness, and verifying data integrity.

Watershed pattern of the urbanized zone of the city has examined on macro and micro levels to follow the coherence with other published results with similar studies. Considering the imperviousness changes from 2013 to 2018 the researcher has taken to rectify the digitalization on high resolution image to identify the built-up change clearly. On stormwater quality results from highly urbanized catchments, although the researcher has taken sample from one event from dry to wet season, simulation results and literature reviews has used to triangulate the results. Similarly, the control variable that is storm water collected that has not washed off the urbanized catchment or directly collected from the sky has compared with results on samples taken on surface runoffs on selected urbanized catchments specifically.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Result

4.1.1 The Imperviousness level of the urbanized landscape

The urbanized landscape of Hawassa city is characterized by both sprawl and infill into the existing urban environments. In the years 1986, 2000 and 2011 the land use land cover (LULC) change of Hawassa watershed has shown an increment for the cultivated, agricultural and built-up area and whereas decrement for forest covers, the water body, wetlands, shrubs and grasslands. The built-up change has increased from 5.2 % to 14.4 % in the respective years (Paulos, 2014). A recent result of LULC change of the region from EMA (Fig. 3.3-1) shows the built-up/settlement/ change with 1.68% from the year 2008 to 2013 and 86.7% from the year 2013 to 2018 is 89.86% within fifteen years period (Table. 3.1-1). Similarly, in this study the built-up change in catchments that directly drain to the lake has changed from 12.2 to 20.32 % within five years (2013 to 2018) is 40% within five years period as presented in (Table. 3.9-2) and (Fig. 3.9-3) as follows.

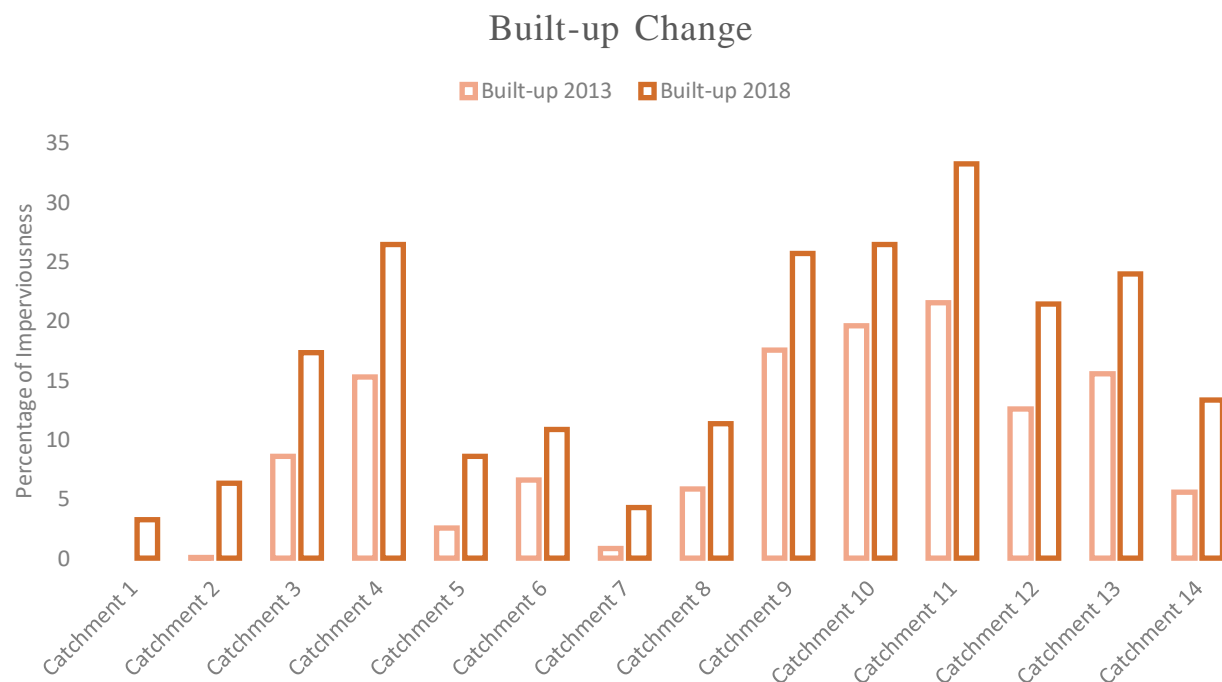


Figure 4.1-1 The Built-up change in 2013 and 2018 for catchments that directly drain to the lake.

The impervious runoff, total runoff and peak flow show an increment of 43%, 13% and 25% respectively. Based on the catchment size and imperviousness level within specified catchments, the peripheral catchments from the city center to the fringe have shown the highest percentage of change because of the urban sprawl. On catchments 1, 2 and 7 the change is 100, 99.2 and 81.4 respectively showing the sprawl of the city. In the case of the highest catchments by

imperviousness, on a catchment 11, 9 and 10 the change of percentage is 35.2, 34.2 and 26.0 respectively.

Runoff From Impervious Surfaces

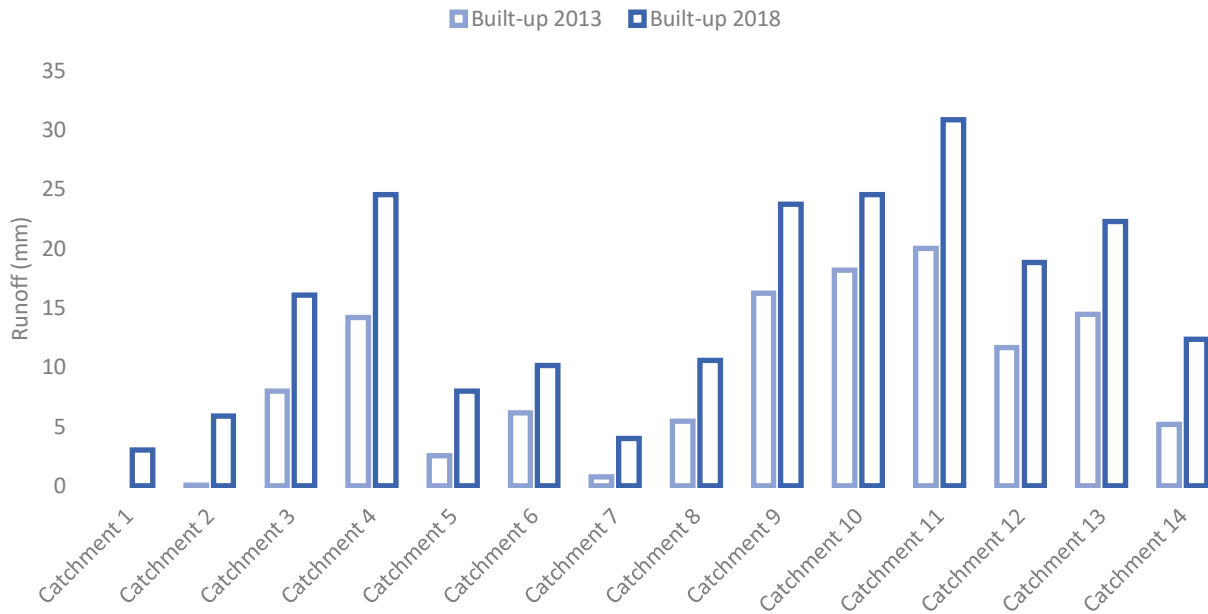


Figure 4.1-2 Impervious runoff change in 2013 and 2018 from delineated catchments.

As shown in (Fig. 4.1-1) and (Fig. 4.1-2) the built-up change and runoff generated from the urbanized landscape show similar flows that have a pattern.

Imperviousness and Runoff on Impacted Catchments

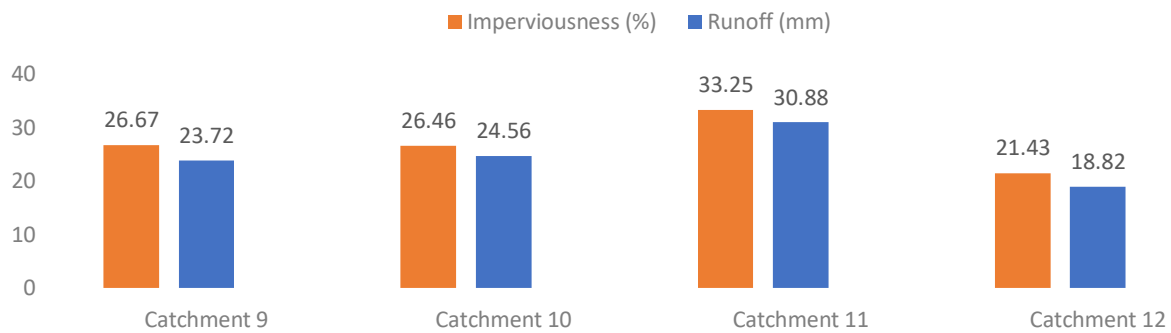


Figure 4.1-3 Imperviousness and Runoff on Impacted Catchments

Results from the selected catchments in graph (Fig. 4.1-3) the imperviousness and runoff has shown a direct relationship that show impact of urbanization to the increments of impervious runoff and the relation has shown linear progress as shown on (Fig. 4.1-4).

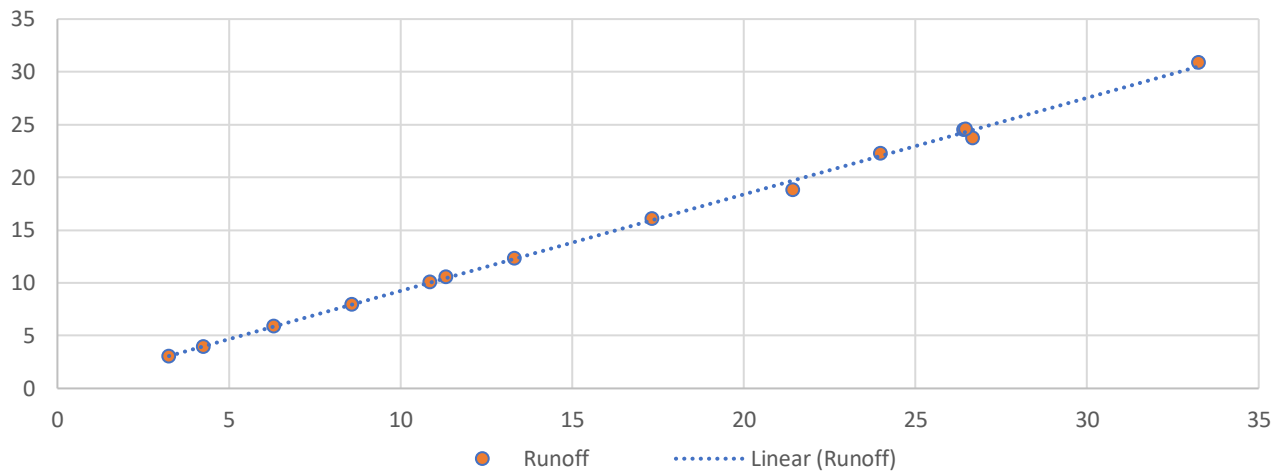


Figure 4.1-4 Imperviousness vs Runoff relationship

Source: Authors presentation

As shown in (Fig. 3.9-4) the development of infrastructures geographically relates to the sprawl of the city. Paved surfaces such as asphalt, cobblestone to red ash expand from the center to the fringe of the city as a trend in urban developments. That has an impact on runoff generated in urban centers is higher in the peripheral zones of the city because of developments.

On the catchment scale, (Fig. 4.1-5) the level of imperviousness to 37.91 % is degraded, 54.5 % is impacted and 7.57 % is on stressed stream levels. Consecutively, the impervious runoff has shown 43% to the total runoff. The trend of impervious cover (IC) change and the level it has reached has shown how the built environment has been extensively expanded. That lead degradation to quantity and quality from the urban hydrology.

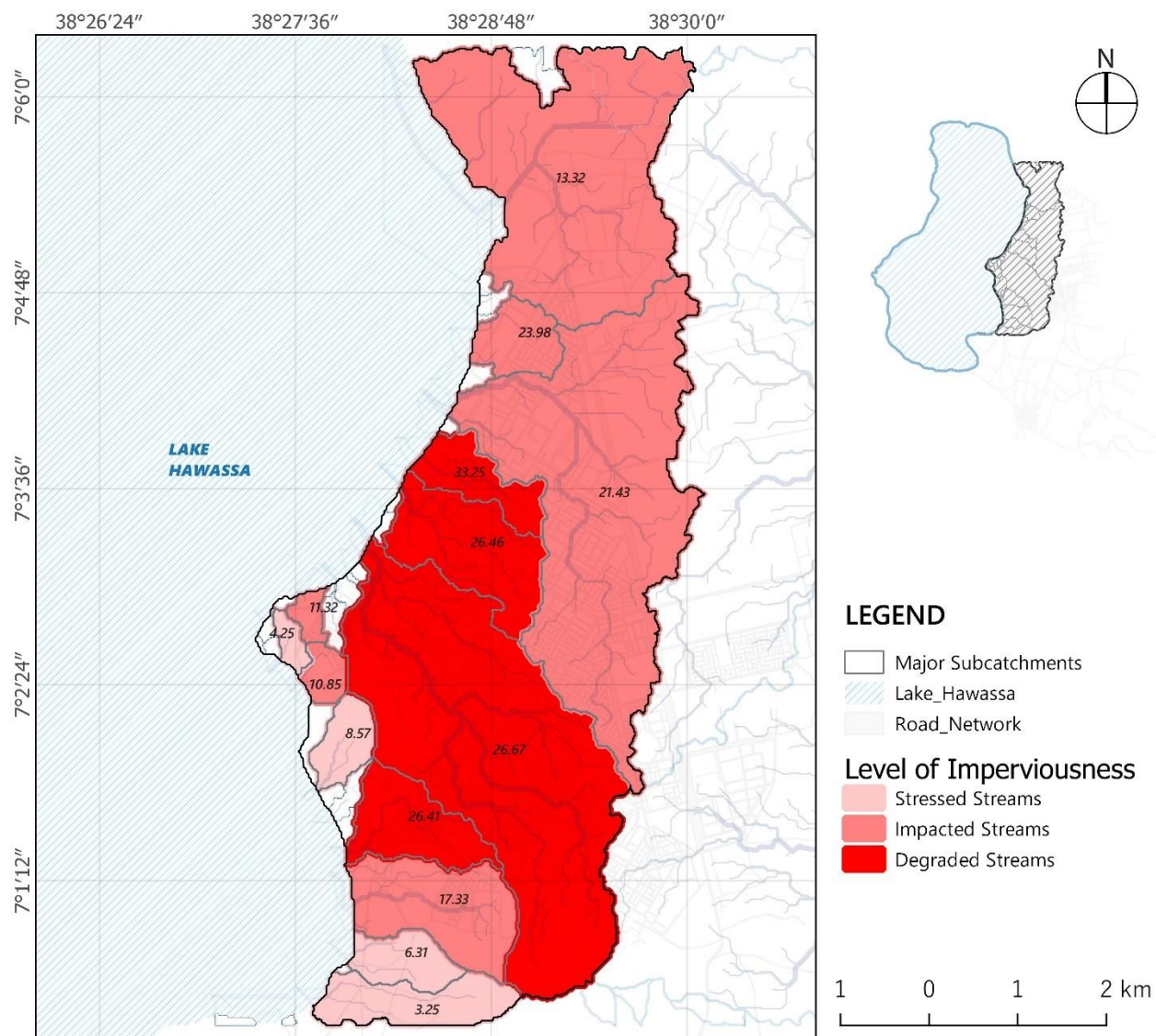


Figure 4.1-5 The Imperviousness and Impact level of the urbanized catchments

4.1.2 Pollutant Loads from the Major Catchments Identified.

To understand the urbanization impacts from land use perspective (EMC values computed by SWMM) and contextual assessments from water quality samples of the urbanized landscape, the pollutant load from urbanized catchments has shown the impact level from diffused pollutants. On the first assessment of categorized major land uses to simulate pollutant load the urbanized catchment, results (Fig. 4.1-6) have shown. The land use factors and catchment sizes are major determinants on this assessment and as presented on (Table. 4.1-1) catchment 9 and 12 show highest pollutant loads. Based on the above assessment and the imperviousness results on chapter 4.1.1, purposive selection of catchments to take water quality samples are identified that are at degraded level of imperviousness and highest in impervious and runoff levels.

Pollutant load on existing simulation.

