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ADDIS ABABA UNIVERSITY
ETHIOPIAN INSTITUTE OF ARCHITECTURE, BUILDING CONSTRUCTION
AND CITY DEVELOPMENT (EIABC)

NATURE-BASED DRAINAGE SOLUTION FOR MINIMIZING THE RISK OF
FLOODING IN NEKEMTE CITY

BY:
NUYWALIF FEYISA GOBENA

DECEMBER, 2020
ADDIS ABABA, ETHIOPIA



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Ethiopian Institute of Architecture, Building Construction and
City Development (EiABC)

Nature-Based Drainage Solution for Minimizing the Risk of Flooding in Nekemte City

By:
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**A Thesis Submitted to the School of Graduate Studies of Addis Ababa University, Ethiopian
Institute of Architecture, Building Construction and City Development, in Partial Fulfillment of
the Requirements for the Award of Masters of Science Degree in Urban Design and
Development**

Advisor:
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December, 2020
Addis Ababa, Ethiopia

Declaration

I, the undersigned, declare that this thesis is my own and original work and has not been presented for a degree or diploma in any other institution or university, and that all sources of material used for the thesis have been duly acknowledged, following the scientific guidelines of the Institute.

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December 2020

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Approval

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Abstract

In Ethiopia, the recent urban expansion and increment of impervious surfaces in high rainfall areas resulted in flooding and associated environmental problems. Nekemte city is one of the urban centers in the country facing the challenges associated with a high level of imperviousness and flooding. This study mainly focused on estimating the level of impervious surfaces and introducing nature-based drainage design solutions for sustainable stormwater management of the city by targeting water-resilient strategies for the future of Nekemte. Spatial data collected and processed by using ArcGIS for mapping & quantification of impervious surfaces eventually for calculating stormwater runoff generated from the most impacted watershed. None spatial data collected to understand the perception of local people about the situation of flooding using questionnaires, structured interviews, observation & focus group discussions. Published and unpublished documents from the municipality of Nekemte and planning institutes utilized for verification of both spatial and non-spatial data. The collected primary data analyzed statistically under SPSS version 20. The principal result of this research showed that factors enabling flooding problems are the sum of factors associated with impervious surface increments, intensive recurrent rainfall in the area, densification of settlements in the higher slopes, and inadequate drainage facilities for stormwater management. Based on this factor, the watershed that covers the area around Bake Jama and nearby neighborhoods estimated to be 201.06ha watershed area identified as the most impacted with 95.77ha of impervious surface coverage. The problem associated with imperviousness in this particular watershed can be reduced by retrofitting through the application of nature-based drainage solutions using the available open spaces and public realms. The study also developed watershed level strategies applicable in different parts of the city with similar flooding problems. Finally, the study recommended further assessment of the socio-economic aspect of flooding in the area to link the nature-based drainage solutions with more co-benefits for the local people affected by flooding. In this regard, the designed nature-based solutions as a blue-green system have the potential for creating more jobs and income for the local people through water harvesting and urban farming schemes.

Key Words: Urban densification, land-cover, surface runoff, impacted watersheds, retrofitting strategy, blue- green system

Table of contents

Contents

Abstract.....	ii
Table of contents.....	iii
List of Tables	viii
List of Figures.....	ix
Acronyms and Abbreviations	xi
CHAPTER ONE: INTRODUCTION.....	1
1.1. Background of the Study.....	1
1.2. Problem Statement	2
1.3. Research Objective.....	4
1.4. Research Questions	4
1.5. Scope of the Study.....	5
1.6. The Significance of the Study	5
CHAPTER TWO: REVIEW OF RELATED LITERATURE.....	7
2.1. Introduction	7
2.2. Mapping and measuring urban built up areas and identifying level of imperviousness	
7	
2.2.1. Quantifying Impervious surface area components	7
2.2.2. On-screen Digitization for impervious surface from high resolution satellite	
image	8
2.3. Watershed level increments in Impervious Surfaces and implication on urban flooding	
and river ecosystem.....	9

2.3.1.	Urban Watersheds level of imperviousness increments	10
2.3.2.	Level of Imperviousness increment implication on flooding and river ecosystem in urban settings.....	10
2.3.3.	Identification of affected micro-watershed and level of imperviousness	11
2.3.4.	Major problems associated with urban imperviousness increments.....	13
2.4.	Sustainable urban drainage solution in stormwater management	14
2.4.1.	Nature-based drainage solution for flood protection (Using Green Along-side Grey as an Alternative Approach to Flood Protection).....	14
2.4.2.	Good practice in the design of nature based drainage design solution for sustainable stormwater management of urban areas	16
2.4.3.	Nature-based urban drainage solution as community benefits (types and description and provisions).....	18
2.4.4.	Public realm and nature-based drainage solution	19
2.5.	Developing sustainable urban drainage system strategy: NbDS for strategy of water- relation and socio-economic aspect.....	19
2.5.1.	NbDS for strategy of water-relation	20
2.5.2.	The Benefits for Water Management and Community	21
2.5.	Models to calculate impervious surface areas and compute storm water runoff	21
2.5.1.	Deterministic statistical model to calculate impervious surface areas.....	22
2.5.2.	Rational and Modified Rational models to Compute Storm Water Runoff Rates and Volume.....	22
2.6.	Lesson learned from literature review.....	25

CHAPTER THREE: RESEARCH METHODOLOGY	27
3.1. The Study Area.....	27
3.2. Data Types.....	28
3.3. Data Source	28
3.4. Population of the study.....	28
3.5. Sampling Technique and Sample Size	28
3.6. Method of Data Collection	30
3.7. Summary of Methodology	31
3.8. Data Analysis Tools	32
2.7. Work flow diagram of the study	34
CHAPTER FOUR: RESULT AND DISCUSSION	35
4.1. Map, measured built-up areas and level of imperviousness in Nekemte city	35
4.1.1. Overview of impervious surfaces increments and built up areas of the study area within two decades	35
4.1.2. Map and amount of current built up area of the study area	36
4.1.3. Level of imperviousness of Nekemte city	37
4.2. Respondent’s response analysis and result.....	40
4.2.1. Respondents by Location	40
4.2.2. Respondents by duration lived at the location	40
4.2.3. Respondents by age.....	40
4.2.4. Respondents by level of Education.....	41
4.2.5. Respondents response by means of liquid waste disposal	41

4.3.	Respondents response on questions	42
4.3.1.	Respondents response on Urbanization the study area	42
4.3.2.	Respondent’s response on problems occurred with imperviousness in the study area	43
4.3.3.	Respondent’s response on the origin of flooding the study area	43
4.3.4.	Respondent’s response on Types of rain events causing flooding in the study area	44
4.3.5.	Respondent’s response on the types of flooding occurs in the study area.....	45
4.3.6.	Respondent’s response on Land use type and storm water runoff created by land uses	46
4.4.	Micro-watershed by Level of Imperviousness	47
4.4.5.	Slope analysis of the study area	51
4.4.6.	Micro-watershed by level of imperviousness	52
4.5.	Designing Nature-based Drainage Solution (NbDS) vulnerable micro-watershed ..	59
4.5.2.	Detail Design Solution/Proposal.....	73
4.5.3.	Objectives	73
4.5.4.	Strategies.....	73
4.6.	Strategies to Develop Sustainable Urban Drainage System for Entire Nekemte city	84
4.6.1.	Scale upping Site-specific NbDS design to the City level	84
4.6.2.	Potentials and Challenges of Nekemte city and Opportunity and Limitation of Nature-based Drainage solution	85

4.6.3.	Design Criteria	86
4.6.4.	Design intent	86
4.6.5.	Citywide Proposals	86
4.6.6.	Objective of the strategy	87
4.6.7.	The Strategy	88
4.6.8.	Scenarios	88
4.6.9.	Plant species selection strategies	90
4.7.	Key Findings	98
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS		100
5.1.	Conclusion.....	100
5.2.	Recommendation.....	101
References.....		103
Appendixes		106

List of Tables

Table 1: Components of impervious surfaces.....	8
Table 2: Nature-based urban drainage solution as community benefit.....	18
Table 3: Values of relative imperviousness for use in rational formula	24
Table 4: Summary of Methodology	31
Table 5: Respondents response by means of liquid waste disposal.....	41
Table 6 : Respondents response on Urbanization the study area.....	42
Table 7: Respondent’s response on problems occurred with imperviousness in the study area	43
Table 8: Respondent’s response on the origin of flooding the study area	43
Table 9: Respondent’s response on Types of rain events causing flooding in the study area.	44
Table 10: Respondent’s response on the types of flooding occurs in the study area.....	45
Table 11: Respondent’s response on Land use type and storm water runoff by land uses.....	46
Table 12: Watersheds with codes	55
Table 13: Level of micro-watersheds imperviousness.....	56
Table 14: Runoff Coefficient (C) factor for different land covers in the site	65
Table 15 : Elevation of the site	67
Table 16 : Site for respective NbDS	72
Table 17: Designed Benefits from Nature-based drainage solutions for community.....	78
Table 18: Land-use Land Cover Design proposal	79
Table 19 : Potentials and Challenges of Nekemte city and Opportunity and Limitation of Nature-based Drainage solution.....	85

List of Figures

Figure 1: On-screen Digitization for impervious surface from high resolution satellite image	9
Figure 2: Natural ground and impervious cover water percolation	11
Figure 3: A demonstrative sustainable urban drainage system in residential area, UK	16
Figure 4: The project of sustainable urban drainage for infiltration basin, green roof, swales, was implemented in six sites across the Valencia region	17
Figure 5: permeable parking lots were created, Netherlands.....	17
Figure 6: Geographical location map of the study area	27
Figure 7 : segmentation of satellite image of study area and selected sample areas	29
Figure 8: Work-flow	34
Figure 9 : impervious surfaces increments and built up areas of the study area within two decades.....	35
Figure 10: Built-up Area of Nekemte city	36
Figure 11: Un-built-up Area of Nekemte city.....	36
Figure 12: Components of impervious surfaces	37
Figure 13: Components of Impervious surfaces by graph.....	38
Figure 14: Respondents response by means of liquid waste disposal	41
Figure 15: DEM of Study Area.....	48
Figure 17: Flow Accumulation	50
Figure 18: Stream Order of the study area.....	50
Figure 19: Slope value and category analysis of the study area	51
Table 20: statistical analysis of slope of the study area	51
Figure 21: Micro-watershed of the study area	52
Figure 22: Micro-watershed falling in the study area.....	53
Figure 23: current level of imperviousness within each watershed.....	54

Figure 24: Contour map of the site	59
Figure 25: Slope of the site	60
Figure 26: Flow Accumulation map Shows direction of stream flow out of the site	61
Figure 27: location map Shows direction of stream flow out of the site	62
Figure 28: Major five months maximum Rain fall of the study area.....	62
Figure 29: Existing land uses in the site	63
Figure 30: Existing Land use % ages diagram.....	64
Figure 31: Runoff Coefficient (C) factor for different land covers in the site by graph.....	66
Figure 32: Categorizing the site into relative elevation and slope.....	67
Figure 33: Elevation of the site.....	67
Figure 34: Drainage line and flowing direction in the site	68
Figure 35: Site’s suitable areas for public realm design	69
Figure 36: Site’s suitable areas for rain garden design	69
Figure 37: Site’s suitable areas for Pond’s design	70
Figure 38: Site’s suitable areas for designing vegetation and buffer from the river.....	71
Figure 39: Potential areas of developing design for Nature-based drainage systems.....	72
Figure 40: strategy-I (protecting streams from direct urban runoff).....	74
Figure 41: strategy-II (Linking stream and impervious surfaces with greeneries).....	75
Figure 42: proposed Street network	75
Figure 43: proposed parcel map.....	76
Figure 44: proposed building	77

Acronyms and Abbreviations

CWP	Center for Watershed Protection
DEM	Digital Elevation Model
EiABC	Ethiopian Institute of Architecture, Building Construction and City Development
FGD	Focused Group Discussion
GIS	Geographic Information System
IS	Impervious Surface
ISA	Impervious Surface Area
NbDS	Nature-Based Drainage Solution
SUD	Sustainable Urban Design
SUDS	Sustainable Urban Drainage Systems
US EPA	United State Environmental Protection Agency
USGR	United States Global Resource
WAWEFTEC	Washington Annual Water Environment Federation Technical Exposition and Conference
WGA	Resilient Green Cities in Africa
WSUDPA	Water Sensitive Urban Design Practices in Australia

CHAPTER ONE: INTRODUCTION

1.1. Background of the Study

In Nekemte city, the rapid progress of urban development and expansion is causing various environmental problems such as the increase of artificial structures such as rooftops, roads, and parking lots that are covered by impenetrable materials named as impervious surfaces that enables to increase in urban stormwater runoff. In fact, the growth and spread of impervious surfaces within urbanizing watersheds create significant threats to the quality of life in urban settings and the entire environmental system include increased stormwater runoff, reduced water quality, higher maximum summer temperatures, degraded and destroyed aquatic and terrestrial habitats, and the diminished aesthetic appeal of streams and landscapes (Dengsheng and Weng, 2006).

As the threat on concerning about runoff has always raised safety issues associated with flooding, the administrations rules and regulations have been practiced in the study area in recent years to include consideration of flooding and erosion by municipalities. But these rules and regulations fall mitigate the water quality impacts of urban development in the study area (Lee et al., 2012). For instance, the report produced on water resilient green cities in Africa elaborates flooding in Addis Ababa city as during the rainy season that is from June to September many areas of the city are flooded affecting infrastructure, and sometimes claim the life of people (WGA 2015). Thus, an increase in the built-up structure, river buffer degradation, poor solid waste management and low coverage of storm water drainage structure are the causes for the occurrence of flood in the city (Assefa et al., 2013).

Recently, Nekemte city is in the process of rapid urbanization and understanding the pattern of land use change is a prerequisite for addressing the issue of flooding and associated environmental problems. Thus, understanding the level of imperviousness of the urbanized

portion of the city will be helpful for planning of storm water management system of the city as well as for planning of natural environment at local and regional level.

The existing gray-drainage structures in Nekemte city seems older and not designed and developed to accommodate stormwater runoff from uphill areas like Gidelgibu, Calalaqi, Qaso, Hadiya, and Bake Jama. In this regard, developing nature-based drainage stormwater management strategy by estimating the level of imperviousness of Nekemte city can reduce the negative impact of flooding and associate environmental problems.

1.2.Problem Statement

Impervious surface cover is specifically known to lead to extreme disturbances in stream ecosystems, including increased flood flows. The study conducted on examined stream communities across a similar land use gradient in Wisconsin, and likewise found that macro invertebrate and fish diversity, respectively, decreased with the amount of impervious surface cover increased (Moore & Palmer 2005). Nekemte city has a slightly higher average temperature with more than 2080 mm of annual rainfall is one of the rainiest places in the country.

The increment of imperviousness of the catchments causes different problems as valuable landscape indicator of biotic, hydrologic and geomorphic changes in rivers by creating flooding followed by erosion and water pollution (Gergel et al, 2002). The increased rates of urbanization and associated impervious surfaces are likely to intensify those problems within the watershed. This concern alone warrants the need to estimate impervious surfaces and to device appropriate runoff reduction strategy.

Nekemte city is one of cities in Western Oromia Regional State, where urban expansion has been rapidly increasing during the last three decades (Tolera et al., 2018). The extent of such

intensive urban land expansion at the expense of natural environment and its impact has not yet been studied.

The slope of the entire Nekemte city is characterized as combination of high, medium and relatively flat slope at neighborhood level. There are steep slope areas along riversides and existing drainage lines which shows the erosion caused by the higher speed of stormwater runoff. The natural drainage line and riverbanks are more affected by the stormwater runoff generated from the built-up areas. In the city, the slope gradient increases with the higher degree within 200-300-meter distance from the main asphalted road of the city.

The overall development of buildings in Nekemte city is along the major roads from Addis Ababa to Gimbi and Bure. The development mainly concentrates in this area is due to the influence of topography and accessibility of the area to basic infrastructure along the main asphalted roads and resulted in linear development. This shows that the concentration of impervious structures and aggravated by inclined slopes of nature of landscapes invites speedy stormwater runoff with high rainfall, causing flood problem on the low-lying neighborhoods.

The relative higher slope gradient of the natural landscape in Nekemte city varies from neighborhood to neighborhood and increases in the speed and volume of runoff. Moreover, the higher rainfall intensity particularly in the main rainy seasons increase the risk of flooding to settlements developed over hilly areas and the low-lying plains of the city. The problem of flooding in the city with higher annual rainfall and rapid urban densification needs academic concern and sustainable solution to manage the storm storm-water runoff generated from the emerging built up areas of the city.

There are six major stream outlets in Nekemte city, these outlets collect runoff from the entire city and transfer it to the surrounding river system. The central area of Nekemte city contains relatively higher building densities and other infrastructure than the peripheries. The current

expansion trend and density of Nekemte city have never considered any measure for stormwater management from the higher annual rainfall and higher slope terrains. In this case, there is no any comprehensive plan or piecemeal solutions to reduce the impact of runoff generated from the higher rain fall and geophysical characteristics of the city landscape. Moreover, there is no any research conducted to estimate the level of imperviousness of Nekemte city in order to suggest any type of nature-based drainages solutions and sustainable stormwater management strategy.

1.3. Research Objective

General Objective

To estimate the level of imperviousness of urbanized portion of Nekemte City in order to develop context (site) specific Nature-based Drainage Design solutions for sustainable stormwater management of the city

Specific Objectives

1. To characterize and estimate the level of imperviousness of the urbanized part of Nekemte City
2. To identify major Micro-watersheds of the city with the higher level of imperviousness
3. To provide site specific nature-based drainage design solution for the most vulnerable /impacted micro-watersheds
4. To develop sustainable stormwater management strategies for Nekemte city

1.4. Research Questions

1. What is the current level of imperviousness and its characteristics in Nekemte city?
2. Which Micro-watersheds of Nekemte city are more covered with impervious surfaces?
3. Which type of nature-based drainage design solutions applicable for different sites of the most impacted watersheds by the higher level of imperviousness?

4. What type of strategy is more applicable for sustainable stormwater management of Nekemte city?

1.5.Scope of the Study

This study is limited to urbanized portion of Nekemte city where urbanization is taking place at faster rate over the context of higher slopes terrain and highly rainfall climatic zone. The study includes spatially built-up structures, green areas and plants, and under hydrology (Rainfall, Storm water runoff, Watershed and stream network and slope consideration) as it is significant for the study. The study also incorporates the soil type and building of the study watershed. The impact of flooding on socio economy and socio-cultural of the community situation should be investigated, however, the study limited on spatial and biophysical aspects only.

1.6.The Significance of the Study

As Nekemte city is one of highly urbanizing city, the study helps the municipality as data sources for developing sustainable stormwater management strategy in the future. The study can be initial point of considering sustainable stormwater management for Nekemte city depending on systematic measuring of natural landscape and built structures. The study can also help researcher who need to study more on developing nature-based drainage solution and storm water management strategy in different context.

1.7.Limitations of the study

The result of this study was influenced by the Lack of updated vector data from Nekemte city's municipality on the land uses and building registry data. Because of the absence of digitized and updated base map, the researcher pays more time and resource to digitize and update existing base map of 2008 G.C. under GIS on-screen digitization. Another limitation of the study was spatial data Validation because of large area of the site and to overcome this problem,

the research used the old buildings vector data taken from the municipality for cross checking with digitized one.

1.8.Organization of the paper

This paper is organized into five chapters. The first chapter is an introduction which includes background of the study, problem statement, objective of the study, research questions, significance of the study and scope and limitation of the study. The second chapter is review of related literatures which consists theoretical background and important findings from different literatures. The third chapter involves methodologies applied in the study. Chapter four presents the result and discussion of the study. Finally, the last chapter gives conclusion and recommendations of the study.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1.Introduction

The literature was reviewed and structured to support the objectives of the research by identifying the appropriate ways of measuring impervious surfaces. Additionally, the research was guided by literature to address design application of nature-based drainage solution to benefits the local community in addition to runoff/ management stormwater and how to integrate nature-based solutions with the public realm as well as leading to developing of sustainable stormwater management strategies for the study area.

2.2.Mapping and measuring urban built up areas and identifying level of imperviousness

In this section, there viewed pieces of literature help to identify the components of impervious surfaces and quantifying them from satellite images by using Arc GIS software.

2.2.1. Quantifying Impervious surface area components

Impervious surfaces are hard surface area that either prevents or retards the entry of water into the soil mantle or causes water to run off the surface in greater quantities or at an increased rate of flow (Powell et al., 2008). Common impervious surfaces include, but are not limited to rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, and gravel roads (US EPA, 2003).

According to USGR (2006) the impervious surfaces for each watershed should be mapped at highly detailed levels. Existing detailed GIS data sets acquired from the local governments where available and spatially explicit classes of impervious surfaces were digitized from high spatial resolution ortho-imagery to compile highly detailed GIS

datasets for different classes of impervious surface cover to determine the relative contribution of each class of impervious cover.

Table 1: Components of impervious surfaces

Impervious Surface Components	Component/Feature Descriptions
Buildings	All roofed structures including storage sheds and trailers
Roads	Gravel, paved or other hard surfaces that are mainly utilized
Parking Lots	Paved or hard surfaced areas that exist primarily for the temporary storage for Automobiles and other vehicles, equipment, and materials.
Driveways	Hard surface or gravel areas that connect a house, garage, or other structure to a road surface for the purpose of automobile access and storage.
Sidewalks	Narrow hard surface areas that are generally found parallel to roadways and exist primarily for pedestrian traffic. Recreational trails, home and business entryways, park and golf course cart paths are included in this category.
Other	Hard surface recreation areas, such as basketball or tennis courts, patios, swimming pools - to include surrounding patio, any other impervious surface that does not fit in any of the above categories.

(Source: USGS, Reston, Virginia: 2006)

2.2.2. On-screen Digitization for impervious surface from high resolution satellite image

Object-based on-screen digitization for impervious surfaces components is relatively higher accuracy and other methods of generating built-up areas under GIS software checked by manual on screen digitization of components as the result is taken as vector data (Alkanet al., 2010)

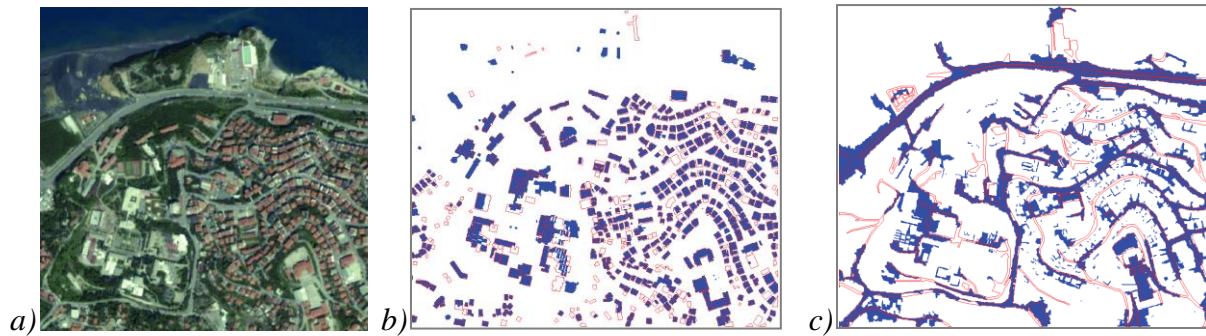


Figure 1: On-screen Digitization for impervious surface from high resolution satellite image
 (Source: *Remote Sensing for Science, Education, and Natural and Cultural Heritage*, 2010)

The figure above represents the satellite image, vector data digitized and the output generated by software as image (a) represents image, (b) shows Vector results of object-based digitization and (c) generated by software's from image which shows that creating a data set is to find or convert existing digital files. However, the final product is limited to the type, quality and scale of the data source and few or none of these data sets may specific to impervious information. Some urban areas may have detailed land cover information in the form of CAD drawings or surveys. If this information already digital and is compatible with available software, it may be possible to select for land cover and impervious features. Problems arise when converting between various file types and when the data itself is incomplete (polygons not closed) (Bauer et al., 2004)

2.3.Watershed level increments in Impervious Surfaces and implication on urban flooding and river ecosystem

This part contains the review of the literatures related to the urban watersheds and increment in the level of imperviousness with its implication on flooding and related issues such as river water quality. This includes the way of measuring and identifying the micro watersheds that are more affected by the higher level of imperviousness and how to calculate surface runoff created from the components of impervious surfaces

2.3.1. Urban Watersheds level of imperviousness increments

A watershed is an area of land from which all water drains, running downhill, to a shared destination, a river, pond, stream, lake, or estuary. A watershed is a catchment basin that is bound by topographic features, such as ridge tops (<https://www.gdrc.org/uem/water/watershed>, accessed July 31, 2020, 4:23 AM).

According to WAWEFTEC (2005) report urbanization creates changes in the hydrology of the area on the timing of the runoff, runoff volume and speed and pollution in receiving waters. So that, water quality problems increase with increasing imperviousness of the watershed of urban area whereas impervious areas cause increased runoff and contaminated discharges from these areas and also contribute to receiving water contamination. The increased impervious surface area is a consequence of urbanization and it is sensitive that an increased quantity of impervious surface brings with it in the shorter times of precipitation and later higher runoff peaks and total volume of runoff in receiving streams (Shuster et al., 2005)

2.3.2. Level of Imperviousness increment implication on flooding and river ecosystem in urban settings

The study conducted on Effects of impervious surfaces and urban development on runoff generation and flood hazard concludes urban development and impervious surfaces increments affects the potential runoff generation and flood hazard in urban area/watershed and identifies as the flood runoff is more affected by urban development (Gholami et al., 2010).

This shows that increased level of urban impervious surfaces allows the increased storm water flows more causing flooding and erodes stream banks. The relationship between impervious cover and surface runoff in a watershed results in increased surface runoff which causes urban flooding and related issues. Impervious surfaces do not allow stormwater to soak into the

ground and most developed areas allow storm water runoff from roofs and paved areas to nearby streams which create the flooding in the area (Smullen et al., 1999).

Impervious surfaces affect the quantity, as well as the quality, of water supply resources. Rainwater entering the soil recharges groundwater aquifers. Water also percolates more slowly through the soil to enter into streams and rivers, contributing to base flows and regulating the stream flow precipitation events. Impervious surfaces do not allow this recharge, thus contributing to potential insufficiencies in water supply for both ground and surface water resources as shown in the following figure.

