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

Potential Solutions for Spatially Disconnected Ginfile sub watershed of Woliso Town, Ethiopia.

By
Demelash Geremew Jebessa

Thesis Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for Master of Science Degree in Urban Design and Development

May, 2023

Addis Ababa, Ethiopia

Approval

This is to certify that the thesis prepared by **Demelash Geremew**, entitled: **Potential Solutions for Spatially Disconnected Ginfile sub watershed of Woliso Town, Ethiopia.** and submitted in partial fulfillment of the requirements for the Master of Science degree in Urban Design and Development; complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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1. **ALAZAR ASEFFA** (PhD)

Advisor	Signature	Date

2. **TIBEBU ASEFFA** (PhD)

External Examiner	Signature	Date

3. **DAGNACHEW ADUGNA** (PhD)

Internal Examiner	Signature	Date

4. **ABUNU AREGA** (PhD)

Chair person	Signature	Date

5. DAGNACHEW ADUGNA (PhD)

Graduate Program Director	Signature	Date

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Addis Ababa, Ethiopia

May, 2023.

Name: Demelash Geremew Jebessa

ID No: GSR/6243/12

Sign: ______________________

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This is to confirm that, Demelash Geremew Jebessa has carried out this research on topic: "Potential Solutions for Spatially Disconnected Ginfile sub watershed of Woliso Town, Ethiopia." under my supervision and it is sufficient for submission for the partial fulfillment for award of degree of Masters in Urban Design and Development.

Advisor – Alazar Assefa (PhD)

Sign: _____________ Date: ______________

Chair of Urban Design and Development

EiABC

ACKNOWLEDGEMENT

Next to the Almighty Lord God, I am immensely grateful to my advisor Alazar Assefa (Ph.D.) for his dedicated support, direction, and insightful advice. His timely responses to my queries, professionalism, and expertise were instrumental in the successful completion of this research. His feedback and recommendations were very helpful in the finalization of the paper. I want to offer my sincere appreciation to the many wonderful friends, who shared ideas with me through our conversations. My thanks also go to the Municipality of Woliso town for the invaluable information and data they provided. Their enthusiasm towards my study was fundamental in ensuring the accuracy of the data and the success of my findings and results. I owe a debt of gratitude to everyone for their wisdom, knowledge, sensitivity, and perspective. Lastly, I want to thank my family for their understanding, love, and support throughout the process. Most importantly, I am thankful to have an incredible source of strength in my life, my beloved wife Architect Feven K., and my sons, who have been an endless source of motivation. Thank you and may the Lord bless you all!

Abstract

The Woliso town, originally centered around the natural spring 'Filwuha,' features abundant natural resources like the valuable hot spring 'Hora Ayetu,' scenic landscapes, and perennial streams sustaining fertile soil year-round. However, rapid population growth and urban expansion are disrupting the delicate ecological balance. Understanding the spatial organization of surface water in urbanized areas is crucial for sustainable water resource management and mitigating environmental impacts. In the study area, the majority of potential blue spots and wetlands are encroached upon by impermeable surfaces, leading to fragmented hydrological channels and limited connectivity with the broader stream network, exacerbating flood risks during extreme events. The research aims to assess the spatial and temporal connectivity of urban streams, considering the influence of land use changes and raising awareness of surface water management in the Omo Gibe sub-basin region. Employing GIS and remote sensing techniques, the study evaluates watershed characteristics and stream connectivity using morphometry, graph metrics, and spatial analysis. Results indicate that urban expansion has significantly altered surface water bodies and riparian zones, leading to their reduction, disappearance, and pollution. Addressing these challenges requires an integrated, proactive approach to land management and planning at both regional and local scales, emphasizing the importance of incorporating water bodies and riparian areas into sustainable urban design strategies to preserve their social and environmental value.

Key words: Graph Metrics, Morphometric, Stream connectivity, Watersheds, Wetlands/blue-spot, Woliso town;

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List of Acronyms and Abbreviations

Abbrev	Descriptions
COHESION	patch cohesion index
CPWD	Community-based Participatory Watershed Development
CWA	Clean Water Act
DEM	Digital elevation model
DPC	delta probability of connectivity
DSS	Decision Support Systems
EiABC	Ethiopian Institute of Architecture Building Construction and City Development
ENN	The Euclidean nearest-neighbor distance
ESDA	Efficient Spatial Data Analysis
FPOM	Fine particulate organic material
GBI	green-blue infrastructure
GIS	Geographic information system
GIS-MCE	GIS-Based Multi-criteria Evaluation
GW	Ginfile watershed
GWD	Groundwater Depth
IIC	integral index of connectivity
IJI	interspersion and juxtaposition index
IPCC	Intergovernmental Panel on Climate Change
IWM	Integrated watershed management
LPI	largest patch index
LU-LC	Land Use/Land Cover
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetland Inventory
PD	patch density
SDCSE	South Design and Construction Supervision Enterprise
SPSS	Statistical Package for the Social Sciences
SW Showa	South West Showa
SWS	Sub watershed
TIA	Total Impervious Area
UH	Urban Hydrology
UHI`	urban heat islands
UN OCHA	United Nations Office for the Coordination of Humanitarian Affairs.
USEPA	U.S. Environmental Protection Agency's
WSUD	Water-Sensitive Urban Design
WSUDP	Water-Sensitive Urban Design and Planning
WWDSE	Water Works Design Supervision Enterprise

CHAPTER ONE
INTRODUCTION

1.1. Back ground of the study

The Woliso town, located 114 kilometers south of Addis Ababa on the Jimma Road, has a long history dating back to 1923 (1919 EC) when it was first established and gained its urban status in 1930. Before the Italian occupation in 1935, a considerable amount of people had already congregated around the hot springs known as "Hora-Ayetu" or "Filwuha", as well as the market, some small business owners, and military personnel in the vicinity of the "*Abune-Gebremenfes-Qidus*" Church. The town originated from the natural spring, 'Filwuha' at the back of the church and in the area of the hilly rock called 'Gara'. This area is known for its natural beauty, including its hot springs (*'Hora Ayetu'*), green hills, panoramic views, and perennial streams that nourish the rich soil throughout the year *(Source: Woliso town socio-economic & spatial report, 2018)*.