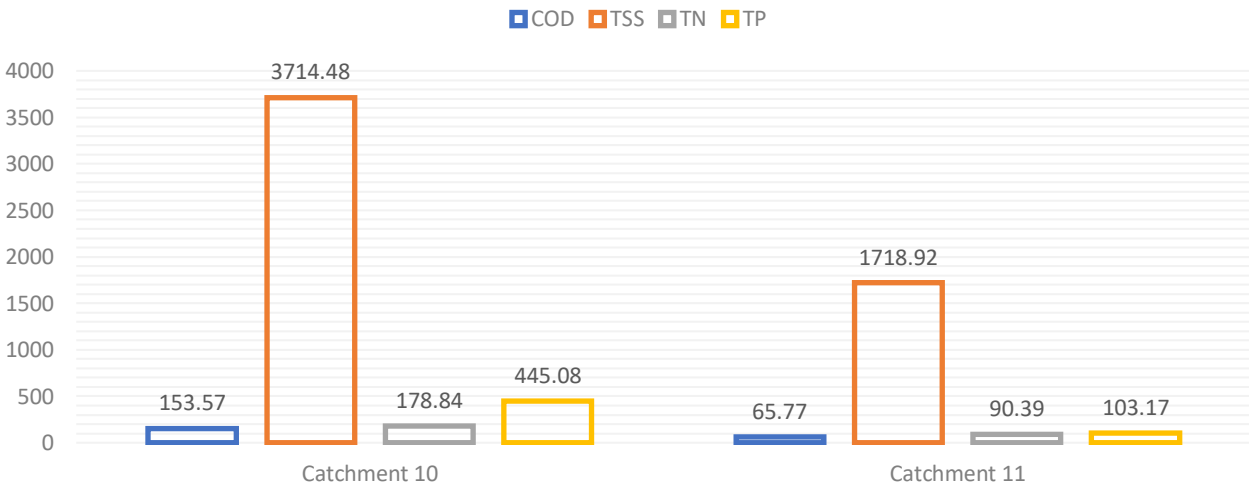


Figure 4.1-6 Pollutant load on existing catchments with simulation.

Selected catchments majorly (catchment 9, 10 11 and 12) have reviewed in detail. On water quality samples taken on the above catchment, the catchment 10 (C10) has the highest pollutant load on the three parameters selected as BOD, COD and TSS levels as shown on (Table. 3.9-3 and 3.9-5).

Pollutant load of catchments from water quality test

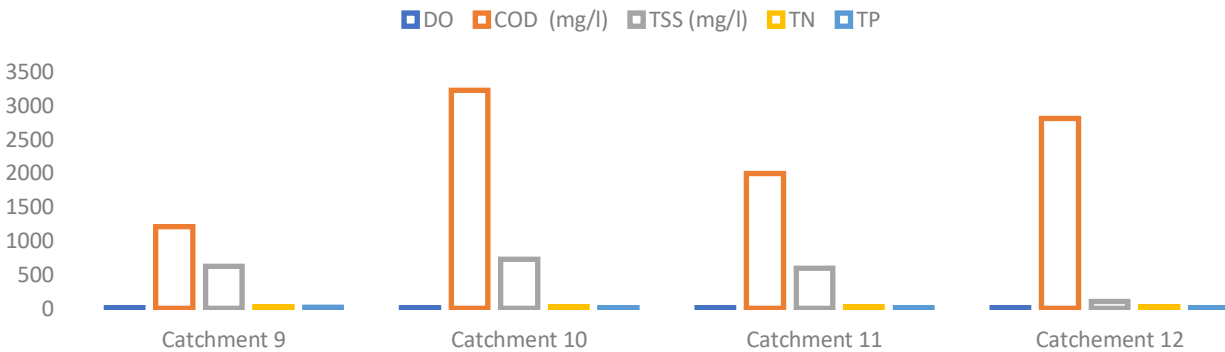


Figure 4.1-7 Pollutant load variance with different catchments.

From the four samples taken at the pour points (Fig. 4.9-8) before flow in and diluted in to the lake, the statistical summary of major variables has been presented (Table. 4.1-1). Catchment 10 has resulted in high pollutant load on TSS, BOD and COD parameters examined. On NH3 (Ammonia) and PO4 (Phosphate) results catchment 9 has recorded the highest results. Reviewing the stormwater quality with the control variable (Table. 4.1-1) (Sample 5: stormwater sample taken with no surface contact in case of the study area) it has shown decrease for DO level. Whereas other results have shown rational changes as it washes of the urban environment.

Table 4.1-1 Statistical summary of major variables from water quality sample.

Parameter	Sample 1 (Catchment 09)	Sample 2 (Catchment 10)	Sample 3 (Catchment 11)	Sample 4 (Catchment 12)	Sample 5 (Control Variable)	Min	Max	Mean	Median
DO	3	2.5	3	3.5	7.2	2.5	3	3	3
COD	1210	3220	1990	2810	178	1210	3220	2307.5	2400
TSS	622	726	592	102	2.5	102	726	510.5	607
NO₃ - -N	22	21.4	22	20	2.4	20	22	21.35	21.7
NO₂ - -N	1.8	1.4	3.1	3.6	0.05	1.4	3.6	2.475	2.45
NH₃	12.48	3.6	1.92	2.54	0.715	1.92	12.48	5.135	3.07
PO₄ 3--P	16.5	9	8.7	7.4	0.13	7.4	16.5	10.4	8.85

NB: Statistical results have been computed only from the samples taken from identified catchment outlets.

Based on the results with statistical computations, the average (mean) result of pollutant load has shown beyond permissible limits for some pollutant types. And the control variable (Table. 4.1-1) Sample 5 has a result showing the stormwater level before it washes off the built environment. It has shown a significant change to decline for DO whereas other results show water quality impairment after it washes off the urban environment.

On both assessments of the urban catchments, the stream water quality levels have shown gross pollution in reference with Taiwan surface water quality level standards (Table. 2.3-7). Comparing results between catchments, C10 has shown the highest result from water quality (Fig. 4.1-7). Because of other factors as the catchment size and dominant land uses in a catchment (C9 and C12 are the highest) on land-use area computations, C9 has the highest results on BOD, COD Total nitrogen and phosphorus results whereas catchment 12 have the highest result on TSS, as per the stated factors above.

Table 4.1-2 Comparative analysis from the mandatory values of specified Pollutants examined.

No	Pollutant	Recommended or Mandatory Limit Values (surface water regulations)	Mean Result from water quality Test	Remark
1	DO	4 mg/l	3	Less than recommended values if it is < 2
2	COD	1,000 mg/l	2307.5	Exceeds beyond the limited value
3	TSS	<60 mg/l	510.5	Exceeds beyond the limited value

4	NH ₃ -N	50 mg/l	5.13	Under the recommended value
5	TN	4 mg/l	23.82	Exceeds beyond the limited value
6	TP	0.2 mg/l	10.4	Exceeds beyond the limited value

NB: The maximum limited values are taken from (Table. 6) referred from different literature reviews.

From the results the Mandatory/ threshold values in (Table. 4.1-2), the level of impacts stream water quality, the BOD and COD results have shown beyond the recommended value of stormwater quality level. Whereas other results have not been identified and the Ammonia nitrogen result is below the mandatory value stated.

Table 4.1-3 Simulation Results before retrofitting with water quality samples

Cases	Runoff (mm)	Peak flow (CMS)	NPS Pollutant Load (mg/l)			
			COD	TSS	TN	TP
Case I (from sample) *	-	-	3220	726	22.8	9
Case I (simulated)**	2861.89	9.86	153.57	3714.48	178.84	445.08
Case II (from sample) *	-	-	1990	592	25.1	8.7
Case II (simulated)**	1904.13	9.76	65.77	1718.92	90.39	103.17

NB.

- All units for pollutant loads are in mg/l.

* The NPS pollutant load results that have been taken from water quality samples were identified directly.

** The simulated results have been calculated for June day 01 to 30 and units in kg.

The simulation model is computed by EMC factors characterized by different land uses.

Considering the study results by imperviousness and water quality levels, identified catchments has selected to develop strategies in mitigation of quantity and quality impacts of stormwater by combined LID site design retrofits. Detail assessments of the natural and built-up structures has covered on chapter 3.9.1.

4.1.3 LID design strategies to Retrofit stormwater quantity and quality.

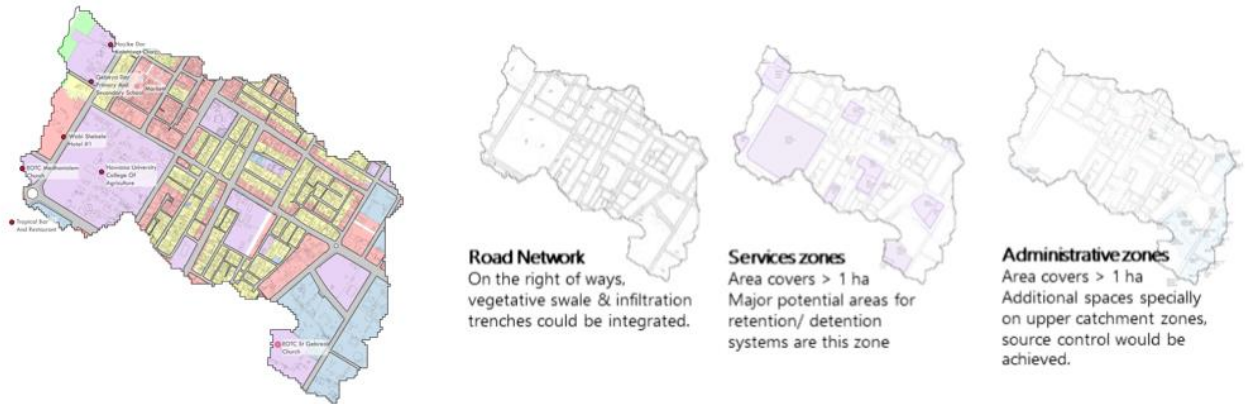
From selected retrofitting techniques reviewed and selected to the specified contexts, potential areas and approaches have been described for selected catchments as follows;

Catchment 10 _ Revitalizing public and institutional areas

The retrofitting strategy for the first case is large-scale intervention to incorporate bio-retention systems that could be dry and wet as the context has been considered (Fig. 4.1-8). It mitigates the

highest rainfall events runoff and the peak flow. Other major strategies incorporate the vegetative swale that drains the stormwater management system from grey to green and infiltration trenches integrated at the ends of drainage points and depression points having the potential to retain and infiltrate easily.

THE CONTEXT and design strategies: catchment 10(C10)



DESIGN STRATEGIES

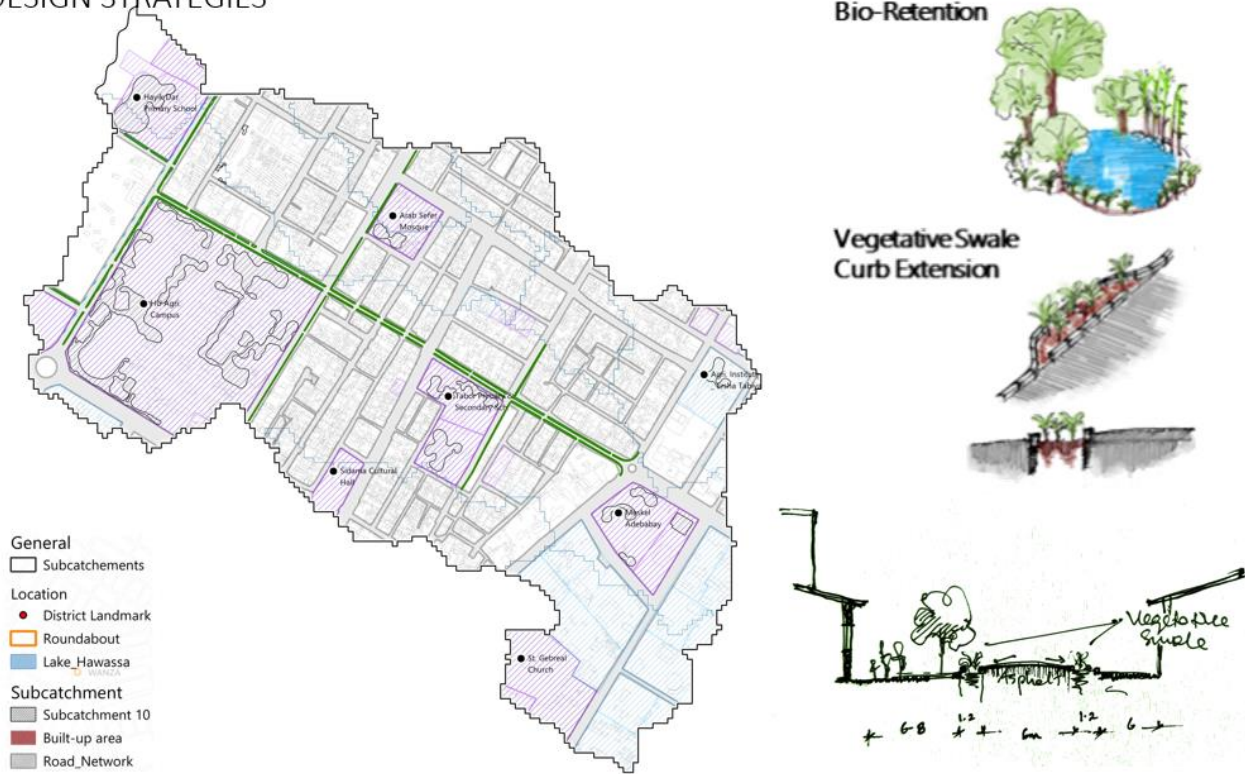


Figure 4.1-8 Design strategies for catchment 10

Table 4.1-4 Potential Sites and systems integrated with C10

No.	Systems	Quantity	Area		Approach	Remark
			(Sq. m)			
1	Bio-Retention Cell	20	78,040.3		Developing open spaces with landscaping elements for dry and wet retention systems.	Computing average area of 7432 sq.m. - 1 in catchment 1, - 2 in catchment 5, - 15 in sub-catchment 9 & 2 in sub-catchment 6
2	Infiltration Trench	-	7,344.8		Integrating on depression of landforms and in between vegetative swales.	Majorly in catchment 9, Similar to bio-retention cell but surface and storage capacities calibrated
3	Vegetative Swale	-	14,876.5		That is to transform grey stormwater drainage systems to green. On major access ways of districts with landscaping and elements.	As it is a consistent element between catchments it has been computed by the area dominantly in sub-catchment 7.

NB.

1. For the convenience of simulation modelling the bio-retention module, the potential site is identified and the computing average area is 7432 sq. m the number of bio-retention units has been simulated on specified sub-catchment areas available.
2. The infiltration trench and vegetative swales have been computed as the total area in a catchment.

In the first case, the area is dominantly service and institutional character that has the potential to integrate large scales LID design interventions such as retention and detention systems. Bio retention ponds and infiltration trenches at educational service areas (Hawassa university agriculture campus, ‘Tabor’ and ‘Hayik dar’ primary and secondary schools) religious service spaces (Hawassa St. Gabriel church, Arab sefer mosque) and administrative land uses in the area could be utilized as a potential area incorporating landscaping features in the catchment.

After integrating LID systems, (Table. 4.1-4) and (Table. 4.1-5), results have shown a reduction of runoff and peak flow up to -16% and -17.4%. Similarly, the pollutant reduction shows -16.5%, -16.2%, -16.3% and -16.3 % for COD, TSS, TN and TP pollutants respectively.

Table 4.1-5 Simulation results for C10 after retrofitting (with combined LID systems)

Sub-catchment	Area (ha)	Runoff and peak flow generated				NPS Pollutant Load (Kg)			
		Total Infiltration (mm)	Imperv. Runoff (mm)	Total Runoff (mm)	Peak runoff (CMS)	COD	TSS	TN	TP
10									
1	13.21	22.74	6.92	68.77	0.69	2.03	94.40	2.32	5.86
2	6.86	32.49	8.91	192.85	0.75	4.74	140.73	5.42	13.65
3	4.72	36.69	10.14	337.78	0.67	1.86	172.76	8.98	22.61
4	7.38	40.14	13.03	267.91	0.59	11.24	217.75	12.85	32.34
5	19.48	38.71	21.62	155.14	0.88	15.27	328.17	17.45	43.92
6	5.19	64.96	67.55	2131.05	5.39	61.92	1210.88	70.66	173.02
7	17.24	23.16	3.65	40.23	0.47	1.16	71.27	1.33	3.35

8	11.25	36.92	12.70	118.66	0.59	3.89	140.39	4.44	11.18
9	90.50	19.43	74.02	121.64	5.61	38.85	1169.63	44.41	111.74
Total	175.83	315.24	218.54	3434.03	15.64	140.98	3546.01	167.90	417.71

The runoff reduction in each sub catchments varies based on the area and retrofitting measures incorporated.