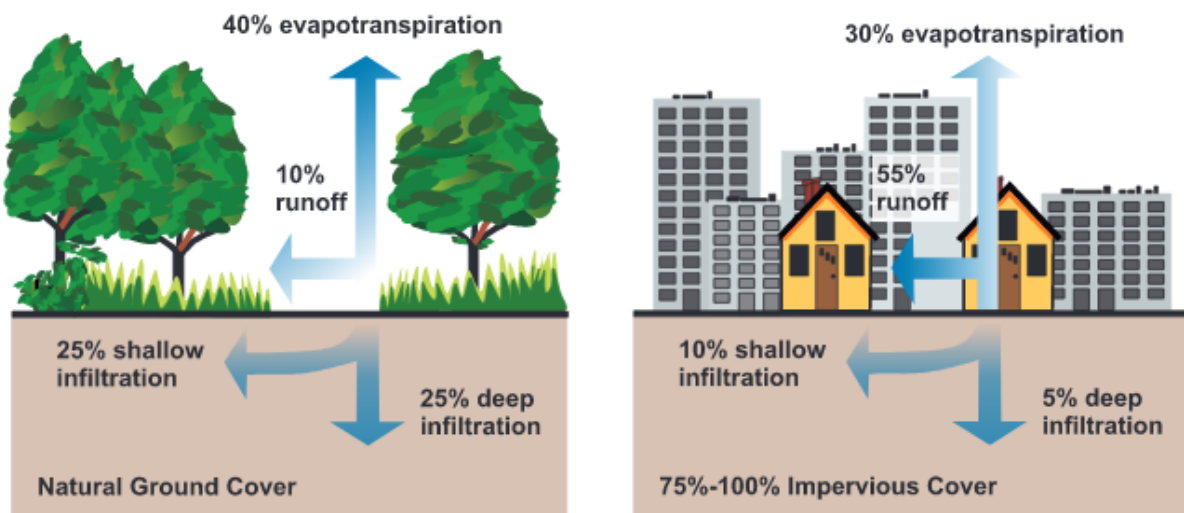


Figure 2: Natural ground and impervious cover water percolation

(Source: USEPA, protecting water quality from urban runoff)

2.3.3. Identification of affected micro-watershed and level of imperviousness

According to the study conducted by Sutjningsih (2016) on impervious cover and stream water quality prediction summarized that watershed impervious cover and stream water quality as impervious covers are a critical contributor to the hydrologic changes that degrade waterways. The major component of the intensive land uses generate pollution, prevent natural pollutant

processing in the soil by preventing percolation, and serve as an efficient conveyance system transporting pollutants into the waterways.

Irreversible environmental degradation of an aquatic ecosystem occurs when a watershed contains more than 25 percent impervious surfaces. Schueler (1994) and Arnold and Gibbons (1996) both observe that research over the last 20 years has consistently reported a correlation between watershed imperviousness and the health of the receiving stream ecosystem. The proposal of classification was prepared by Schueler and concurred by Arnold and Gibbons with a three-tiered threshold classification scheme of urban in stream quality potential based on watershed imperviousness levels as:

- Stressed = 1 to 10 percent imperviousness
- Impacted = 11 to 25 percent imperviousness
- Degraded = more than 25 percent imperviousness

These classes were described in further detail by the CWP (1998), which also modified the names of the first level from stressed to sensitive, and the third level from degraded to non-supporting.

Sensitive streams are of high quality and are typified by stable channels, have an excellent habitat structure, good to excellent water quality, and diverse communities but do not experience frequent flooding (Foody et al., 2004).

Impacted streams show clear signs of degradation due to watershed urbanization and the water quality transitions from good to fair with fair biodiversity (Manis et al., 2014).

Non-supporting streams become a conduit for conveying storm water flows and can no longer support a diverse stream community. The stream channels become highly unstable while the stream reaches experience severe widening, down cutting, and stream bank erosion. Water

quality is consistently fair to poor and water contact for people is no longer possible due to the high bacteria levels. Each of these classes has corresponding best management practices associated with them. These categories could be used as a foundation for a watershed-based zoning approach, using impervious cover as the key measure and unifying theme in the municipal land-use zoning process (Schueler, 1994).

2.3.4. Major problems associated with urban imperviousness increments

2.3.4.1. Flooding and related issues

Increased water flow and volume destabilize streams through widening and incision as well as stream bank erosion and habitat degradation and is characterized as loss of critical in stream and riparian eco-structures such as pool and riffle networks and vegetative cover, in addition to an increase in the width of a channel during high flows (Schueler, 1994).

2.3.4.2. Conveying Urban Pollution

Impervious surfaces efficiently convey urban pollution to receiving streams and directly impact stream water quality. Prior to modern storm water mitigation techniques, urban effluence transported sediments at a rate of an order of magnitude greater than comparably sized rural watersheds (Wright et al., 2011). For instance, sediment transport from a hectare of urban development and highway construction activity can yield 20,000 to 40,000 times the sediment of a comparably sized agricultural or woodland area (Wolman and Schick, 1967)

2.3.4.3. Thermal Properties

Imperviousness has a two-fold effect on the thermal properties of a stream. First, impervious surfaces hold and retain more heat than the natural features they replace. Their heat is transferred down slope (via runoff) and warms the receiving stream. Schueler (1994) notes that impervious surfaces may be 10 to 12 degrees warmer than the fields and forests they replace

and Galli (1991) compared urban related streams in Maryland with a forested reference stream and found a correlation between urban imperviousness and higher relative in stream temperatures. Secondly, this in stream warming reduces streamside vegetative cover that shades the stream. This loss is often due to urban encroachment, as well as to erosion from flooding. Klein (1979) notes a 6 to 11-degree Celsius variation in shaded and not shaded areas on the same stream.

2.4.Sustainable urban drainage solution in stormwater management (Nature-based drainage solutions design for site flood protection, community benefits and public realm linkage with nature-based drainage solution)

The related literature reviewed under this part elaborates the sustainable urban drainage solution in storm water management focusing on nature-based drainage solutions design for site specific flood protection design, community benefits and public realm linkage with nature-based drainage solution.

2.4.1. Nature-based drainage solution for flood protection (Using Green Along-side Grey as an Alternative Approach to Flood Protection)

sustainable urban drainage systems target to slow and reduce the quantity of surface water runoff in order to protect downstream flood risk and reduce the risk of resultant diffuse pollution to urban water bodies which taken as developing grey infrastructure than considering the risk only at the end of the pipe (Rose and Lamond, 2013). Sustainable urban drainage solution realizes and utilize a mix of natural processes and green or grey components to harvest, infiltrate, slow, store, convey and treat runoff onsite (Woods Ballard et al. 2015)

The following solutions are taken as providing illustrative examples of different forms of sustainable urban drainage system which have been implemented across Europe as they are

diverse in nature and can take many different forms both above and below ground (State of Green 2015).

- **Rainwater harvesting systems**-collect and store rainwater from roofs and other paved surfaces (such as car parks) for re-use
- **Green roofs** -involve constructing a soil layer on a roof to create a living surface that reduces surface runoff
- **Permeable pavements**-act as a hard surface for walking or driving, while enabling rainwater to infiltrate to the soil or underground storage
- **Bio-retention systems (such as rain gardens)**-collect runoff in a temporary surface pond before it filters through vegetation and underlying soils
- **Trees**-capture rainwater while also providing evapo-transpiration, biodiversity and shade
- **Swales, detention basins, retention ponds and wetlands**-slow the flow of water, store and treat runoff while draining it through the site and encouraging biodiversity
- **Soak ways and infiltration basins**-promote infiltration as an effective means of controlling runoff and supporting groundwater recharge

Sustainable urban drainage solution can be implemented either as a new development or as a retrofit of existing structures. Regardless of the type, the central objective of all sustainable urban drainage solution is to fully exploit the opportunities and benefits that can be obtained from surface water management (Woods Ballard et al. 2015).

2.4.2. Good practice in the design of nature-based drainage design solution for sustainable stormwater management of urban areas

a) Lamb Drove, Cambourne, United Kingdom

A demonstrative sustainable urban drainage system scheme was implemented in a residential development area in Cambourne results indicate improvements in biodiversity and water quality leaving the site, increased amenity and social values and cost savings to residents by avoiding storm water disposal charges. The project concludes that many aspects of sustainable urban drainage solution can be installed and maintained at lower costs than more traditional forms of drainage as shown in the following figure.



Figure 3: A demonstrative sustainable urban drainage system in residential area, UK

(Source: McKenna Davis and Sandra Naumann)

The project of sustainable urban drainage for infiltration basin, green roof, swales, was implemented in six sites across the Valencia region. Monitoring results showed that sustainable urban drainage system performed well improve the water quality and the following figure showing this project.



Figure 4: The project of sustainable urban drainage for infiltration basin, green roof, swales, was implemented in six sites across the Valencia region

(Source: McKenna Davis and Sandra Naumann)

b) Monnikenhuizen, Arnhem, Netherlands

The site was selected for its unique and challenging topographic and contextual conditions for utilizing sustainable urban drainage system, as it is located on a hill. On a small scale, green roofs and permeable parking lots were created; on a larger scale, water from the road is led via gutters to an infiltration and storage pond as shown in the following figure.



Figure 5: permeable parking lots were created, Netherlands

(Source: McKenna Davis and Sandra Naumann)

2.4.3. Nature-based urban drainage solution as community benefits (types and description and provisions)

Table 2: Nature-based urban drainage solution as community benefit

Benefit category	Description	Aspects of the SUDS design that provide the benefit
Flood risk reduction	Damage to property and people	Peak flow attenuation, volume control
Water quality	Surface water quality Improvements	Pollution prevention strategies, interception, runoff treatment
Security of water Supply	Reduced flows and reduced Pollution	Rainwater harvesting; also see groundwater and soil moisture recharge
Recreation	Involvement in specific recreational activities	Green and blue spaces and play features
Air quality	Reduced damage to health	Air particulate filtering via vegetation
Biodiversity/ecology	Sites of ecological value	Habitat creation and enhancement, connecting habitats
Carbon reduction and sequestration	Reduced energy/water use and planting	Low energy needs (materials)
Economic growth and inward investment	Business, jobs, productivity, tourism, property prices	See visual character, recreation and air and building temperature
Education Opportunities	Enhanced access to and existence of educational possibilities	Community engagement (before and after construction)
Groundwater and soil moisture recharge	Improved water availability or quantity	Interception, infiltration, runoff treatment
Sewerage systems and sewage treatment	Reduced flows and volume to treat in combined systems	Interception and further runoff volume reduction
Visual character	Attractiveness and desirability of area	Visual enhancement (as part of surface SUDS)

Source: Ashley et al. 2015 and Woods Ballard et al. 2015

2.4.4. Public realm and nature-based drainage solution

According to over view of WSUDPA (2006), the opportunities for the integration of storm water management functions with in contemporary urban landscape designs at a range of scales within the public realm and private buildings were important landscapes incorporating storm water management functionality. The role of public ream is a critical in the area's character and function, serving overlapping roles, including:

- **Circulation and Access**-The public street rights-of-way provide for circulation within and through the community
- **Development Framework**-The public street rights-of-way provide the fundamental structure that contains and organizes individual developments into a cohesive whole.
- **Public Open Space**-In addition to the community's parks and plazas, public street rights-of-way play an important role as public open space.
- **Visual Character**- the physical design of the public realm is critical in establishing the community's identity and overall character (<https://www.sandiego.gov/sites/default/files/legacy/planning/>, access Jul, 31, 2020 7:08pm).

2.5.Developing sustainable urban drainage system strategy: NbDS for strategy of water-relation and socio-economic aspect

This section indicates the related literature reviews targeted on sustainable urban drainage system strategy recommended for high rainfall rich cities and selective nature-based drainage solutions for water relation and socio-economic aspects of community.

2.5.1. NbDS for strategy of water-relation

Reconnecting rivers to floodplains: Floodplains are areas of low-lying land along river-side that have developed over time to receive water overflowing the river course and slowing the flow and thereby reducing flood risk.

Forests and vegetated land: Forests and areas with good vegetation cover can moderate extreme events by reducing the likelihood (or frequency) of floods, landslides, mudflows and avalanches, which can cause extensive damage to infrastructure and inhabited areas.

Riparian buffers: Riparian buffers help to maintain water quality in waterways by protecting streams from non-point source pollution (e.g., from surrounding agricultural activities). Riparian vegetation cover provides a barrier to sediments, as well as pollutants such as nitrates, phosphorus and others being washed from the land into water bodies. Vegetation and tree roots also stabilize banks and prevent erosion. During flood events, riparian vegetation slows down runoff by absorbing excess water, reducing peak flow and helping to mitigate potential flood damage downstream. Some studies show that riparian buffers can help to reduce the amount of sediment reaching the streams by as much as 80 percent (UNEP, 2014).

Wetlands: Protecting, restoring or constructing wetlands can help to provide clean water for ecosystems. The ability of wetlands to store large amounts of water, and release it slowly, also plays a key role in the natural regulation of water quantity during periods of droughts and floods. Wetlands can slow flood waters, reducing the potential flood damage downstream and increase resilience to storms, thereby avoiding potential damage to grey infrastructure and human lives.

2.5.2. The Benefits for Water Management and Community

Nature is far too complex to describe in detail here and, while ecosystems are the underlying structures for the management of water resources, they also enable the continuous functioning of the environment, supporting life as we know it. Prioritizing nature-based solutions over or alongside grey infrastructure solutions not only benefits water management but has many economic, social and environmental benefits in the catchment.

The many social, economic and environmental benefits of increased attention to protecting and enhancing environmental services through a nature-based approach;

Protection: Protecting key ecosystems from degradation has obvious benefits for the environment and biodiversity but can also contribute to improved livelihoods (farming, fishing, tourism), social amenities (bio-fuel, recreation), and well-being.

1. Restoration: Restoring full ecosystem function to degraded environments can enhance livelihood opportunities, improve resilience to extreme climate events and provide a social amenity.

2. Extension: Creating new or enhanced ecosystem services for specific water-related services can result in new livelihood (forestry, agriculture, fisheries) and recreational opportunities, increased biodiversity and enhanced protection from extreme climate events.

2.5. Models to calculate impervious surface areas and compute storm water runoff

This part contains two models related to impervious surfaces and runoff computing. The first one is the review of deterministic statistical model to calculate impervious surface areas and the other is the review of rational and modified rational models to compute storm water runoff rates and volume.

2.5.1. Deterministic statistical model to calculate impervious surface areas

Deterministic statistical model used to calculate impervious surface using the type of information available as base map of the area. Base map report containing impervious surface as categorical data in the form of polygons. Impervious surface polygons were summed to produce continuous municipal scale data suitable for statistical analysis. For example, land use land cover categories of polygons in a municipality were summed to produce municipal totals for residential-developed area and residential-related impervious surface areas. The model invites ensuring that all variables, especially the dependent ones, had normal distributions, X^2 is used to tests and Anderson Darling nonparametric tests to identify the variable's distributions (Reilly et al, 2014).

2.5.2. Rational and Modified Rational models to Compute Storm Water Runoff Rates and Volume

The modified rational method is a somewhat recent adaptation of the rational method that can be used to not only compute peak runoff rates, but also to estimate runoff volumes and hydrographs. This method uses the same input data and coefficients as the rational method along with the further assumption that, for the selected storm frequency, the duration of peak-producing rainfall is also the entire storm duration. Since, theoretically, there are an infinite number of rainfall intensities and associated durations with the same frequency or probability, the modified rational method requires that several of these events be analyzed in the method to determine the most severe (Size,2004).

2.5.2.1. Computing Storm water Runoff Rates and Volumes

The proportion of rainfall that eventually becomes stream flow is dependent on the following factors:

A. **The size of the drainage area.** The larger area, the greater the volume of runoff.

An estimate of basin area is needed in order to use runoff formulas and charts.

B. **Topography.** Runoff volume generally increases with steepness of slope. Average slope, basin elevation, and aspect, although not often called for in most runoff formulas and charts, may provide helpful clues in refining a design.

C. **Soil.** Runoff varies with soil characteristics, particularly permeability and infiltration capacity. The infiltration rate of a dry soil, by nature of its intrinsic permeability, will steadily decrease with time as it becomes wetted, given a constant rainfall rate. If the rainfall rate is greater than the final infiltration rate of the soil (infiltration capacity), that quantity of water which cannot be absorbed is stored in depressions in the ground or run off the surface. Peak Discharge can be estimated by the "rational" method or formula;

$$Q = 0.278 CIA$$

where: Q = peak discharge, (m³/s)

I= rainfall intensity (mm/hr)

for a critical time period

A = drainage area (km²).

The runoff coefficient, C, expresses the ratio of rate of runoff to rate of rainfall and is shown below in table below. The variable tc is the time of concentration of the watershed (hours).

Values of relative imperviousness for use in rational formula (American Iron and Steel Institute, 1971)

Table 3: Values of relative imperviousness for use in rational formula

Type of Surface	Factor C
Sandy soil, flat, 2%	0.05-0.10
Sandy soil, average, 2-7%	0.10-0.15
Sandy soil, steep, 7%	0.15-0.20
Heavy soil, flat, 2%	0.13-0.22
Heavy soil, average, 2-7%	0.18-0.22
Heavy soil, steep, 7%	0.25-0.35
Asphaltic pavements	0.80-0.95
Concrete pavements	0.70-0.95
Gravel or macadam pavements	0.35-0.70

Numerous assumptions are necessary for use of the rational formula (<http://www.fao.org/3/t0099e/t0099e04.htm> accessed June, 04, 2020 at 6:22 pm).

Regarding land use and the runoff coefficients, the values of runoff coefficient (C) for Rational Formula illustrated as the following table. As different literatures indicated that the designer can use judgments to select the appropriate C value within the range considering larger areas with permeable soils, flat slopes and dense vegetation should have the lowest C values whereas the smaller areas with dense soils, moderate to steep slopes, and sparse vegetation should assign the highest C values (<http://lectures/runoffcoeffs.html>, access 19/06/2020, 9:05 AM)).

Land Use	C	Land Use	C
Business: Downtown areas Neighborhood areas	0.70 - 0.95 0.50 - 0.70	Lawns:	
		Sandy soil, flat, 2%	0.05 - 0.10
		Sandy soil, avg., 2-7%	0.10 - 0.15
		Sandy soil, steep, 7%	0.15 - 0.20
		Heavy soil, flat, 2%	0.13 - 0.17
		Heavy soil, avg., 2-7%	0.18 - 0.22
		Heavy soil, steep, 7%	0.25 - 0.35
Residential: Single-family areas Multi units, detached Munti units, attached Suburban	0.30 - 0.50 0.40 - 0.60 0.60 - 0.75 0.25 - 0.40	Agricultural land:	
		<i>Bare packed soil</i>	
		*Smooth	0.30 - 0.60
		*Rough	0.20 - 0.50
		<i>Cultivated rows</i>	
		*Heavy soil, no crop	0.30 - 0.60
		*Heavy soil, with crop	0.20 - 0.50
		*Sandy soil, no crop	0.20 - 0.40
		*Sandy soil, with crop	0.10 - 0.25
		<i>Pasture</i>	
*Heavy soil	0.15 - 0.45		
*Sandy soil	0.05 - 0.25		
		Woodlands	0.05 - 0.25
Industrial: Light areas Heavy areas	0.50 - 0.80 0.60 - 0.90	Streets:	
		Asphaltic	0.70 - 0.95
		Concrete	0.80 - 0.95
		Brick	0.70 - 0.85
Parks, cemeteries	0.10 - 0.25	Unimproved areas	0.10 - 0.30
Playgrounds	0.20 - 0.35	Drives and walks	0.75 - 0.85
Railroad yard areas	0.20 - 0.40	Roofs	0.75 - 0.95

Source: <http://lectures/runoffcoeffs.html>, access 19/06/2020, 9:05 AM

2.6. Lesson learned from literature review

Most of the environmental problem of high rainfall and different slope categories in the cities like tropical climate is caused by the impervious surface creating flooding, water pollution and soil erosion. So, it is possible to measure the level of imperviousness of the cities to identify impacted areas to design the solution for flooding (storm water management design). There is different mechanism of measuring level of imperviousness, the most familiar and simplest is Existing Digital Information but since it lacks the fully updated land cover information it needs updating the existing base map. Computing the volume and amount of runoff and rainfall helps

to design the nature-based solution. Rational method can be used to compute peak runoff rates but also to estimate runoff volumes and hydrographs.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. The Study Area

The study area is Nekemte town which is located 328km West of Addis Ababa city and capital of East Wollega Zone, Oromia Regional State. The city has two layers of governmental structure which are city government and sub-city administrations. The total demarcated area of the city is about 5380 hectares, but this research focused on the area currently in the process of urban expansion. There are no watersheds feeding micro watersheds within the city except the watersheds in the study area that are spatially joined together at some points.

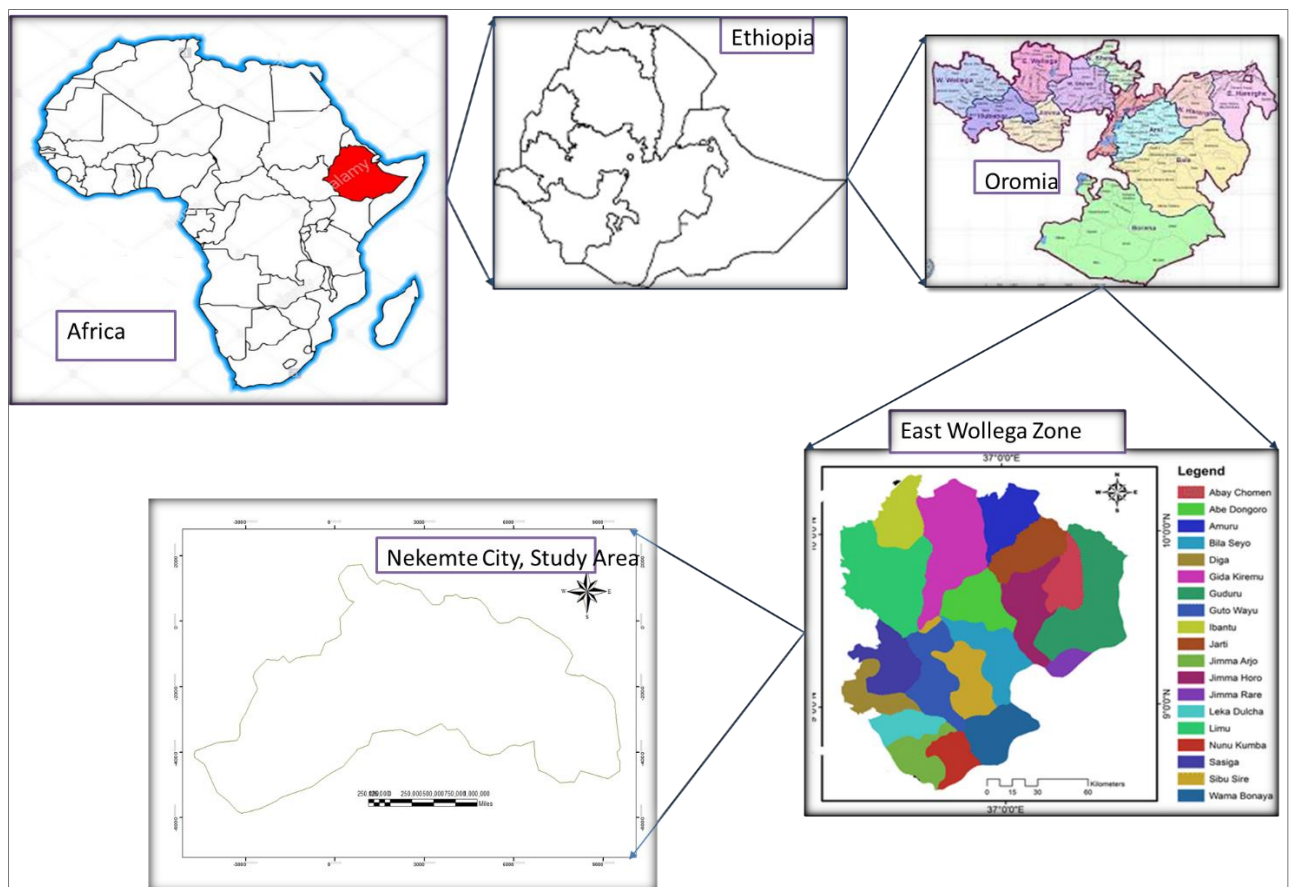


Figure 6: Geographical location map of the study area

3.2.Data Types

Both spatial data and survey data was used in this study. Data such as DEM, municipal base map, satellite image, soil and rainfall data of the study (watershed, flow direction, flow accumulation), soil type, and, land use/ land covers categories area were employed.

3.3.Data Source

The quantitative data are regarding hydrology and spatial data (watershed, flow direction, flow accumulation, soil type, and rainfall, land use/ land covers categories) were collected from the municipality of Nekemte. In addition, data such as size of the legal boundary of the study area and quantity of impervious surface components were collected from Nekemte City administration office and satellite image of the site respectively. Survey data such as perception of community on the flooding problems were collected from residents of Nekemte city.

3.4.Population of the study

The population of the study was identified as spatial population (legal boundary of the city) and residents (people of Nekemte city). Thus, Population of the study was spatially the legal boundary of Nekemte city which contains 5380 hectares of land and 210688 estimated peoples of the city. From legal boundary of Nekemte city, urbanized portion of the city was selected for this study.

3.5.Sampling Technique and Sample Size

Because of it is difficult to meet all community and professionals in short time; it is needed to use sampling method to get community and professionals perception. Systematic random sampling method was employed to get both sample area and selected households in identified study area. The procedures were started from segmentation of satellite images in to 29 segments by using the main and collector street boundary for spatial sampling. The approach used in

spatial sampling is centric systematic sampling. After the entire built-up area of the study area is segmented, each segmented area was numbered from 1-29. The systematic sampling of using interval with three gaps from 1-29 results 10 identified areas (1, 4, 7, 10, 13, 16, 19, 22, 25 and 28). Selection of house hold is considered in the approach of counting the door facing to the drainage line as affected by storm water runoff. Thus, the street faced or drainage line faced houses area counted in the interval of seven from one house to the next. This is considering the probability of storm water runoff speed/volume to make a difference.

From each selected sample area 380 households are selected; 10 individuals were additionally interviewed as 1 representative from each (7 kebele) and 3 professionals, 1 from municipality, 1 from natural and environmental protection sectors and 1 from institute of Oromia urban planning western branch in the city. 6 individuals are the part of respondents as the FGD participants. So, from each of selected sample 342 individual from 9 segments=38 households are responded to the questionnaires as 1 segment fall in Wollega University and it is nonresidential area, no household, 10 interviewed and 6 FGD participants. Totally, 356 total sample size were selected the following map shows the segmentation of satellite image of study area and selected sample areas.

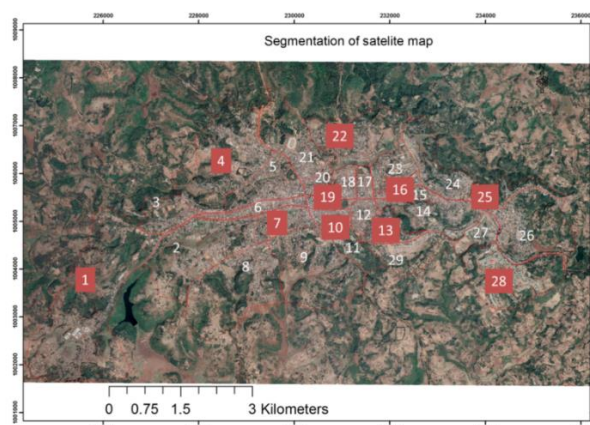


Figure 7 : segmentation of satellite image of study area and selected sample areas

3.6.Method of Data Collection

The primary qualitative data such as perception of community, professionals and officials were collected through questionnaire, interviews, observation and focus group discussion whereas secondary data were collected from websites and reports from the municipal and sectoral offices both by soft and hard copy. Different features were digitized from satellite image of the study area. The overall methods of data and data collection were summarized below.