The expansion of urban areas, both in terms of their geographical footprint and population density, profoundly impacts the natural infrastructure and disrupts its inherent processes (Ampatzidis, et al. 2020). This urbanization trend often entails a proliferation of impervious surfaces, hindering the unimpeded flow of water along interconnected stream networks and infiltration into the soil (Snyder et al. 2005). In the specific study area under consideration, a significant portion of potential blue spots and wetlands has been enveloped by impermeable materials, resulting in the disconnection of urban streams from the broader network of watercourses. Consequently, these areas are particularly susceptible to flooding, as evidenced by observations in the region. Moreover, this phenomenon exerts a detrimental impact on the health and ecological integrity of the urban landscape, leading to ecosystem degradation and biodiversity loss attributable to the disregard for stream connectivity and the wetland components of the natural watershed.

Putting the current surge of scientific interest in water systems interconnectivity and the cumulative effect of land use on bodies of water into account, the study provides an overall understanding of the topic and approaches to the problem. The purpose of the research is to evaluate the Spatial Connectivity of urban water streams for Rehabilitation, with the aim of raising its environmental and communal value by upholding the eco-hydrologic functionality of detached streams with a Water Sensitive Urban Design approach.

1.2. Statement of the problem

The expansion of urban areas leads to a proliferation of impervious surfaces, obstructing natural water flow into the ground and through interconnected streams. This disruption alters the hydrological characteristics of watersheds, resulting in significant physical and ecological repercussions, including ecosystem degradation and biodiversity loss (Ampatzidis, P. 2020).

However, the implementation of water-sensitive urban design, (WSUD), particularly pertinent to inner-city development, is hindered by the existing built environment's failure to account for natural surface water patterns and streams. Consequently, rapid urban population growth and infrastructure demands have escalated imperviousness levels and associated physical and ecological consequences.

Within the study area, nearly all potential blue spots and wetlands have succumbed to impermeable coverings, severing streams from the broader network and escalating flood risk during extreme events. This exacerbates urban environmental degradation, diminishing biodiversity and ecosystem health due to inadequate consideration of natural watershed streams and wetlands.

The Assessment on Spatial Connectivity of Urban Hydrologic Streams for Rehabilitation of Ginfile sub-watershed in Woliso Town, Ethiopia, identifies a research gap regarding insufficient information on spatial stream connectivity and hydrological analysis. While previous hydrological studies exist, they lack detailed insights into stream connectivity and its contribution to watershed hydrology. Hence, this study aims to bridge this gap by conducting a spatial stream network analysis and assessing connectivity to provide recommendations for watershed rehabilitation.

1.3. Objectives

1.3.1. General Objective

To identify a potential solution for spatially disconnected watershed of Urbanized areas.

1.3.2. Specific Objective

1. To characterize the geo-morphological characteristics of the sub watersheds.
2. To identify the level of stream disconnectedness.
3. To investigate the land use dynamics causing the stream disconnection.
4. To assess the spatial impact of urban flood inundation due to stream disconnectedness.

1.4. Research Questions

1. What are the Geo-morphological characteristics of Ginfile sub watershed that shape the existing stream patterns?
2. What is the degree of disconnectedness of the streams in the sub-watershed?
3. How the change in land use dynamics influence stream connectivity?
4. What are the spatial impacts of urban flood inundation due to stream disconnection within the study area?

1.5. Significance of the study

The primary importance of this study is to address critical surface water management issues within spatial planning and urban development processes. By enhancing the understanding of landscape connectivity in relation to surface-water dynamics and land use variations, particularly in urban environments, this study contributes to maintaining the eco-hydrologic performance of disconnected streams. Moreover, it serves to raise awareness among planners and policymakers regarding the spatial connectivity of urban streams and their linkages to the broader stream network. The research underscores how fabricated land cover, such as imperviousness, alters hydrological characteristics and stream connectivity within the Ginfile sub-watershed.

The study holds both academic and administrative significance:

For city authorities and local governments, the findings provide valuable insights that aid in the formulation of informed strategies for managing development plans, significantly enhancing surface water management practices in urban growth and spatial planning processes. Academically, the research offers a foundation for future studies in urban hydrology. Other researchers can build on these findings to explore watershed hydrological characteristics and stream-wetland connectivity, contributing to a broader understanding and sustainable water resource management in urban environments.

1.6. Scope of the study

The research delves into the thematic domain of urban hydrology, specifically honing in on the spatial connectivity of surface water, notably streams, within a designated sub-watershed. It aims to dissect the intricate interplay between changes in land use dynamics and imperviousness, seeking to unravel their impacts on hydrological characteristics. While the concept of connectivity may harbor multifaceted connotations, this study primarily delves into its spatial dimension.

The study area encompasses the Ginfile watershed within Woliso town, spanning 460 hectares. Geographically, it extends between 37° 58′ 18″ and 37° 59′ 40″ east longitude, and between 8° 31′ 10″ and 8° 33′ 35″ north latitude. This geographical boundary aligns with the recommended range of 200-500 hectares for effective watershed planning, as proposed by CPWD (Central Public Works Department).