Catchment 11 _ Source controls with Low Impact development systems

The second case, which is dominantly characterized by residential land use (Fig 4.1-9) and cobblestone surfaces for collector and linkage street networks of the residential zone has a possibility to intervein with rainwater harvesting and landscaping elements at the household level, rain gardens and infiltration trench at neighborhood levels and vegetative swales and bio-retention ponds at districts and institutional spaces with a wider plot area.

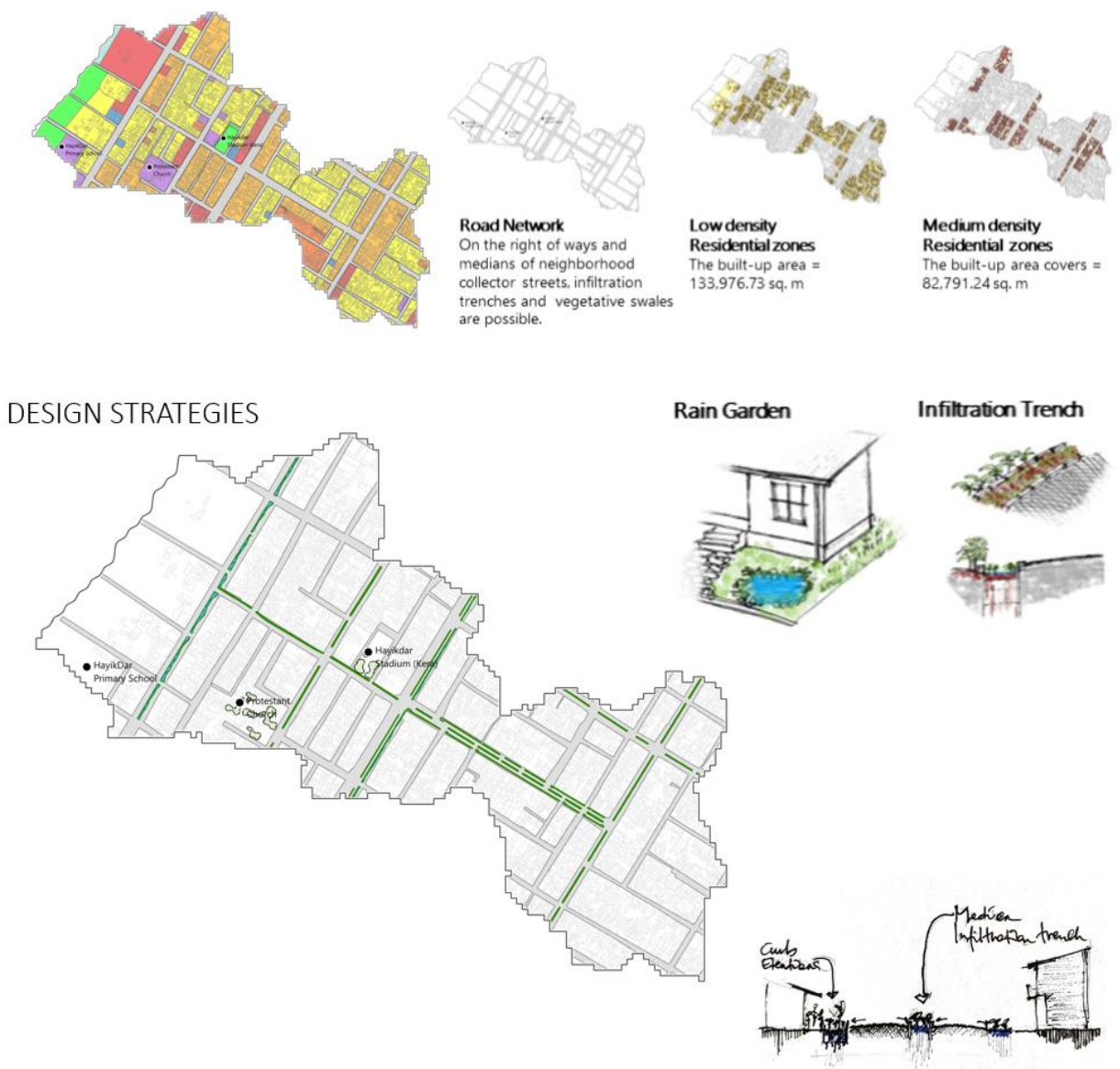


Figure 4.1-9 Design strategies for catchment 11.

Table 4.1-6 Potential Sites and techniques integrated into Catchment 11(C11)

No.	Systems	Quantity	Area (Sq. m)	Approach	Remark
1	Rain Barrel	637	1	Connecting with the roof catchments gutter system.	It can be a metal, plastic or constructed (concrete) water tank with a dedicated average area of 1 sq. m.
2	Rain Garden	637	75 each for low density & 25 for medium density residential land uses.	Connecting the overflow from the rain barrel and pavement surface.	Aesthetic and functional factors such as landscaping elements for porosity and plants for evapotranspiration could be incorporated.
3	Infiltration Trench	-	3,766	Integrating into the middle and lower sub-catchments that mitigate runoff and peak flows to the lower catchments.	On wider combined, vehicular and pedestrian accessways have the potential to incorporate median with infiltration systems.
4	Vegetative swale	-	5,650.00	Converting and enhancing the drainage systems with ecological elements that accommodate infiltrate and drain overflows.	The drainage infrastructure is integrated with the road networks and major access ways dominantly connected with local drainage systems; the central drainage system has the potential to integrate this system as well.
5	Permeable pavement	-	18,714.5	considering the refurbishment of IC only 50% of the right of way.	Integrating this system in the upper zone to minimize the generation of runoff to lower sub-catchments.

NB.

1. Assuming the average plot area for Low-density residences (500 sq. m) is 603 Plots and Medium density residences (250 sq. m) 672 residential plots. 2. And considering the implementations of the selected systems rain barrel and rain gardens on 50% of the plots for that is 637 elements. 3. Infiltration Trench and vegetative swale on 2% and 3% of the right of way respectively and, 4. permeable pavements to 45% of the existing cobblestone surfaces (42,736 sq. m).

Integrating LID systems like rain barrels, rain gardens, infiltration trenches permeable pavements and vegetative swales results (Table. 4.1-7) have shown significant reductions in the total runoff and pollutant loads (COD, TN and TP) as 66.3, 26.7, 26.6 and 26.2 % respectively.

Table 4.1-7 Simulation results for C11 after retrofitting with LID techniques

Sub-catchment	Area (ha)	Runoff and peak flow generated				NPS Pollutant Load (Kg)			
		Total Infiltration (mm)	Imperv. Runoff (mm)	Total Runoff (mm)	Peak runoff (CMS)	COD	TSS	TN	TP
1	6.48	17.79	30.71	75.17	0.35	1.00	51.04	1.36	1.57
2	7.94	19.74	50.98	134.62	0.74	3.04	113.84	4.15	4.76
3	7.23	19.07	30.70	73.87	0.37	1.09	55.96	1.50	1.72
4	4.17	21.42	72.97	199.69	0.56	2.68	89.37	3.66	4.21

5	12.86	30.88	78.83	210.63	1.34	10.39	293.45	14.19	16.30
6	14.97	20.75	30.71	72.18	0.7	2.21	112.7	3.02	3.47
7	7.73	31.48	145.80	410.3	1.27	16.02	353.83	21.08	25.13
8	12.71	14.61	30.81	78.47	0.8	2.06	104.53	2.81	3.23
9	8.39	32.70	1197.85	566.63	1.91	26.72	535.84	36.48	41.91
Total	82.48	208.44	1669.4	1821.56	8.04	65.24	1710.59	88.28	102.33

From the selected cases, the existing and mitigated scenarios have been presented as follows;

Table 4.1-8 Comparison of Simulation Results after LID retrofitting.

		LID calibrated results					
Catchment		Runoff	Peak flow	NPS Pollutant Load			
		(mm)	(CMS)	COD	TSS	TN	TP
C10	Before	3568.37	15.76	156.57	3714.48	178.84	445.08
	After	3175.31	13.93	137.60	3295.95	157.47	392.26
		-16.0	-17.4	-16.5	-16.2	-16.3	-16.3
C11	Before	1900.19	8.97	73.46	1886.16	100.29	115.22
	After	1821.56	8.04	65.24	1714.1	85.34	98.07
		-66.3	5.0	-26.7	-13.1	-26.6	-26.2

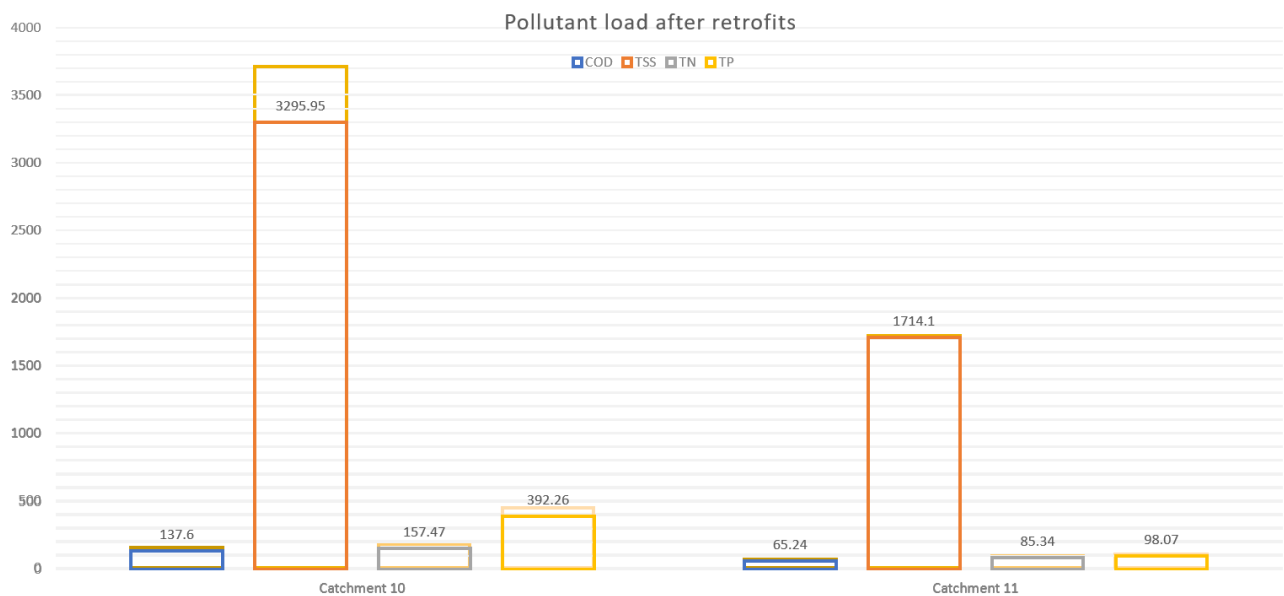


Figure 4.1-10 Comparison for pollutant load before and after LID retrofits

Comparing the pollutant load before and after (Table. 4.1-8) retrofitting strategies. The detail design considerations to meet comprehensive advantage of this system is required in case of specific site. The LID systems have reviewed as strategies so as to assess the potential of this areas. The retrofitting strategies as identifying mapping and proposing appropriate methods has included in (Appendixes 4).

4.2 Discussion

4.2.1 Change of the impervious surfaces

Based on natural and governmental forms of the city boundary the urbanization trend of the city has an increment to infill developments. That changes the urbanization pattern from sprawl towards density and infill developmental pattern whereas environmental impacts on the urban environment exceed substantially. Schueler (1994) discussed the implication of imperviousness to runoff, which is similar to the result on computed catchments (Fig. 4.1-5) and degraded catchment covers that cover 37.91 % of a category of degraded stream water quality level.

In smaller catchment areas the impact of imperviousness is higher (USEPA, 2005) as described in (Table. 3.9-2). Simulation results in impacted catchments (C11 and C12), Case II has resulted from more runoff and peak flow considering the catchment area. The impact of imperviousness is indirect to the catchment the lower the catchment area higher its impact by imperviousness.

From literature studies, the natural factors such as slope show cross correlational implications to impervious runoff generated. On flat surfaces, the urbanization trend increases whereas the direct relation slope with runoff is lower. Comparing impacted catchments C10 and C11, Catchment 11 has a lower catchment area whereas higher in the impervious runoff. On selected results of runoff and peak flow on different land uses, considering the catchment area the residential areas show a higher impact on both results (Runoff and peak flow).

4.2.2 Pollution generated from the urbanized landscape

Most studies on water quality evaluation of Lake Hawassa have focused on the comprehensive impact of watershed contributors that are imposed on the major wetland that is Lake Hawassa. Whereas the nature and exponential growth of the urban environment have a significant impact that could be observed as physical characteristic of the lake front adjacent to the urban environment. Constructed wetlands in between the city and the lake has contributed to trap suspended solids before it has flowed into the lake. Whereas overflows and other pollutants from the urbanized catchments has flowed directly. As presented on the results session the water quality level of streams that flow directly to the lake could be categorized as ‘grossly polluted’.

The results from the water quality parameters and simulation model have shown discrepancies. Similar studies in Finland by (Tuomela, et al., 2019) have shown exceeded results of pollutant load from water quality results examined. In this case factors as:

- Seasonal variance as the water quality sample has taken on the second-highest rainfall event. The first wash off erodes and cleans pollutant load during the dry season partially.
- The size of the catchment simulation model is directly developed by area of land use and,
- Built-up factors as activities related to the description of land use, as commerce whereas open market area should be taken as a point source pollutant,

Considering the above factors stated, (Table. 3.9-12) shows the water quality results that show the level of water quality is beyond permissible limits stated mandatory values of BOD and COD results of the mean value. The mean results from the water quality test have shown 2307.5, 510.5, 28.96 and 10.4 mg/l for COD, TSS, TN and TP respectively, compared to the water quality index of Taiwan (Table. 2.3-7) these results are in the range of ‘grossly polluted’. Similarly, with EPA recommended value for health and sanitary significances (Table. 2.3-6), the results show, that is beyond permissible limits for all parameters (COD, TSS and TN) other than Ammonia (NH₃).

4.2.3 LID retrofits to runoff and pollutant load control.

Retrofitting measures for urban stormwater management are rare relative to agricultural watershed studies covered that is broad-scale approaches followed (Martin-Mikle, et al., 2015). Whereas considering the stormwater management challenges in cities, different approaches and technologies has developed as source control systems, retention/ detention systems and infiltration systems at different contexts. The LID retrofitting shows significant results in a different scenario, a study taken in Dresden, Germany. A catchment area of 85 ha area of school campus catchment shows a reduction of runoff up to 23.2% to 27.3 % (Yang, 2020). In a similar study in Addis Ababa, stormwater runoff from the urbanized landscape intervention with combined LID techniques has reduced up to 75% of urban flooding (Jemberie, M.A.; Melesse, A.M., 2021). In the context of Hawassa, by the simulation result taken in this case, it has a maximum reduction level of 66% of runoff on residential catchment with combined LID systems of rain barrels, rain gardens permeable pavements and infiltration trenches. In case of service and administrative catchment (C10), with combined integration of bio-retention, vegetative swales and infiltration trenches. The runoff has reduced up to 17%. The catchment size to the area of LID systems has less result in cases of the effectiveness of simulation model for smaller catchment areas.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The urbanization trend and the impacts related to flooding and NPS pollution have shown the severity of the rapid urbanization. Although there is less urbanization scale compared to highly developed urban environments of the western world, the trend shows critical considerations to urban development practices. By this study assessing the impervious cover change and contribution of these surfaces to the stormwater quantity and quality impacts, results have shown a significant level of degradation to the lake. The study examines factors of the urbanization trend, the natural factors (the landform, geology, and metrological factors) and impacts of the built environment (the built-up, land uses, and the road infrastructures) that escalate flooding and stream water degradation to the natural environments.

If urbanization proceeds in such a spontaneous trend, both sprawl and infill development show a trend to cause more risk of flooding and water quality impairments. Considering global climatic factors and regional contexts an increment in runoff and flooding events has become redundant. Although the water quality degradation caused by the urban environments has a significant impact on the ecological balance of the lake. Possible sustainable stormwater management systems such as LID could enhance the existing challenges of urban flooding and water quality impairment with strategic interventions to the context. From the stated major challenges identified, the study recommends the integration of green infrastructures to mitigate the impact of the built environment that could mitigate both the runoff and NPS pollutants loads to the contexts required.