3.7. Summary of Methodology

Table 4: Summary of Methodology

No	Specific objectives	Types of data	Source of data	Data collection method	Data collection instrument used	Analysis	
1.	To map and measure built up areas of Nekemte city to determine the level of imperviousness	Base map, Land use/ land covers	Nekemte city administration and satellite image	Observation, Digitization, Reclassification, Layer's extraction and conversion	Camera, software (GIS, AutoCAD, Microsoft office)	Quantifying the values, by percent, identifying level of imperviousness	
2.	To identify major micro-watersheds of the city that affected by level of imperviousness	DEM, Shape file (GIS data), Watersheds, land covers, IS components	Observation, Digitized, Layers extracted by SIC and converted Cad file	Micro-Watershed delineation, Overlaying, Map Generating, observation	GIS and AutoCAD software, Camera,	Overlay analysis, map interpretation and standards, micro-watershed imperviousness, runoff analysis	
3.	To provide site specific nature-based drainage solution for the most vulnerable watersheds	Site with high level of imperviousness, plants types, rainfall data, soil type, population, land cover	Generated watershed identified land covers, Nekemte city Structural plan, need and responses of society	Micro- and covers, Structural need and responses of society	Extracting, converting, clipping features and raster data, site survey	software (GIS, AutoCAD), camera, Questionnaire, interviews and FGD, Observations,	Calculating/estimating and comparing runoff volume before and after development, need and responses by descriptive statistics
4.	To develop sustainable Storm water management strategies for Nekemte city	Existing coping strategies	Literatures community standards	and asking respective bodies	Observation and Interview, FGD, questionnaire	Comparison with theories and literatures	

3.8.Data Analysis Tools

ArcGIS Software was used to measure/calculate the percentage of impervious surface area within selected study areas (sites). Existing base-map is imported to GIS data set and updated with the raster-based land cover or land use Polygon data set, for which percentage of impervious surface is calculated, analyzed in spatial analysis tools of Arc GIS. Set of land cover impervious surface coefficients for soil, slope and land use are used in calculating the level of imperviousness and its impacts. The correlation between an increase in impervious surfaces and change in flooding problem has been well established. The output of analyzed set of data is used to predict volume of storm water runoff in the study watershed and for modeling the capacity of newly proposed nature-based drainage solution.

3.9.Data presentation

Presentation of data was held by understanding of data analyzed and according to its necessity of elaborations and meaningful presentation. Accordingly, the conversion software outputs to graph, map plus text elaborations by percent and standards to interpret the figures was the presentation techniques used in this study. Finally, the study was used the Data analyzed under deferent tools and software under Microsoft word PowerPoint 2016 version for presentation of the overall data.

3.10. Data Validity Analysis

3.10.1. Accuracy assessment of spatial data

Raster data imputed to Arc GIS software is checked by the coordinates of vector data established by the government as base map of the city in year 2008 G.C. Since digitization was processed by updating existing base map of the study area, the accuracy of the input data and output were estimated at more than 95% accurate.

3.10.2. Reliability Analysis of the questionnaire

The reliability of the questionnaire was checked under SPSS version 20, by scale analysis of Cronbach's Alpha coefficient as the following

Scale: ALL VARIABLE

Case Processing Summary

		N	%
Cases	Valid	342	100.0
	Excluded ^a	0	.0
	Total	342	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.802	27

According to different literatures, Cronbach's alpha of 0.70 and above is good, 0.80 and above is better, and 0.90 and above is best. So, the result of Cronbach's alpha was telling the tools have designed accurately and measured the variable of interest with 0.80 Cronbach's Alpha coefficient.

2.7. Work flow diagram of the study

The arrangement, of data collection and data analysis that targeted to realize relevance of data and procedures to the research purpose was illustrated as the following conceptual organization within which the study is conducted as showed in figure 8 below.

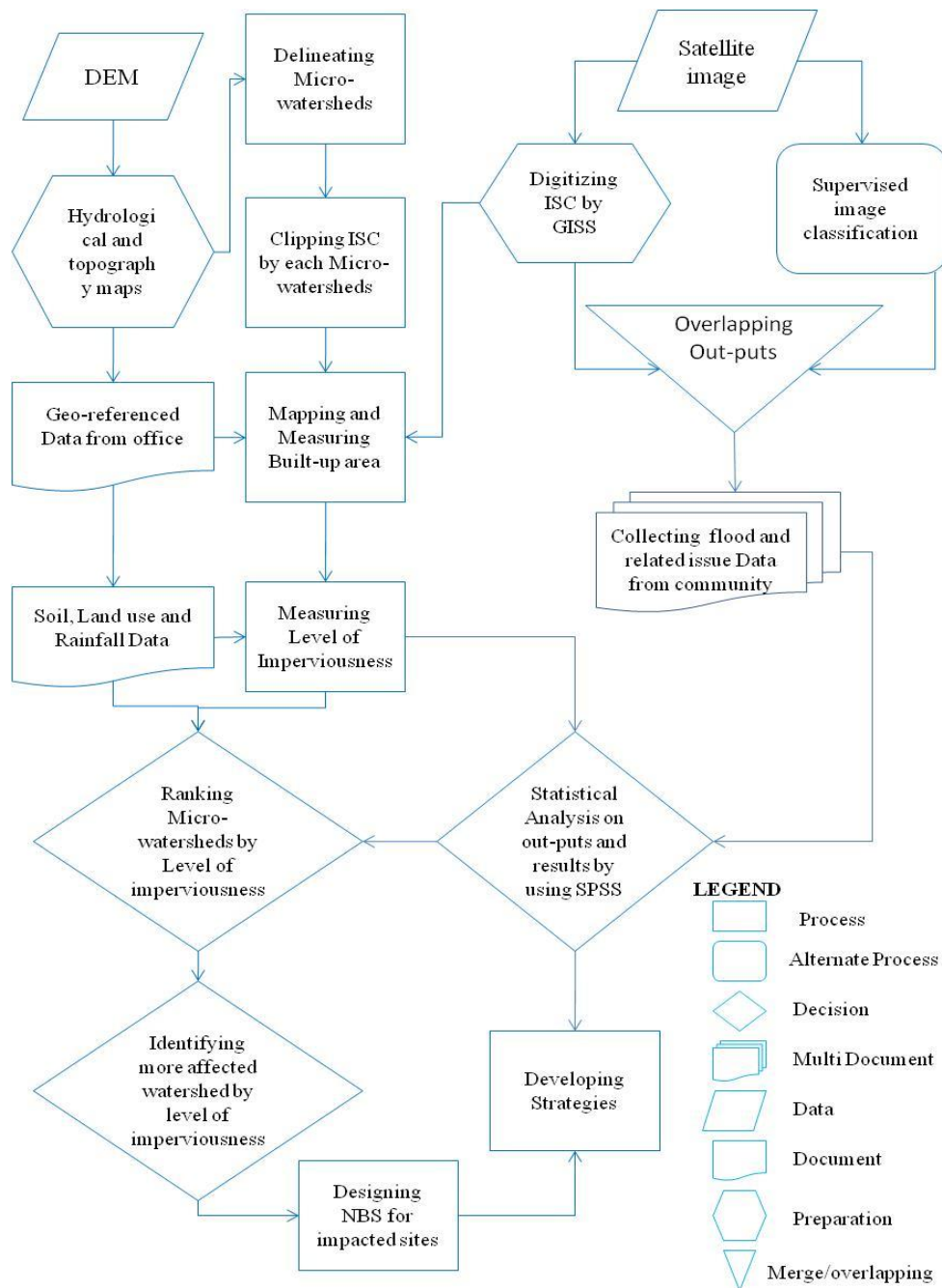


Figure 8: Work-flow

(Source: Developed by the researcher)

CHAPTER FOUR: RESULT AND DISCUSSION

4.1. Map, measured built-up areas and level of imperviousness in Nekemte city

4.1.1. Overview of impervious surfaces increments and built-up areas of the study area within two decades

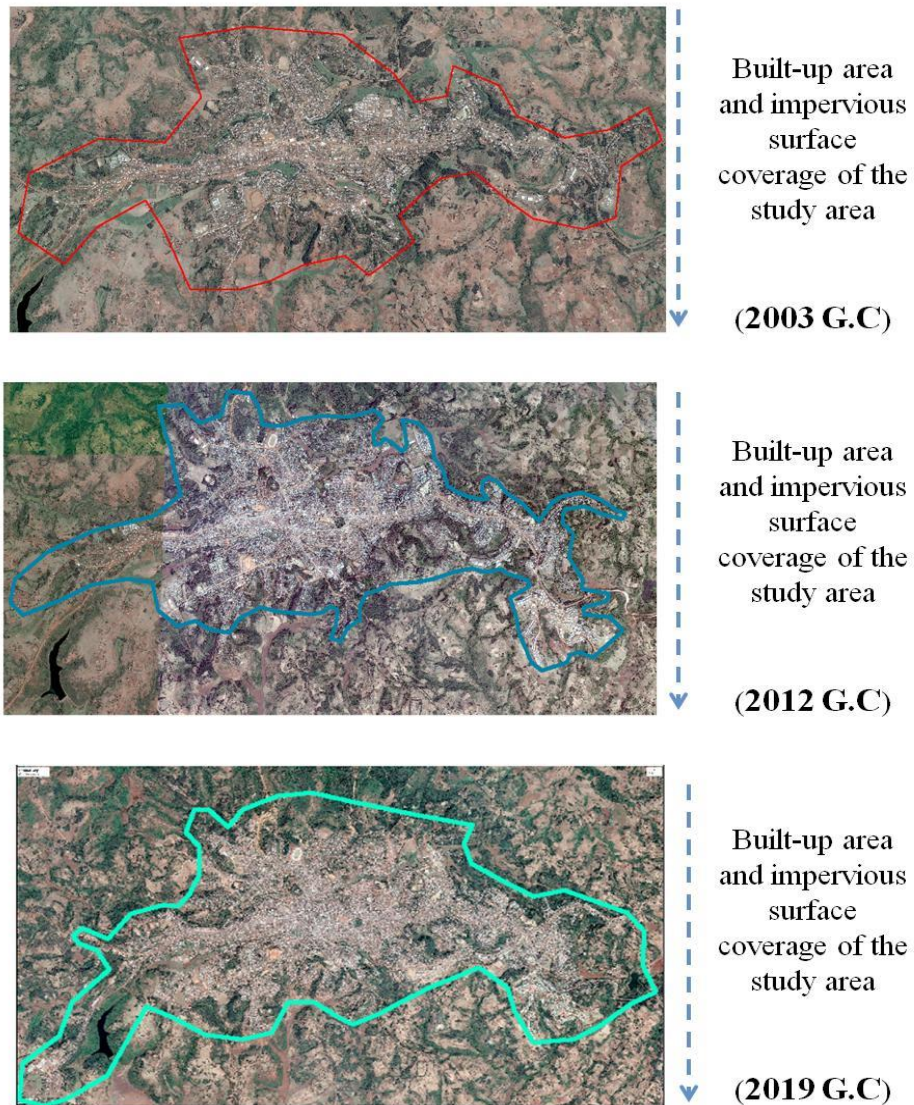


Figure 9 : impervious surfaces increments and built up areas of the study area within two decades

4.1.2. Map and amount of current built up area of the study area

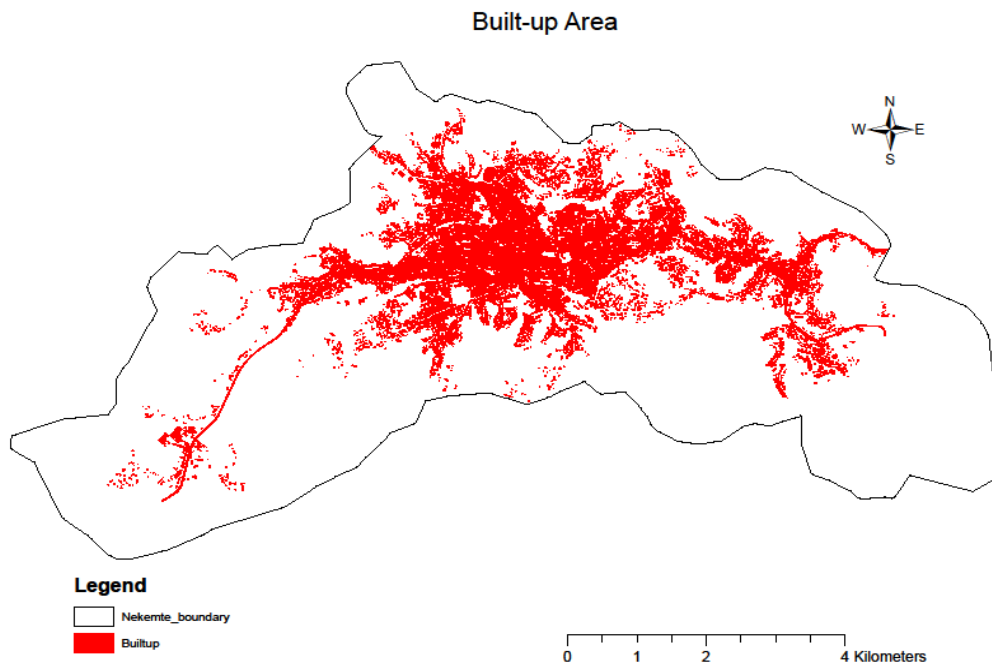


Figure 10: Built-up Area of Nekemte city

(Source: Digitized by the Researcher)

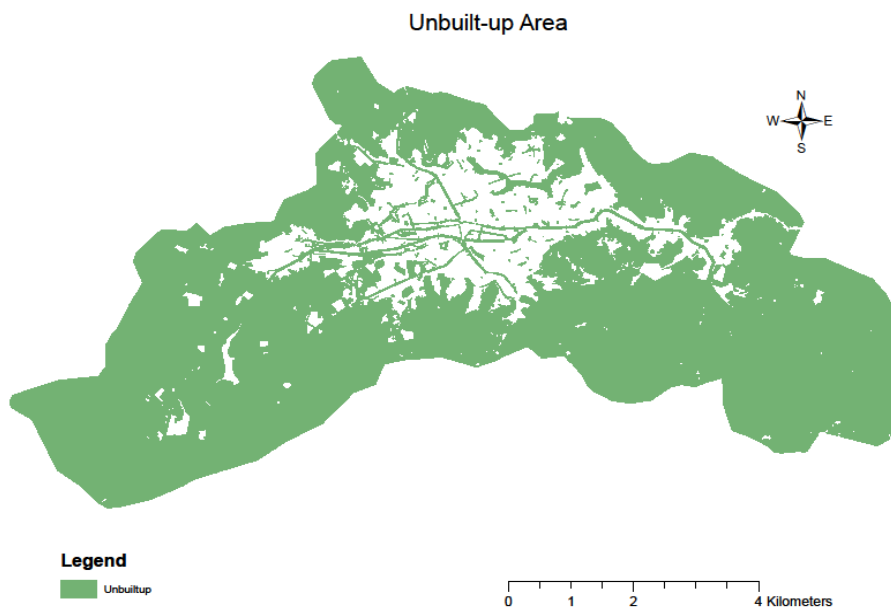


Figure 11: Un-built-up Area of Nekemte city

(Source: Digitized by the Researcher)

No	Items	Area in (ha)	Percentage
1	Built-up area	4839.21	89.94
2	Un-built-up area	540.79	10.06
	Total	5380.00	100

From the total area of Nekemte city built up area is 89.94%. This means, out of 5380ha of land 4839.21 ha fall in built up area. This indicates the components of impervious surfaces measured in the boundary of the built-up area in order to get level of imperviousness.

4.1.3. Level of imperviousness of Nekemte city

Built up area delineated is taken as the sample for the study and components of Imperviousness calculated using built up ratio parameters as the following.

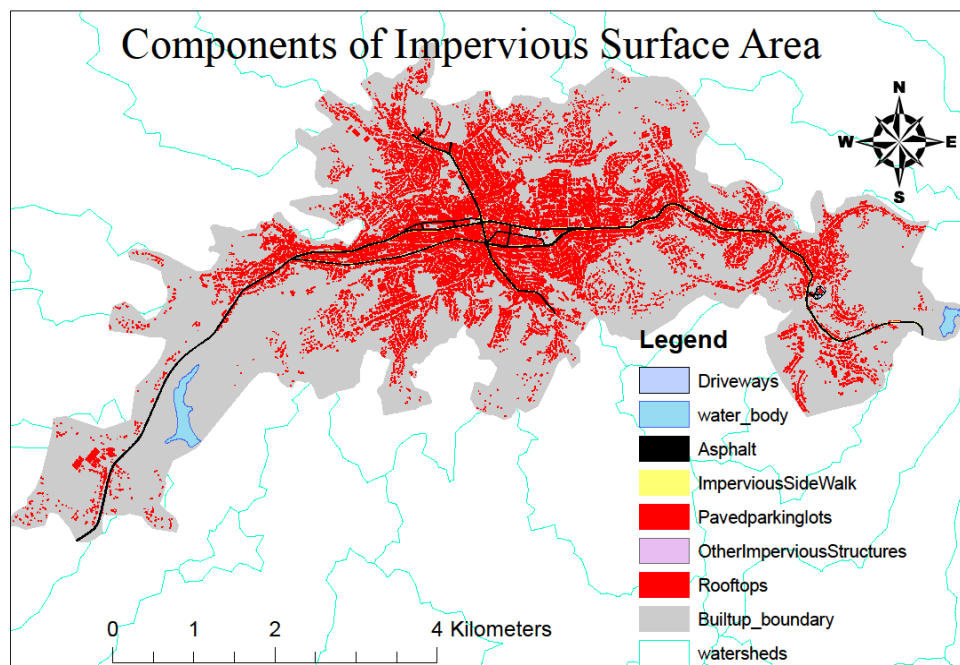


Figure 12: Components of impervious surfaces

(Source: Digitized by the researcher)

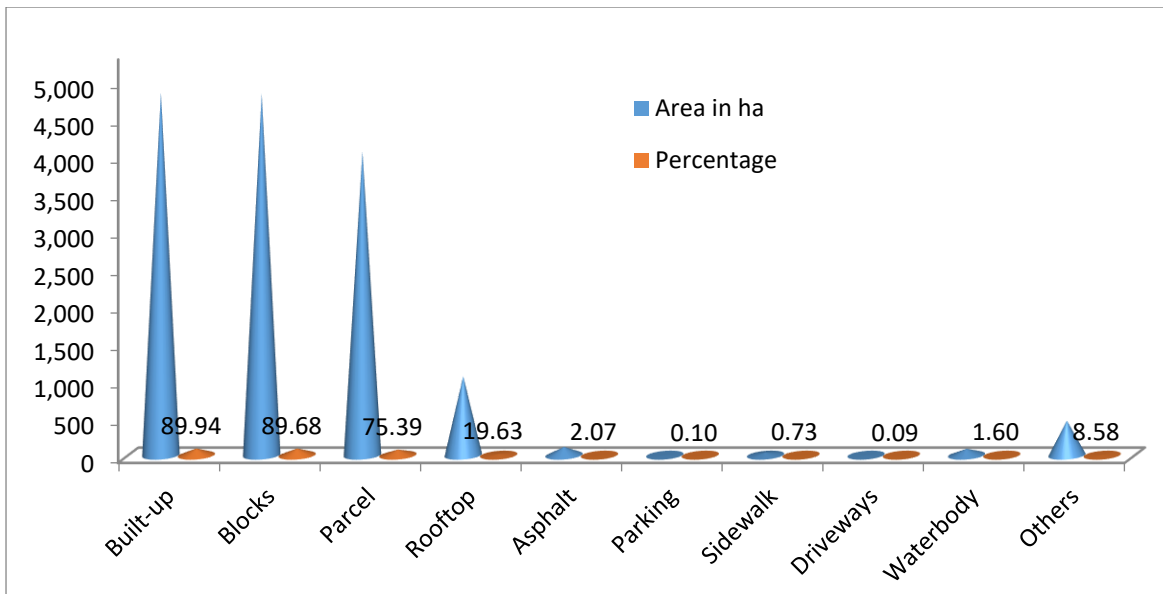


Figure 13: Components of Impervious surfaces by graph

As shown in the above map and graph, 4839.21ha (89.94%) of Nekemte city is built-up area, 4824.77ha (89.68%) of the built-up area are identified urban blocks for different functions and 4056.48ha (75.39%) of the land within built-up area is legally known and occupied parcel subdivisions. Within these parcel, blocks and built-up areas, there are components of impervious surfaces such as 155.97ha (19.6%) buildings/rooftops, 111.41ha (2.07%) of Asphalt road, 0.10ha (0.73%) of paved parking lots, 4.60ha (0.09%) of impervious sidewalks, 85.76ha (1.60%) of driveways, 461.82ha (8.58%) of water bodies and 35.11 ha (1.99%) of other impervious surfaces are covered the urbanized portion of Nekemte city. This shows that majority of impervious surface components covering the study area are buildings/rooftops with 1055.97ha and followed by 461.82ha of others impervious surfaces in the study area. Existing parking lots are small in percent (0.09%).

Depending on the above results, Imperviousness level of the study area can be measured by using digitized components of impervious surface components at parcel, blocks and built-up area as the following.

$$\% \text{ Impervious surface area} = \frac{\text{Sum of impervious surface area components}}{\text{Parcel Surface area}} \times 100$$

$$= (1055.97+111.41+5.52+39.33+4.60+85.76+461.82) / (4056.48) \times 100$$

$$= (1764.42 / (4056.48) \times 100$$

43.40%-of imperviousness at parcel level

% Impervious surface area(block level)

$$= \frac{\text{Sum of all impervious surface area components}}{\text{block Surface area}} \times 100$$

$$= (1055.97+111.41+5.52+39.33+4.60+85.76+461.82) / (4824.77) \times 100$$

$$= (1764.42 / (4824.77) \times 100$$

36.57%-of imperviousness at block level

% Impervious surface area(city level)

$$= \frac{\text{Sum of all impervious surface area in block}}{\text{area of city}} \times 100$$

$$= (1055.97+111.41+5.52+39.33+4.60+85.76+461.82) / (5221.72) \times 100$$

$$= (1764.42 / (5380) \times 100$$

33.79%-of imperviousness at built-up area level

Percentage of imperviousness level of the study area at parcel, built-up and block level shows 43.4%, 36.57% and 33.79% respectively. This implies that the impervious surface coverage of Nekemte city fall above 25% and it is degraded.

4.2.Respondent's response analysis and result

4.2.1. Respondents by Location

The above table shows that the respondents are equally taken from all locations segmented for sample as 38 (11.1%) respondents. This implies there is no difference in number of respondents per locations.

4.2.2. Respondents by duration lived at the location

The majority of respondents 162 (47.4%) duration lived in the area are 1-5 years followed by 97(28.4%) respondents lived 6-10 years. Respondent lived for 11-15 years were 11.1% whereas 7% and 6.1% of the respondents lived at the area for 16-20 and above or equal to 21 years respectively. This shows that there is variety of the duration lived among respondents. Majority of the respondents are lived at the location for 1-5 years which is enough to identify the stormwater runoff condition and urbanization trends of the area. The respondents lived at the area for more than or equal to 21 years are very good source of information for this particular study. As they stayed in the area for long period of time with good understanding and sensation of the local climatic condition and physical characteristics of the study, their responses are very helpful for the researcher.

4.2.3. Respondents by age

The age variations of the respondents show that 191 (55.8%) are 25-54 age whereas 42.7% (146) respondents age is 15-24 age. 5(1.5%) of the respondents responded the age of 55-64 years and no response to the age above or equal to 65. This indicates that majority of the respondents are from the age of 25-54 which implies there are enough educated and mature respondents in the study area, so that the data from such respondent can bring relevant information.

4.2.4. Respondents by level of Education

The majority of the respondents (147/43%) education level is degree. Respondents these take up to Preparatory and secondary school were participated in the response by 14% and 12.9% respectively next to degree holders. Masters/PhD holder respondents were 9.9% whereas illiterates and primary school educated are 5.8% and 4.7% respectively. This implies that majority of the respondents are educated and the range extends up to PhD holders which shows the possibility of relevant data and information taken from respondents is high.

4.2.5. Respondents' response by means of liquid waste disposal

Table 5: Respondents response by means of liquid waste disposal

Response	Frequency	Percent
Sewerage line	80	23.4
On-street disposal	37	10.8
Direct to drainage	150	43.9
Direct to river	29	8.5
Underground	34	9.9
Others	12	3.5

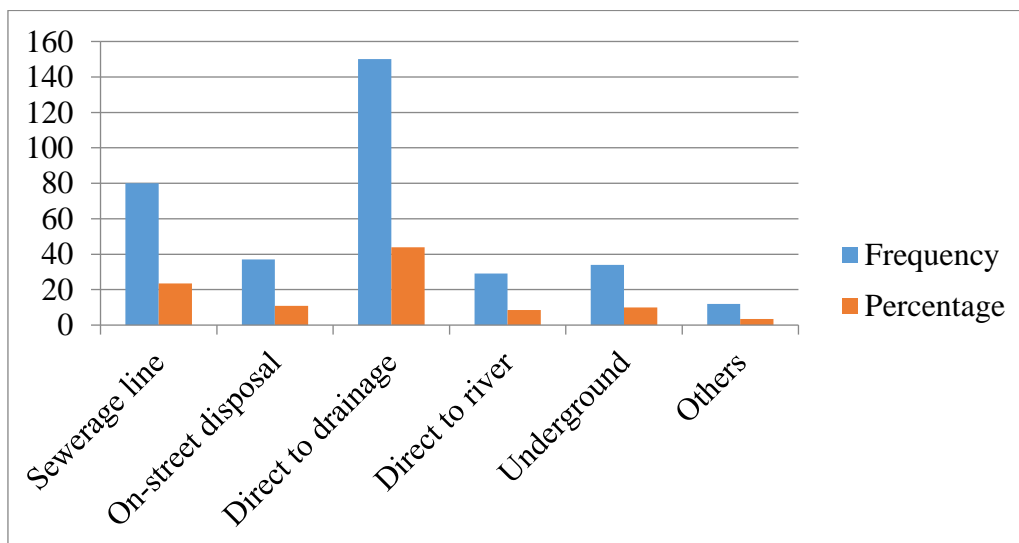


Figure 14: Respondents response by means of liquid waste disposal

The graph and table above show that majority of the respondents (150 (43.9%)) responded that the stormwater drained in their locality directly to drainage line and the second 80(23.9%) responded were to sewerage line whereas others dispose liquid wastes to the river, underground and others such as using for plants in the compound. This implies that as the majority of liquid wastes disposed directly to drainage line; there may be existence of solid wastes to close the channel to support the overflow of runoff which invites flooding problems.

4.3.Respondents’ response on questions

4.3.1. Respondents’ response on Urbanization the study area

Table 6 : Respondents response on Urbanization the study area

Questions	Descriptive Statistics				
	N	Minimum	Maximum	Mean	Std. Deviation
How do you rate Urbanization of Nekemte city	342	1	5	3.71	1.201
How urbanization is affecting on natural environments in Nekemte city	342	1	5	3.09	.880

the mean of the response is 3.71 for urbanization of Nekemte city and the mean for response on urbanization effects on natural environment is 3.09. This indicates that the scale of 1-5 contains 3 under normal condition and both of urbanization and its effects on environment in the study area fall to high and very high responses from the respondents. Thus, the comparisons of the means show that the urbanization is on rapid process with highly damaging the natural environments.