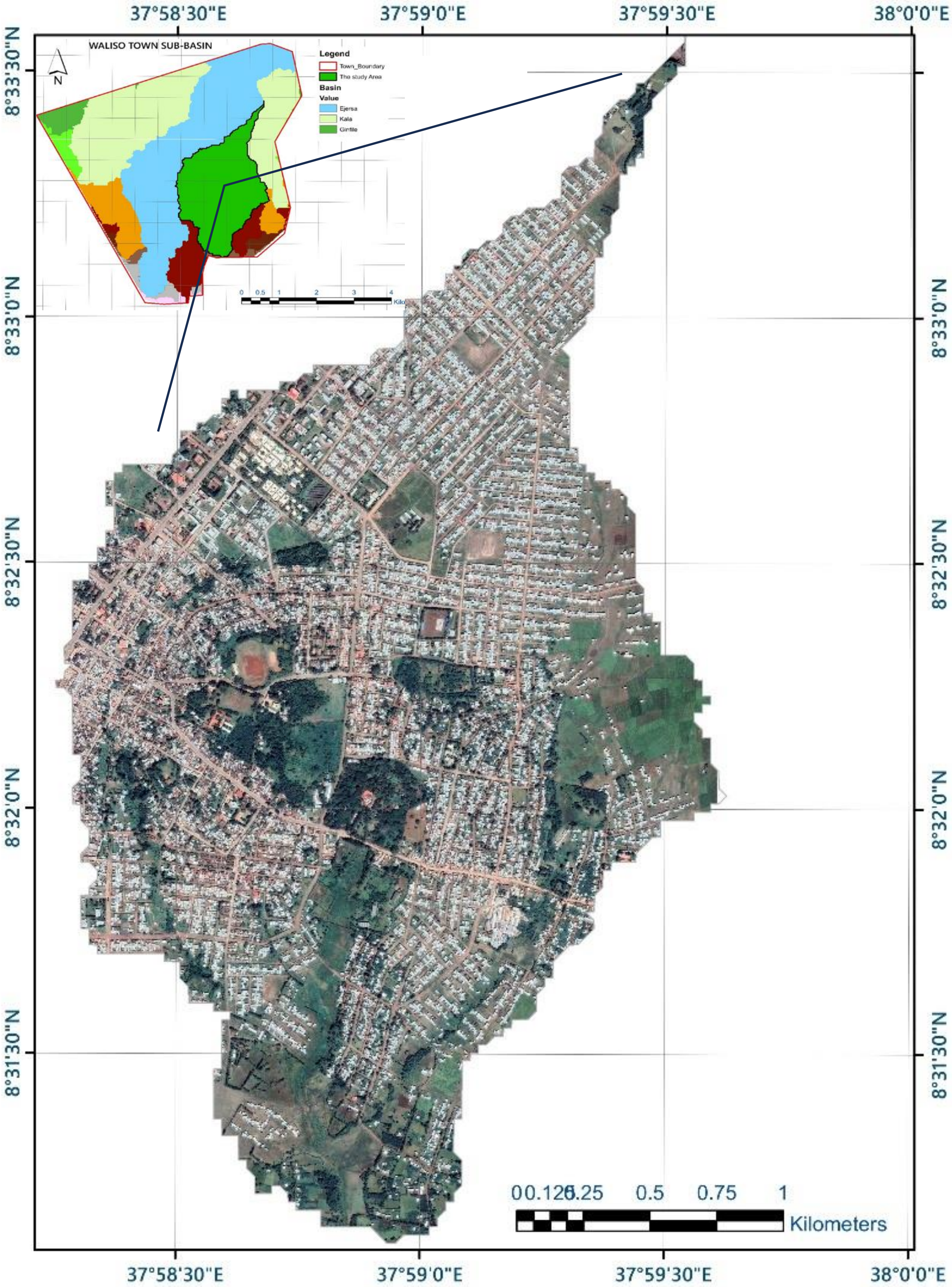


Figure 1. google imagery of the study area delineated watershed using ArcGIS.

1.7. Research limitations

While this study has provided valuable insights into the impact of urbanization on the spatial connectivity of surface water, it is important to acknowledge several limitations that warrant further investigation. Firstly, the imprecision of topographic data, particularly contour maps, may have introduced inaccuracies into the analysis. Ground surveys and total station measurements, although commonly used, are prone to errors and may not fully capture the complex terrain of the study area. Additionally, the accessibility of data on groundwater table depths was limited, which could have influenced the accuracy of the analysis. The difficulty in defining the base and thicknesses of the clogging layer within the streambeds further compounded this limitation, as large-scale heterogeneity posed challenges to accurate measurements. Moreover, the availability of data pertaining to aquifers and hydraulic conductivities was lacking, hindering a comprehensive understanding of groundwater dynamics. Addressing these limitations through improved data collection methods and enhanced accessibility to relevant data sources would strengthen future research efforts aimed at unraveling the complexities of hydrological stream connectivity in urban environments.

CHAPTER TWO
LITRATURE REVIEW

2.1. Introduction

The volume of water on Earth is the same as it has been since its inception. This volume is approximately 1.386 billion cubic kilometers, with most of it being in the ocean (97%), and the rest being fresh water. This includes all forms, such as liquid, vapor, and solid forms (USGS, U.S. Geological Survey). As shown in (figure 2), the global hydrologic cycle is made up of three subsystems: atmospheric water, surface water, and subsurface water. Surface water flows through rivers and eventually reaches the ocean, and ground water moves laterally until it reaches the rivers and then the ocean. Solar radiation causes