5.2 Recommendation

From the study covered and research findings, the following considerations and approaches to retrofit the urban stormwater challenges are recommended as follows;

Overviewing the cause-and-effect relations of the IC change in cities and stormwater quantity and quality impacts to the natural environment, identifying the sources and effective retrofitting measures should address the scenario. Based on causality of the stated problems and considerations from different literatures, *regulating* the urbanization trend, considering watershed *management* systems and design *retrofitting* systems has identified as recommendations stated as follows;

1. **Regulate** the built-up change of the urbanized landscape;

- The regulatory frameworks on built-up area ratio (BAR) with open spaces,
 - Conservation of natural depressions (wetlands) that sustain the ecological balance,
 - Restriction of built-up developments on public open spaces and similar land uses that have the potential to integrate multiple uses for the public interest.
2. Watershed **management** system for peak runoff
- Multilayered analysis and retrofitting systems with natural and built-up factors exist,
 - Source control systems to urban stormwater management approach,
 - Identification of flood-prone areas and retrofitting strategy developments,
 - Performance evaluations of the existing scenario and developments of watershed management systems are needed.
3. Sustainable stormwater management strategies to **Retrofit** pollutant loads control on impairment of the stream water quality.
- Retrofitting LID systems that disconnect pollutant load and peak flow from the urbanized landscape,
 - Natural systems that balance soil-water-plant integrations in the reduction of runoff and retention/ detention systems in retrofitting of overflows are recommended as a solution to identified challenges.
 - And thirdly, concepts of conserving the natural environment as placemaking (Friedman, 2021) that is considering the water and ecological environment with the urban design could enhance the quality of the urban environment with nature and urban life comprehensively.

Although the identifying the specific impacts and develop remedials for the specific challenge is a way to enhance the context. comprehensive watershed management systems as a source control, nature-based solutions and low impact developments are sustainable solutions in developments of cities. Integration of green infrastructure as low impact development techniques could enhance the built environment in a comprehensive way of environmental, social and economic benefits to address a sustainable built environment with nature.

Further Studies

Beyond the objectives stated in this research, factors and cases related to this topic for further research has identified as follows;

- Integration of city-wide LID design retrofits to maximize efficient and effective stormwater management,
- The temporal variance on water quality impairments from urbanized catchments,

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Appendixes 1: Publishable Manuscript

Site-Level LID Retrofits to Safeguard Lake Hawassa from Nonpoint Source Pollution from Densely Developed Catchments.

ABSTRACT

Rapid urbanization has become a prevalent trend in the twenty-first century, putting development pressures on existing urban areas as a result of socio-economic changes, which has an impact on the natural system, particularly the hydrological system, by increasing flooding and degrading water quality. The recent expansion and densification of Hawassa city contribute greatly to the generation of more pollutants, which are transported to the city's lake through stormwater runoff from built-up areas. Using spatial analysis tools in QGIS 3.6.3 and a simulation model in SWMM 5.1, the quantity and quality of stormwater runoff impacting the lake environment was evaluated. The imperviousness level of 14 catchments that directly flow into the lake, as well as the pollution load from impacted catchments, have all been investigated to determine which sub-watersheds contribute the most pollutants to the lake. The study revealed that between 2013 and 2018, the imperviousness level in catchments that directly drain to the lake increased from 12.20 % to 20.32 %. That shows an increment of 43.4 % of runoff from impervious covers within five years period. COD, TSS, TN, and TP levels in water samples tested from the degraded catchments' lake intake streams were 2307.5, 510.5, 2.09, and 10.4 mg/l, respectively, which are all above the permitted range. The SWMM model's simulation results also show that surface water quality is substantially degraded and exceeds acceptable limits. Finally, disruptions in the urban hydrologic cycle resulting from the construction of more impermeable surfaces have contributed to the degradation of Hawassa Lake's water quality. Considerable combined LID retrofit systems that follow systemic interventions as source control and

Keywords

Hawassa, Imperviousness, Low Impact Development, Urban Hydrology, Urbanization

INTRODUCTION

Under the development pressures and socio-economic changes of cities, urban and urbanizations have become a pervasive trend of our future. The fundamental character of the urban area has been reviewed as the presence of lots of people, anthropogenic activities on land uses, and altered forms of land cover – which have ramifications on biota, ecosystem processes and social patterns (e.g., sense of community). And the term "urbanization" means an expansion of an existing human population. Specifically, the proportion of total population or area in urban locations or areas (cities and towns). That has shown an exponential rate at which the urban proportion is growing (UNEP, 2008). As the spaces and environment

of cities get into expansive sprawl and densification, an environmental challenge to the urban hydrologic and climatic effects to the surrounding natural features. As space is a finite resource, the ever-increasing demand for land to urban uses, such as housing, workplaces, recreation, infrastructure, and transportation networks, intensifies the pressure onto the natural environment and ecosystems (Costa, 2015). The sustainable environmental approaches through the lens of cities, that comprehend the built and natural environment in focus of inclusive, safe, resilient and sustainable cities stated on the new urban agenda (NUA) 2016.

The urbanization trend shows both the sprawl and densification by diverse anthropogenic activities of living, working and transportation systems in cities. Imperviousness is one of the major indicators for the change of land covers in the urban environment that leads an increment to urban flooding (Schueler, 1994) (US EPA, 2018). Beyond the flooding impacts, urban pollution led to environmental degradation onto the water, air and soil of the urban areas. Pollutants from impervious surfaces are defined as nonpoint sources of pollution (Schweitzer, Noblet, 2018). That is also called diffused sources by land covers, activities and behaviour of urban areas (Petrucci, et al., 2014).

The natural land cover change to impervious surfaces has significantly impacted the water environment with increased runoff and degradation of the stream water quality. And any action in a catchment that alters the existing land use will have a significant influence on the water environment's quantity and quality features (Goonetilleke, 2004). Stormwater runoff from steadily increasing impermeable surfaces in cities has emerged as a major concern to water quality (US EPA, 2018). And the level of stream water quality degradation shows activity within the catchment that has generated from point and non-point source pollutants washed off to the stormwater outlets. Pollutant loads are caused by urban stormwater, agricultural runoff, overgrazing, deforestation, and soil erosion whereas the pollution impact from the urbanized landscape flows to this natural feature (Melaku, et al., 2019). Similarly, Atnafu (2014) describes the pollution impacts of the lake not only by the urban runoff but groundwater flows to the lake Hawassa. The diffused pollution from the urbanized landscape has been discussed in some literature studies as Desta (2003) states the Lake, river and swamps are in serious ecological problems due to harmful anthropogenic activities. Most studies focus on point source and gross impacts on the lake environment. Whereas the contribution of the urbanized area has a significant impact on the lake environment.

RESEARCH MATERIALS AND METHOD

2.1 Description of the Study Area

The study area is located in southern part of Ethiopia that is the lower rift valley zone. It is located in Sidama region and the city to the regional state. Hawassa city is one of the developed and multifaceted urban environments to study on the water and urbanizations. The city administration covers an area of 157.2 km² (15,720 ha), divided into eight sub-cities and 32 Kebeles.

From the landform of the region, Lake Hawassa is placed in the middle of the rift valley basin. And it is an enclosed watershed in the valley. The city is bounded by Lake Hawassa on the west, Cheleleka marshy area on the east, Tikur Wuha River on the north and Alamura Mountain on the south. It lies on a relatively flat plain topographically having an average elevation of around 1,690 meters above sea level (m.a.s.l.) with approximate geographical coordinates of about 38°29' East longitude and 07° 03' North latitude (FUPI, 2006). The natural environs of the area are sustained lives of the community with the utilization of the wetlands as a livelihood source as irrigations, bathing, recreation and as drinking water for domestic uses and wildlife (Desta, 2003).

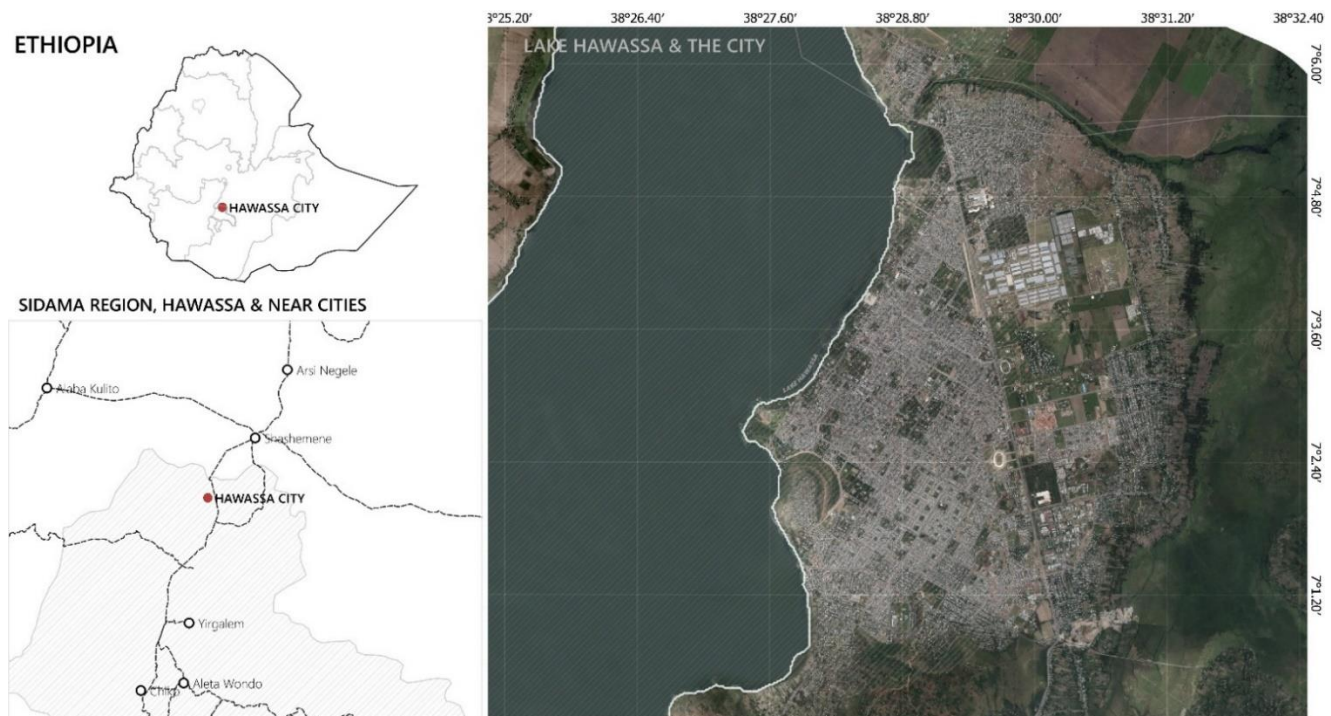


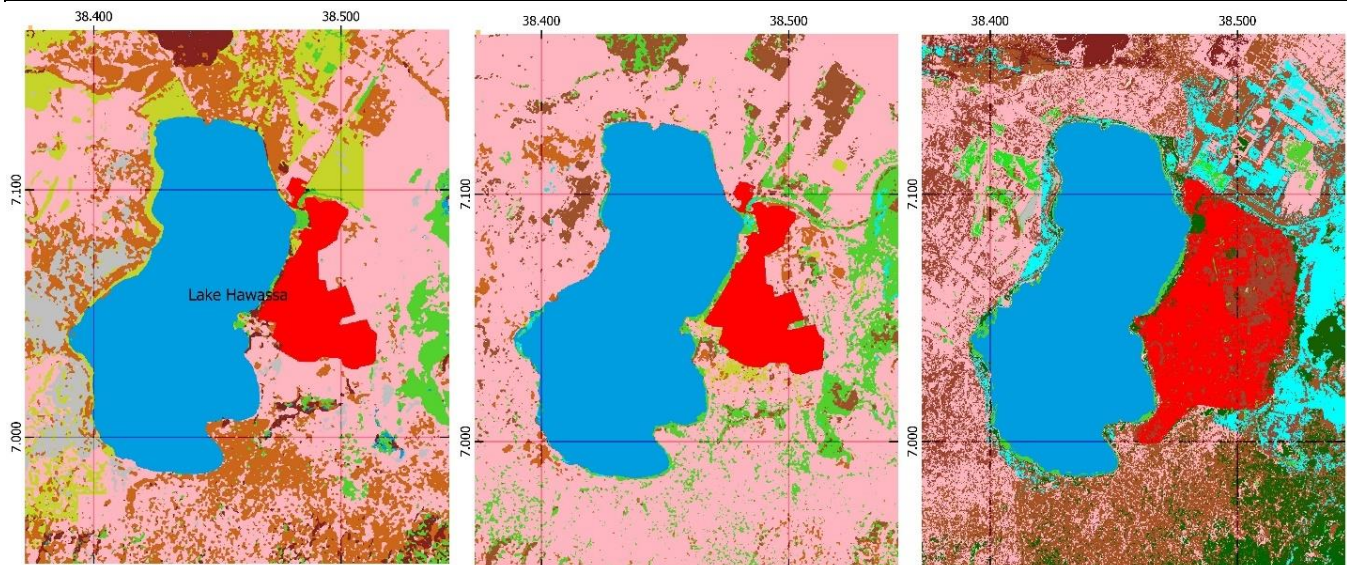
Figure 1 Location of the Study area

The urbanized zone has been changing tremendously for the last 10 years that has reviewed by the land cover change in the past 15 years shown below (Fig. 2). Owing to its recent growth the Hawassa city, that

has been assessed on both sprawl and infill developments A few years back the majority of the area in the provided boundary was occupied by state and household farms. Whereas, currently, most of the area is being changed to the built-up area (G.Wahid, 2007). From major LULC factors the data shown below (Table. 1) the LULC change for 2003, 2008 and 2018 respectively inside 25 km area has been taken and evaluated to examine the change under different periods.

Table 9 Major Land Cover change in year 2003, 2008 and 2018.

No	Major LC Class	2003 (ha.)	2008 (ha.)	2018 (ha.)
1	Bare Soil	5066.254	695.2426	204.39
2	Settlement	2015.035	2048.926	3825.81
3	Water Body	9940.498	9487.28	8915.13
4	Wet Land	126.4317	254.6442	8074.35



Legend

LULC_change	■ Salt pan	■ Rockout Crops	■ Water Body	■ Closed Shrub Land	■ Wood Land	■ Open grass land
Landuse Class	■ Sparse Forest	■ Moderate Forest	■ Perennial Crop	■ Open Shrub Land	■ Bare Soil	
	■ Lava flow	■ Dense Forest	■ Annual Crop Land	■ Wet Land	■ Settlement	■ Closed Grassland

Figure 2 LULC change 2003,2008 and 2018 left to right respectively

Source: Map from EMA and graphical presentation by the authors.

Climate: The climate zone is in the area that ranges from *dry to sub-humid* (Belete, 2018). That is characterized as "Woina Dega" Agro-climatic zone that has moderate and reliable rainfall that create rain feed agriculture (FUPI, 2006). The long term annual average magnitude record at Hawassa weather station is 961mm, which spread as 44% to 50% for Kiremt, 20% for Bega, and 30% for Belg seasons. That is in a category of "Summer Maxima" and most hinterlands receives "small rain" in spring. (FUPI, 2006). Adane (2019) covers the frequency distribution pattern to rainfall intensities and quantities within 24hr is

by his study recorded as 52.75, 68.367, 79.20, 92.51, 102.4, and 112.2 mm/hr. for return period of 2, 5, 10, 25, 50 and 100 years of period respectively. Considering the steady-state water balance for Lake Hawassa precipitation accounted for 56% of the total inputs and 44% of runoff (Gebreegziabher, 2004)cited (Telford 1998, Lamb et al. 2002).

Geological Context: the town is overlaying volcano lacustrine sediments of almost 30 meters thick, though it shows variability laterally and vertically. On lithological views, there are three types of soils in the study area, these are clay soils, sandy silt soils, and silty sand soils (G.Wahid, 2007). The soil group based on FAO is FLe ‘Eutric Fluvisols’ soil group. On review of different studies, the dominant soil texture of the area is clay loam soil (Gebreegziabher, 2004); (G.Wahid, 2007)

2.2 Material and Methods

The study uses mixed research methods. Those are descriptive and correlational research assessments by using quantitative data collected.

The study used a data set that included a Digital Elevation Model (DEM), a high-resolution satellite image, an existing land use map, precipitation data, and water quality samples. Using spatial analysis tools in QGIS 3.6.3 and a simulation model in SWMM 5.1, the quantity and quality of stormwater runoff impacting the lake environment was evaluated. The imperviousness level of 14 catchments that directly flow into the lake, as well as the pollution load from impacted catchments, have all been investigated to determine which sub-watersheds contribute the most pollutants to the lake.

To delineation of catchments and generating spatial analysis of the natural landform, 12.5 m DEM has been used. Considering the land cover of urban environment, on 10 km² area that cover the major settlement area of the city, the watershed pattern of the area is extracted. Identifying the sub-watershed pattern that directly drain to the lake and the major catchments (above 1ha) has identified. It covers a total area of 3,137.7 ha. And major 14 catchments have identified. Analyzing the impervious cover of the sub watershed, the change in five years and level of imperviousness with in the catchments has identified. Using the built-up data from municipal agency for 2013 and digitizing the built-up area for 2018 from high resolution satellite image, the built-up change and level of imperviousness has computed (Table 2). Identifying the level of imperviousness and runoff contribution from impervious cover has assessed by QGIS 3.6.3 and SWMM 5.1 tools.