4.3.2. Respondent's response on problems occurred with imperviousness in the study area

Table 7: Respondent's response on problems occurred with imperviousness in the study area

Questions on:	Descriptive Statistics				
	N	Mini mum	Maxi mum	Mea n	Std. Deviation
The extent of urban heat increase relating with imperviousness	342	1	5	3.01	.849
The extent of air pollution relating with imperviousness	342	1	5	3.31	.894
The extent of water pollution relating with imperviousness	342	1	5	3.44	1.008
Magnitude of storm water runoff relating with imperviousness	342	1	5	3.54	.908

The highest mean value of the response is 3.54 which responded for magnitude of storm water runoff relating with imperviousness and followed by water pollution relating with imperviousness. Another is responses for air pollution and urban heat increase with the mean value of 3.31 and 3.01 respectively. This indicates that there is nearly normal urban heat and there is also air pollution in the study area associated with flooding problems.

4.3.3. Respondent's response on the origin of flooding the study area

Table 8: Respondent's response on the origin of flooding the study area

Questions on:	Descriptive Statistics				
	N	Mini mum	Maxi mum	Mean	Std. Deviation
Rank Storm water Runoff from urban street	342	1	5	3.76	1.053
Rank Storm water runoff from urban buildings	342	1	5	3.17	.967

Rank Storm water runoff from Elevated site	342	1	5	3.19	1.024
Rank Storm water overflow from filling the drainage line	342	1	5	3.32	1.004
Rank Storm water runoff overflow from river side	342	1	5	3.48	1.060

The above table indicates that the highest mean value is 3.76 which are responded for storm water runoff from urban street and the mean value responded for storm water runoff overflow from riverside is 3.48 which implies the major known source of flooding in the study area is storm water runoff from urban street followed by overflow from river side. Another source of flooding is responded with the mean value of 3.32 for Storm water overflow from filling the drainage line, 3.19 for Storm water runoff from Elevated site and 3.17 for Storm water runoff from urban buildings. This shows that the increase of urban imperviousness enables the more flow of runoff to streets and then to the rivers in the watersheds.

4.3.4. Respondent's response on Types of rain events causing flooding in the study area

Table 9: Respondent's response on Types of rain events causing flooding in the study area

Questions On:	Descriptive Statistics				
	N	Mini mum	Maxi mum	Mean	Std. Deviation
Rank Short intense rain causing flooding in Nekemte city	342	1	5	3.48	1.009
Rank Long moderate rain causing flooding in Nekemte city	342	1	5	3.36	1.054
Rank Long heavy moderate rain causing flooding in Nekemte city	342	2	5	3.54	.958

The above table shows that the smallest mean value 3.36 is responded for long moderate rain causing flooding Nekemte city and the mean value 3.48 is of short intense rain cause flooding in Nekemte city whereas the highest mean value 3.54 is responded for long heavy moderate rain causing flooding in Nekemte city. This result shows that the rain type which is more repeated in the area is long heavy moderate rain.

4.3.5. Respondent’s response on the types of flooding occurs in the study area

Table 10: Respondent’s response on the types of flooding occurs in the study area

Questions	Descriptive Statistics		
	N	Mean	Std. Deviation
Level of business/home flooding type you experienced	342	3.87	.972
Sewer yard flooding of extended duration type you experienced	342	3.70	.918
Pluvial (Due to incapacity of drainage systems) you experienced	342	3.65	.852
Fluvial (Out of River Flooding) type you experienced	342	3.40	.922
Flash flooding type you experienced	342	3.68	.897

Interpretations: the highest mean value 3.87 is of responded for business/home flooding type experienced in the area followed 3.7 of response for Sewer yard flooding type. The mean value of 3.68 is for response on flash flooding type in the study area and 3.65 mean value scored for Pluvial (due to incapacity of drainage systems) flooding type whereas small mean value 3.4 is scored for the Fluvial (Out of River Flooding) type. This implies that the major flooding type occurs in the study area were Business/home flooding type and sewer yard flooding type.

4.3.6. Respondent’s response on Land use type and storm water runoff created by land uses

Table 11: Respondent’s response on Land use type and storm water runoff by land uses

Questions on:	Descriptive Statistics				
	N	Mini mum	Maxi mum	Mean	Std. Deviation
Residential area creating storm water runoff	342	2	5	3.89	.783
Commercial area creating storm water runoff	342	1	5	3.91	.867
Organizations, industries and school’s area creating storm water runoff	342	1	5	3.35	.855

The respondents mean value shows 3.91 for Commercial area creating storm water runoff and 3.89 for Residential area creating storm water runoff as well as 3.35 mean values is scored for organizations, industries and schools area creating storm water runoff. This indicates that the more land uses which is creating more storm water runoff and enable flooding in the study area is commercial areas followed by residential area and small part of flooding issues created from organizations and schools.

The built-up area information was used to calculate the percentages of built-up area of study area from high resolution satellite image of the area in the year 2019 G.C. as the method of using high resolution satellite image under GIS software is recommended (Sinha et al, 2016). The measured built-up area of the total Nekemte city’s shows more than 50% is built-up area, and mapping the built-up area helps to shows direction of urban expansions. Furthermore, the advantage is to prepare input for municipal and environmental sectors for determining storm water management considerations (Goldblatt et al, 2018).

According to Slonecker (2001), there is different number of methods to measure accuracy of methods and the built-up area of Nekemte city was measured at built-up area boundary as the population of the study and components of impervious surfaces identified through built-up ratio parameters. Depending up on the result of the built-up area measured, the level of imperviousness of the study area at parcel, block and city/built-up area level was calculated. The result of level of imperviousness of Nekemte city at built-up area level is fall above 25% and it is degraded according to stream quality classification in different literatures (Arnold and Gibbons, 1996).

The city has no any map showing the built-up area that represent updated land information of rooftops, asphalted roads, green spaces, bare land and other land cover to determine the level of imperviousness. So, this study fills the gap of spatial information relating with built-up area within the city boundary which helps urban designers, planners, environmentalists as well as policy makers who need the boundary and built-up areas of Nekemte city.

4.4. Micro-watershed by Level of Imperviousness

4.4.1. DEM setup for Analysis

DEM is raster data used in this research to processes hydrological and topographic information of the study area. Flow direction and accumulation, watershed, stream order, stream networks and slope gradients are the data processed from DEM of the study area which is taken from Earth Explorer site with 30x30 image resolution. Since downloaded raster data DEM is geo-referenced and accurate data, the following data shown in figure is DEM data of the study area.

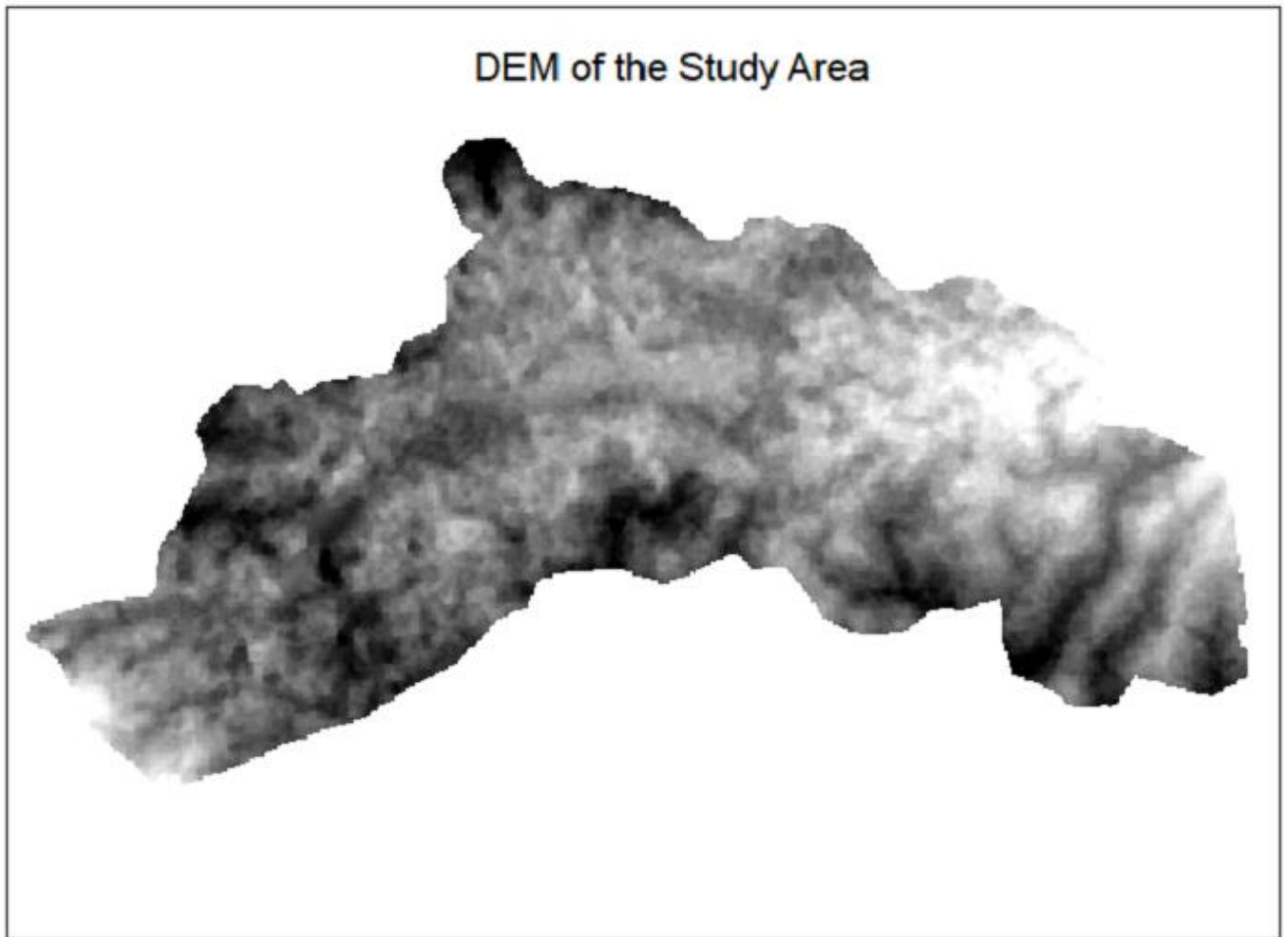


Figure 15: DEM of Study Area

(Source: taken from Google earth Explorer site by 30mX30m)

4.4.2. Flow Direction of the Study Area

Flow direction calculates the direction water will flow using slope from neighboring cells. In a given grid cell, water can flow to one or more of its eight adjacent cells. Slope is the ultimate factor how water flows in this model.

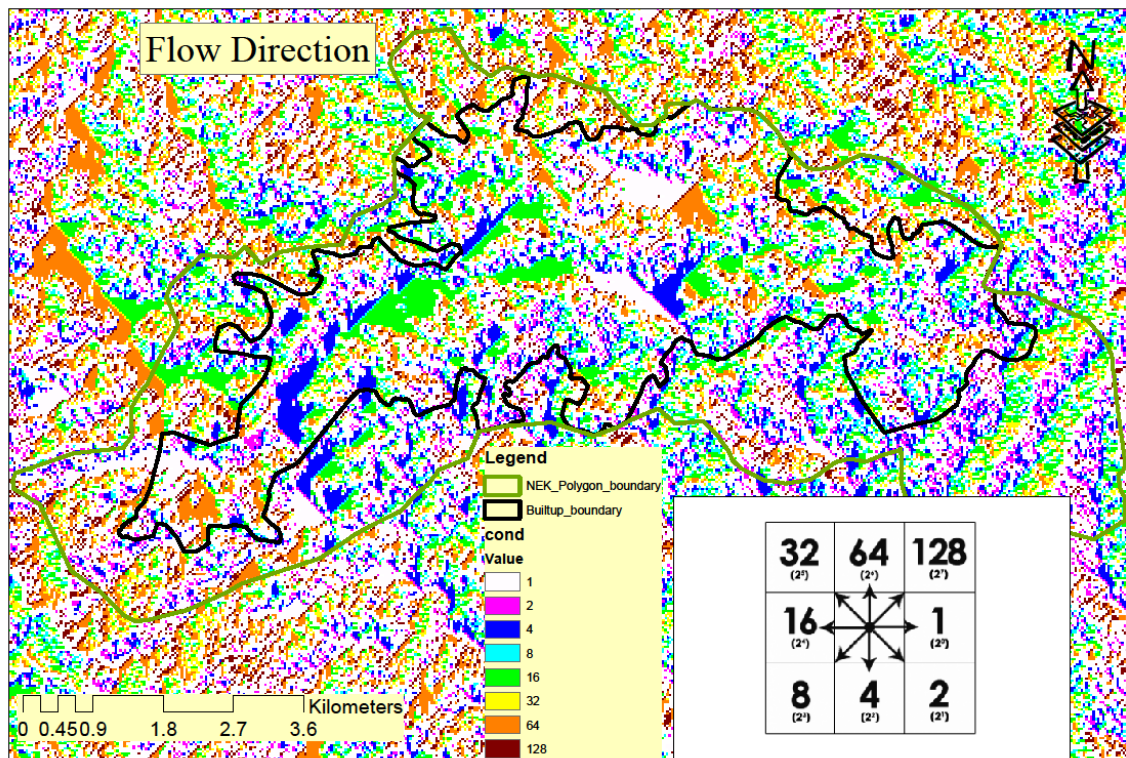


Figure 16: Flow Direction with Eight Direction Pour-Point Model

(Source: Prepared by the researcher)

According to flow direction map generated from the DEM of the study area, the flow direction is calculated for every central pixel of input blocks of 3 by 3 pixels, each time comparing the value of the central pixel with the value of its 8 neighbors. The output map shows, flow directions as 1 (to the East), 2 (to the South East), 4 (to the South), 8 (to the South West), 16 (to the West), 32 (to the North West), 64 (to the North) and 128 (to the North East).

4.4.3. Flow Accumulation of the Study Area

The Flow Accumulation tool shows accumulated flow as the accumulated weight of all cells flowing into each down slope cell in the output raster. If no weight raster is provided, a weight of 1 is applied to each cell, and the value of cells in the output raster is the number of cells that flow into each cell.

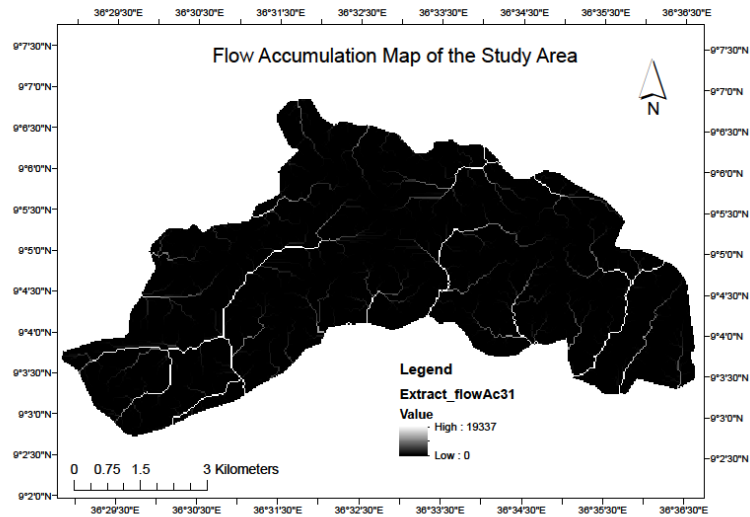


Figure 17: Flow Accumulation

(Source: Prepared by the researcher)

The cells with a high flow accumulation are areas of concentrated flow and used to identify stream channels. This is discussed in Identifying stream networks. Cells with a flow accumulation of 0 are local topographic highs and used to identify ridges.

4.4.4. Stream Order of the study area

The stream order is used to identify the origin of the river, runoff and the load of each stream.

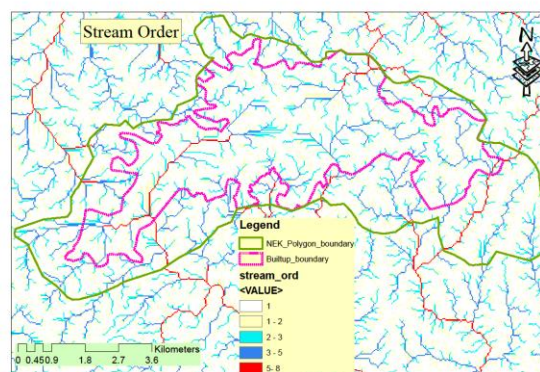


Figure 18: Stream Order of the study area

(Source: Prepared by the researcher)

Stream order map showing the discharge combined at the network to show the load of urban runoff.

4.4.5. Slope analysis of the study area

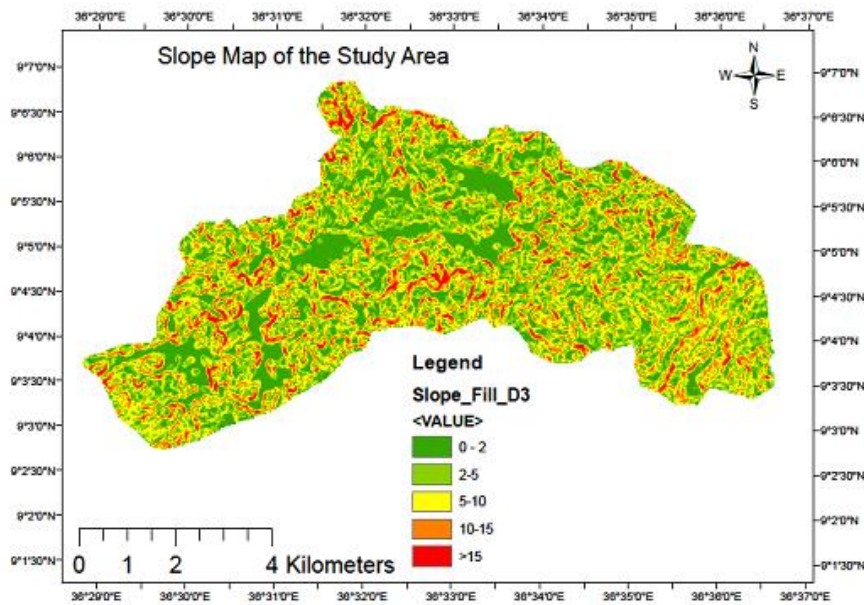


Figure 19: Slope value and category analysis of the study area

(Source: Prepared by the researcher)

Table 20: statistical analysis of slope of the study area

No	Slope value	Area in ha	%ages	Min slope	Max slope	Mean slope	St. Dev
1	0-2	739.75	13.75				
2	2-5	1349.84	25.09				
3	5-10	1941.10	16.08	0	44.04	13.96	7.382577
4	10-15	1043.18	19.39				
5	>15	1382.12	25.69				

The above map and table indicate the topography of the study area as the slope value of 2.1-7 intervals with 25.09 percent and followed by 12.1-15 slope value intervals which contain 19.39 percent of the study area. Whereas above 20 slope value consist of the smallest part but at

different location and 0-2 slope interval that is seizing 739.75ha (13.75%) of the study area. Another identified slope interval is 15.1-20 (18.76%) and 7.1-12 (16.08%) by covering 1009.29ha and 1941.10ha of the study area respectively.

The implications can be understood from slope values are; there is high slope variations with in short distance of the area which invites the speedy flow of storm water runoff. In other side, there are flat areas receiving storm water runoff from high slope value sites. As the statistical analysis of slope values indicated in the above table; the minimum value is 0 and maximum value is 44.04 whereas standard deviation is 7.382577 shown as there is variation in slope category.

4.4.6. Micro-watershed by level of imperviousness

Watershed is the precipitation collector and penetrates to the ground or transfer the water to the stream. Boundary of watershed is identified (polygon, color and Legends) as the following map. The map shows the impervious surfaces lying in corresponding watershed to identify the watershed holding more percentage of impervious surfaces.

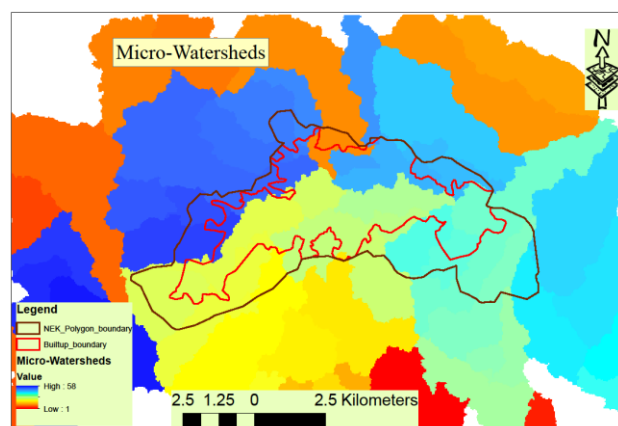


Figure 21: Micro-watershed of the study area

(Source: Prepared by the researcher)

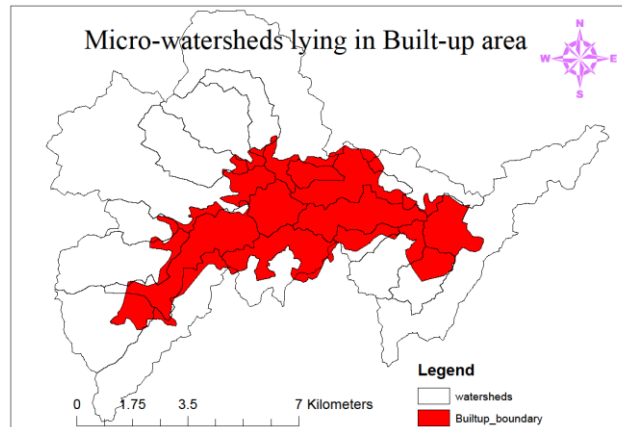


Figure 22: Micro-watershed falling in the study area

(Source: Prepared by the researcher)

The approach to determine the micro-watersheds was selection of every micro-watershed falling in the boundary of built-up area in the study area. The whole boundary of micro-watershed touching the built-up boundary were selected considering watershed definition.

4.4.6.1.Measuring and Ranking current level of imperviousness within each watershed

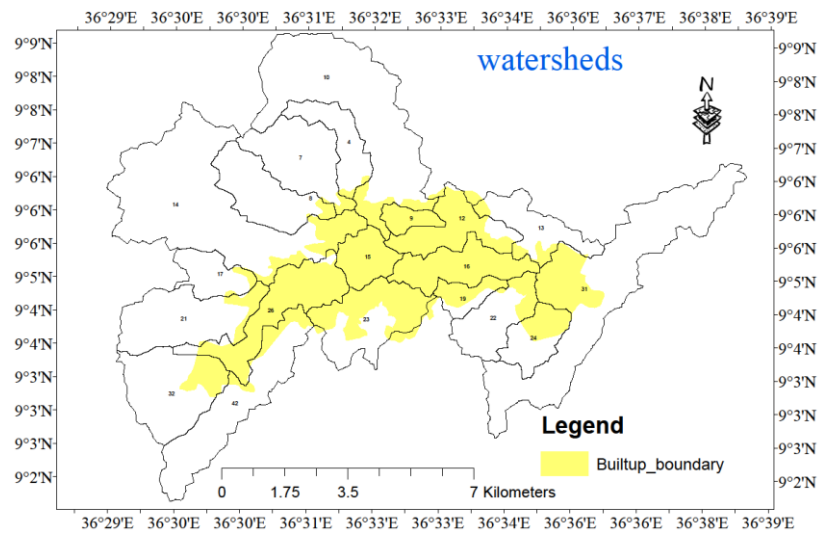


Figure 23: current level of imperviousness within each watershed

(Source: Prepared by the researcher)

Table 12: Watersheds with codes

No	M/Watershed Codes	M/Watershed area in ha	Slope In %age	Soil type	Major Land use types	Sum of IS area in ha
1.	4	250.87	2-7	Sandy	Residential	61.11
2.	7	449.38	2-7	Sandy	Residential	88.62
3.	8	403.40	2-7	Sandy	Residential	127.88
4.	9	92.92	2-7	Sandy	Residential	37.79
5.	10	1154.18	2-7	Sandy	Residential	160.20
6.	12	327.95	2-5	Sandy	Commercial	151.22
7.	13	305.36	2-7	Sandy	Residential	48.80
8.	14	1387.61	8-12	Sandy	Residential	99.77
9.	15	201.06	2-7	Sandy	Commercial	95.77
10.	16	341.58	2-7	Sandy	Commercial	158.63
11.	17	206.29	2-7	Sandy	Residential	8.50
12.	19	125.71	12-15	Sandy	Residential	38.84
13.	21	529.33	12-15	Sandy	Residential	6.09
14.	22	313.58	2-7	Sandy	Residential	76.58
15.	23	487.03	8-12	Sandy	Residential	111.63
16.	24	233.30	2-7	Sandy	Organization	74.17
17.	26	458.25	8-12	Sandy	Commercial	182.75
18.	31	1283.50	2-7	Sandy	Residential	174.94
19.	32	538.31	2-7	Sandy	Residential	56.41
20.	42	613.30	2-7	Sandy	Residential	4.72
	total	9702.91				1764.42

Depending on results on the above table; the following results of calculations performed **Level of micro-watersheds imperviousness**: The following formula is used to calculate and identify more affected micro-watersheds by level of imperviousness

$$\% \text{ Impervious surface area} = \frac{\text{Sum of impervious surface components area}}{\text{Micro - watershed area}} \times 100$$

Table 13: Level of micro-watersheds imperviousness

No	M/Watershed Codes	M/Watershed area in ha	Sum of IS area in ha	Level of imperviousness of MWSH in %
1.	4	250.87	61.11	24.36
2.	7	449.38	88.62	19.72
3.	8	403.40	127.88	31.70
4.	9	92.92	37.79	40.67
5.	10	1154.18	160.20	13.88
6.	12	327.95	151.22	46.11
7.	13	305.36	48.80	15.98
8.	14	1387.61	99.77	7.19
9.	15	201.06	95.77	47.63
10.	16	341.58	158.63	46.44
11.	17	206.29	8.50	4.12
12.	19	125.71	38.84	30.89
13.	21	529.33	6.09	1.15
14.	22	313.58	76.58	24.42
15.	23	487.03	111.63	22.92
16.	24	233.30	74.17	31.79
17.	26	458.25	182.75	39.88
18.	31	1283.50	174.94	13.63
19.	32	538.31	56.41	10.48
20.	42	613.30	4.72	0.77

According to above table, more impacted micro watershed (site) by containing high level of impervious surfaces component is the one which contains 47.63%. This micro-watershed falls in the site of the study area around Bake Jama neighborhood and touches some areas from nearby neighborhoods in all direction. The micro-watershed covers about of 201.06ha and 95.77ha impervious surface covers.