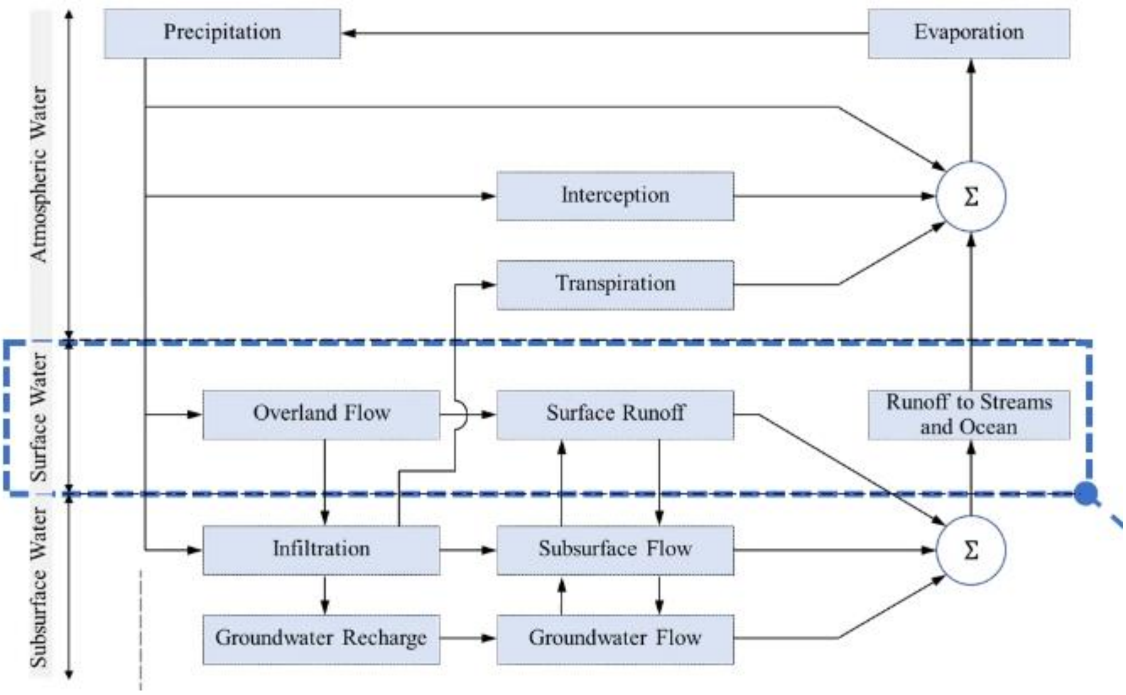


Figure 2. *The three subsystems of hydrologic cycle adapted from Mays (2005, p. 229).*

evaporation and mixing of vapor in the atmosphere, and gravity is a driving force for the water to move from one reservoir to another. Precipitation falls on land or oceans in the form of rainfall or snow. When it falls on land, it may be intercepted by vegetation, infiltrate the soil, or become surface runoff. The water may then evaporate or transpire back to the atmosphere, or percolate down to the aquifer and become groundwater.

2.1.1. Recent Studies on Aquatic Connectivity

Recently, aquatic sciences have progressed from analyzing the characteristics and behavior of singular ecosystems (Valiela and Teal 1979) to comprehending the connections between multiple ecosystems and how these connections play a role in larger-scale landscape operations (e.g., Cohen et al. 2016). Aquatic ecosystem (e.g., streams, rivers, lakes, and wetlands) are able to interact because of their capacity to transport and exchange energy and material, and by their capacity to modify the fluxes of these substances. A key factor influencing these interactions is connectivity, which is the level to which components of a river system are linked, or connected, by various transport systems (USEPA 2015). Therefore, numerous studies have looked into aquatic connectivity, including: (1) connectivity between wetlands (e.g. McIntyre et al. 2014; Uden et al. 2014; Hayashi et al. 2016; Leibowitz et al. 2016; Vanderhoof et al. 2016); (2) connectivity between hillslopes and streams (i.e. Jencso et al. 2010; Jencso and McGlynn 2011; Bracken et al. 2013; Reaney et al. 2013; Janzen and McDonnell 2015); (3) connectivity between rivers, floodplains, and floodplain wetlands (Rooney et al. 2013; Vilizzi et al. 2013); (4) connectivity between wetlands found in non-floodplain areas and rivers (McLaughlin et al. 2014; McDonough et al. 2015); and (5) connectivity between other river system components (Giblin et al. 2014; Harvey and Gooseff 2015; Moore 2015; Hauer et al. 2016). Recent research has also explored how connectivity plays a role in providing ecosystem services (Mitchell et al. 2013; Jordan and Benson 2015) and its significance for watershed and aquatic ecosystem supervision and protection of delicate waters (Uden et al. 2014; Crook et al. 2015).

Much of the recent research done on cities and metropolitan areas has been devoted to examining the impacts of spatial development patterns on quality of life. One particular area of interest is the measurement of the hydrologic connectivity of streams, which looks into the connections between upstream parts of urban streams and their downstream tributaries. This is of paramount importance because of its relevance to the Clean Water Act (CWA) of the United States, which seeks to restore and maintain the chemical, physical, and biological integrity of the country's waters (Wohl, 2017). Thus, there has been a focus on connectivity with respect to the effects of wetlands and non-perennial streams on downstream waters (Leibowitz and Nadeau 2003; Caruso 2011). Additionally, the lack of connection (i.e., isolation) has been identified as a contributing factor to these systems (USEPA 2015). As a result, research is now focusing on the full connectivity-isolation spectrum of aquatic ecosystems (Cohen et al. 2016; Rains et al. 2016), including ephemeral and intermittent streams, as well as geographically isolated wetlands (wetlands surrounded by uplands); (Leibowitz 2015; Mushet et al. 2015).

2.1.2. Concept and definition of Urban Hydrology

Hydrology is the discipline of water that studies its origin, movement, distribution, and properties in the environment (Gburek, 1998). In urban environments, extensive modifications to the physical landscape, including the construction of roads, buildings, and various structures, have significantly altered the natural hydrological processes (Dhakal et al., 2018). These alterations influence the flow, storage, and movement of water within the area, particularly during precipitation events. In addition to natural factors such as soil and topography, man-made structures such as roads, walls, and impermeable surfaces play a crucial role in shaping water movement by creating physical barriers (Herrmann et al., 2016). While these modifications facilitate the prediction of water flow patterns, they also present challenges due to the rapid transition in materials across urban landscapes. Moreover, urban water flows exhibit dynamic changes over time, driven by high levels of impermeability and the presence of infrastructure such as channels and underground pipes designed to swiftly drain water from the area and mitigate flood risks (Zhang et al., 2019).

2.1.3. Stream, river, and wetlands

Rivers and streams provide a major source of water for people, supplying it for activities such as irrigation, food production, energy generation, drinking, and transportation. Though these two words may seem interchangeable, they are not. Streams are a necessary precursor for rivers, without which they could not exist (Robert, et all., 2018). There are distinct differences between a stream and a river.

Before delving deeper into streams and the details of their processes, it is important to familiarize oneself with the wider fields of geo-morphology and fluvial geomorphology, which involve the movement of water before it reaches a stream and the subsequent actions of the stream.