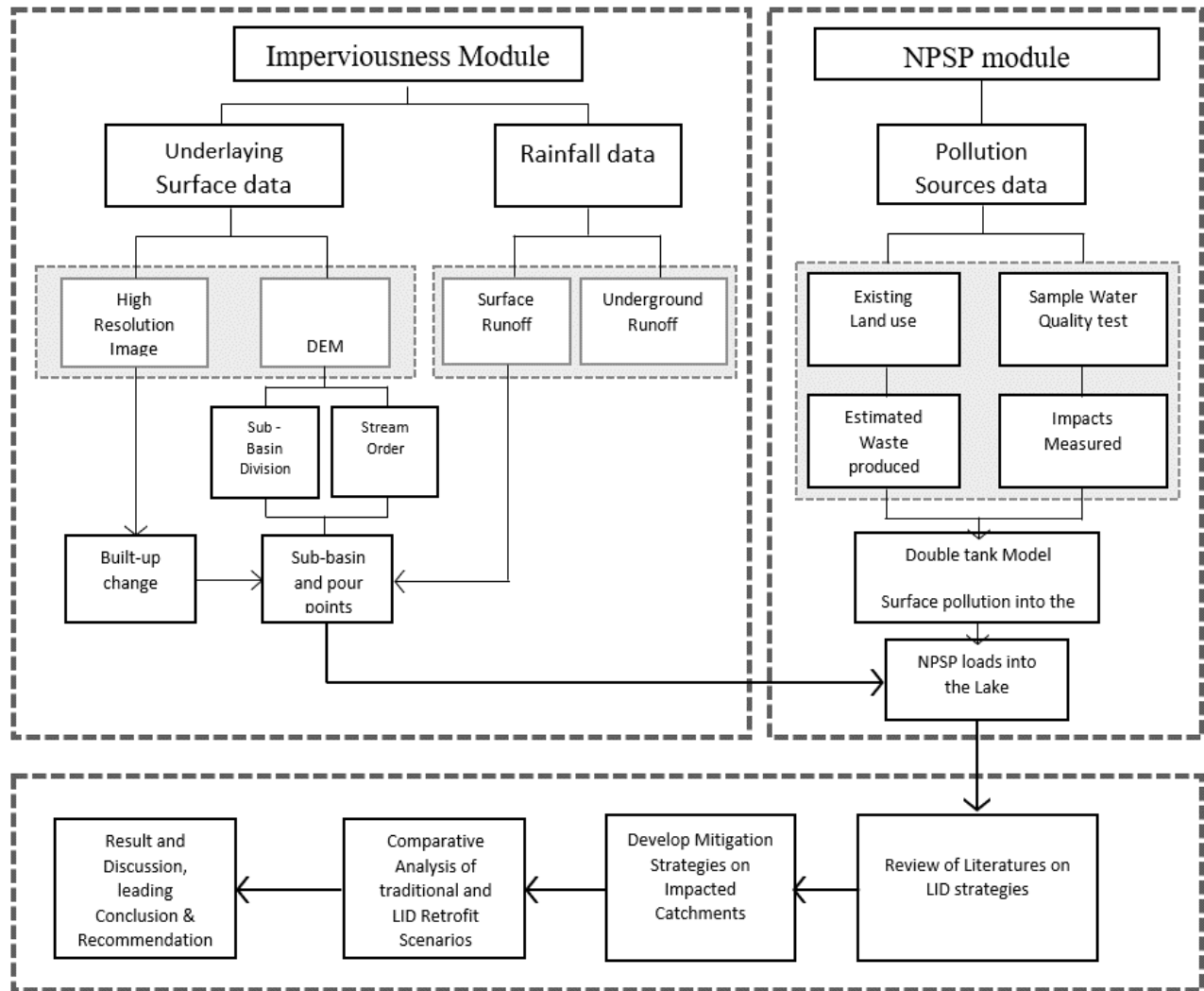


Figure 3 The Research Design

Source: Adapted from A Combination Model for Quantifying Non-Point Source Pollution Based on Land Use Type in a Typical Urbanized Area (Authors presentation).

On the assessment of the stream water quality impacted by the imperviousness has examined on two methods. An event mean concentrations (EMCs) function has been used with a coefficient of variation from literature standards (EPA, 2016) referred and the water quality test on purposively sampled degraded catchments identified by the imperviousness level and runoff generated. Considering and the two results the level of impact has shown which can imply the context.

RESULT AND DISCUSSION

Results the context of this study as discussed to shows the causality of urbanization with IC and the pollutant load generated that wash off from the urban environment.

3.1 The Watershed Delineation and Identifying Level of Imperviousness

The urbanized landscape of Hawassa city is characterized by both sprawl and infill into the existing urban environments. In the years 1986, 2000 and 2011 the land use land cover (LULC) change of Hawassa watershed has shown an increment for the cultivated, agricultural and built-up area and whereas decrement for forest covers, the water body, wetlands, shrubs and grasslands. The built-up change has increased from 5.2 % to 14.4 % in the respective years (Paulos, 2014). A recent result of LULC change of the region from EMA (Fig. 2) shows the built-up/settlement/ change with 1.68% from the year 2008 to 2013 and 86.7% from the year 2013 to 2018 is 89.86% within fifteen years period (Table. 12). Similarly, in this study the built-up change in catchments that directly drain to the lake has changed from 12.2 to 20.32 % within five years (2013 to 2018) is 40% within five years period as shown in (Fig. 4) and (Table. 2) below.

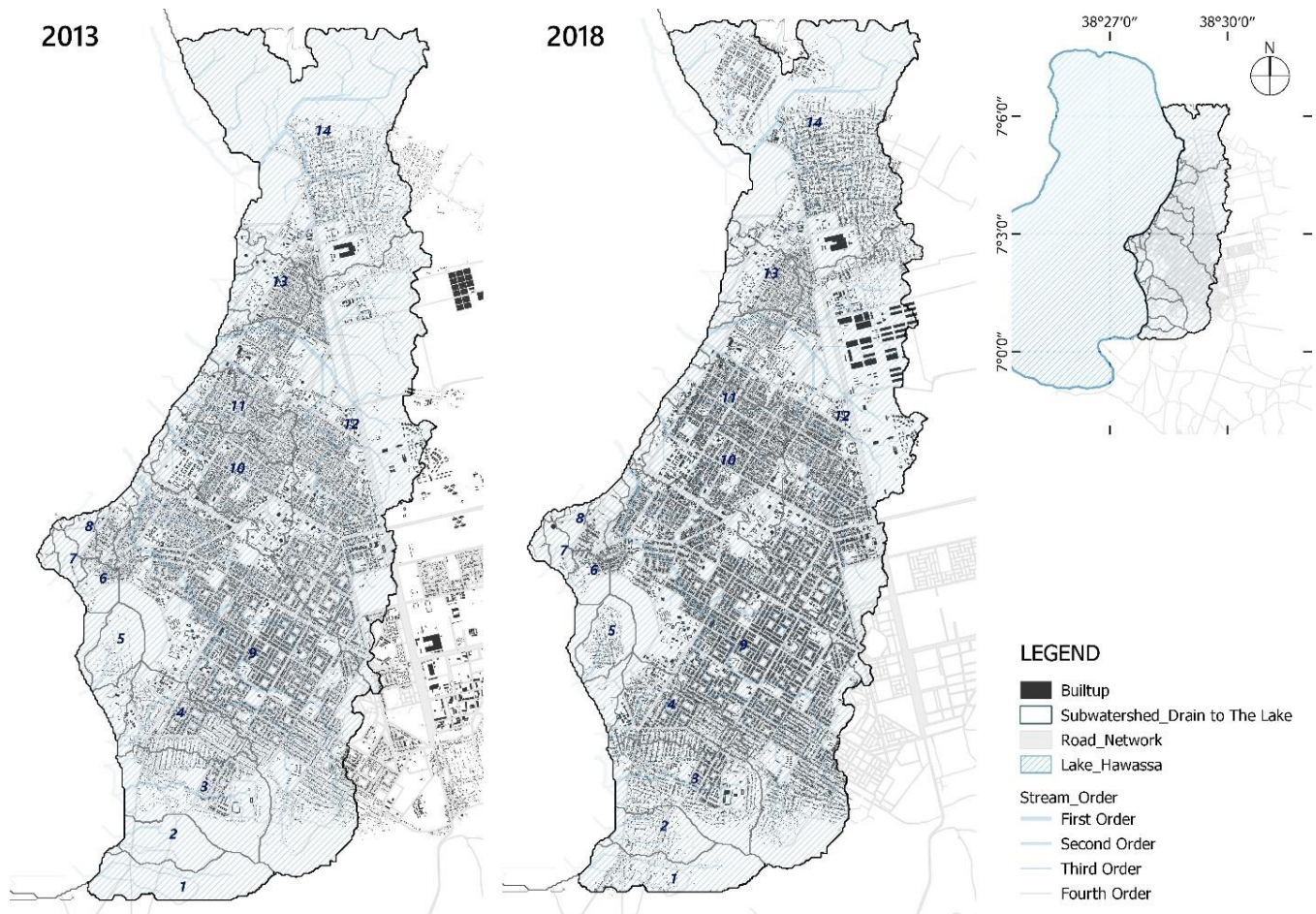


Figure 4 Built-up area for Catchments that directly drain to the lake, the years 2013 and 2018
Source: (Authors presentation)

The impervious runoff, total runoff and peak flow show an increment of 43%, 13% and 25% respectively. Based on the catchment size and imperviousness level within specified catchments, the peripheral catchments from the city center to the fringe have shown the highest percentage of change because of the urban sprawl. On catchments 1, 2 and 7 the change is 100, 99.2 and 81.4 respectively showing the sprawl of the city. In the case of the highest catchments by imperviousness, on a catchment 11, 9 and 10 the change of percentage is 35.2, 34.2 and 26.0 respectively.

Table 10 Simulation results of impervious runoff and pollution.

No.	Catchment Area (ha.)	For the year 2013					For the year 2018					Pollutant Load				
		Built-up 2013 (sq. m)	% Of Built-up area	Imperv. Runoff (mm)	Total Runoff (10 ⁶ ltr.)	Peak flow (CMS)	Built-up 2018 (sq. m)	% Of Built-up area	Imperv. Runoff (mm)	Total Runoff (10 ⁶ ltr.)	Peak flow (CMS)	BOD	COD	TSS	TN	TP
1	103.88	-	-	-	34.69	0.63	33,788.29	3.25	3.03	37.19	0.86	223.1	483.5	185.9	31.6	6.3
2	63.52	355.4	0.05	0.05	25.88	0.61	40,082.69	6.31	5.88	28.52	0.88	171.1	370.7	142.6	24.2	4.8
3	180.9	155,484.43	8.59	8.00	75.37	2.30	313,575.4	17.33	16.1	86.44	3.34	518.6	1123.6	432.1	73.4	14.69
4	116.67	177,923.1	15.25	14.18	57.09	2.17	311,603.6	26.41	24.54	65.57	3.00	393.4	852.3	327.8	55.7	11.1
5	52.54	13,290.58	2.53	2.37	23.29	0.66	45043.95	8.57	7.99	25.31	0.87	151.8	329.0	126.5	21.5	4.3
6	28.44	18,761.41	6.59	6.16	15.56	0.64	30,880.42	10.85	10.12	16.21	0.72	97.2	210.6	81.0	13.7	2.75
7	17.67	1,412.359	0.79	0.74	10.25	0.50	7,522.09	4.25	3.98	10.54	0.54	63.2	136.7	52.6	8.9	1.79
8	17.60	10,258.99	5.82	5.44	9.71	0.41	19,942.21	11.32	10.56	10.21	0.47	61.2	132.7	51.0	8.6	1.73
9	814.93	1,430,048	17.54	16.28	299.66	10.17	2,092,605	26.67	24.73	357.14	12.68	2142.8	4642.8	1785.6	303.5	60.7
10	175.6	343,583.4	19.56	18.18	83.99	3.34	461,359.7	26.46	24.58	92.47	4.04	554.8	1202.0	462.3	78.5	15.7
11	82.41	177,430.8	21.52	20.00	43.22	1.83	274,088.1	33.25	30.88	49.47	2.40	296.8	643.0	247.3	42.0	8.4
12	775.5	976,539	12.59	11.70	301.88	9.97	1,662,293	21.43	19.90	351.80	13.89	2110.8	4573.4	1759.0	299.0	59.8
13	67.67	105,351.3	15.56	14.49	36.73	1.54	162,352.2	23.98	22.30	40.06	1.91	240.3	520.7	200.3	34.0	6.8
14	640.23	305,273.1	5.58	5.20	203.47	5.30	728,927	13.32	12.38	234.40	8.12	1406.4	3047.2	1172.0	199.2	39.4
Total	3,137.7	3,715,711	12.20	122.79			6,187,587	20.32	216.97			16,950	36,725	14,125	2401.2	480.2

Source: Authors computation from GIS watersheds and SWMM modelling.

According to (Schueler, 1994) level to imperviousness in a catchment, identified 14 catchments (Fig. 6(B)) are in the range of 37.91 % is degraded, 54.5 % is impacted and 7.57 % is on stressed stream levels. Consecutively, the impervious runoff has shown 43% to the total runoff. The trend of impervious cover (IC) change and the level it has reached has shown how the built environment has been extensively expanded. That lead degradation to quantity and quality from the urban hydrology.

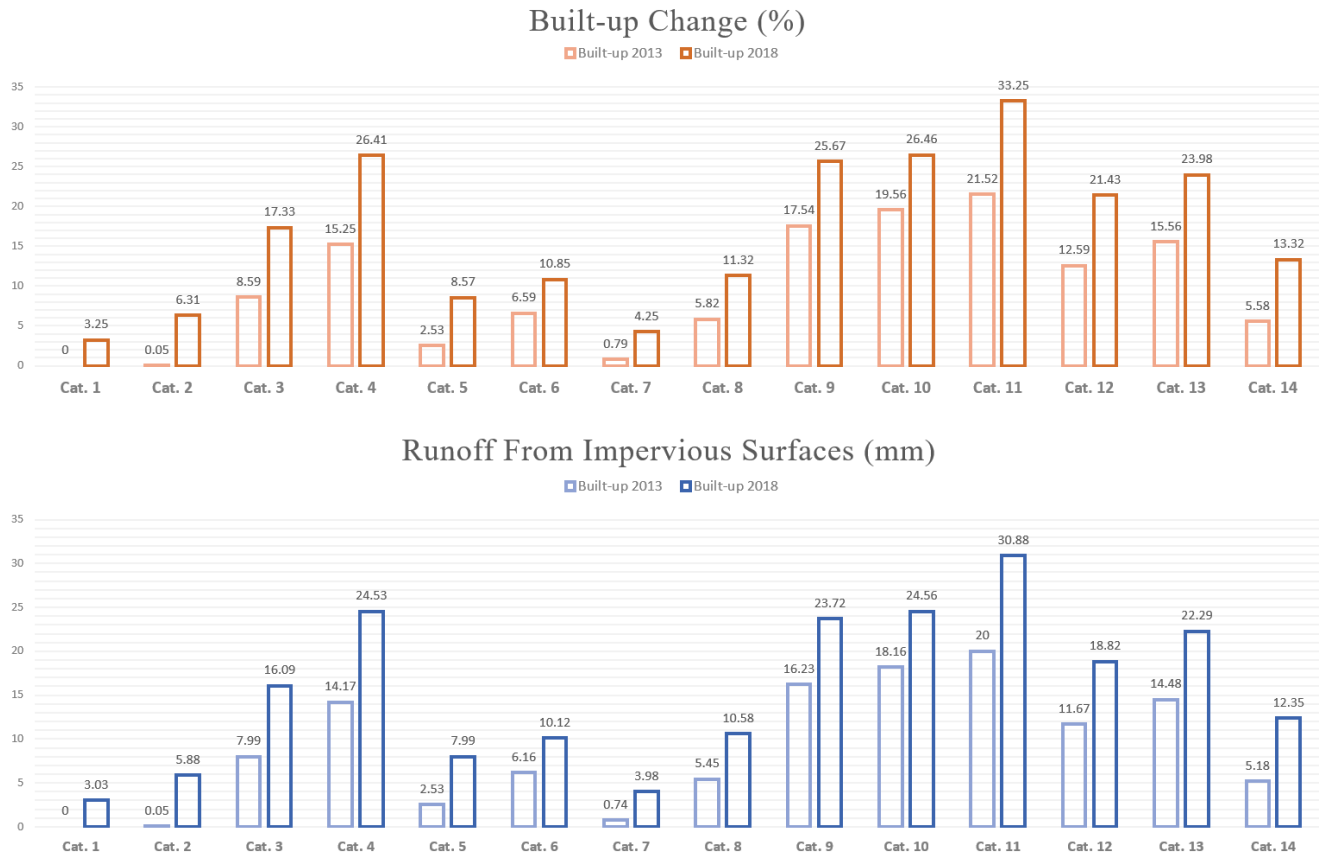


Figure 5 Imperviousness and Runoff catchments simulation change between year 2013 and 2018.