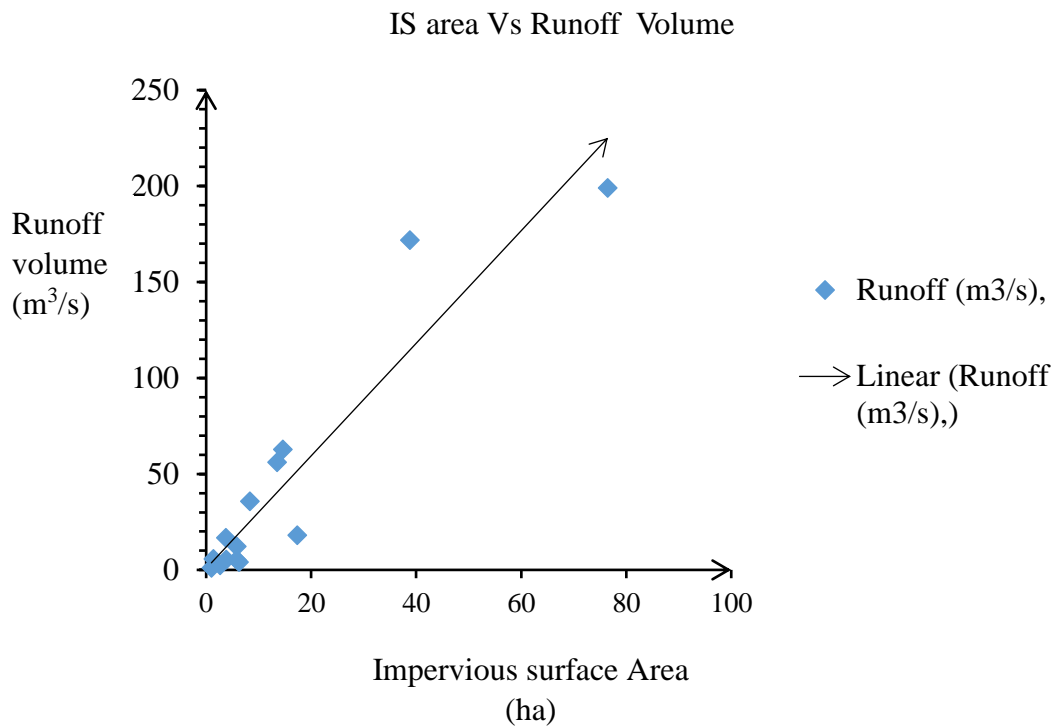
The identification of micro-watersheds and the level of imperviousness of Nekemte city is held by process of delineating micro-watershed and overlying with measured components of impervious surfaces according to (*Schueler, 1994*) by using impervious cover as the key measure and unifying theme in the municipal land-use zoning process. The comparison and ranking of the micro-watersheds by level of imperviousness in study area shows the degree of micro-watershed impacted by level of imperviousness.

The boundary of Nekemte city's micro-watersheds can be included out of the selected sites as it is a natural hydrological entity that covers a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. As a result, the researcher forced to measure the level of imperviousness of micro-watershed including all delineated part of micro-watershed touching the built-up area.

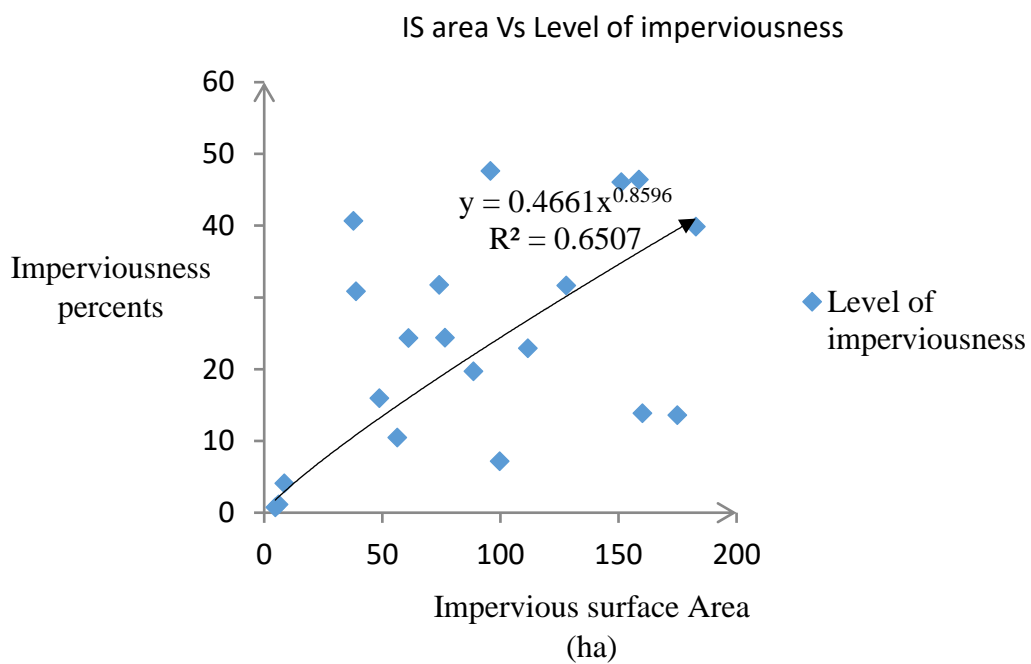
The measured and identified site of micro-watershed from Nekemte city built-up are based on the classification of urban stream by Arnold and Gibbons (1996) are above 10 percent labeled as imperviousness and the one with above 47 percent imperviousness is a source of flooding the natural stream in this area is highly impacted. The result of the interview with the residents of the area also confirms, the inner city of Nekemte is generating more urban runoff than peripheries of the city, thus the amount identified was affecting the stream and creating flooding problem for the downstream areas of the city.

4.4.6.2. Correlational analysis of variables

Impervious surface cover and urban runoff volume



Area of impervious surfaces and Percent of imperviousness



4.5.Designing Nature-based Drainage Solution (NbDS) vulnerable micro-watershed

4.5.1.1.Natural Feature Analysis

4.5.1.1.1. Topography

Topography of affected watershed (site) falls within the range of 2080-2110meters asl. The central part of the site contains more impervious surface coverage and to both South and North part of the site are relatively steep slope and allows runoff flowing to the river.

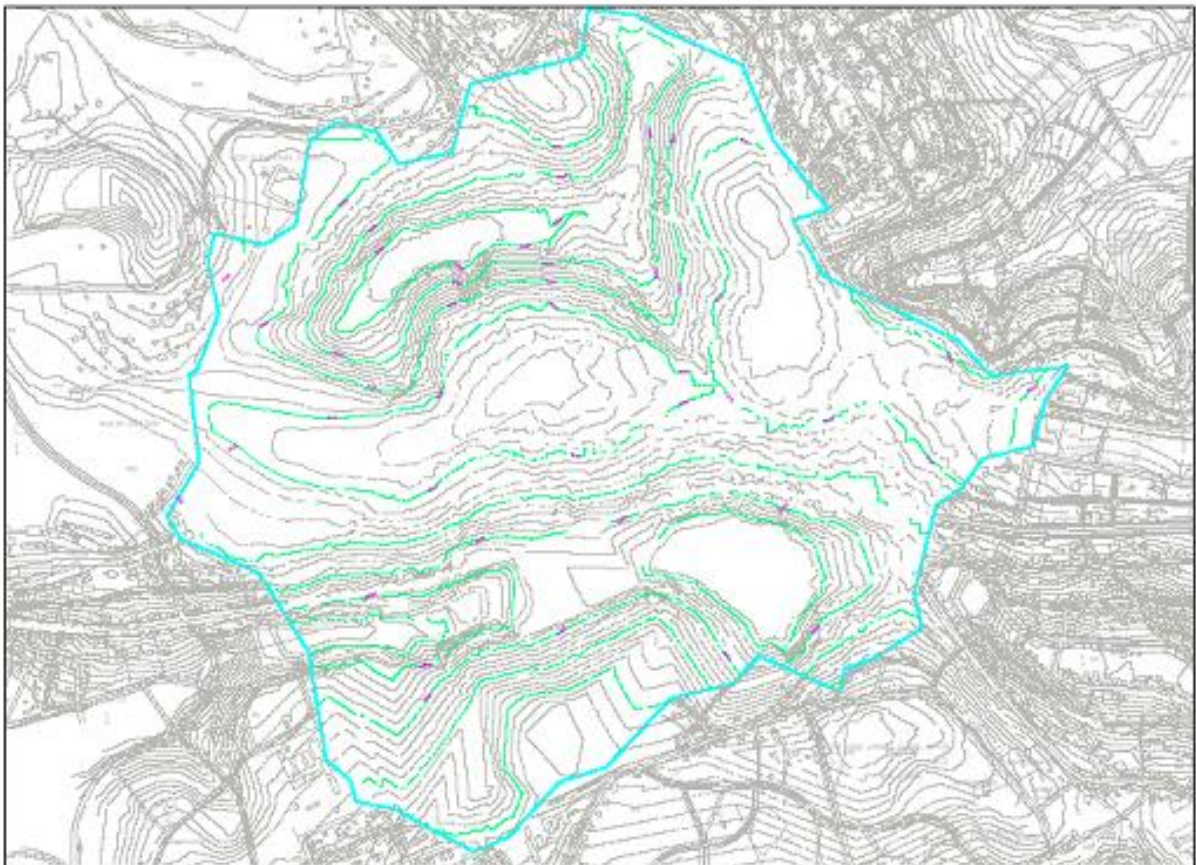


Figure 24: Contour map of the site

Slope map of the site

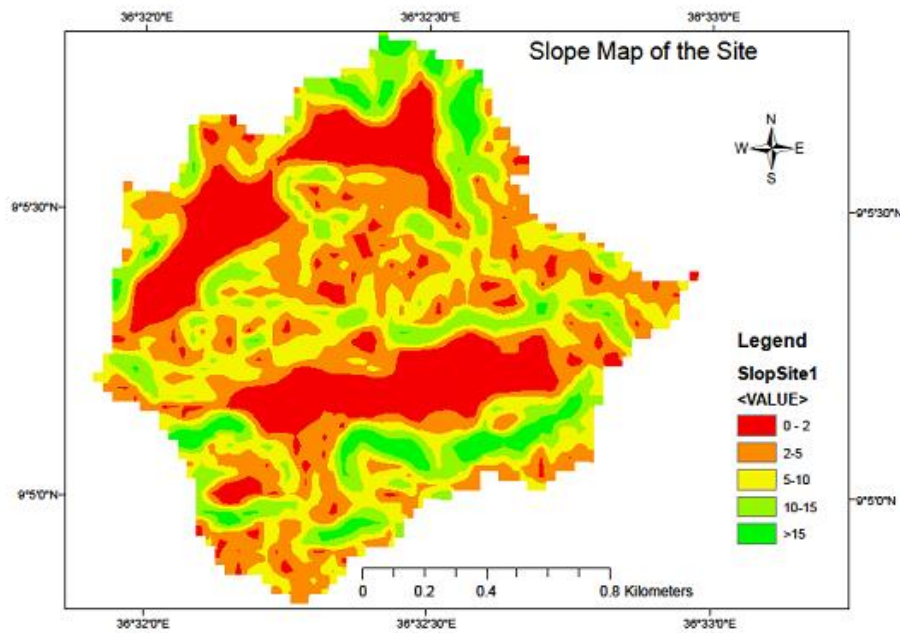


Figure 25: Slope of the site

(Source: Prepared by the researcher)

The above map indicates that the slope of the site shows more variation in value. The variation of the slope value indicates that there is more opportunity of water movement from the higher to lower elevations. Majority of the slope categories fall in 0-2% value located relatively at the lower elevation sites. On the other hand, steep slope located relatively at medium elevation sites whereas slope values 2-5, 5-10 and 10-15 percent area the dominants at relatively higher elevation sites. This implies that the design of nature-based drainage solution should consider the speed and volume of the storm water runoff.

4.5.1.2. Hydrological Data Analysis

4.5.1.2.1. Flow Accumulation of the Site

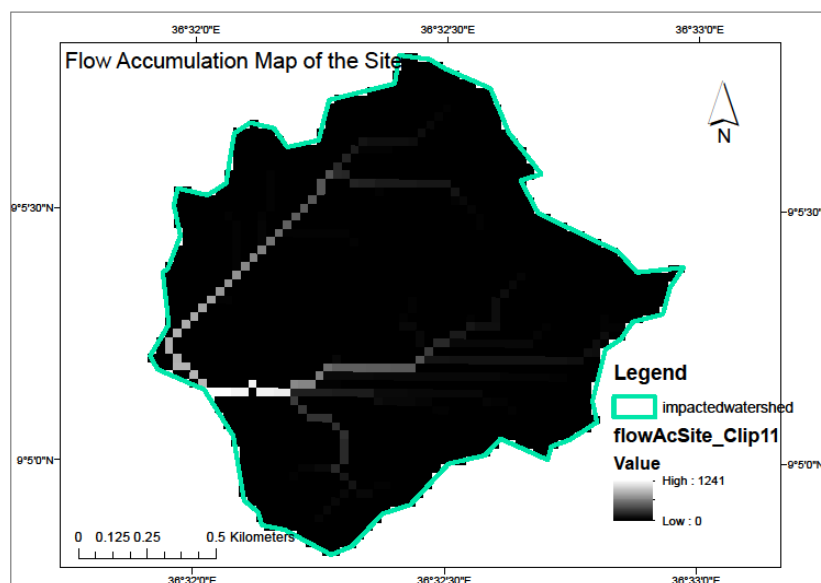
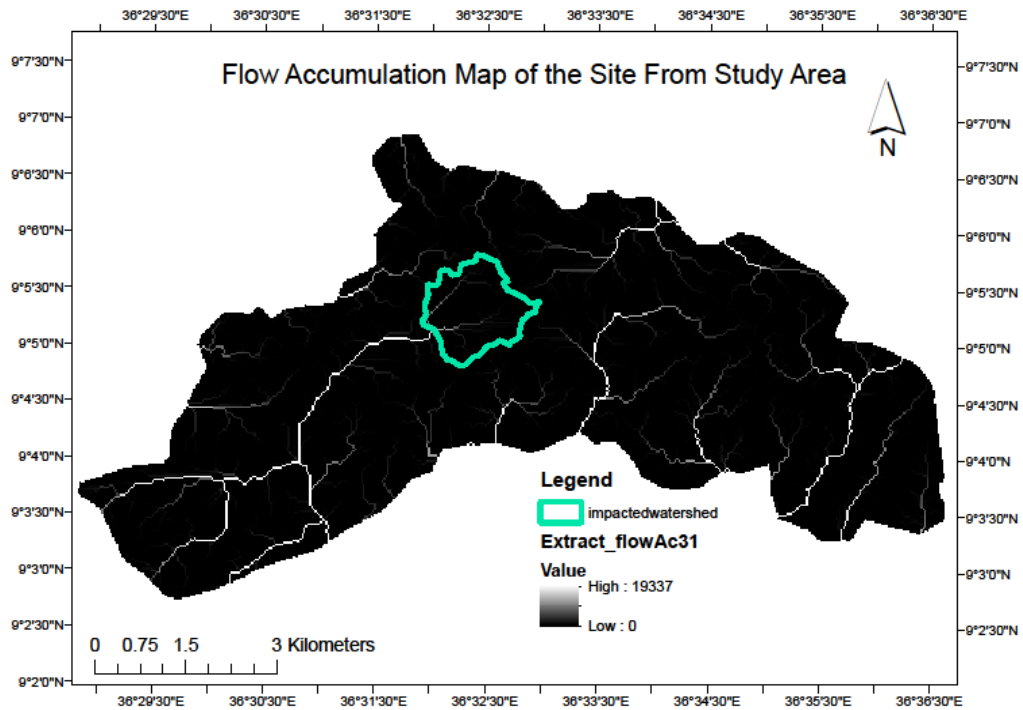


Figure 26: Flow Accumulation map Shows direction of stream flow out of the site

(Source: Prepared by the researcher)

Flow accumulation of the site indicates the direction of stream flow and the stream entering to or going out of the site. Accordingly, there is no stream entering to the site and there is two outlets of the sites through which the streams out going from the site. This is indicator for consideration for riverside greeneries and blue-green infrastructure utilization during design of NbDS for the site. The following map shows the direction and stream origin in the site.

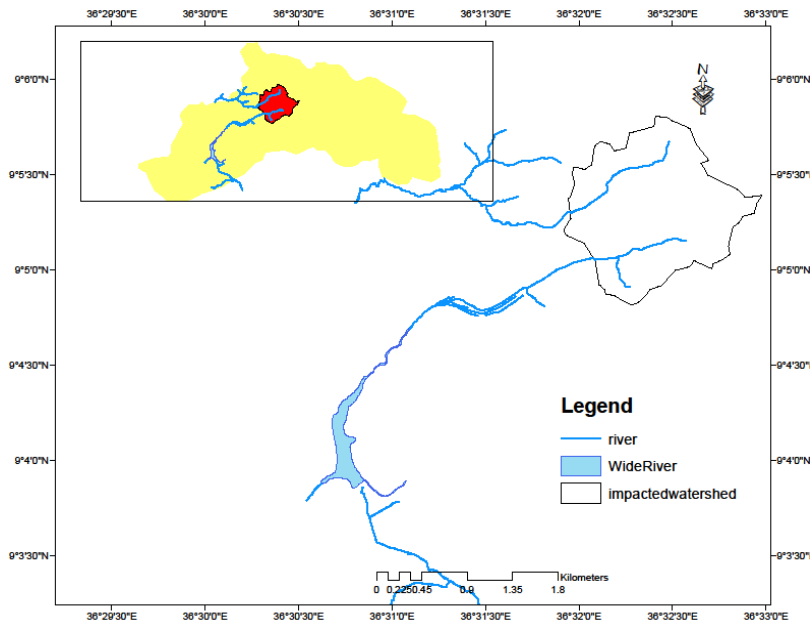


Figure 27: location map Shows direction of stream flow out of the site

4.5.1.2.2. Major five months maximum Rain fall of the study area

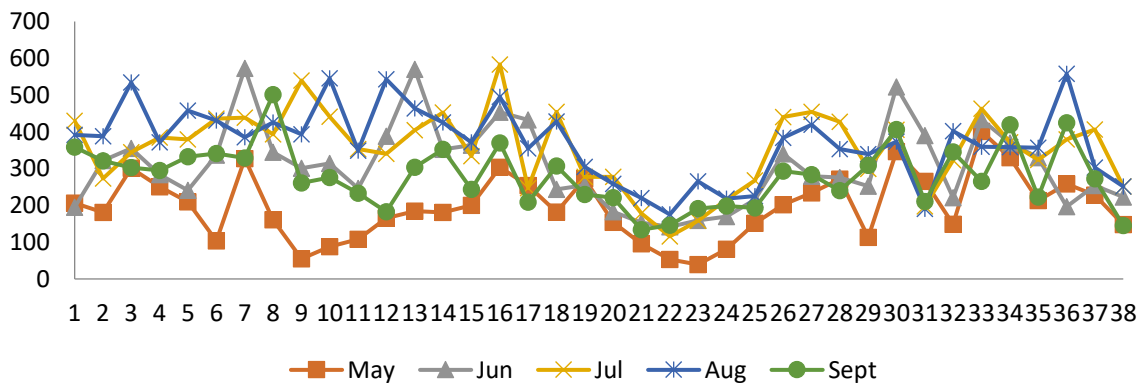


Figure 28: Major five months maximum Rain fall of the study area

(Source: Prepared by the researcher)

The above graph shows that, August is the richest month in rainfall amount as continually above $350\text{mm}^3/\text{hrs.}/\text{year}$ rain is occurred for out of identified five months in August and followed by June and July as above $300\text{mm}^3/\text{hrs.}/\text{year}$ for more than 25years. Whereas September is medium rainfall amount from five months high rainfall months of the study area scored in 38 years and may is the relatively small but not least in rainfall data. So, it is possible to use average of the five months scored per year in calculation of rational formula in order to model or designing drainages which is the total average of main five rains rich month's rainfall amount is $301.85\text{mm}^3/\text{hrs.}/\text{month}/\text{year}$.

4.5.1.3.Existing land use/land cover

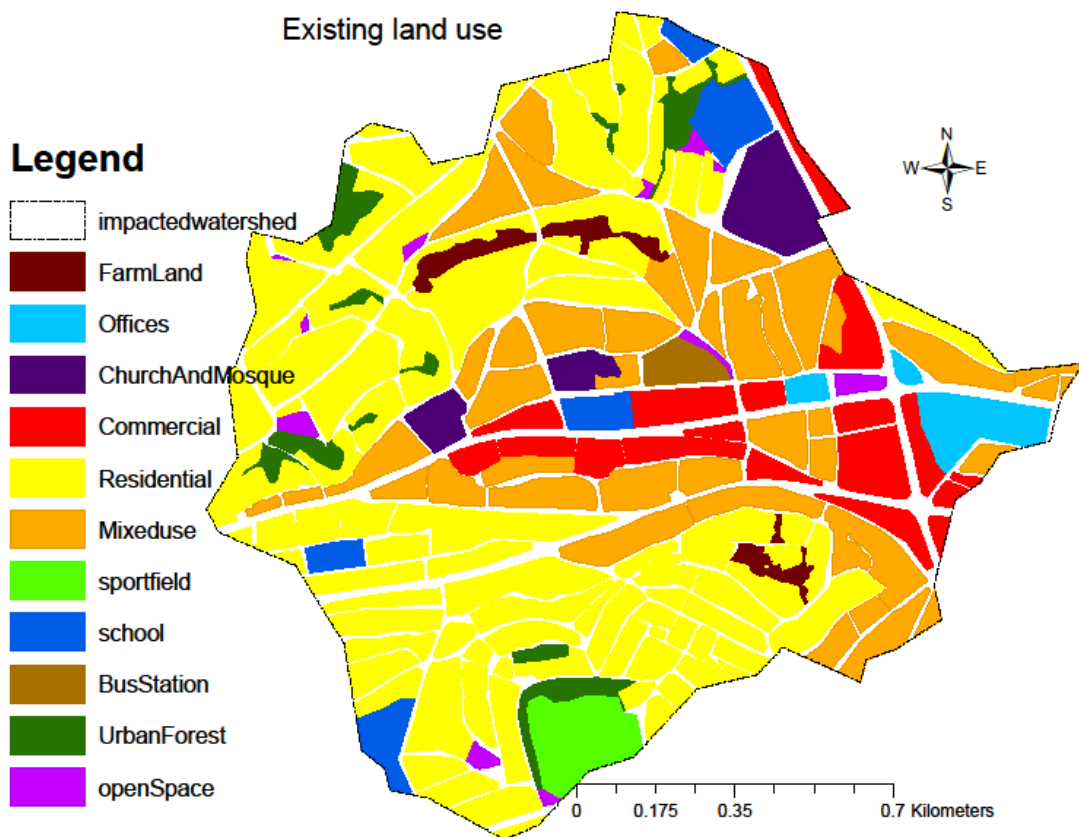


Figure 29: Existing land uses in the site

(Source: Prepared by the researcher)

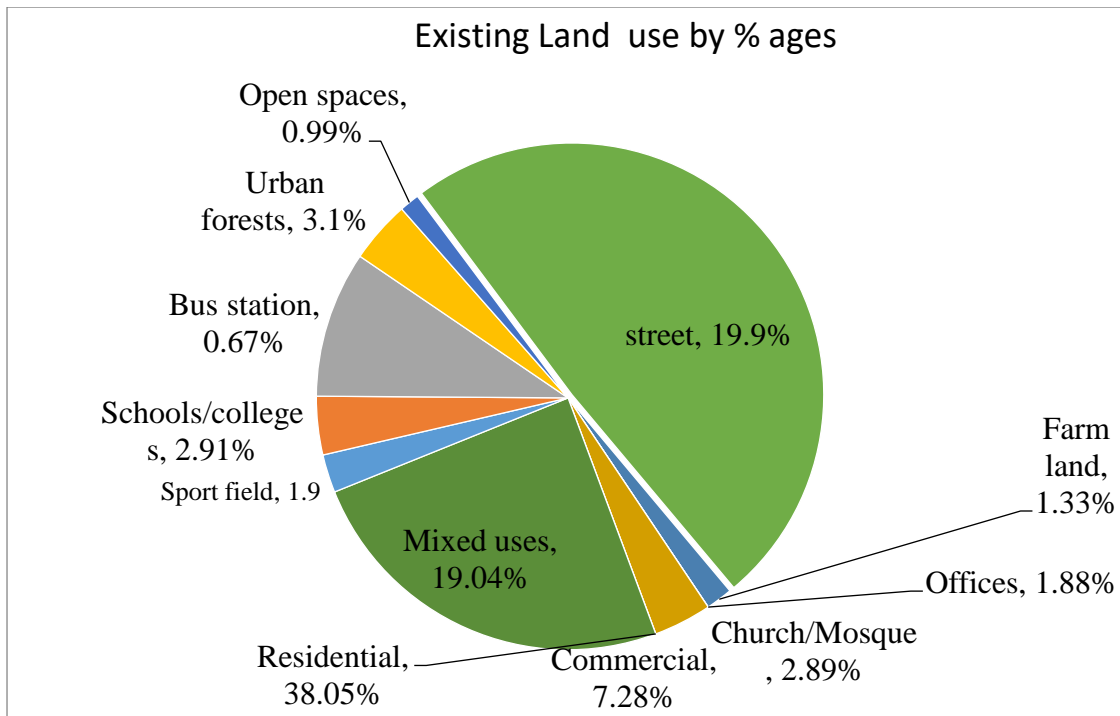


Figure 30: Existing Land use % ages diagram

4.5.1.4. Rain fall data Analysis and runoff estimates for the site

Modified Rational formula $Q = CIA$

Where,

Q = Run off

I = Intensity of rain fall

A = Area

C = Coefficient of runoff.

The coefficient of Runoff, C , is considered as per topography, slope and nature of the soil in the study area.