Geomorphology concerning the passage of water across the landscape is referred to as fluvial geomorphology. Two significant fluvial activities are surface runoff and watercourse streamflow. Surface runoff carries away eroded particles to streams where many of the materials are moved as sediment in the liquid. Then, watercourse streamflow can take the sediment load downstream. (George; Robert E; et all., 2018)

a) Streams

Streams, essential components of hydrological systems, significantly influence landscapes and ecosystems. They form the fundamental units that converge to create larger river systems (Vannote et al., 1980), characterized by their shallow depths and turbulent flows, which shape surrounding terrain (Gregory et al., 1991). Commonly known as creeks in certain regions, streams traverse diverse landscapes, carving valleys and molding topography as they flow from higher to lower elevations (Wohl et al., 2015). With variable flow patterns and volumes, streams can exhibit consistent flow year-round, experience seasonal fluctuations, or rely solely on rainfall (Stanley et al., 2002). Despite these differences, streams serve as vital pathways for water, sediment, and nutrients, facilitating ecological processes across landscapes (Benda et al., 2004).

stream Length: According to Horton's second law, the stream patterns of a sub-watershed can be explained by the 'laws of stream length', which suggests a direct geometric ratio between the average length of streams of each order in a drainage basin (Horton 1945). Research has revealed that the number of streams of a particular order is logarithmically related to its order, and the points on the graph generally form a straight line (Chow 1964).

i. What Happens Before the Stream Forms?

Precipitation that brings water to a watershed can have a major effect on bare soil. When rain drops fall onto exposed earth, they can push particles into new locations, known as splash erosion (Figure 3a). If the rainfall is more than the soil can absorb, it will create surface runoff, and thin layers of soil may be taken away in sheet erosion (Figure 3b). This can lead to deeper channels formed by the flow of water in rill erosion (Figure 3c). (George Z. et all., 2018).

When a river's depth increases, the speed of the current can cause the erosion of soil, forming channels, known as gullies (Figure 3d). The formation of these gullies is preceded by rill erosion, a process between sheet and gully erosion.

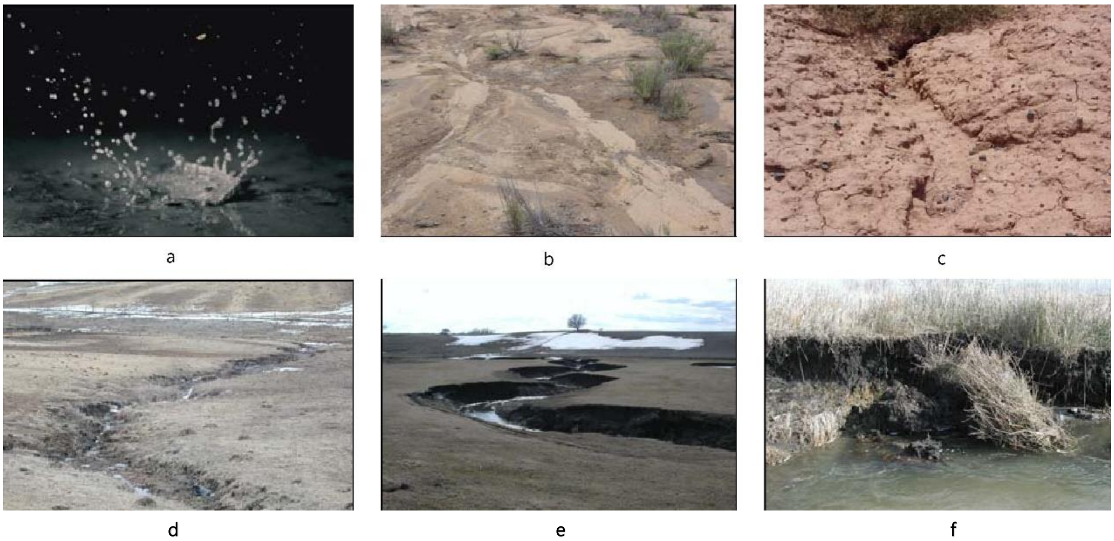


Figure 3. *Different types of soil erosion:* ***(a)***. *splash erosion (Courtesy of NRCS);* ***(b)***. *sheet erosion;* ***(c)***. *rill erosion;* ***(d)***. *gully erosion;* ***(e)***. *and* ***(f)***. *streambank erosion (Sourse: courtesy of G. Zaimes).*

ii. Stream Classifications

Streams display a wide array of characteristics and behaviors, contributing to considerable diversity within their ecosystems. To effectively implement restoration efforts, it is crucial for watershed managers to classify streams based on their distinct attributes. The main objectives of stream classification include assessing stream behavior based on physical characteristics, establishing hydrological and sediment connections unique to specific streams or conditions, comparing streams with similar geomorphic features, and applying data from streams with comparable traits (Montgomery and Buffington, 1997; Rosgen et al., 1996). This classification process provides administrators with valuable insights into stream dynamics, enabling them to choose appropriate management strategies tailored to the specific characteristics of each stream within the watershed.

Classification of a streams can differ depending on the location and may change over time. Common classifications include:

- Classification Based on Stream Pattern: The shape of a channel (planimetric view) can be described by its stream pattern. Differentiating between them can be done by observing the quantity of streams (one or several), the degree of winding, and the permanence of islands when there are multiple streams. Streams that have a curvature index greater than 1.5 are considered to be meandering. The four mainstream patterns are shown on Figure 4.

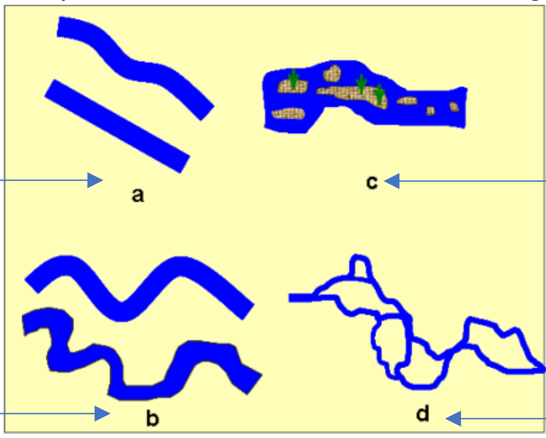


Figure 4. *The different stream patterns: a) straight, b) meandering, c) braided, and d) anastomosed.*

- Classification Based on Stream Flow Conditions: This classification is based on the characteristics of the water flow and how it is connected to the groundwater (Figure 5). Some deep, short-lived gullies may be categorized as ephemeral streams. (George; Robert E; et all., 2018).