That changes the urbanization pattern from sprawl towards density and infill developmental pattern whereas environmental impacts on the urban environment exceed substantially. Schueler (1994) discussed the implication of imperviousness to runoff, which is similar to the result on computed catchments (Fig. 6) and degraded catchment covers that cover 37.91 % (Map 16) of a category of degraded stream water quality level.

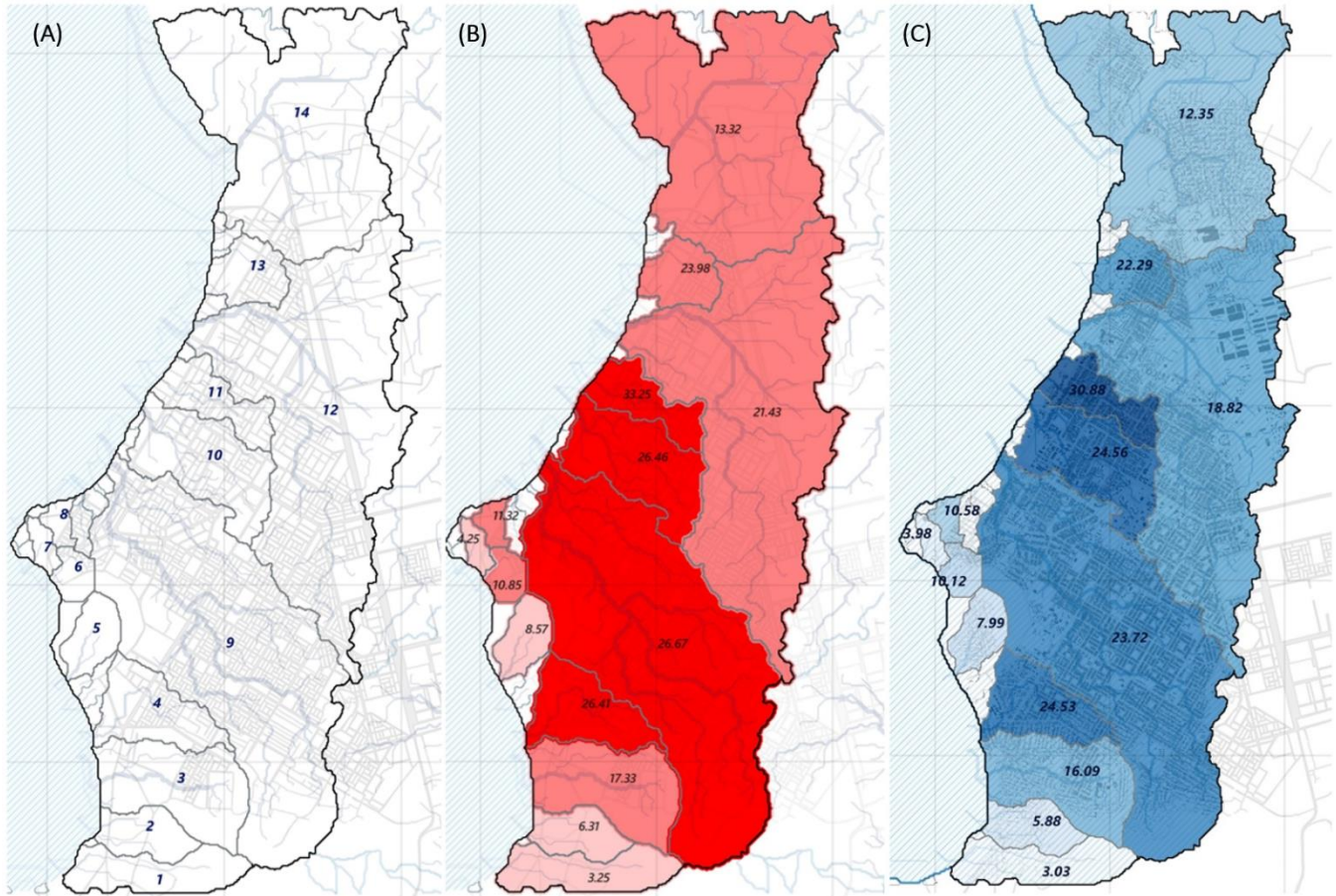


Figure 6 (A) Delineation of catchments, (B) Imperviousness level and (C) Runoff Generation from catchments that directly drains to the Lake.

Source: (Authors presentation)

3.2 Pollutant load from the Urbanized Landscape

To understand the urbanization impacts from land use perspective (EMC values computed by SWMM) in consideration of major land uses as presented on (Fig. 7) has resulted (Table. 2). And the contextual assessments of the stormwater quality samples taken at pour points of identified catchments (Table. 3), the pollutant load from urbanized catchments has shown the impact level from diffused pollutants. On the first assessment of categorized major land uses to simulate pollutant load the urbanized catchment (9, 10, 11 and 12) has presented on (Table. 3). Physical factors of catchment and land use area determine the simulation results of disused pollutants the result shows catchment 9 and 12 show highest pollutant loads. While on the water quality results catchment 10 (C10) has recorded the highest pollutant load on TSS, BOD and COD parameters examined. On NH3 (Ammonia) and PO4 (Phosphate) results catchment 9 has recorded the highest results.

Based on the above assessment and the imperviousness results on objective one, purposive selection of catchments to take water quality samples are identified that are at degraded level of imperviousness and highest in impervious and runoff levels. From the four samples taken (Fig. 6 (A)) before flow in and diluted in to the lake, the statistical summary of major variables has been presented (Table. 3).

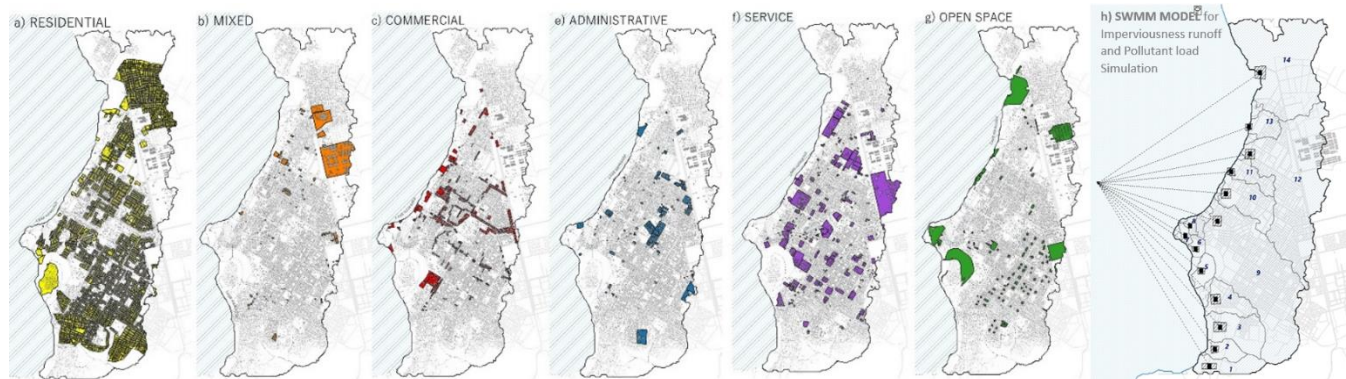


Figure 7 Land use and Built-up area in sub-watershed directly drain to the lake.

Table 11 Statistical Summary of major variables from water quality sample

Parameter	Sample 1 (Catchment 09)	Sample 2 (Catchment 10)	Sample 3 (Catchment 11)	Sample 4 (Catchment 12)	Sample 5 (Control Variable)	Min	Max	Mean	Median
DO	3	2.5	3	3.5	7.2	2.5	3	3	3
COD	1210	3220	1990	2810	178	1210	3220	2307.5	2400
TSS	622	726	592	102	2.5	102	726	510.5	607
NO ₃ - -N	22	21.4	22	20	2.4	20	22	21.35	21.7
NO ₂ - -N	1.8	1.4	3.1	3.6	0.05	1.4	3.6	2.475	2.45
NH ₃	12.48	3.6	1.92	2.54	0.715	1.92	12.48	5.135	3.07
Po ₄ 3--P	16.5	9	8.7	7.4	0.13	7.4	16.5	10.4	8.85

NB: - All unites are in mg/l.

- Statistical results have been computed only from the samples taken from identified catchment outlets.

Reviewing standards on literature with mean results from the water quality sample (as simulation model results show an assessment by the land use factors and exceeds from water quality results) it has shown exceeded values for all water quality parameters identified. Whereas recommended values have considered the maximum permissible limits from reviewed regional and national standards.

Table 12 Comparative analysis from the mandatory values of specified Pollutants examined

No	Pollutant	Recommended Values (surface water regulations)	Mean water quality test results	Remark
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1	DO	4 mg/l	3	Less than recommended values if it is < 2
2	COD	1,000 mg/l	2307.5	Exceeds beyond the limited value
3	TSS	<60 mg/l	510.5	Exceeds beyond the limited value
4	NH3-N	50 mg/l	5.13	Under the recommended value
5	TN	4 mg/l	23.82	Exceeds beyond the limited value
6	TP	0.2 mg/l	10.4	Exceeds beyond the limited value

3.3 LID design strategies to retrofit stormwater quantity and quality factors.

From selected retrofitting techniques reviewed and selected to the specified contexts, potential areas and approaches have been described for selected catchments as follows (Table. 5);

Catchment 10 _ Revitalizing public and institutional areas

The retrofitting strategy for the first case is large-scale intervention to incorporate bio-retention systems that could be dry and wet as the context has been considered. It mitigates the highest rainfall events runoff and the peak flow. Other major strategies incorporate the vegetative swale that drains the stormwater management system from grey to green and infiltration trenches integrated at the ends of drainage points and depression points having the potential to retain and infiltrate easily.

Catchment 11 _ Source controls with Low Impact development systems

The second case, which is dominantly characterized by residential land use and cobblestone surfaces for collector and linkage street networks of the residential zone has a possibility to intervene with rainwater harvesting and landscaping elements at the household level, rain gardens and infiltration trench at neighborhood levels and vegetative swales and bio-retention ponds at districts and institutional spaces with a wider plot area.

Table 13 Comparison between impacted catchments.

Major factors	Catchment 10	Catchment 11	Remark
Average slope	2.07 %	2.18 %	Similar zone
Soil type (Top soil)	Eutric Fluvisols, It has clay loam soil texture	Eutric Fluvisols, It has clay loam soil texture	Similar zone, data from soil map data of FAO.
Built-up area	26.46 %	33.25 %	-
Asphalt surface (%)	55.42 %	25.27 %	-
Cobble Stone (%)	37.5 %	66.1 %	-
Dominant Land use	- Service - Administrative	- Residential (low density) - Residential (medium density)	Based on the dominant land uses the LID retrofitting strategies are considered.

Strategic considerations	- Wide public/ institutional open space, right of ways	- Small scale source controls of stormwater harvesting systems
Identified LID systems to retrofit And potential site area to integrate.	1. Bio-Retention Cell (78,040.3 Sq. m) 2. Infiltration Trench (7,344.8 Sq. m) 3. Vegetative Swale (14,876.5 Sq. m)	1. Rain Barrel (637 units of 1m3) 2. Rain Garden (637) 3. Infiltration Trench (3,766 Sq. m) 4. Vegetative swale (5,650 Sq. m) 5. Permeable pavement (18,714.5 sq. m)

NB. Details considerations and assessment to catchment has covered on the report.

The runoff reduction in each sub catchments varies based on the area and retrofitting measures incorporated. The retrofitting factors the summary of results has shown below (Table. 6), After design retrofits LID systems, (Table. 5) and (Table. 6), results have shown a reduction of runoff and peak flow up to -16% and -17.4%. Similarly, the pollutant reduction shows -16.5%, -16.2%, -16.3% and -16.3 % for COD, TSS, TN and TP pollutants respectively. In catchment 11, integrating LID systems like rain barrels, rain gardens, infiltration trenches permeable pavements and vegetative swales results (Table. 37) have shown significant reductions in the total runoff and pollutant loads (COD, TN and TP) as 66.3, 26.7, 26.6 and 26.2 % respectively.

Table 14 Simulation Result after design retrofits.

Catchments	Total runoff	Peak flow	% of COD	% of TSS	% of TN	% of TP
10	-16.0	-17.4	-16.5	-16.2	-16.3	-16.3
11	-66.3	5.0	-26.7	-13.1	-26.6	-26.2

Retrofitting measures for urban stormwater management are rare relative to agricultural watershed studies covered that is broad-scale approaches followed (Martin-Mikle, et al., 2015). The LID retrofitting shows significant results in a different scenario, a study taken in Dresden, Germany. A catchment area of 85 ha area of school campus catchment shows a reduction of runoff up to 23.2% to 27.3 % (Yang, 2020). In a similar study in Addis Ababa, stormwater runoff from the urbanized landscape intervention with combined LID techniques has reduced up to 75% of urban flooding (Jemberie, M.A.; Melesse, A.M., 2021).

In the context of Hawassa, by the simulation result taken in this case, it has a maximum reduction level of 66% of runoff on residential catchment with combined LID systems of rain barrels, rain gardens permeable pavements and infiltration trenches. In case of service and administrative catchment (C10), with combined integration of bio-retention, vegetative swales and infiltration trenches. The runoff has reduced up to 17%. The catchment size to the area of LID systems has less result in cases of the effectiveness of simulation model for smaller catchment areas.

CONCLUSION AND RECOMMENDATION

Although there is less urbanization scale compared to highly developed urban environments of the western and Asian cities of the world, the trend shows critical considerations to urban development practices. By this context, assessing the impervious cover change and contribution of these surfaces on to the stormwater quantity and quality impacts, results have shown a significant level to degradation to the lake. Considering the cause-and-effect relations between imperviousness, flooding and diffused pollutants from the urbanized landscape, the study reflects the rapid changes of the urban environment and the level of impact to the lake ecology.

If urbanization proceeds in such a spontaneous trend, both sprawl and infill development show a trend to cause more risk of flooding and water quality impairments. Considering global climatic factors and regional contexts an increment in runoff and flooding events has become redundant. Although the water quality degradation caused by the urban environments has a significant impact on the ecological balance of the lake. Possible sustainable stormwater management systems such as LID could enhance the existing challenges of urban flooding and water quality impairment with strategic interventions to the context. From the stated major challenges identified, the study recommends the integration of green infrastructures to mitigate the impact of the built environment that could mitigate both the runoff and NPS pollutants loads to the contexts required.

From the assessment of the urbanization trend, the impacts of urban flooding and diffused pollution to the aquatic environment, sustainable approaches are needed to meet the upcoming urban development challenges. By this study, considerations to identify and simulate LID site design retrofits systems has shown a significant level of reduction on both runoff and diffused pollution from urbanized catchments. Whereas the stormwater management system needs to comprehend regulatory (regulation and frameworks of the urban developments), management (in consideration of the natural watershed systems and function) and retrofits (efficient and effective measures for specific site conditions in detail).

Appendix 2: Precipitation data for Hawassa city

Summarized precipitation data from NMA (National Meteorology Agency).