$Q = (\text{mm/hr})(\text{ha})(10,000 \text{ m}^2/\text{ha})(1 \text{ m}/1000 \text{ mm})(1 \text{ hr}/3600 \text{ sec})$, or

$Q = 0.0028 CiA$, with i in mm/hr, A in ha, and Q in m^3/s f S.Junit

4.5.1.5.Runoff Coefficient (C) factor for different land covers in the site

Table 14: Runoff Coefficient (C) factor for different land covers in the site

Land Cover	Area (ha), A	Runoff Coefficient			Rainfall intensity, I (mm/hr/yr)	Runoff (m ³ /s), Q=0.0028CiA	
		description	Value	C			
Farm land	2.67	Sandy soil, with crop,	0.10 - 0.25	0.175	1859.011	2.432144091	
Offices	3.78	Roofs	0.75 - 0.95	0.85	1859.011	16.72440656	
Church/Mosque	5.83	Parks/cemeteries	0.10 - 0.25	0.175	1859.011	5.310636724	
Commercial	14.63	Downtown areas	0.70 - 0.95	0.825	1859.011	62.82583445	
Residential	76.50	Multi units, detached	0.40 - 0.60	0.50	1859.011	199.1000781	
Mixed uses	38.83	Roofs	0.75 - 0.95	0.85	1859.011	171.8012452	
Sport field	3.83	Sport field/playground	0.20 - 0.35	0.275	1859.011	5.48240934	
Schools/colleges	5.85	Same to Single-family areas	0.30 - 0.50	0.40	1859.011	12.18024007	
Bus station	1.36	Drives and walks	0.75 - 0.85	0.80	1859.011	5.66329111	
Urban forests	6.24	Lawn, Sandy soil, avg., 2-7% slope	0.10 - 0.15	0.125	1859.011	4.060080024	
Open spaces	1.00	Unimproved areas	0.10 - 0.30	0.20	1859.011	1.04104616	
Street	Asphalt	8.34	Asphaltic	0.70 - 0.95	0.825	1859.011	35.81459052
	Cobblestone	13.49	Drives and walks	0.75 - 0.85	0.80	1859.011	56.17485079
	Earth	17.38	Unimproved areas	0.10 - 0.30	0.20	1859.011	18.09338226
Total	201.06					596.7042354	

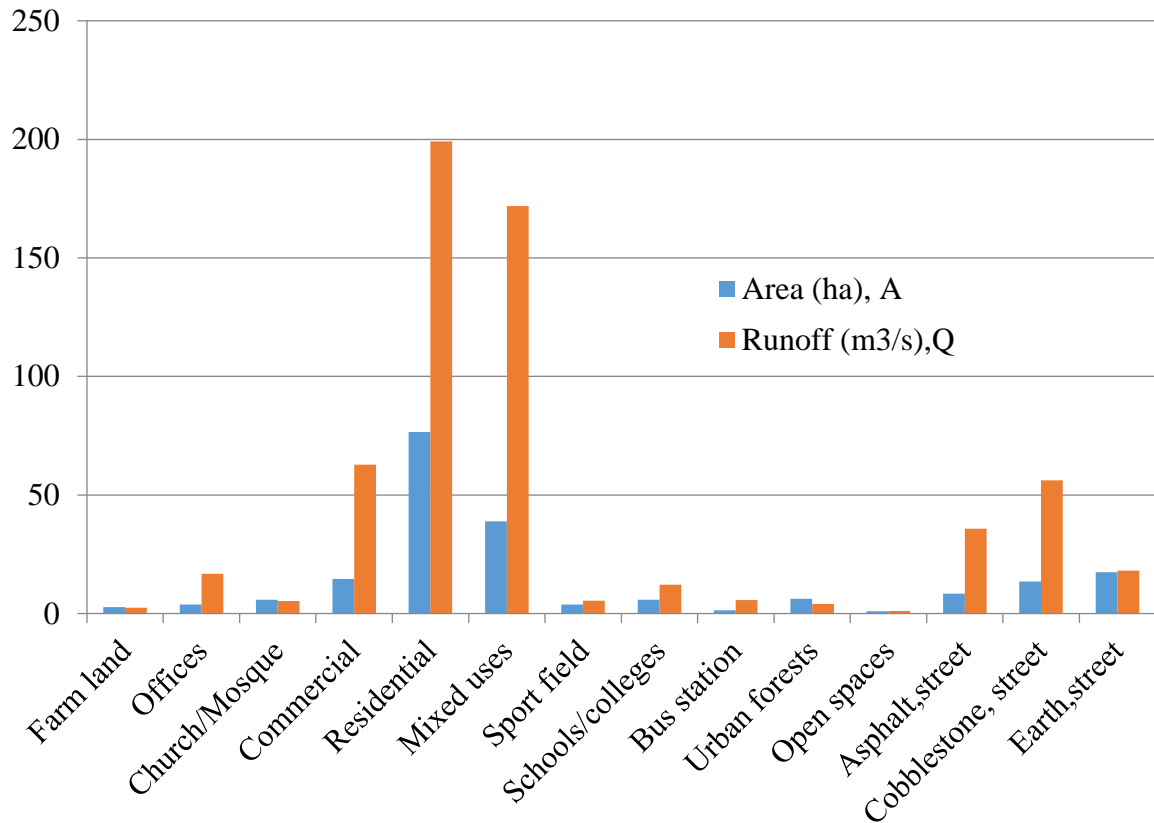


Figure 31: Runoff Coefficient (C) factor for different land covers in the site by graph

Depending of the above result, it is possible to identify the area with potential for creating urban runoff and designing proper nature-based drainage solution. Accordingly, residential area, mixed use area, commercial area, cobble stone street area, asphalt street area is from highest to lowest runoff creators of the site respectively.

4.5.1.6. Potential areas for nature-based drainage solutions and constraints of the site on flooding issues

4.5.1.6.1. Elevation of the site

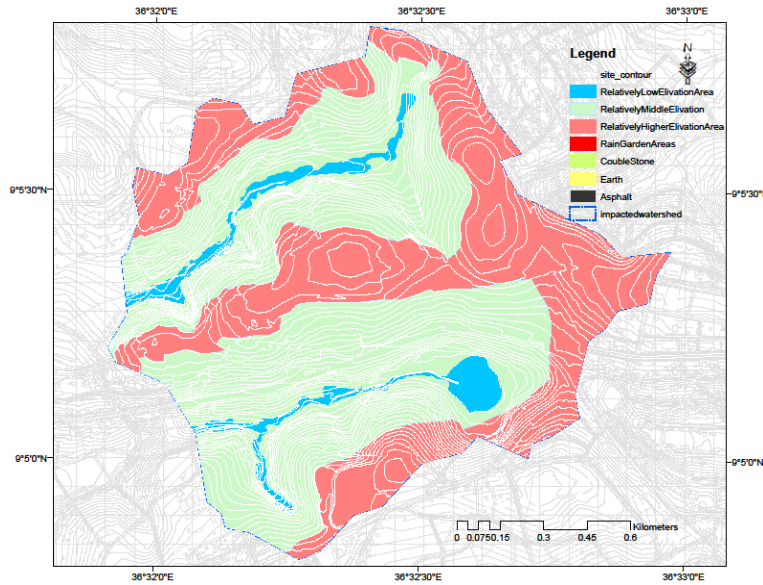


Figure 32: Categorizing the site into relative elevation and slope

(Source: prepared y the researcher)

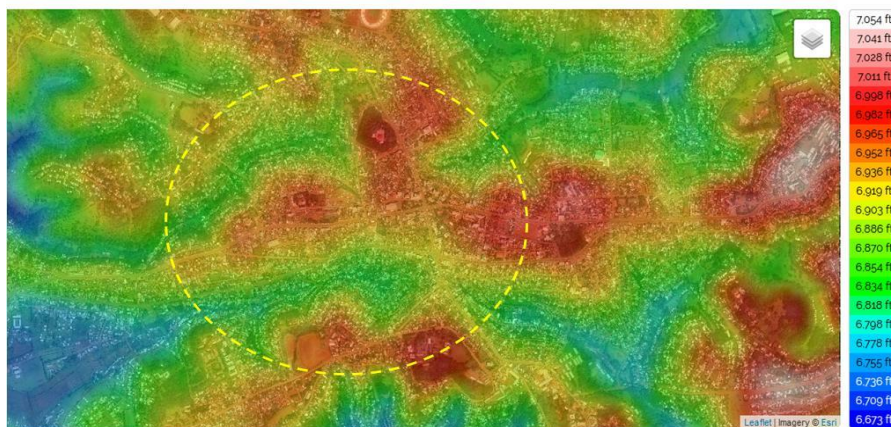


Figure 33: Elevation of the site

(Source :(<https://en-gb.topographic-map.com/maps/p7qu/Nekemte/>)

Depending up on the above map, the results of the elevation of the site in the area are summarized as the following table

Table 15 : Elevation of the site

Relative Elevation	Slope description	Area, ha	Percentages
Higher areas	Majority 0-5%	81.02	40.29
Middle areas	Majority 2-7%	110.80	55.10
Lower areas	Majority 0-5%	9.27	4.61
Total		201.06	100

Middle elevation of the areas of the site falls in the slope of 2-7% dominate the site by 55.10% - hectare land and 40.29% of the land in the site contains 0-5% of slope value in higher elevation areas. The small part of the site contains lower elevation with 0-5% of slope value that is 4.61% hectare of the land. This indicates the higher and lower elevation areas are relatively gentle slope and the middle elevation areas were enabling the speed of the stormwater runoff to create flooding problem on the area. Thus, the consideration elevation and location of NbDS design should be thought in the process of designing for the solution.

4.5.1.6.2. Surface runoff flow direction of the site

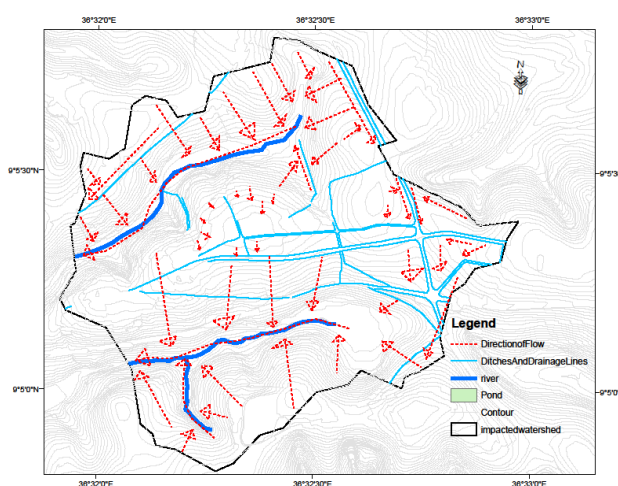


Figure 34: Drainage line and flowing direction in the site

(Source: Prepared by the researcher)

4.5.1.6.3. Site's suitable areas for public realm design

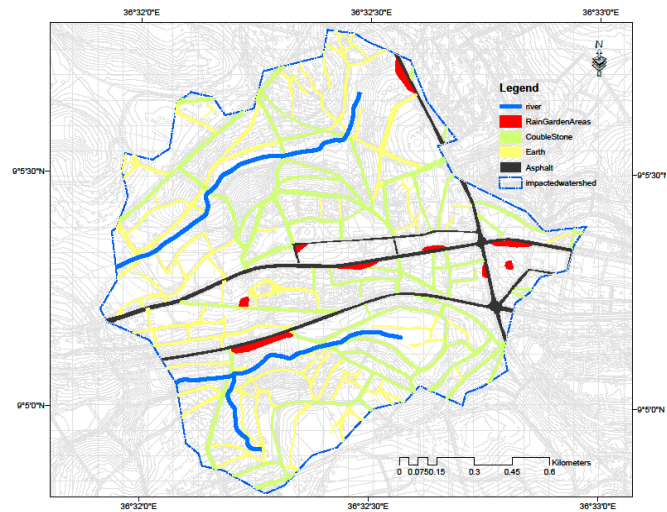


Figure 35: Site's suitable areas for public realm design

(Source: Prepared by the researcher)

The above map illustrates the locations of public realm where there is appropriate spaces and suitable slope to apply NbDS for stormwater management. Asphalt streets were selected in more percent and the places in the blocks area were also identified to serve as public realm.

4.5.1.6.4. Site's suitable areas for rain garden design

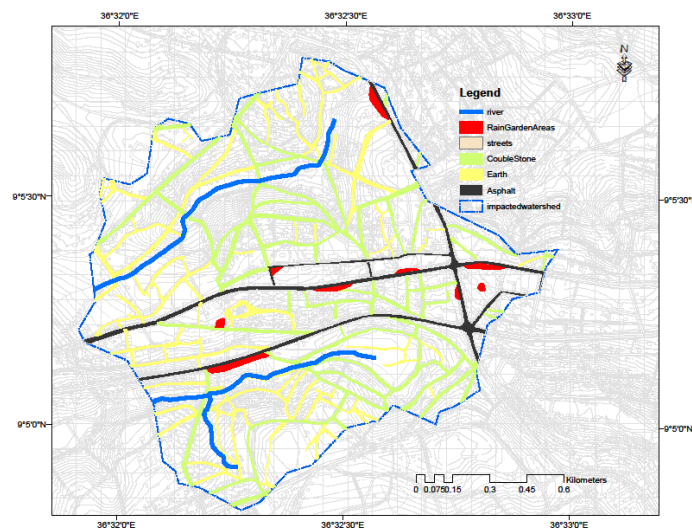


Figure 36: Site's suitable areas for rain garden design

(Source: Prepared by the researcher)

Site identified on the above maps are the place where public realm and rain garden designed to manage stormwater runoff. As the character of rain garden is to catch, filtrate and reduce stormwater runoff, the place suitable for public realm design is applicable also for rain garden design.

4.5.1.6.5. Site's suitable areas for wet ponds design

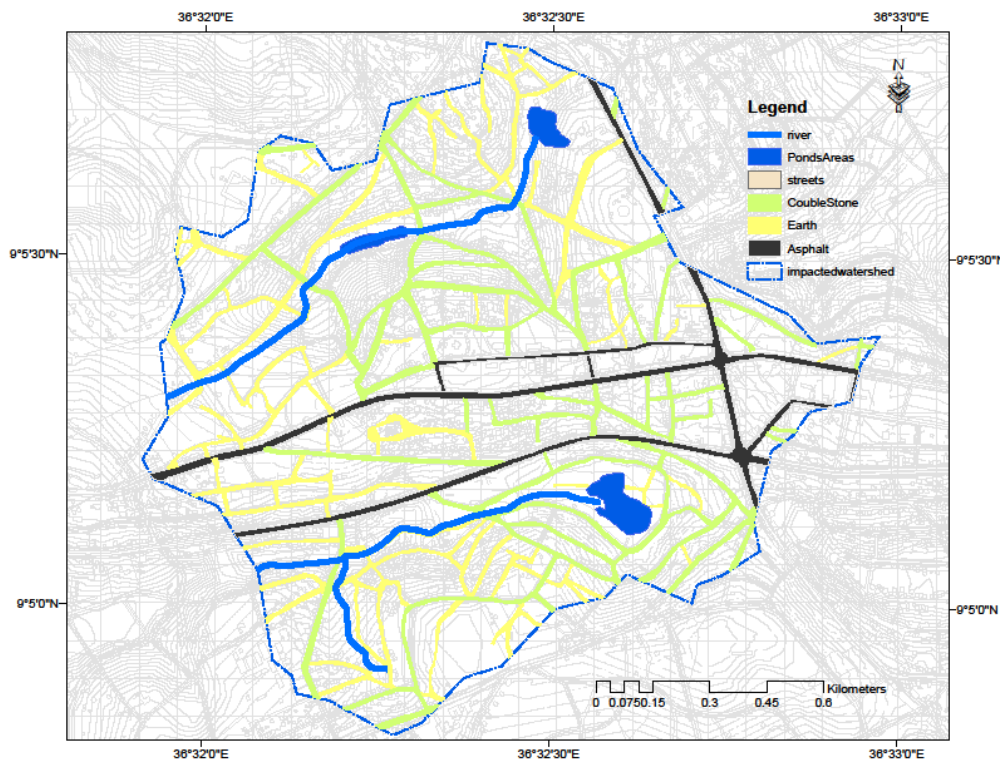


Figure 37: Site's suitable areas for Pond's design

(Source: Prepared by the researcher)

Wet ponds designed and mapped on the above figure shows that two major wet ponds can be constructed on the site, as well as minor wet ponds can be integrated to the riverside where the slope of the site can determine size and locations. The determining factor taken to design the ponds on the above map were the location of existing wetland and origin of the river with the relatively flat slope. This indicates that the stormwater runoff from upper elevation site can be managed for a while and the speed and volume of the runoff can be also reduced.

4.5.1.6.6. Site's suitable areas for designing vegetation and buffer from the river

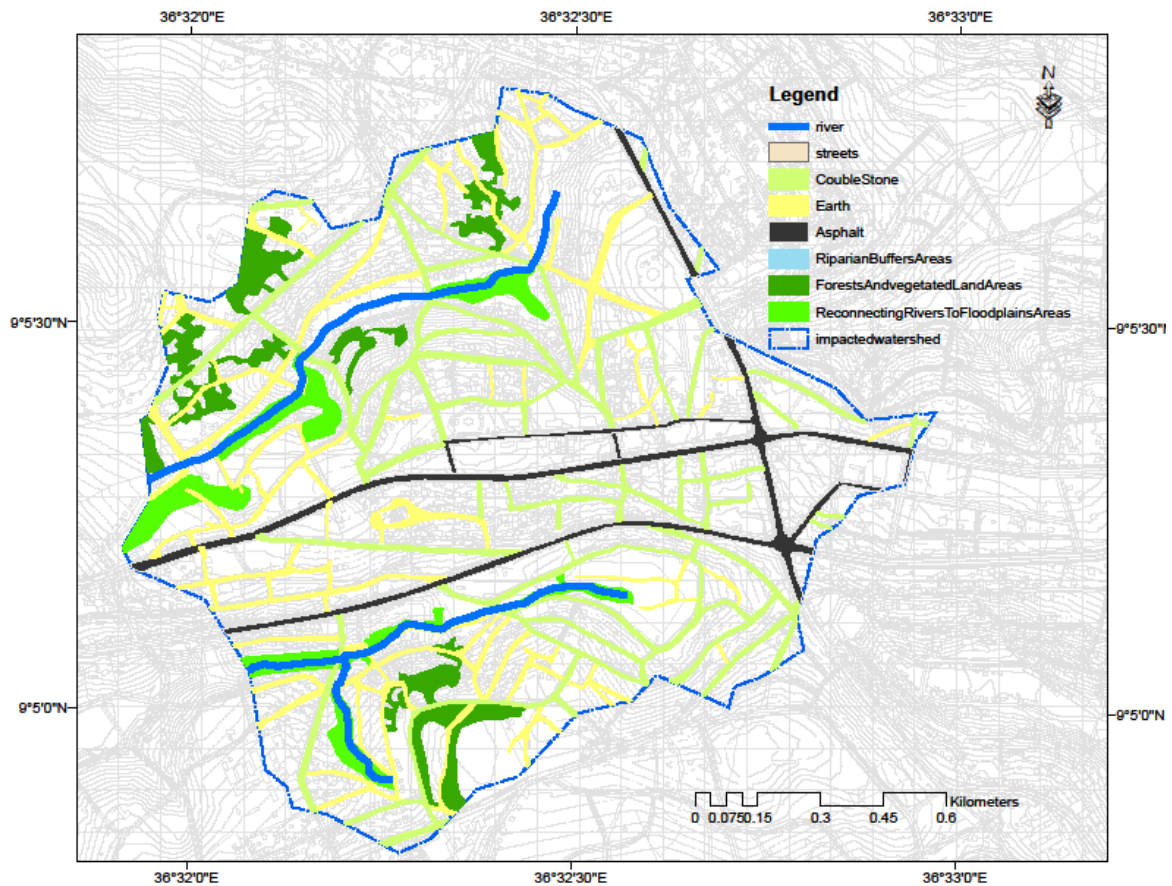


Figure 38: Site's suitable areas for designing vegetation and buffer from the river

(Source: Prepared by the researcher)

The above map shows that the area suitability for designing of plants and buffering zones were designed considering land use compatibility dimensions. The riverside area is suitable to buffer with vegetations and the existing big tree, forest areas are suitable to upgrade with selective plants.

4.5.1.6.7. Potential areas of developing design for Nature-based drainage systems

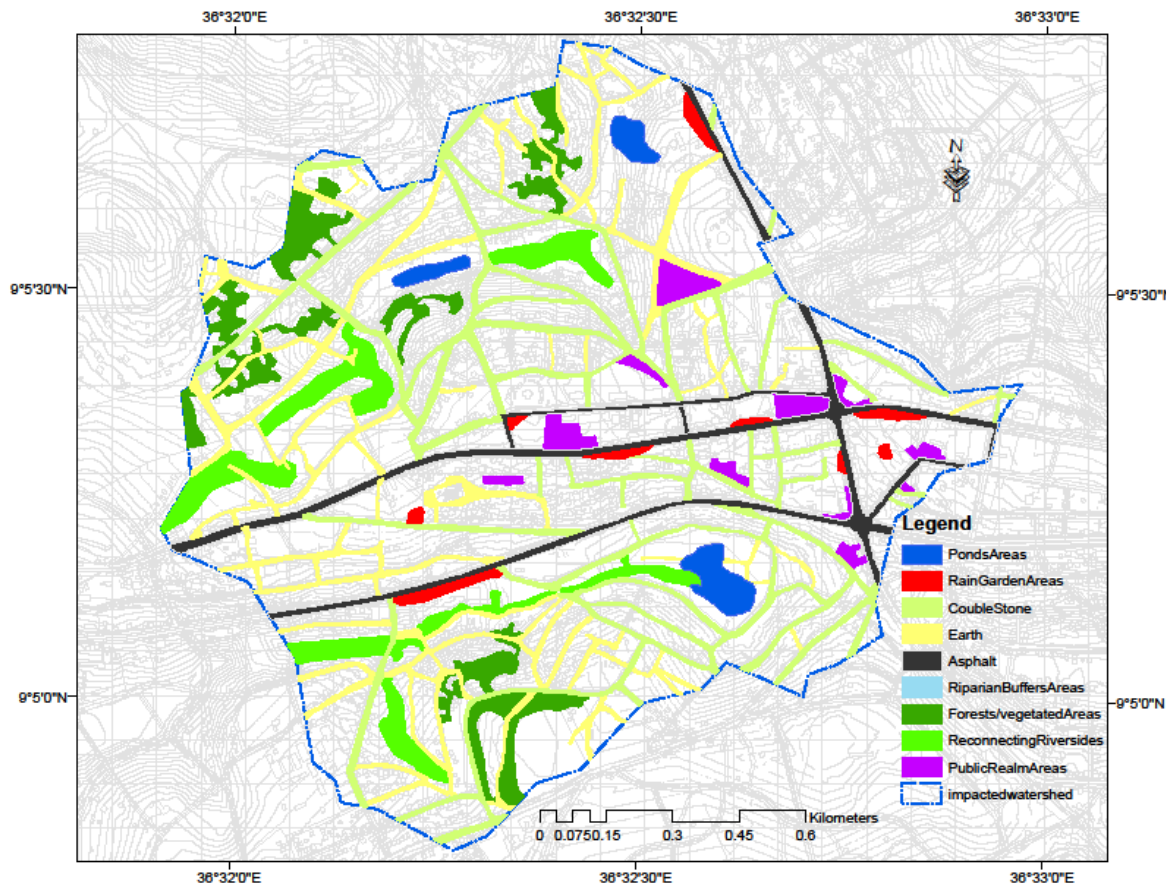


Figure 39: Potential areas of developing design for Nature-based drainage systems

(Source: Prepared by the researcher)

Table 16 : Site for respective NbDS

Site for respective NBDS	Description	Area, ha	Percentages
Ponds	At the beginning of water and wider riverside area	2.68	1.33
Rain Garden	Along street and in the blocks/plots	1.50	0.75
Plants/vegetation areas	Riverside, street, in blocks/plots	8.68	4.31
Floodplain reconnecting to rivers	Riverside and undeveloped areas	8.77	4.36
Public realm areas	At frontages and in blocks/street side	3.50	1.74
Total		25.13	12.49

The above map and table show that the site has the major potential areas of about 12.49% of the total site to apply the NbDS design. This indicates that stormwater management of the site can be incorporated through nature-based drainage solutions which can help the community through recreational and economical dimensions.

4.5.2. Detail Design Solution/Proposal

Design for flood risk management is a complex endeavor often involving a lot of variables, uncertainty, large temporal and spatial scales. Nevertheless, it is possible to identify three broad approaches and the design philosophies associated with each. These approaches are characterized by different functional objectives such as persistence, adaptation and transformation (Lennon, M. et al 2014).

4.5.3. Objectives

- Designing to reduce runoff and improve groundwater recharging
- To minimize impervious surfaces and enhancing the capacity of the available open spaces and street to retain and infiltrate more stormwater
- Design the nature-based storm drainage design solution to link with community benefit
- To develop and suggest sustainable storm water management strategy for the entire city

4.5.4. Strategies

- Designing to harvest rainwater for non-potable
- Designing nature-based drainage solutions at building, block and neighborhood level
- Designing to link nature-based drainage solution with place making and public realm
- Designing and preparing design guide line for job creation and economic aspect of nature-based drainage solution to benefit community.
- Designing Bio-retention and ponds
- Maximizing pervious road surface (cobble stone) and considering to Minimize plot runoff.

Nature-based drainage solution for storm water management strategies are taken to address the target of the design. Accordingly, 14% of the land is available for additional land uses such as buffer, greeneries, plazas, and ponds.

4.5.4.1.NbDS strategy development for different types of open spaces and drainage areas

Strategy-I (protecting streams from direct urban runoff)

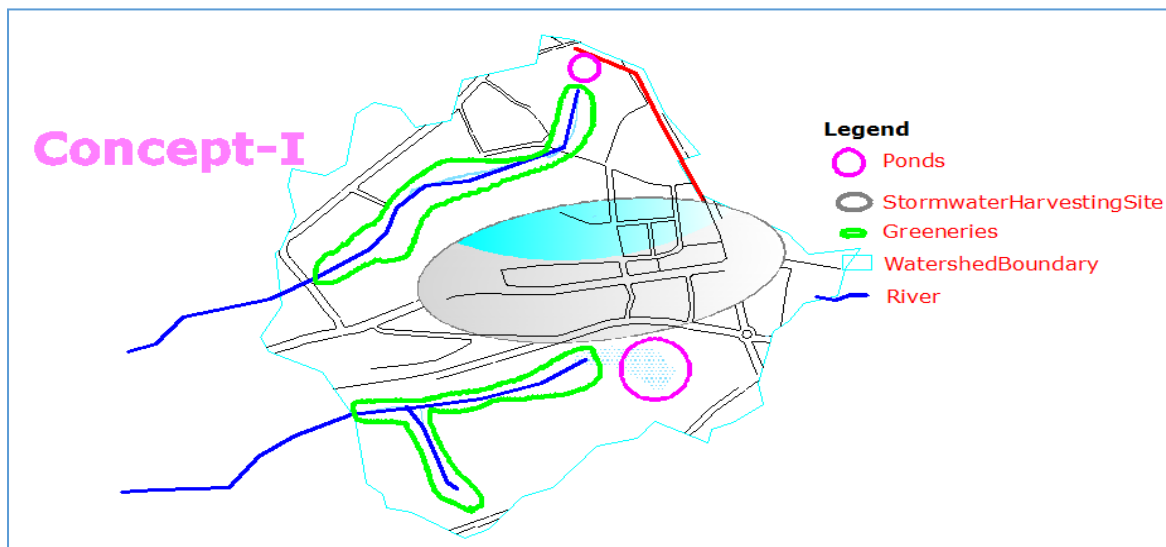


Figure 40: strategy-I (protecting streams from direct urban runoff)

Description (strategy-I): The concept shows the Consideration between lower and higher elevation on storm water runoff management. At the higher elevation are the points where runoff begins and drains to riverside so, it needs to cover the river-sides by greeneries.

Strategy-II (Linking stream and surfaces with greeneries)

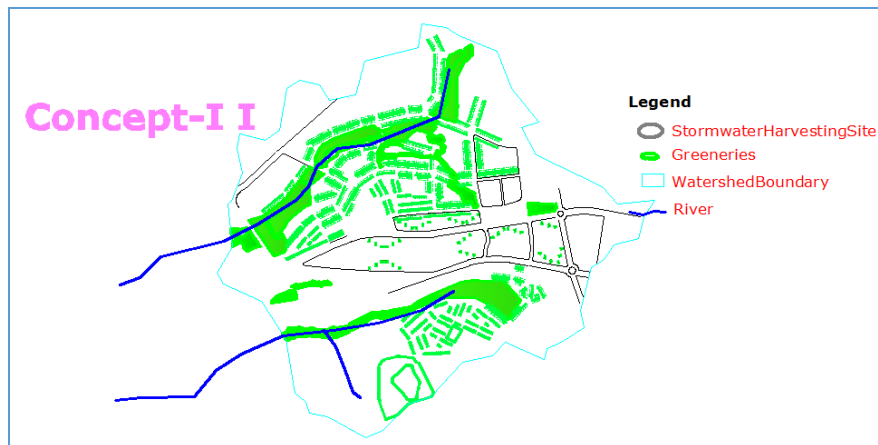


Figure 41: strategy-II (Linking stream and impervious surfaces with greeneries)

4.5.4.2. Street proposal Design

4.5.4.2.1. Street network and material proposal Design for the site

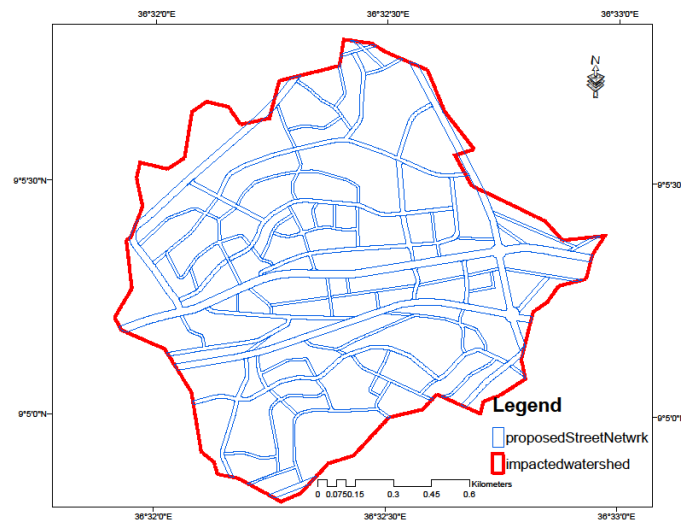


Figure 42: proposed Street network

(Source: Taken from Nekemte city Structural plan and modified by the researcher)

The design modification done on the existing street contains the reduction of the street area and the shape to create D-shape streets that is recommended for the water sensitive urban design.