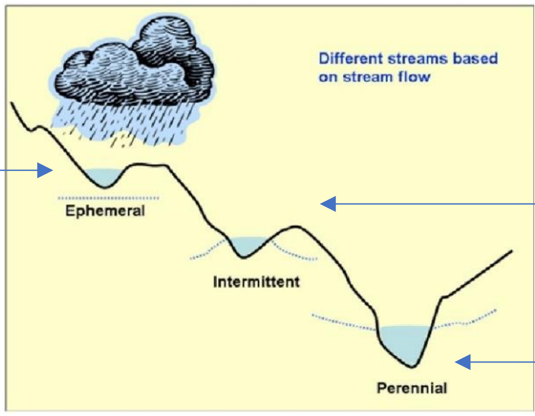


Figure 5. *Ephemeral, intermittent and perennial streams.*

- Classification Based on Stream Order: Stream order is a system of numerical designations that show the place of a certain stream segment in a drainage basin. Small flows from the highlands, like springs and seeps, which keep a consistent stream bed every season, are assigned as first order. When two of these first order streams join, they form a second order stream, and when two second order stream join, they form a third order stream (Strahler, 1952). The hypothetical stream system at left has been labeled to indicate the stream order of the various segments. (fig. 6).

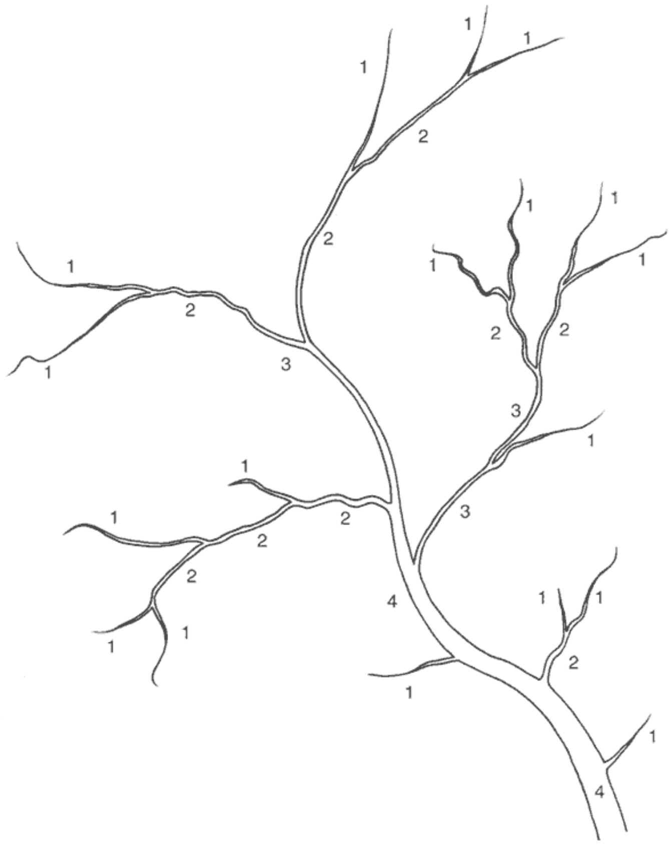


Figure 6. *Stream order classification systems and numerical designations that indicate the particular stream segments (according to Strahler, 1952.)*

The middle reaches are comprised of 4th through 6th order streams. The streams are wider in these sections so even with natural undisturbed riparian vegetation, more sunlight gets to the water and the larger rocks and logs can support films of algae and bacteria, known as periphyton. Lower reaches are of 7th order and greater. These large rivers drain areas of thousands to more than a million square miles (i.e., Nile River). Fine particulate organic material (FPOM), in the drift from upstream segments, remains a feature and an important energy input.

b) River

Rivers, primarily originating from elevated terrains such as hills and mountains, serve as essential components of Earth's hydrological cycle. As precipitation descends from higher elevations, it coalesces into numerous streams, progressively merging at confluences to form larger, more formidable watercourses known as rivers (Wohl et al., 2015). Unlike their smaller counterparts, rivers exhibit greater depth, width, and flow volume, enabling them to transport substantial quantities of sediment and dissolved substances across vast landscapes (Stanley et al., 2002). These watercourses play a pivotal role in the redistribution of materials, conveying them from upstream sources to larger water bodies such as oceans or lakes (Benda et al., 2004). Distinguished by their expansive banks and sustained flows, rivers occupy a crucial position in aquatic ecosystems, harboring diverse flora and fauna and supporting a multitude of ecological functions (Vannote et al., 1980). Within the framework of stream order classification, rivers typically fall within the higher orders, ranging between 6th and 12th order, reflecting their significant size and hydraulic complexity (Ward and Stanford, 1995). At the terminus of rivers where they meet oceans or lakes, anaerobic respiration processes often predominate, shaping unique aquatic environments characterized by distinct biological communities (Smith et al., 1999).

i. The River Continuum Concept

The River Continuum Concept offers an explanation for the differences in physical and biological components along and within a stream from its source to the end of the watershed. It is dependent on the quantity of organic matter, the type of vegetation that can be found along the banks, the sedimentation, and the amount of light that penetrates the stream. This concept explains the interrelationship between the various parts of a river system, how riverside vegetation influences the stream's environment, and how macro invertebrates are impacted by these changes. (Vannote, 1980; Schultz et al., 2000).

ii. Urban Wetlands/ blue spots

According to the Ramsar Convention on Wetlands (RCW), wetlands within urban areas encompass both natural and constructed elements. Natural wetlands include rivers, lakes, swamps, and estuaries, while constructed wetlands comprise artificial features like channels, ponds, and stormwater management sites (Ramsar Convention, n.d.). These ecosystems, with a typical water depth of up to six meters, play a vital role in urban environments, offering benefits such as water purification, flood reduction, carbon storage, and habitat provision for diverse flora and fauna (Mitsch and Gosselink, 2007). Despite their ecological significance, wetlands face significant threats and require conservation efforts to safeguard their integrity (Davidson et al., 2015). Research has revealed that the modification of landscapes and the degradation of upstream wetlands can be damaging to downstream and watershed health. The placement of the wetland in the landscape, as well as its quality and size, can have a big effect on the stream condition. (Robert P Brooks, Abbey Tyrna. et.al. 2021).