Yearly Average		Monthly Average		Daily Average			
Row Labels	Average of Precipitation Hawassa (SUM) (mm)	Row Labels	Average of Precipitation Hawassa (SUM) (mm)	Row Labels	Average of Precipitation Hawassa (SUM) (mm)		
2014	1.899386503	1	0.207142857	1	2.869230769	16	1.443137255
2015	1.870921986	2	0.803550296	2	2.542307692	17	2.588
2016	0.422222222	3	1.308163265	3	1.069230769	18	2.916
2017	2.816997167	4	2.528	4	1.08627451	19	2.812
2018	0.130645161	5	5.234710744	5	1.680769231	20	2.08
2019	0.30952381	6	2.917894737	6	1.384	21	1.764
2020	3.080327869	7	3.016842105	7	1.905882353	22	2.656
2021	0.479166667	8	3.520430108	8	2.053061224	23	2.82
	2.01704918	9	3.414141414	9	1.130612245	24	1.623529412
		10	3.405660377	10	2.228571429	25	1.529411765
		11	0.268888889	11	2.02	26	1.726530612
		12	0.153846154	12	1.326530612	27	1.375
		Total	2.01704918	13	1.968	28	2.248
				14	1.72	29	3.168888889
				15	1.803921569	30	2.558139535
						31	3.013333333
						Average	2.01704918

Annual data for Year 2014 - 2021

Month	Year							
	2014	2015	2016	2017	2018	2019	2020	2021
JAN	0	5.27	10.55	0	5.27	0	42.19	126.56
FEB	47.46	10.55	10.55	63.28	84.38	5.27	52.73	31.64
MAR	89.65	42.19	36.91	100.2	121.29	31.64	158.2	36.91
APR	189.84	68.55	342.77	105.47	374.41	174.02	500.98	219.05
MAY	358.59	189.84	247.85	363.87	163.48	131.84	437.7	144.83
JUN	131.84	179.3	84.38	68.55	105.47	121.29	216.21	32.44
JUL	189.84	121.29	116.02	168.75	10.55	58.01	142.38	113.71
AUG	174.02	131.84	179.3	210.94	152.93	210.94	232.03	338.43
SEP	221.48	68.55	116.02	232.03	63.28	406.05	353.32	265.3
OCT	195.12	163.48	158.2	174.02	121.29	268.95	179.3	287.33
NOV	42.19	110.74	100.2	110.74	131.84	147.66	47.46	93.44
DEC	26.37	94.92	31.64	5.27	5.27	63.28	58.01	99.46
Total	1666.41	1186.52	1434.38	1603.12	1339.45	1618.95	2420.51	1789.11

Source: NASA/POWER CERES/MERRA2 Native Resolution Monthly and Annual

Appendix 3: Water Quality result report and Summary

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HAWASSA UNIVERSITY
Institute of Technology
Department of Water Supply and
Environmental Engineering

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Date: 17/10/2013

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Ref.No:WSEE/155/13

To: Yared Dereje

From: Yebeltal Agegnehu
(Department of WSEE delegate Head)



Subject: - **Water Quality Test Result**

Based on your request dated 15/10/2013 E.C for water quality test result, we have conducted the physical and chemical testes in our laboratory and the result is sent attached to this cover letter.

With Regards,

Obligation of the Organization

- With Organization sealed letter shall request detail specific activities to HIoT.
- As per CUEng – HIoT activities cost estimation; it shall transfer the money to Hawassa University – Institute of Technology Corporate Finance before commencement.
- The Organization shall submit the official copy of money transfer receipt to CUEng – HIoT.
- After accomplishment of activities as per the agreement, date shall receive the result report.

Obligation of CUEng – HU

- ❖ As per the legal letter request, it shall prepare the cost of activities and announce for the honored organization.
- ❖ As per the total cost estimation, it shall receive money transfer copy receipt before commencement.
- ❖ It shall carry out activities as per the agreement.
- ❖ It shall hand over the result report for honored organization within the agreement date.
- ❖ 25% of the payment shall transfer for 1000013602728 the Hawassa Institute of Technology Financeas per Senate Legislation Article No 132/3.
- ❖ Material & Chemical cost shall transfer to the Institute of Technology Finance.

The one who breach the agreement shall pay Birr 100.00 (one hundred birr only) for partner and Birr 100.00 (one hundred birr only) for government.

On behalf of HIoT

Name Desalegn Girma Mengistu (i. h. D)
Deputy Director for
Academic Affairs
Signature [Signature]
Date 16/10/2013

On behalf of Organization

Name Yared Dereje
Signature [Signature]
Date 15/10/2013 E.C

**HAWASSA UNIVERSITY
INSTITUTE OF TECHNOLOGY
FACULTY: BIOSYSTEMS AND WATER RESOURCES ENGINEERING
DEPARTMENT: WATER SUPPLY AND ENVIRONMENTAL ENGINEERING
ENVIRONMENTAL ENGINEERING LABORATORY**

Aim : water quality tests

Sampling Date: 12/10/13

Sampled By: Cleint

Name of sample	Ammonia	Phosphate	Nitrate	Nitrite	So ₄	PH	Do	COD	TDS	E.C	Turbidity	T° (°c)
Ha_urb_s pot01 tropical	12.48	16.5	22	1.8	25	8.1	3	1210	90	190	128	25
Ha_urb_s pot02 haugari	3.6	9	21.4	1.4	20	7.9	2.5	3220	114	284	121	25
Ha_urb_s pot03 gebe ya	1.92	8.7	22	3.1	2	8.5	3	1990	77	154	33.6	25
Ha_urb_s pot04 mobile	2.52	7.4	20	3.6	13	8.4	3.5	2810	88	156	93.8	25
Ha_urb_s pot05 souths	3.24	10.5	26	1.3	25	8.18	3	1420	127	194	99.5	25
Ha_urb_s pot06 millinium	17.76	5.2	24	5.9	70	7.82	2	699	322	624	150.9	25
Ha_urb_s pot07 ceramic	2.16	6.1	24	0.7	15	8	5	1810	83	148	117	25

Analyzed by:

FENTAHUN YEHUNIE:

Signature  Date 12/10/13

TIBEBU DESALEGN:

Signature  Date 12/10/13

Approved by: YIBELTAL AGEGNEHU



Note: The first four samples have referred on this study that has identified on sub-catchment (9,10 11 and 12 respectively) pour points of that directly drain to the lake

Appendix 4: LID Strategies to Retrofit on Impacted Catchments

The Existing Scenario

The Natural and Built-up Features:

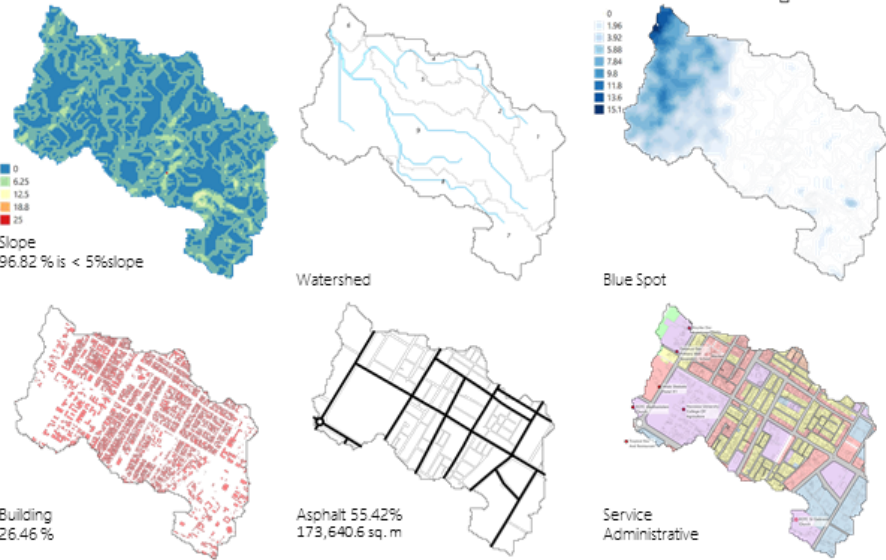
The natural factors are similar as of the adjacency with catchments, whereas on the built environment has distinctive characters of dominant land use and road networks in the catchment. Case one shows institutional land use with arterial roads with asphalt. And case II dominantly characterized by residential land use with collector and linkage roads by cobble stone surfaces.

CATCHMENT 10

Catchment area = 175.6 ha
Width = A/L = 830 m

Dominant characters as:

- Service and administrative land uses
- Asphalt
- Old open market
- Hawassa University Agriculture campus



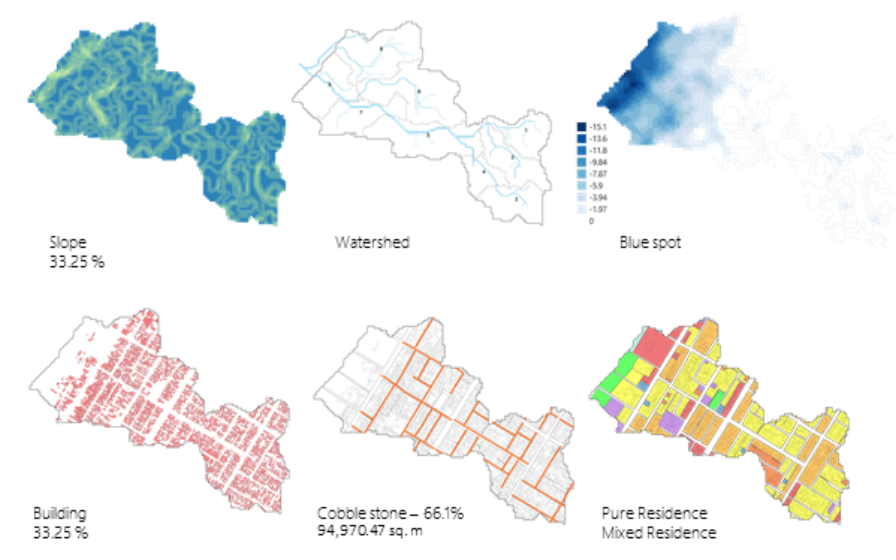
In case I, that has shown the highest pollutant load result and second on imperviousness level, the natural and built-up factors has shown the impact and possibilities of this catchment for sustainable storm water management systems.

CATCHMENT 11

Catchment area = 82.41 ha
Width = A/L = 516 m

Dominant characters as:

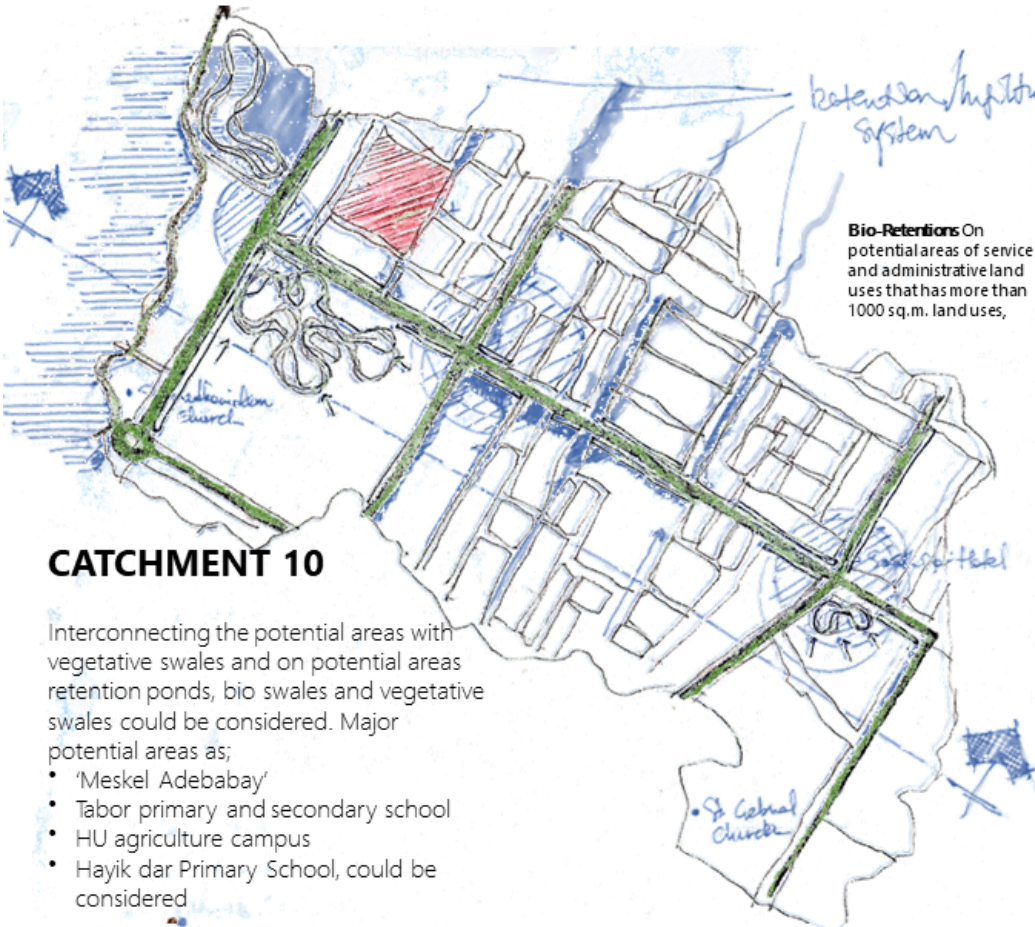
- Residential Land uses(pure and mixed)
- Cobble stone
- Neighborhood open spaces
- Wide right of ways



Case II, has similar natural condition whereas on the built environment the land use and road networks has dominantly relied to residential and cobble stone surfaces. That has relatively less impacts by relative permeability of the surface. Whereas the imperviousness level is highest of all the catchments.

Interwoven systems;

Potential Areas: the design recommendation focuses on identification of potential sites for LID elements to mitigate flooding and NPS pollutants. It only focuses to identify the spatial factors, other hydrologic and hydraulic factors need to be studied in further.



CATCHMENT 10

Interconnecting the potential areas with vegetative swales and on potential areas retention ponds, bio swales and vegetative swales could be considered. Major potential areas as;

- 'Meskel Adebabay'
- Tabor primary and secondary school
- HU agriculture campus
- Hayik dar Primary School, could be considered

Bio-Swale

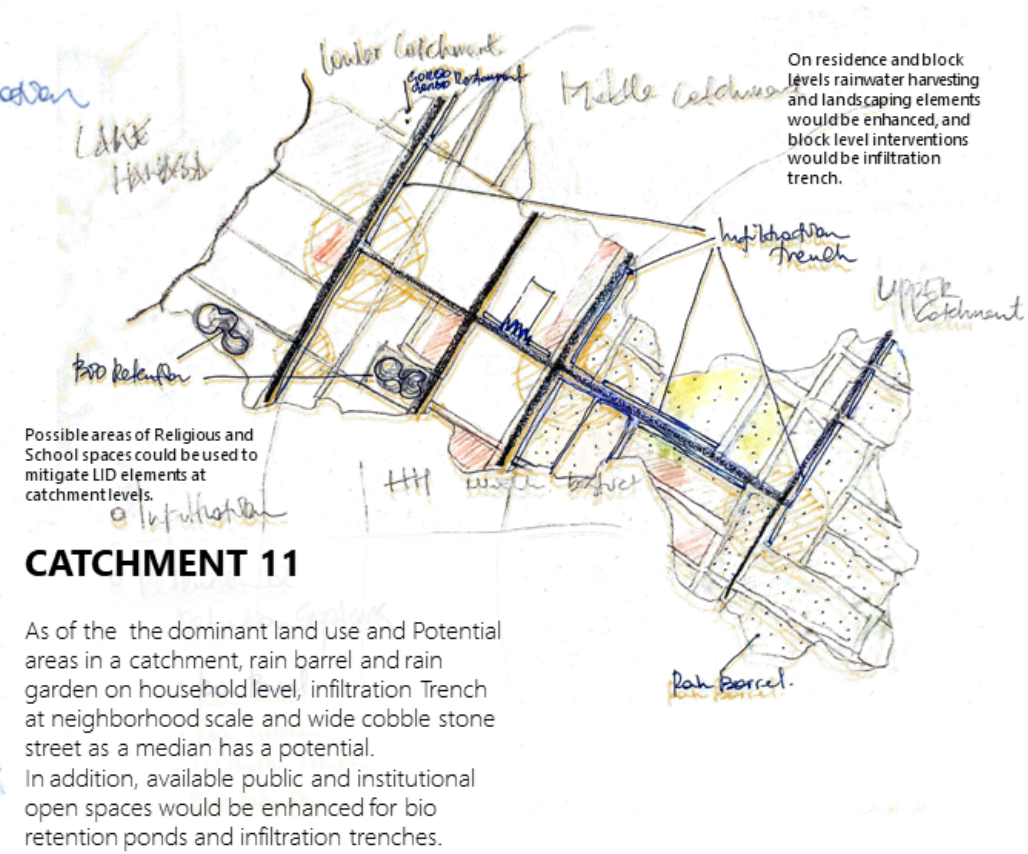


Curb Extension



Vegetative Swale In case of major streets with impervious surfaces like asphalt and buffer spaces needed. Vegetative swales could be provided in between the pedestrian and vehicular paths. The stormwater management and spatial values would be enhanced in further.

Systems	HH	Neighborhood	District	Catchment
Infiltration	Rain Garden	Rain garden	• Vegetative swale • infiltration trench	Vegetative swale
Retention & Detention	Rain Barrel			Bio Retention



CATCHMENT 11

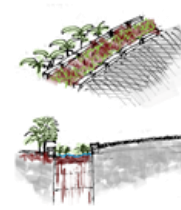
As of the the dominant land use and Potential areas in a catchment, rain barrel and rain garden on household level, infiltration Trench at neighborhood scale and wide cobble stone street as a median has a potential.

In addition, available public and institutional open spaces would be enhanced for bio retention ponds and infiltration trenches.