The street network showed on the above map illustrates the site contains the variation of slopes and the streets bends at different places to follow the terrain.

Existing streets of structural proposal of the city was measured by AutoCAD software and majority of the streets considers the principle of WSUD to follow the slope with 45 degree. Street proposal for the water sensitive urban design is measured and taken as it is appropriate from Structural plan of the city prepared 2008 G.C. for the city and modified at some areas.

4.5.4.3.Parcel level strategy

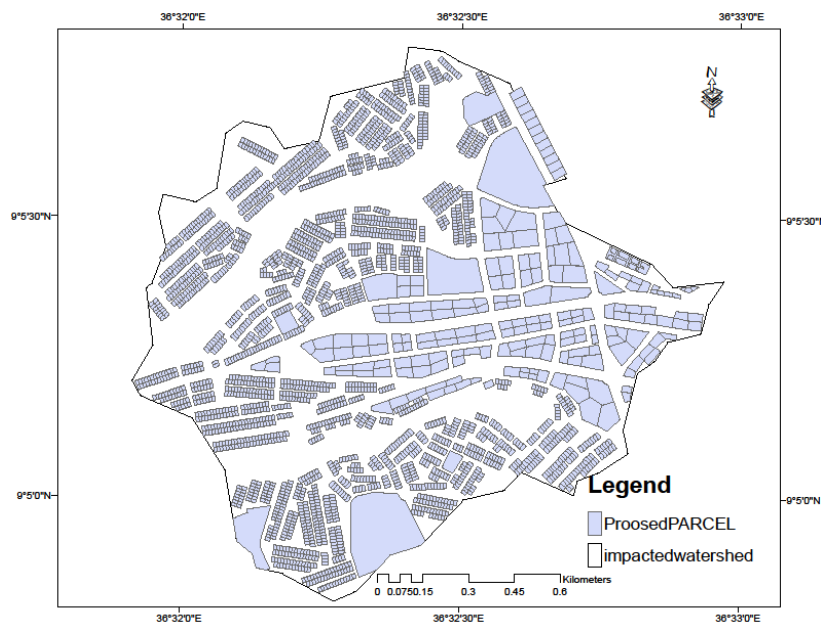


Figure 43: proposed parcel map

(Source: proposed by the researcher)

The above map shows the design land parcel proposed the researcher by considering of stormwater burden created by individual land parcels to support incentives to manage stormwater on site, to notify stormwater management practices and to increase public awareness of the connections between individual land uses (Keeley, 2007).

The parcel design proposed on the above map shows the inner part of the site with large parcel considering mixed use area and high-rise buildings with reduced roof footprint and excess open

and for application of NbDS designs. The peripheries of the site contain the single-family residential parcels considering the farming or agricultural land uses integrations as it is the part of NbDS design. There are also governmental areas those are preserved as it is.

4.5.4.4. Buildings level strategy

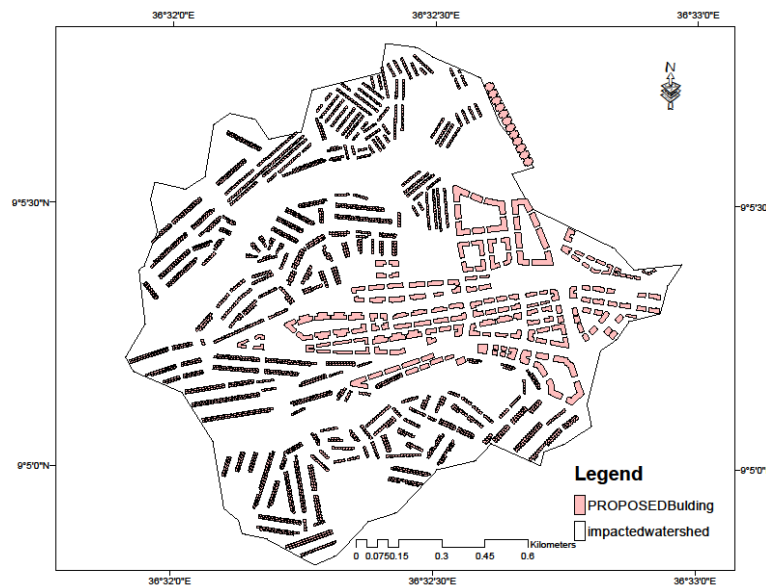


Figure 44: proposed building

(Source: proposed by the researcher)

The design of the building proposed following the parcel design and the handling of stormwater runoff. The building shape, size and location in the parcel also designed considering the slope of the site to manage the stormwater runoff. For example, the building located in a parcel with the site slope in 2-7% was designed at the upper point of the parcel. This is to capture the own stormwater by own parcel from buildings. The developments of the site designed to enhance sensitive ecological areas through protecting micro-watersheds from flooding and related issues

4.5.4.5. Nature-based Drainage Solution Components detail design at different levels

4.5.4.5.1. Designed Benefits from Nature-based drainage solutions for community

Table 17: Designed Benefits from Nature-based drainage solutions for community

Scale/Levels	Design Benefits (Activity)	Planned SWM	Activity to be taken	designed Mitigation
Building	<ul style="list-style-type: none"> ✓ Non-potable Storm water harvesting ✓ Vertical Farming (Wall) ✓ Reduce Building Footprints 	2%	<ul style="list-style-type: none"> Harvesting Urban farming 	Reducing runoff amount
Plot	<ul style="list-style-type: none"> ✓ Non-potable Storm water harvesting ✓ Rain Gardening ✓ Farming 	3%	Dairy farm and underground water harvest	Catching storm water for a period of time to use
Block	<ul style="list-style-type: none"> ✓ Rain Gardening ✓ recreational place design ✓ Green infrastructure design ✓ street Designing (application of D-shape, contour following and cul-de-sac type) 	10%	Common open space, play grounds and reducing street cover	Increasing pervious surfaces to allow water entering the soil (infiltration)
Street	<ul style="list-style-type: none"> ✓ Rain garden ✓ Street greeneries ✓ Minimizing street to 15% of the site ✓ D-shape and 45° to the major contour line 	5%	reducing street cover and adding green infrastructures and using pervious materials	Increasing pervious surfaces to allow water entering the soil (infiltration)
Neighborhood	<ul style="list-style-type: none"> ✓ street Designing (D-shape, and cul-de-sac type and 45° to the major contour line) ✓ street tree ✓ Ponds 	10%	reducing street cover and adding green infrastructures	Increasing pervious surfaces to allow water entering the soil (infiltration)
Site (city)	<ul style="list-style-type: none"> ✓ Urban Forest ✓ landscape restoration design ✓ City farming design 	30%	Maximization of plants and using city farming for economical perspective of WSUD	Increasing pervious surfaces of MWSH to allow water entering the soil (infiltration)

(Source: summarized by the researcher)

4.5.4.5.2. Land-use Land Cover Design proposal

Table 18: Land-use Land Cover Design proposal

Land uses	Existing Area Sq.meter	%ages	Proposed Area Sq. meter	%ages	Remark
Farm land	26736.42	1.33	26736.42	1.33	In Resident plots
Offices	37779.10	1.88	24114.31	1.2	13664.79 free
Church/Mosque	58250.58	2.89	58250.58	2.89	Preserved
Commercial	146322.96	7.28	100496.54	5	45826.42 free
Residential	765018.98	38.05	596118.68	30	168900.3 free
Mixed uses	382830.37	19.04	502665.92	20	119835.55 needed
Sport field	38309.88	1.90	38309.88	1.9	preserved
Schools/colleges	58537.23	2.91	40231.77	2	18305.46 open
Bus station	13629.44	0.67	13629.44	0.67	Preserved
Urban forests	62419.35	3.10	30202.91	1.5	32216.44 open
Open spaces	20047.14	0.99	101248.18	4	81201.04 Needed
street	400171.35	19.9	301636.69	15	98534.66 open
Plazas	None	0	26681.943	2	Of 14% open (281407.39)
Recreational area	None	0	56985.603	4	Of 14% open (281407.39)
Buffers and greeneries, Ponds, rain gardens	None	0	92743.934	8	Of 14% Open (281407.39)
Total land use	2010052.80	99.94	2010052.80	99.49	constant
Total (site)	2010652.80	100	2010652.80	100	constant

(Source: Summarized by the researcher)

The site is containing 12 (twelve) land cover categories covering 2010052.80 Square meters as existing land uses. In the proposal part of the design the aim of reducing building footprint, reducing street in to 15%, preserving religious services parts and getting additional excess land for integration of nature-based drainage solution.

4.5.5. Estimated site' level of imperviousness before and after NbDS application

4.5.5.1.Components of impervious surfaces before and after design

Components of IS	Existing		proposed	
	Area in (ha)	% age	Area in (ha)	% age
Rooftop	85.26	89.02	32.24	64.03
Asphalt	8.34	8.70	8.34	16.56
Parking	0.02	0.02	2.31	4.59
Sidewalk	0.13	0.13	1.3	2.58
Driveways	0.16	0.17	3.06	6.08
Water body	1.72	1.79	2.81	5.58
Others	0.14	0.14	0.29	0.58
Total	95.77	100	50.35	100

4.5.5.2.Block and parcel before and after designed strategy

Sub divisions	Existing		proposed	
	IS area in ha	% age	Area in (ha)	% age
Block	168.17	83.64	151.70	75.45
parcel	143.15	71.19	92.74	46.12
Built-up area	201.06	100	201.06	100

4.5.5.2.1. Sites' Level of imperviousness before the design

Level of imperviousness at parcel level

$$\text{level of imperviousness at the parcel} = \frac{\text{sum of IS components}}{\text{area of the parcels}} \times 100$$

$$\text{level of imperviousness at the parcel} = \frac{95.77 \text{ ha}}{143.15 \text{ ha}} \times 100$$

$$=66.97\% \text{ at parcel level}$$

Level of imperviousness at block level

$$\text{level of imperviousness at the block} = \frac{\text{sum of IS components}}{\text{area of the blocks}} \times 100$$

$$\text{level of imperviousness at the block} = \frac{95.77 \text{ ha}}{168.17 \text{ ha}} \times 100$$

$$=56.94\% \text{ at the block level}$$

Level of imperviousness at the site level

$$\text{level of imperviousness at the site} = \frac{\text{sum of IS components}}{\text{area of the site}} \times 100$$

$$\text{level of imperviousness at the site} = \frac{95.77 \text{ ha}}{201.06 \text{ ha}} \times 100$$

$$=47.63\% \text{ at the site level}$$

4.5.5.2.2. Sites' Level of imperviousness after the design

Level of imperviousness at parcel level

$$\text{level of imperviousness at the parcel} = \frac{\text{sum of IS components}}{\text{area of the parcels}} \times 100$$

$$\text{level of imperviousness at the parcel} = \frac{50.35 \text{ ha}}{92.74 \text{ ha}} \times 100$$

$$=54.29\% \text{ at parcel level}$$

Level of imperviousness at block level

$$\text{level of imperviousness at the block} = \frac{\text{sum of IS components}}{\text{area of the blocks}} \times 100$$

$$\text{level of imperviousness at the block} = \frac{50.35 \text{ ha}}{151.70 \text{ ha}} \times 100$$

$$=33.19\% \text{ at the block level}$$

Level of imperviousness at the site level

$$\text{level of imperviousness at the site} = \frac{\text{sum of IS components}}{\text{area of the site}} \times 100$$

$$\text{level of imperviousness at the site} = \frac{50.35 \text{ ha}}{201.06 \text{ ha}} \times 100$$

$$=25.04\% \text{ at the site level}$$

4.5.6. Amount of stormwater runoff controlled by application of NbDS in the site

Type of NbDS	Area of NbDS in ha	Materials and soil	Rainfall intensity/mm/hr/yr	Runoff coefficients	Estimated stored Runoff volume in m ³ /s
Public Realm	3.49	Open graded stone	1859.011	0.375	6.812346
Flood plains	8.77	Vegetation	1859.011	0.125	5.706234
Vegetation cover	8.68	vegetations	1859.011	0.125	5.647675
Rain Garden	1.50	Shrubs/grass/soil/stone	1859.011	0.375	2.927942
Wet ponds	2.68	Soil/grass/shrubs/plant	1859.011	0.125	1.743752
rainwater harvest	0.002 (Average)	Plastic/metal/cement	1859.011	0.85	0.008849
Green roof	21.32 (25% of the buildings)	Vegetations	1859.011	0.125	13.87194
Total	46.442				36.71874

The total area of NbDS designed was 46.44 hectare and can catch 36.72m³/s runoff volumes from the site. This indicates that in addition to the strategy designed on parcel and building arrangements which can reduce the volume of urban runoff in the site by 15.86 m³/s (2.66%) and also the designed NbDS catch the 36.72 m³/s (6.15%) runoff volume on the site. In summary, the SUDS strategy of NbDS and can minimize 8.81% of runoff volume.

4.6.Strategies to Develop Sustainable Urban Drainage System for Entire Nekemte city

4.6.1. Scale upping Site-specific NbDS design to the City level

The site-based designed NbDS is developed on the site from the study area and contains similar character which can represent the entire city. The site was similar with the entire city by through containing similar type and material of streets, land use types, slope variation, rainfall events and soil characteristics. Thus, the difference seen between the site and entire city is almost the hectare of the lands. So, if the designed NbDS scaled up to the entire city; the runoff reduced in the site can be scaled up through calculating the area cross the runoff volume representing as follows.

If 201.06 ha of land generates (Site – based) = 596.7042354m³/s runoff,

how much 5380ha of land generates (city level) = X m³/s runoff

The calculation of rational formula to get the volume of the runoff generating from existing city level performed as follows.

$$Q=0.0028CiA$$

$$Q=0.0028 (0.35) (1859.011) (5380)$$

$$=9801.4495964\text{m}^3/\text{s of runoff estimated at city level}$$

The amount of the runoff generated was when calculated by land use category, the following estimation was calculated after the site-based strategies in the land use category re-arranged.

From the existing site, the amount of before designed was 596.7042354m³/s and 580.841574m³/s after design. This indicates that

$$596.7042354\text{m}^3/\text{s} - 580.841574\text{m}^3/\text{s}$$

$$=15.8626614\text{m}^3/\text{s (at site-level)}$$

2.66% of runoff reduced at site-level only by arrangement of land use zoning.

2.66% of 9801.4495964m³/s –at city level was estimated to scale-up the land use zoning as

260.5597m³/s of runoff reduced at city level only by land use zoning strategies.

The estimated values of runoff indicate that, if the land use zoning performs this much runoff volume reduction; the application of NbDS can do better reduction of stormwater runoff than only rearranging land uses.

4.6.2. Potentials and Challenges of Nekemte city and Opportunity and Limitation of Nature-based Drainage solution

Table 19 : Potentials and Challenges of Nekemte city and Opportunity and Limitation of Nature-based Drainage solution

Existing Potentials in Nekemte city	Existing Challenges in Nekemte City
<ul style="list-style-type: none"> • Existing opens spaces and riversides • Existing spaces for NBDS intervention • People are motivated for tree plantation idea • People are severely affected by and interested in alternative coping strategies towards excessive storm water and flood runoff 	<ul style="list-style-type: none"> • Micro-watersheds with high level of imperviousness • Severe erosion of river bank • Unmanaged waste • Vulnerable flooding problem and excessive storm water runoff
Future opportunities with NBDS	Future Limitations of NBDS
<ul style="list-style-type: none"> • Better climate in the area • Flood protection • Ground water recharge • Increased nature and biodiversity • Infiltration of water • Management of storm water • Multi-benefit solution • Potential income generation • Upgrading of green and blue infrastructure in the city • Water harvesting 	<ul style="list-style-type: none"> • Requires removal of houses • Requires some kind of knowledge or education of inhabitants • Space dependent

(Source: prepared by the researcher)

4.6.3. Design Criteria

Based on the findings the design should be:

- Open for the public
- Provide access to the river
- Nature-based drainage solutions (sustainable Solution)
- Prevent against flooding problem and related issues
- Considering community benefits (recreational and economic benefit)

4.6.4. Design intent

The intent of the design is to create a nature-based drainage system and green infrastructure which can manage storm water runoff to prevent flooding and benefits the local community for recreational as a public good/ realm.

4.6.5. Citywide Proposals

4.6.5.1. Proposal to Catchment Strategy

Green River Restoration

The river side should be covered by plants/trees/shrubs to remove wastes from the river and significant green infrastructures with NBDS should be implemented. The GI and NBDS would create resilience towards flooding problem and related issues.

Inclusion of government owned land for NbDS

Land owned by government such as military camp, offices, schools are in relation to nature and biodiversity and could serve for implementing wetlands or retention basins for storm water as there is space for interventions in these areas.

Greening of Streets

The flow of water could be slowed down by implementing more vegetation along streets. This could be done in terms of planting trees and implementing small raingardens (curb extensions) along the streets.

Extension of flood plains downstream

This could be applied in the areas downstream where flooding is severe. It could also be applied more in land owned by governments by developing stormwater detention ponds.

Proposal for Vulnerable site in Nekemte city

The proposal consists of a concept containing different scenarios of green infrastructure and NBDS which could be implemented at the site.

4.6.6. Objective of the strategy

In relation to water, the main objectives are:

1. To manage the flow and volume
2. To protect the soil along the riverbank from eroding
3. To protect and increase the quality of the rivers
4. To increase ground water recharge (water harvesting)

In relation to the socio-economic aspect, the main objectives are:

- To provide an economic benefit for the river side community through integrating urban farming in the area
- To upgrade the existing environment and nature in the area
- To solve other socio-related issues in the area

4.6.7. The Strategy

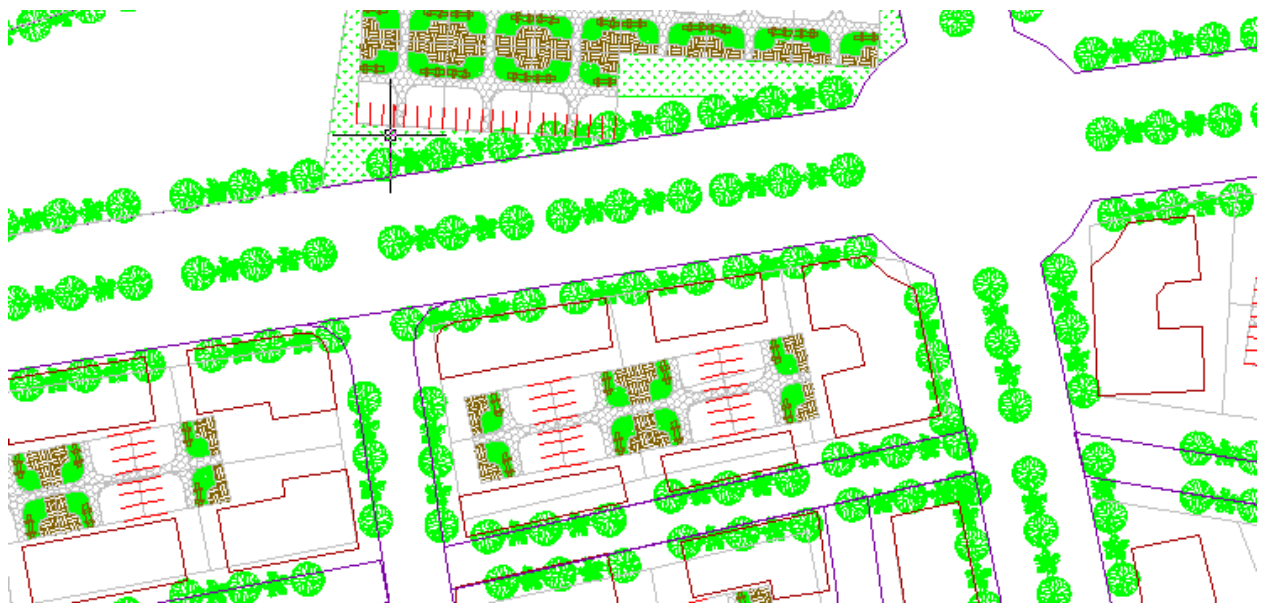
The strategy consists of a significant green belt along the river which is expressed differently in scenarios. By planting trees and vegetation along the river bank, it is possible to;

- a. Influence the runoff acceleration or flow as trees and vegetations cover will create a higher resistance for the water to enter
- b. The amount of water runoff will be reduced
- c. Increase the water quality in the area
- d. Harvest fruits from the tree

4.6.8. Scenarios

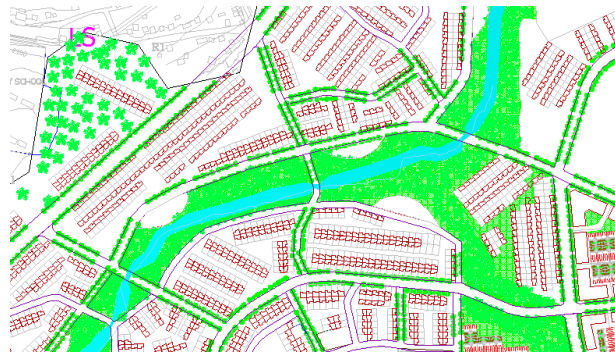
Scenario-I Tree Plantation

The first scenario should be planting trees around and in part to the street at different locations considering standards. The scenario requires the man power and budget to create jobs for unemployment as the tree plants needs management in the cities.



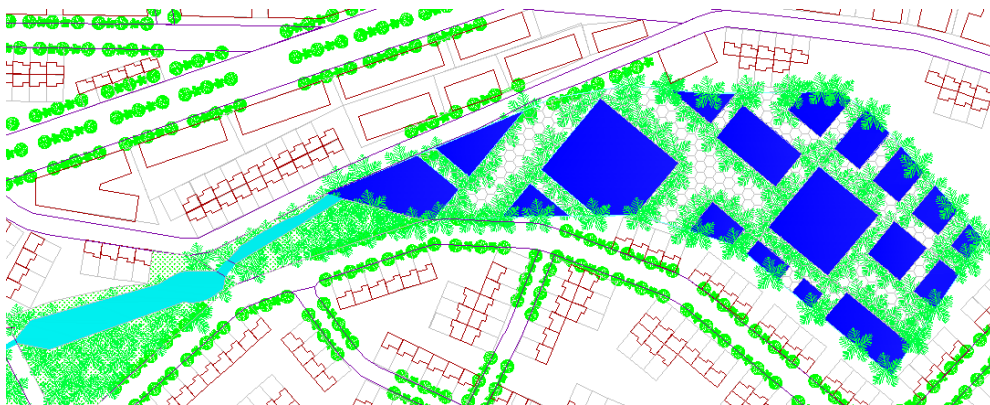
Scenario-II Mosaic Landscape/agriculture-forestry

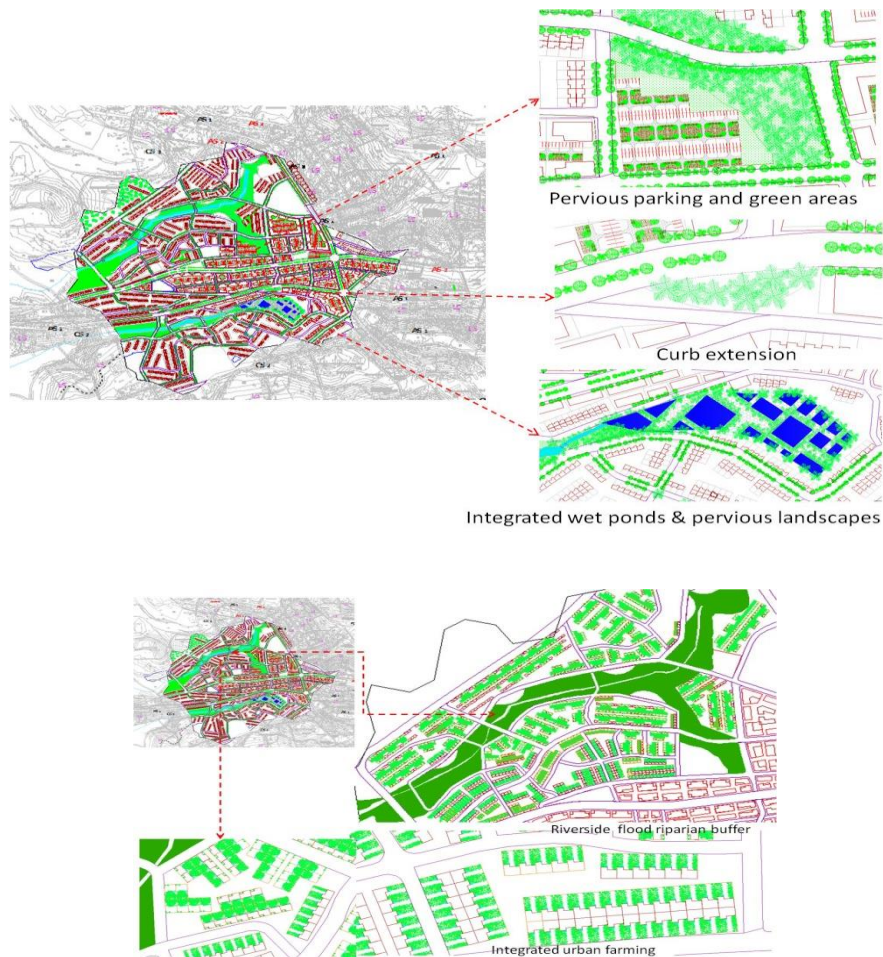
The second scenario is mix of tree plantation and agricultural crop production. The tree plantation should be planted in the areas most prone to flooding according to vulnerability of the site/area. The mosaic landscape should have the different tree species. The Mango and Bananas which can profit families in smaller amount and the trees that can serve as stabilizer of the soil and used for non-timber products such as honey should be integrated in the areas.



Scenario-III Mosaic landscape integrated with public realm and recreations

The third scenario contains the integration of public realm and activities. The area with public realm should be designed and works for multiple functions in addition to recreational areas. The wet ponds curb extensions and flood riparian buffer and the street site areas for recreation services should consider the stormwater management strategies.