iii. Watershed

A watershed, often referred to as a hydrologic unit, constitutes a contiguous area of land that channels water runoff into a common outlet, typically a stream, lake, or wetland (USGS, 2019). This concept, fundamental in hydrology, provides a vital framework for the effective management and planning of water resources within its delineated boundaries (Bosch & Hewlett, 1982). Watersheds play a crucial role in regulating the distribution and flow of water across landscapes, exerting significant influence on the ecological, hydrological, and geomorphological processes within their confines (Bosch & Hewlett, 1982). By understanding the intricacies of watershed dynamics, stakeholders can devise informed strategies for water conservation, flood control, and sustainable land use management, thereby ensuring the resilience and integrity of aquatic ecosystems and human communities alike.

iv. Watershed spatial characteristics

Water is a critical component for both physical and chemical weathering. It has the capability to break down rocks, move soil particles, or even change the contours of an entire hillside. These geological processes are essential for watersheds as they shape the surface which water is transported through (George; Robert et all., 2018). The movement of water within urban environments is influenced by the topography and morphological characteristics of the watershed, mirroring the dynamics observed in natural watersheds (George et al., 2018). Investigating the attributes of a watershed is instrumental in mitigating hydrological issues encountered in uncharacterized or ungauged watersheds, particularly where data availability is limited. Such studies facilitate the quantification of patterns and inherent characteristics of the watershed, thereby aiding in the development of effective management and conservation strategies (George et al., 2018).

2.1.4. Hydrologic connectivity of urban stream and wetland

2.1.4.1. Urban stream connectivity

Urban stream connectivity, crucial for urban ecosystem health, denotes the extent to which streams in urban areas interconnect with each other and their surrounding landscapes (Leibowitz et al., 2018). It enables the movement of water, nutrients, and organisms within the system, establishing vital pathways for physical, chemical, and biological components (Fullerton et al., 2010; Fausch et al., 2002). This hydraulic network facilitates the alteration of material and energy fluxes as water traverses through streams and wetlands (Newbold et al., 1981; Ensign and Doyle, 2006).

Understanding connectivity entails recognizing both structural and functional aspects, with the former concerning the level of connection between system components and the latter focusing on material movement (Pringle, 2001). Isolation, characterized by a lack of transport pathways, inhibits material flow between components. Various factors, such as physical barriers, impervious surface cover, and stream habitat quality, influence urban stream connectivity (Booth & Roy, 2012). Addressing these factors through land use planning, stormwater management, and habitat restoration is imperative for enhancing connectivity and restoring urban stream health (Roy et al., 2011). Implementation of green infrastructure, utilizing natural systems to manage stormwater, is an effective strategy for improving connectivity and restoring hydrological balance in urban areas (Pitt et al., 2015; Shuster et al., 2005). Overall, enhancing urban stream connectivity is essential for promoting sustainability and resilience in urban ecosystems, benefiting both natural habitats and human communities (Fletcher et al., 2015).

2.1.4.2. Connectivity and Transport of Materials to and from Streams and Wetlands

Connectivity encompasses the intricate interplay and interdependence among diverse components within a system, facilitated by various modes of transportation. This structural understanding as tried to be illustrated in (figure 7) contrasts with the functional perspective, which centers on the actual flow of materials between components (Pringle, 2001). Extensive research on river systems underscores the importance of comprehending these connections. The *River Continuum Concept*, for instance, views rivers as gradients of hydrologic structure and function, emphasizing the influence of upstream processes on downstream communities (Vannote et al., 1980). Similarly, the *Spiraling Concept* examines how materials cycle downstream through various forms, such as dissolved substances and living organisms (Webster and Patten, 1979; Newbold et al., 1981; Elwood