Rain Garden



Infiltration Trench



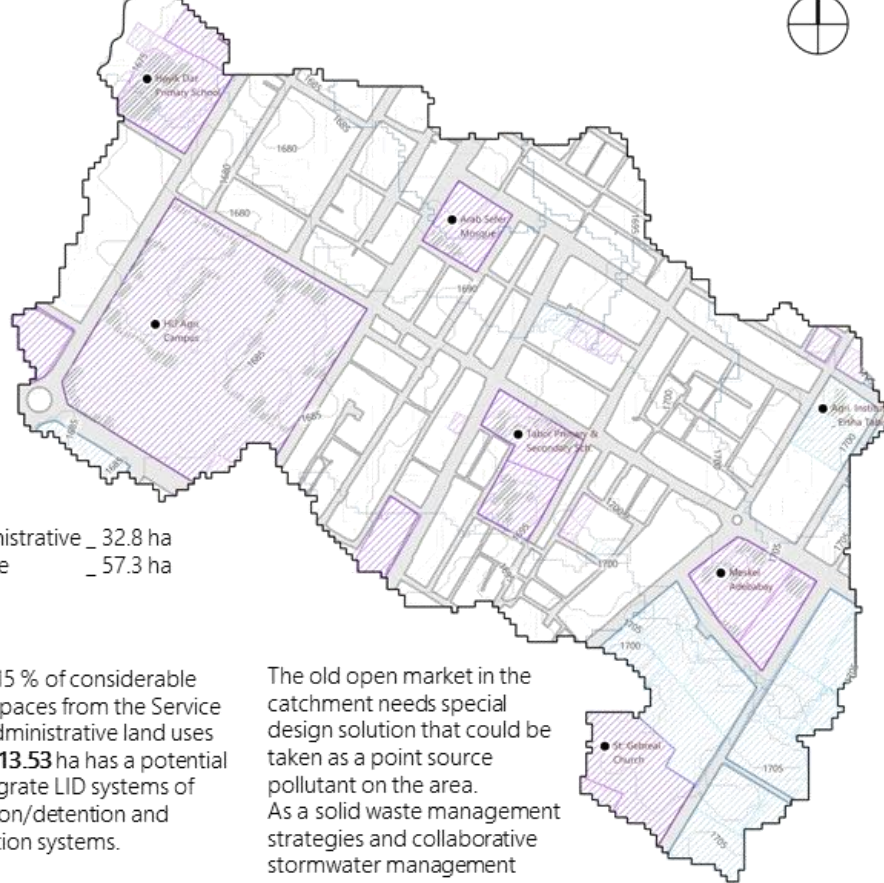
Infiltration Trenches on wider cobblestone surfaces there is a potential to integrate these systems as a space defining element and stormwater management element. Runoff from the road networks and right of ways medians can accommodate the stormwater runoff in support of the main vegetative swale and other LID systems integrated.

Systems	HH	Neighborhood	District	Catchment
Infiltration	Rain Garden	Rain garden	Vegetative swale	Vegetative swale
Retention & Detention	Rain Barrel			Bio Retention

Retrofitting Strategy

Identification of potential sites for LID elements

CATCHMENT 10



Administrative _ 32.8 ha
Service _ 57.3 ha

Using 15 % of considerable open spaces from the Service and Administrative land uses that is **13.53 ha** has a potential to integrate LID systems of retention/detention and Infiltration systems.

The old open market in the catchment needs special design solution that could be taken as a point source pollutant on the area. As a solid waste management strategies and collaborative stormwater management system is needed



Road Network

On the right of ways, vegetative swale & infiltration trenches could be integrated.



Services zones

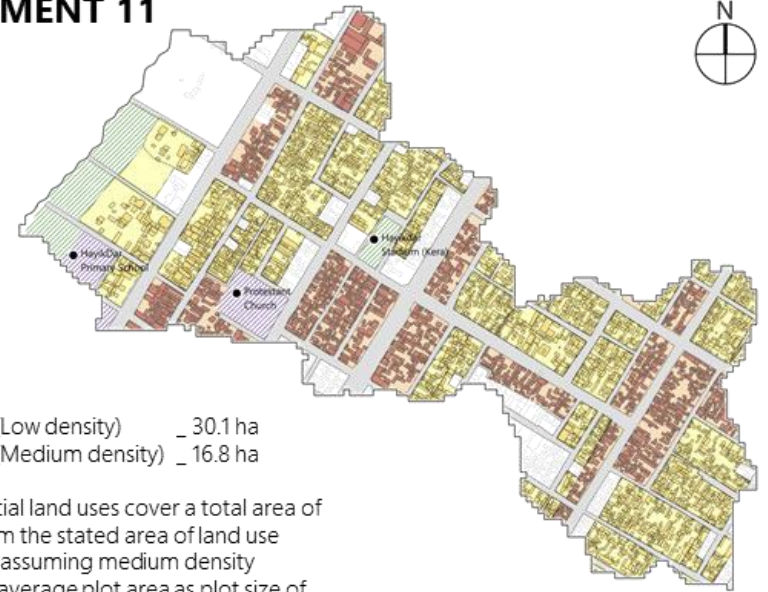
Area covers > 1 ha
Major potential areas for retention/ detention systems are this zone



Administrative zones

Area covers > 1 ha
Additional spaces specially on upper catchment zones, source control would be achieved.

CATCHMENT 11



Residential (Low density) _ 30.1 ha
Residential (Medium density) _ 16.8 ha

The residential land uses cover a total area of 46.9 ha. From the stated area of land use characters, assuming medium density residentials average plot area as plot size of 250 sqm that reaches 672 individual plots and low density plots as 500 sq. m that reaches 603 individual plots.

Considering the average plot area for low and medium density residential areas respectively. Integrating rain barrel and rain gardens for the two types has proposed.



Road Network

On the right of ways and medians of neighborhood collector streets, infiltration trenches and vegetative swales are possible.



Low density Residential zones

The built-up area = 133,976.73 sq. m

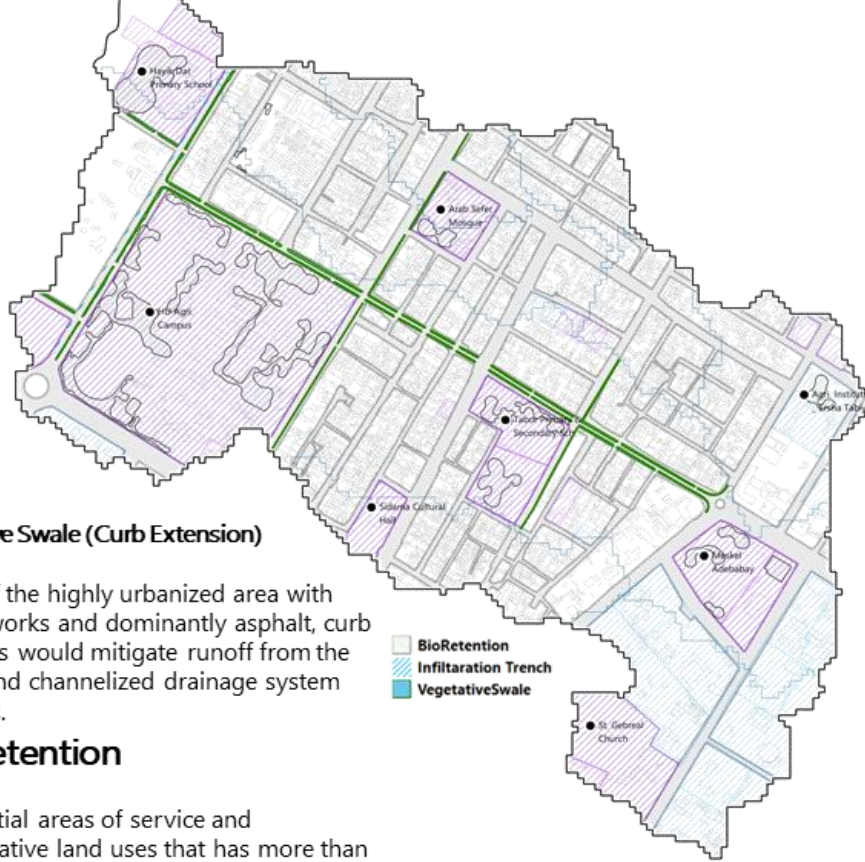


Medium density Residential zones

The built-up area covers = 82,791.24 sq. m

Design Approaches

CATCHMENT 10

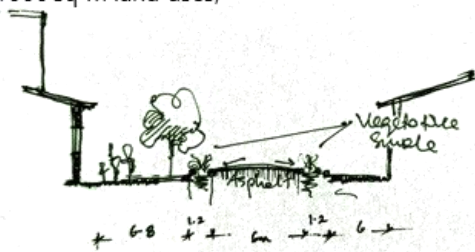


Vegetative Swale (Curb Extension)

In case of the highly urbanized area with road networks and dominantly asphalt, curb extensions would mitigate runoff from the surface and channelized drainage system overflows.

Bio-Retention

On potential areas of service and administrative land uses that has more than 1000 sq m land uses,



Vegetative Swale

In case of major streets with impervious surfaces like asphalt and buffer spaces needed. *Vegetated swales* could be provided in between the pedestrian and vehicular paths. The stormwater management and spatial values would be enhanced in further.

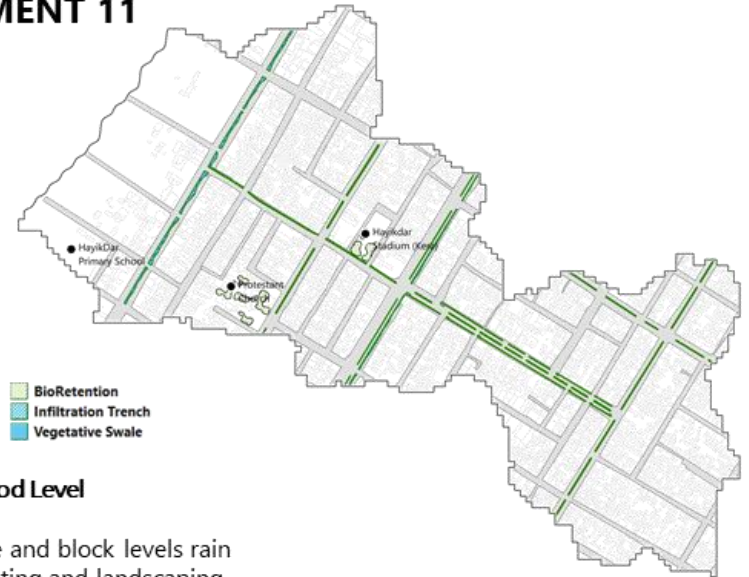
Bio-Retention



Vegetative Swale Curb Extension



CATCHMENT 11



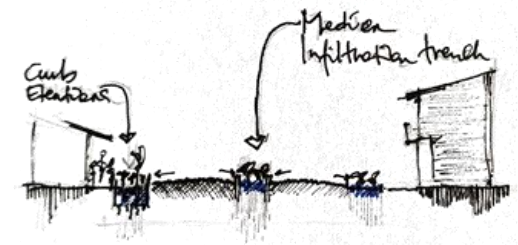
Neighborhood Level

On residence and block levels rain water harvesting and landscaping elements would be enhanced and block level interventions would be infiltration trench.

District and Catchment Level

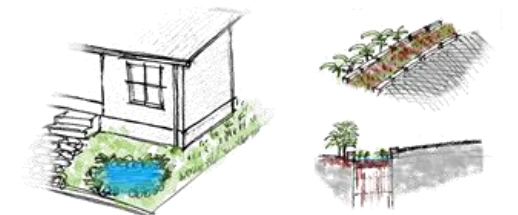
Neighborhood open spaces, public institutions and related spaces has a potential to incorporated as considered on case I.

Infiltration Trenches on wider cobblestone surfaces there is a potential to integrate these systems as a space defining element and stormwater management element. Runoff from the road networks and right of ways medians can accommodate the stormwater runoff in support of the main vegetative swale and other LID systems integrated.

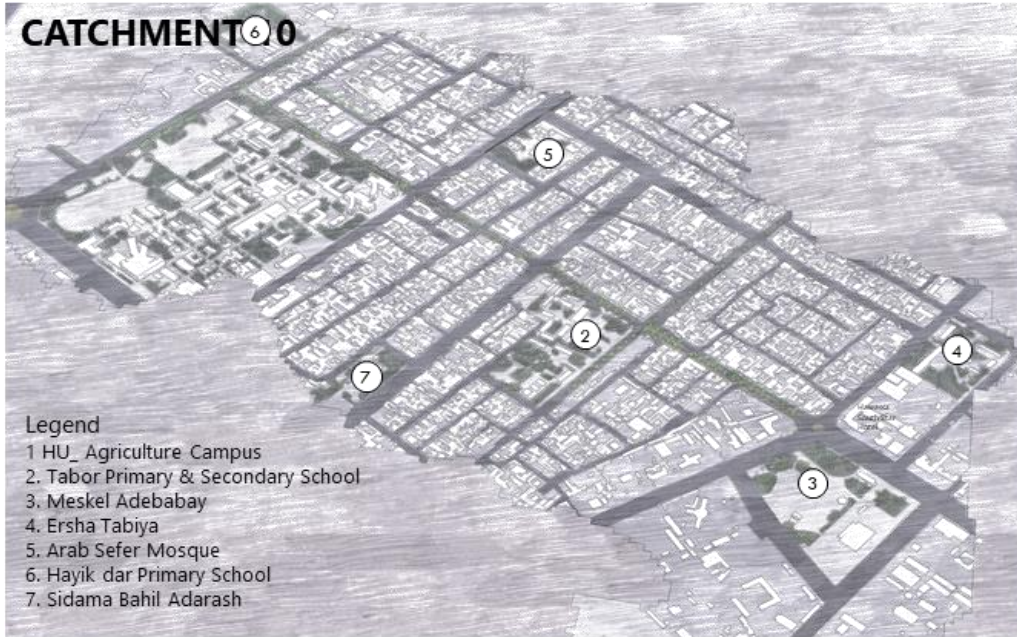


Rain Garden

Infiltration Trench



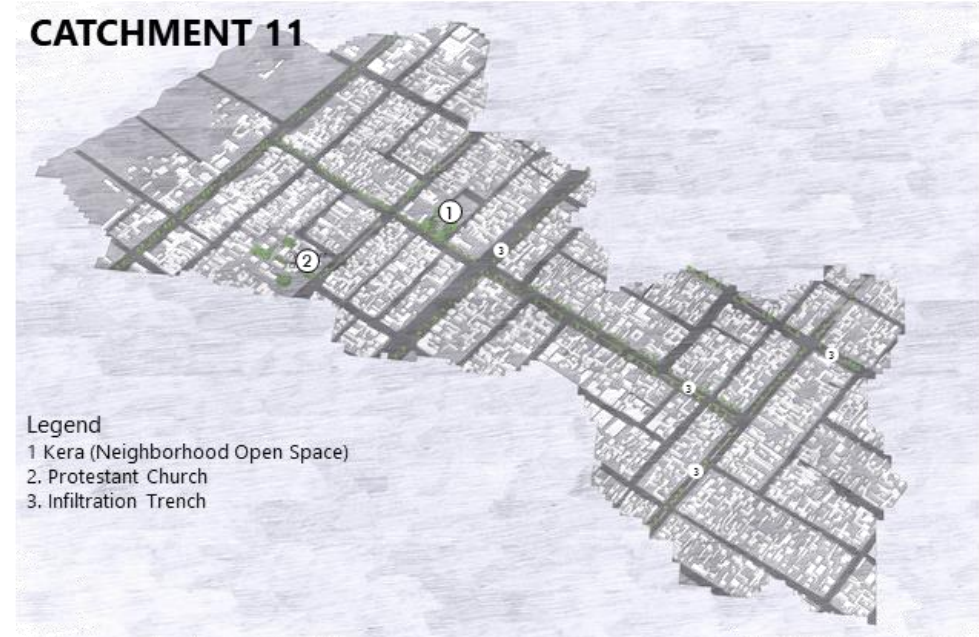
Design Recommendation



As on case I that is services and institution dominated land uses, interconnecting the potential sites with stormwater management systems as infiltration and retention/ detention systems would mitigate the urban flooding and diffused pollution from the urban environments.



Systems stated on the design approach that are: bio-retention, vegetative swale and infiltration trenches has incorporated



In case II, based on the character of the catchment that is residential dominated, small area interventions are recommended. On residence and block levels rainwater harvesting and landscaping elements has recommended, and at neighborhood and district levels swale and infiltration trenches.



The stormwater management systems on household and neighborhood level has incorporated as rain barrel and rain garden at plot levels, vegetative swale and infiltration trenches at neighborhood and district levels as shown on the illustration above.