4.6.9. Plant species selection strategies

4.6.9.1. Species for Tree plantation

Main function: Stabilize soil along the riverbank and be an asset for the community. Accordingly, the following species tree plants should be applied.

1. *Musa sapientum* (sweet banana)-2-6m: The specie should be a part of the tree plantation and function as supplement source of income. Its function is cash crop already to be more found in the residential areas.
2. *Moringa oleifera* (drumstick tree)-up to 8m, which is characterized by its Deciduous tree, fast growing tree, the tree should be planted in plantation zone, good soil stabilizer, vegetable (leaves) and fruitful tree, and bark is used for medicine

3. *Anacardium occidentale* (broad spread tree) - up to 10m –Cash nut. This plant is also strategic because of it is Good soil stabilizer, Income generator and The Cash nut tree is good cash crop
4. *Mangifera indica* (ever green tree)-up to 10-15m, Mango tree is also the tree ever green and sustain the stormwater runoff risk control The specie should be a part of the tree plantation and stabilize the soil; it is the source of income. Its function is cash crop and already to be found in residential and in public areas.
5. *Ficus sycomorus* (wide root system tree) - up to 20m-sycamore, semi-deciduous tree, used for riverbank stabilization and good for water conservation.

4.6.9.2. Plant Species Secretion Strategies for Agricultural Zones

Majority of the agricultural species are intercropping in the first years of the plantation

1. *Phaseolus vulgaris* (Common beans/dry beans), The dry beans should be planted in the agricultural zone. The small crop should be used for subsistence or income activity. Bean species are seen always in residential areas.
2. *Arachis hypogea* (peanut, groundnut)- 15-60cm high plant, should be planted in agricultural zone and it is subsistence and cash crop
3. *Amaranthus* (cash crop) up to 35cm, can function as a subsistence crop or cash crop, can grow in various soils, prefer irrigation, prefer in residential areas
4. *Chrysopogon zizanioides* (vetiver grass) 50-150cm, should be planted on terraces and uses for intercropping, good for erosion control, deep root-system, good for pest control and can be planted together with crops
5. *Pennisetum alopecuroides* (grass/reed for stabilization of soil), soil stabilizer, reduction of soil erosion and waste removal from river.
- 6.

4.6.10. 3D Design Illustration of NbDS Strategies

4.6.10.1. Typical Riverside flood riparian 3D design

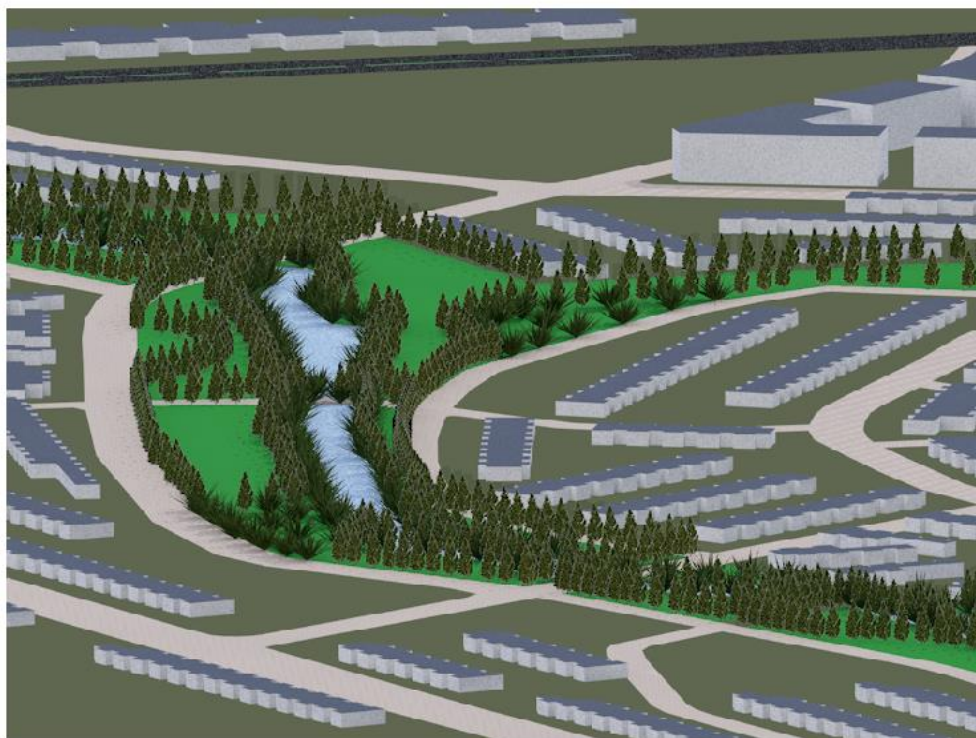
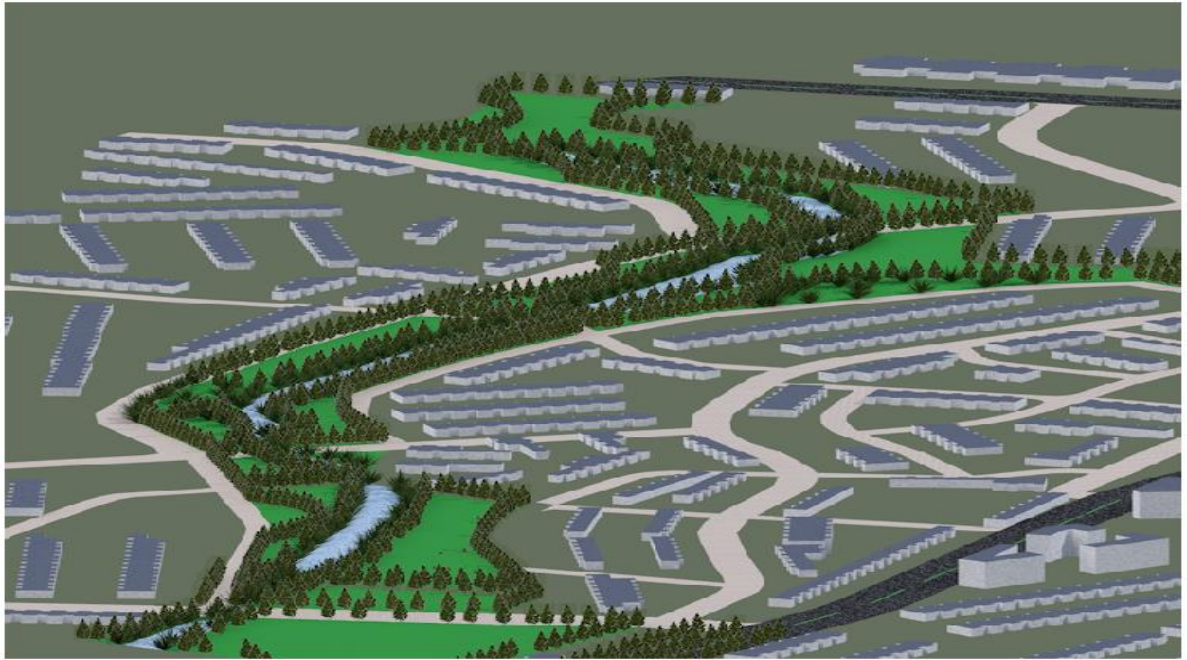
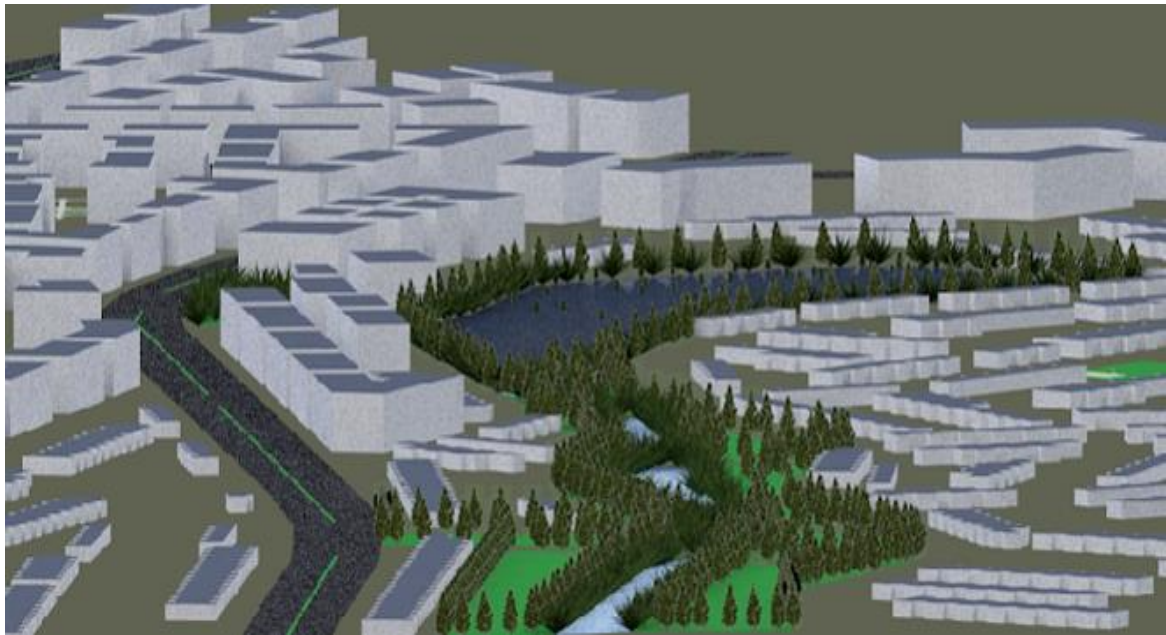


Figure 50 Riverside flood riparian 3D design

4.6.10.2. 3D Design of wet pond



4.6.10.3. 3D design of Rain Garden and wet pond



Figure 51 3D Design of wet pond

4.6.10.4. 3D design of parking area and greeneries

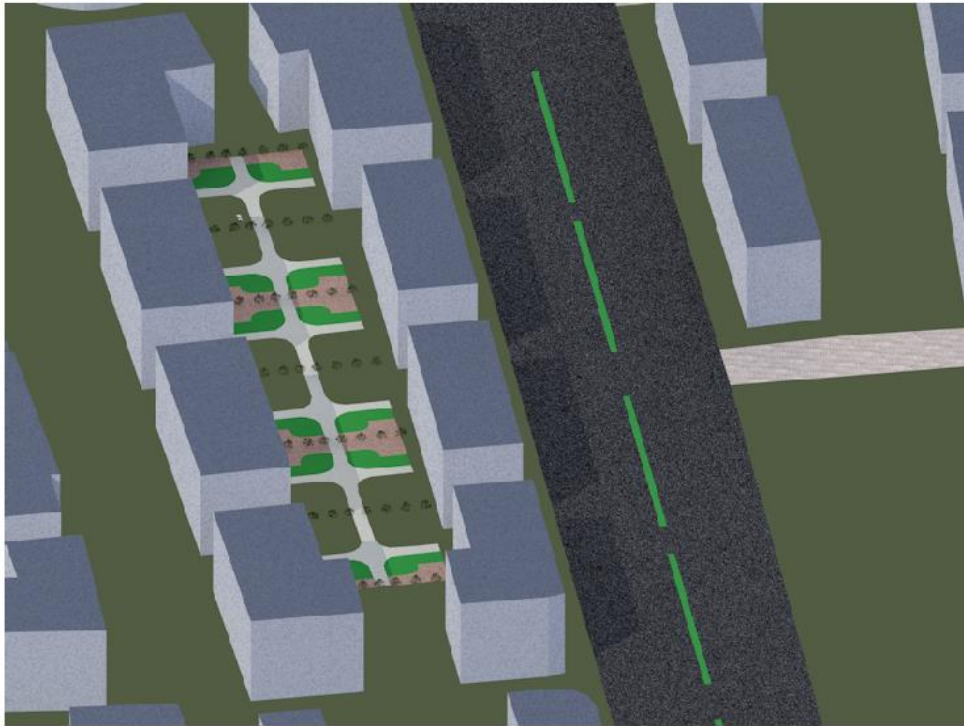
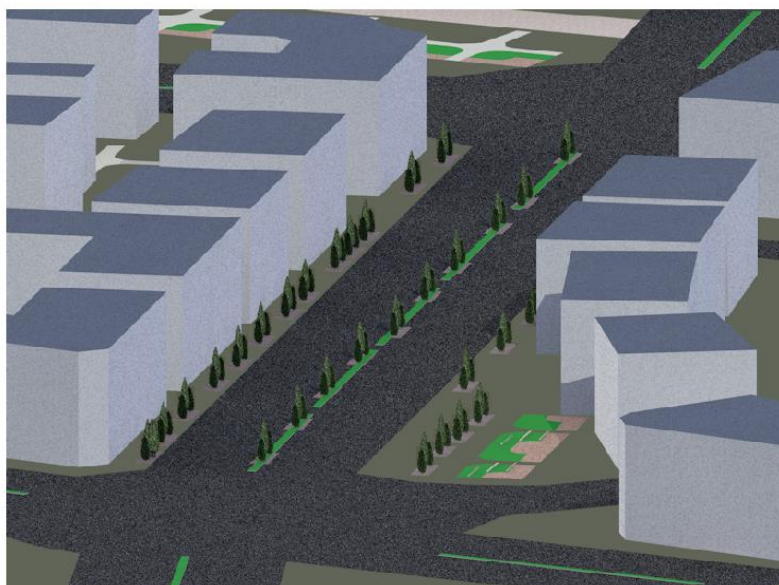
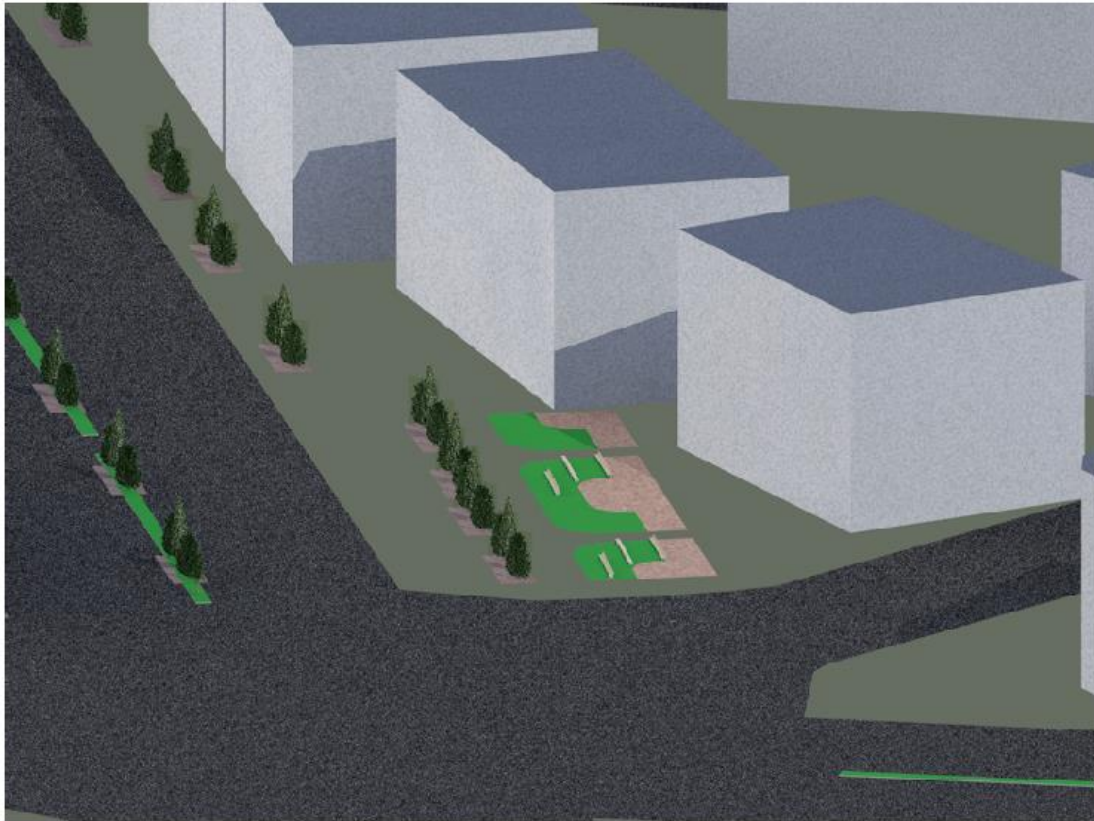


Figure 52 3D design of Rain Garden and wet pond

4.6.10.5. 3D Design of Tree Pits and Street greeneries



4.6.10.6. 3D design of Public realm areas



Nature-based drainage solution design for vulnerable site was done by referencing water sensitive urban design. The site selection from the study area is parametrically based on the more affected micro-watershed by high level of imperviousness than other micro-watersheds. The boundary of the selected site is the boundary of the delineated micro-watershed and identified as affected area.

The site contains two outlets (river/stream flowing out from the site) and no inlet (river/stream flowing in to the site) from nearby micro-watersheds. The first stream which collects more runoff from the center of the site flows to the ponds exists out of the site locally called ‘Haroo Sorgaa’ mean Sorga Lake. The direct contact of runoff from impervious surfaces and sewerage lines attached to the drainage line enhancing the pollution of water and flooding origins in the site.

The result of data analysis shows that there is high rainfall data, variety of slope gradient, high level of site imperviousness, and direct connection of streams with impervious surface areas. The existing residential area of the site is the largest land uses in the area and when calculated by rational formula, the residential areas runoff coefficients result is highest and from the streets the existing largest land cover is cobblestone streets.

The site relative elevation is categorized in to three parts as relatively lower, middle and higher elevation area. The lower and upper elevation areas are relatively gentle slope areas, whereas the relatively middle elevation areas are the area connecting higher and lower elevation areas with relatively steep slope.

Relatively higher elevation areas with high rainfall, high level of imperviousness collects the storm water and bring the runoff to the street, then the relatively middle elevation sites also collect the runoff and initiates the runoff speed and volume to create flash flooding in the area (Schueler, 1994). The situation in relatively lower elevation areas is under the sink of high volume of the storm water and collection of water pollutants from urban areas (Wolman and Schick, 1967).

The site contains different opportunities for implementing the nature-based drainage solutions as different open spaces are exists in the area. The residential land uses areas are expected farming lands in the garden indirectly increasing pervious surfaces in designed manner. The riverside areas buffering with standards with recreational area and greeneries derive the water purification, protection of streams from damage/erosion and increasing soil infiltration (Rose and Lamond, 2013). The public realm design is developed by linking with the multi-functions such as recreational, sittings and parking areas benefiting communities in addition to responding urban flooding problems. Nature-based drainage solutions designed for the site to respond flooding and benefiting the community are design of pond, rain garden for street site

and in blocks/plots, integration of plants and greeneries, floodplain reconnecting to rivers and integration design of public realm areas (Woods Ballard et al. 2015).

4.7.Key Findings

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

- The separate boundary of built-up and un-built-up area of Nekemte city was mapped by delineating densely clustered arrangements of buildings on small scale maps.
- The connection of urban edges such as building polygons dictated by the location of other features were identified for a more generalized representation was map of built-up area of the study area
- The current measured Built-up area of Nekemte city was 89.94% of total legal boundary of city that is 5380.00 hectare in area.
- Impervious surface areas components in Nekemte city were calculated by using built-up ratio parameters and used to measure level of imperviousness of Nekemte city at parcel, block and delineated built-up area level
- As the result of the study shows, the measured level of imperviousness of Nekemte city was 43.40% at parcel level, 36.57% at block level and 33.77% at built-up area level.
- The existing spatial analysis result of the result shows there is variation of slope in Nekemte city and 20 (twenty) micro watersheds fall in built-up area of the city
- Micro-watershed with 47.63% level of imperviousness which covers Bake Jama Neighborhood and some areas of nearby neighborhoods in all direction was identified as more affected watershed from the Nekemte city.
- As the result of site analysis for identified site shows, there was high level of imperviousness and originating more runoff than other micro-watersheds.
- The site selected contain space opportunity to implement the nature-based drainage solution

- As the result of developed sustainable drainage solution for entire Nekemte city shows, the core focus should be targeted on maximization of impervious surfaces considering the strategy needed for the water relation and socio-economic aspects.
- Multipurpose public realm design was the essential element of nature-based sustainable drainage solution as linked with nature-based drainage solution for Nekemte city.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The increment of urban areas in level of imperviousness causes Urban flooding which is more of a human induced problem than natural. In this study GIS software is used to measure and map the built-up area of an urban area in order to identify the level of imperviousness through quantifying the impervious surfaces components. Delineation of micro-watersheds in Nekemte city held to categorize the urban area in to different boundaries, this helps to identify the level of imperviousness at micro-watershed area by using built-up ratio parameter.

The micro-watershed with higher level of imperviousness n Nekemte city, around Bake Jama neighborhood is affected site of urban areas as it is less infiltration area of storm water in to the soil. However, the problems those have arisen due to the increase of urban catchments in level of imperviousness can be treated through integration of nature-based drainage solution to the appropriate areas in order to reduce the problem of flooding and related issues.

Depending on the site-based detail water sensitive design for vulnerable area of the city, the study suggests strategy of water relation and socio-economic aspect enhanced by nature-based drainage solution linked with the public realm design. Therefore, the problems cannot be completely solved, but the damages can be reduced. Indications from this study can be taken to reduce the overall urban flooding vulnerability and the damages during urban flooding in Nekemte city.

5.2.Recommendation

Sustainable storm water management strategies through applying Nature-based drainage solution system should be supported in urban areas. It is known that not only for storm water management strategy, but also a way to bring more bio-diversity enhancements, socio-economic support for community, green improvements and mixed-use spaces for community benefits.

In addition to reduction of urban flooding and related issues in Nekemte city, the sustainable storm water management strategies developed to reduce the potable water consumptions in urban areas by developing storm water harvesting sites as ponds/wetlands. Thus, if nature-based drainage solution system should be integrated to vulnerably affected micro-watersheds by high level of imperviousness in urban areas, the benefits are more including environmental and social.

The solutions are helpful to reduce the problem of storm water runoff causing flooding problems and related issues, especially by applying in the river side, open spaces and government owned institutions. In these regards, government own vacant lands should be taken as the area of potential site to design and implement nature-based drainage solution the system. In general, the following recommendations would be forwarded based on the result of the study.

- Built-up area of Nekemte city should be measured and mapped to identify the extent of built-up area and direction of urban expansion occurring as to know the level of imperviousness that create urban flooding problems in order to give attention for responding through water sensitive urban design interventions.
- Scientifically, it is possible to measure the urban micro-watershed level of imperviousness by using digitizing components of impervious surface areas and it

should be supported by asking the local communities and stakeholders to identify clear problems occurred because of urban imperviousness in Nekemte city.

- Site-specific design of nature-based drainage solution system should be developed with support of relevant data and standards to verify effectiveness of the selected nature-based drainage solution before and after development of the design.
- The implementation of nature-based drainage solution should get government and non-governmental interventions as the financial and management process are mandatory

Finally, developing sustainable storm water management strategy needs systematic analysis of spatial, hydrological and socio-economic data of the existing situations. In this study the researcher limited to focus on spatial and hydrological data because of the time and financial resource limitations. Moreover, the researcher suggests including study of the socio-economy condition of local community that are vulnerable to flooding to give clear picture of the problem for the policy makers. In this regards, further research is needed to address the impact of imperviousness and resulted flooding on the livelihood of local communities in the study area. Moreover, the nature-based drainage solutions proposed for the Nekemte city can be linked with socio-economic benefits to improve the livelihood of the urban poor by involving in water harvesting and urban farming activities. The detail analysis of socio-economy and response with nature-based drainage solution in creating job opportunity for unemployed is further study area for Nekemte.

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Appendixes



Addis Ababa University, EiABC-campus
Masters of Science in Urban design and Development



Research Questionnaire

Introduction: This questionnaire is designed for the purpose of collecting data for research being undertaken for partial fulfillment MSc degree in urban design and development, with the title of ‘**Measuring the Level of Imperviousness for Developing Nature-Based Drainage Solutions and Sustainable Stormwater Management of Nekemte City.** Responses to this questionnaire provide and valuable information that will be used to assist in measuring, mapping built up area in order to show storm water management strategies. I would be very grateful if you would take the time to complete and return this questionnaire

Questionnaire code _____

Part-I background of the respondents

- 1 Age? _____
2. Gender? Male Female
- 3 Education level? _____
5. Area of the building in M²? _____
7. Paved surface area in M²? _____
- 4 Occupations? _____
6. Plot area in M²? _____
- 8 Current arrangement? _____
Own lease rental Kebele condominium Other: _____
- 9 What is the duration you lived at location in years? _____
- 10 Means of liquid waste disposal?
sewerage line onstreet disposal direct to drainage direct to river underground Other: _____

Part-II questions

Please read the following question items and respond your answer by marking "v" sign under your choice listed from 1-5 ranks

Cod e	Questions	1 Very small	2 Small	3 undecide d	4 high	5 Very high
	Urbanization of Nekemte city					
1	How do you rate Urbanization of Nekemte city					
2	How urbanization is affecting on natural environments in Nekemte city					
	Impact of urbanization in Nekemte city					
3	What is the extent of urban heat increase relating with imperviousness					
4	What is the extent of air pollution relating with imperviousness					
5	What is the extent of water pollution relating with imperviousness					
6	What is magnitude of stormwater runoff relating with imperviousness					
	Stormwater runoff in Nekemte city (How do you Rank the origin of flooding in your environment?)					
7	Storm water Runoff from urban street					
8	Stormwater runoff from urban buildings					
9	Stormwater runoff from Elevated site					
10	Stormwater overflow from filling the drainage line					
11	Stormwater runoff overflow from river side					
Cod e	Questions	1 Very small	2 Small	3 Undecide d	4 high	5 Very high

	Types of rain events (How do you rank the rain events causing flooding in your area?)					
12	Short intense rain cause flooding					
13	Long moderate rain cause flooding					
14	Long heavy moderate rain causing flooding					
	Types of flooding (What is the level of type of flooding problem did you experienced)					
15	Business/home flooding					
16	Sewer yard flooding of extended duration					
17	Pluvial (Due to incapacity of drainage systems)					
18	Fluvial (Out of River Flooding)					
19	Flash flooding					
	Land use type and storm water runoff created by land uses (how do you the following land use creating runoff in your area)					
20	Residential area creating stormwater runoff					
21	Commercial area creating stormwater runoff					
22	Organizations, industries and school's area creating stormwater runoff					

Thank You for taking your time to complete this questionnaire.

*If you have any queries relating to this questionnaire, please contact me.
Contact Details: nuywalif@gmail.com or 0912100291*

Part-Three-Interview Questions

1. Are there any projects implemented in your area to manage stormwater runoff?
2. What is the strongest part of projects done in Nekemte city for stormwater management?
3. Which area specifically degraded or erosion affects do you know?
4. In your area, what mechanisms do you use in order to protect your property from urban flooding?
5. Traditionally which mechanism of stormwater management is appropriate for you?
6. How do you look using rain water for your house?
7. Do you harvest rain water from your building's roof?
8. How do you explain releasing of rain water as its rain can affect the increase of urban runoff volume and speed?

Part four- Focus group discussion questions

1. How we can explain the area affected by storm water runoff in Nekemte city?
2. What is the major problem that causing the increase of urban stormwater runoff volume and speed?
3. Which mechanism is more sustainable to implement for stormwater runoff?
4. How we can practice nature based- stormwater management strategy for Nekemte city?