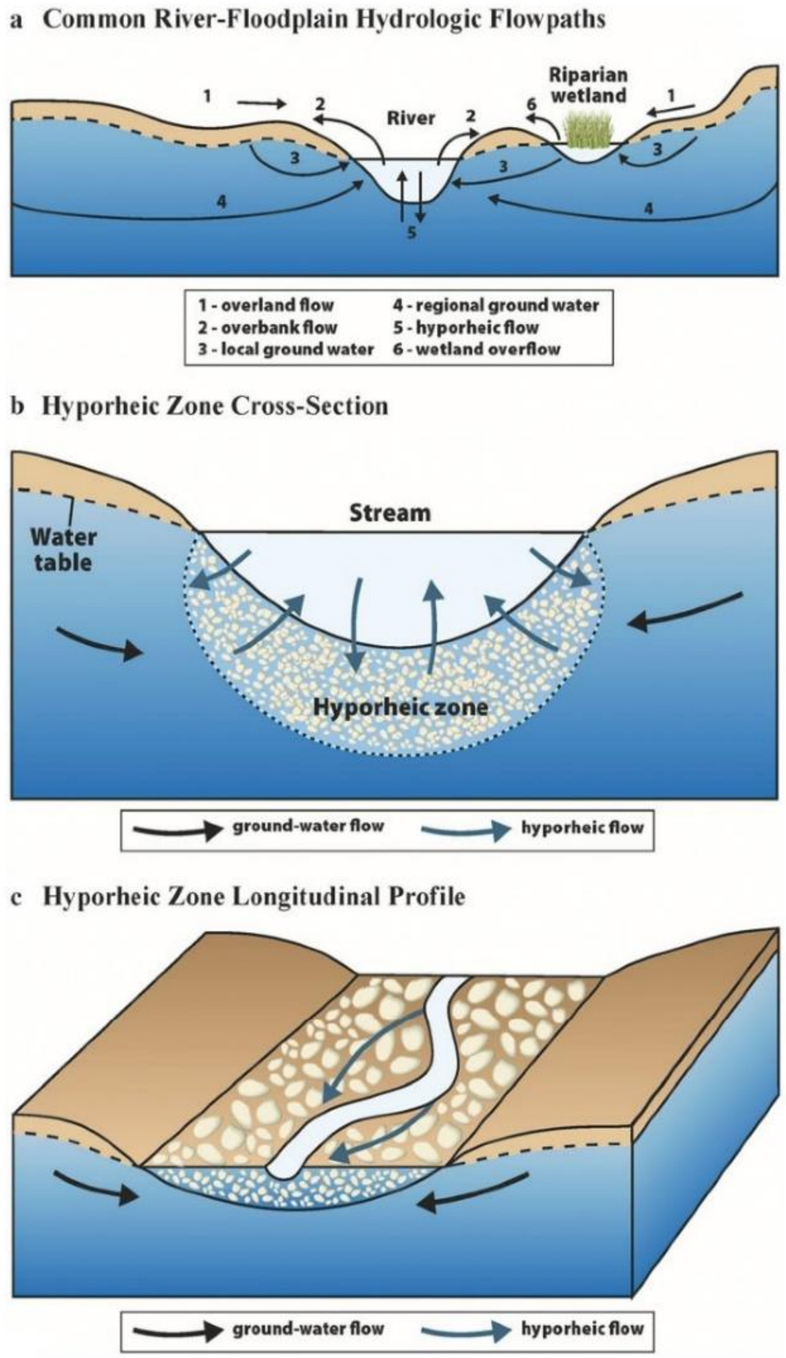


Figure 7. Water movement in river systems. Common hydrologic flow paths, laterally, and longitudinally. Source: USEPA (2015), as modified from Winter et al. (1998).

et al., 1983). The *Flood Pulse Concept* considers lateral connectivity between river channels and floodplains, particularly during seasonal expansions and contractions (Junk et al., 1989). Ward (1989) introduced four dimensions of connectivity in running water ecosystems, highlighting their interactive nature with contiguous habitats. Euliss et al. (2004) expanded on these concepts with the Wetland Continuum Concept, elucidating wetland changes over time amid dynamic climate variations.

Hydrologic connectivity involves the movement of water (figure 7), creating pathways for the transportation of materials and organisms (Fullerton et al., 2010). This process varies depending on connectivity types, such as fill and spill or fill and merge (Leibowitz et al., 2016). Fill and spill occurs when water input exceeds a wetland's capacity, leading to overflow into other water bodies (Leibowitz and Vining, 2003). Conversely, fill and merge happens when one basin's depth surpasses another's, but combined, they can manage total water input. Wetland expansion can establish continuous surface-water connections to streams over long distances (Vanderhoof and Alexander, 2016). Moreover, hydrologic connectivity can occur through groundwater, linking rivers, the hyporheic zone (figure 7), and alluvial aquifers.

Streams and rivers are not simply pipes but dynamic systems that interact with their surroundings, altering material fluxes as they flow (Bencala, 1993; Bencala et al., 2011). Connectivity between streams and wetlands enables the modification of material and energy along their path downstream, potentially changing the composition and form of materials reaching their destination. Sediment retention or biological uptake can extend the time it takes for materials to reach their endpoint (Newbold et al., 1981; Ensign and Doyle, 2006), impacting downstream water condition and function. Connectivity can facilitate nutrient spread and flood reduction, but isolation can prevent contaminant, pathogen, and invasive species spread, enhancing local adaptation (Fraser et al., 2011; Hess, 1996; Bodamer and Bossenbroek, 2008). Therefore, both connectivity and isolation must be considered to comprehend material fluxes from streams and wetlands, striking a balance between the two (Hess, 1996; Bodamer and Bossenbroek, 2008).

Directionality is crucial when evaluating the influence of streams and wetlands on downstream waters. In riparian or floodplain settings, wetlands can exhibit lateral and bidirectional hydrologic connections, while non-floodplain wetlands are generally connected to the stream network via unidirectional, lateral flows (G'orski et al., 2014; Yurek et al., 2016). However, the type of connection can determine directionality, with fill and spill connections being unidirectional, and fill and merge connections potentially bidirectional. Land slope, relief, and climate can affect the frequency of hydrological connections (Tromp-van Meerveld and McDonnell, 2006). Non-floodplain wetlands linked through filling and overflowing can only transport water-borne substances away from the wetland into the river network, while those connected through filling and merging, as well as riparian or floodplain wetlands, can both receive and send material. However, the direction of hydrological connections doesn't necessarily dictate the directionality of geochemical or biological flows, as demonstrated by mobile creatures such as fish moving against the current to upstream areas (Leibowitz et al., 2016; Schofield et al., 2018). Geographically isolated wetlands, surrounded by higher ground, can still link to downstream waters through various hydrological connections, influencing the water, chemical, and biological state of other watershed areas (Tiner, 2003; Marton et al., 2015; Cohen et al., 2016). Yet, further research is needed to fully comprehend the hydrologic connection of these wetlands (Leibowitz, 2015; Mushet et al., 2015).

2.1.4.3. Spatial and Temporal Variability of Connectivity

Connectivity is not a constant element of a system, but varies over time and distance (Ward 1989; Leibowitz et al. 2003/16). According to Cohen (2016), the hydrologic operation of watersheds is reliant on the connection-isolation continuum generated by this variability. This variation in hydrological connection comes from the longitudinal, lateral, and vertical extension and contraction of the river network (figure 5), as well as short-term connections with other parts of the watershed (e.g., through temporary and sporadic connections). Poff et al. (1997) discussed this variation in terms of frequency, duration, magnitude, timing, and rate of change of links between system components.

The extent, amount, timing and type of hydrological linkages are all altered by the growth and shrinkage of river networks. This is particularly noticeable with intermittent and ephemeral streams, which comprise the majority of streams in the contiguous United States (Nadeau and Rains 2007). During seasonal or brief high-flow events, the exchange of water between rivers, wetlands and downstream waters increases dramatically (Fig. 8) (Wigington et al. 2005). Expansion and contraction of rivers also alter the magnitude of connectivity, with larger flows having a greater potential to transport material (Fritz et al. 2018).

Changes in the size and strength of hydrologic linkages have an effect on the timeframe and sequence of flows along different streams gave examples that showed (fig. 8) the importance of intermittent and ephemeral streams (Goodrich et al. 2018). The temporal relationship of these connections is determined by the length, intensity, and timing of precipitation. Similarly, the connection between wetlands and downstream waters could be constant, seasonal, or irregular.

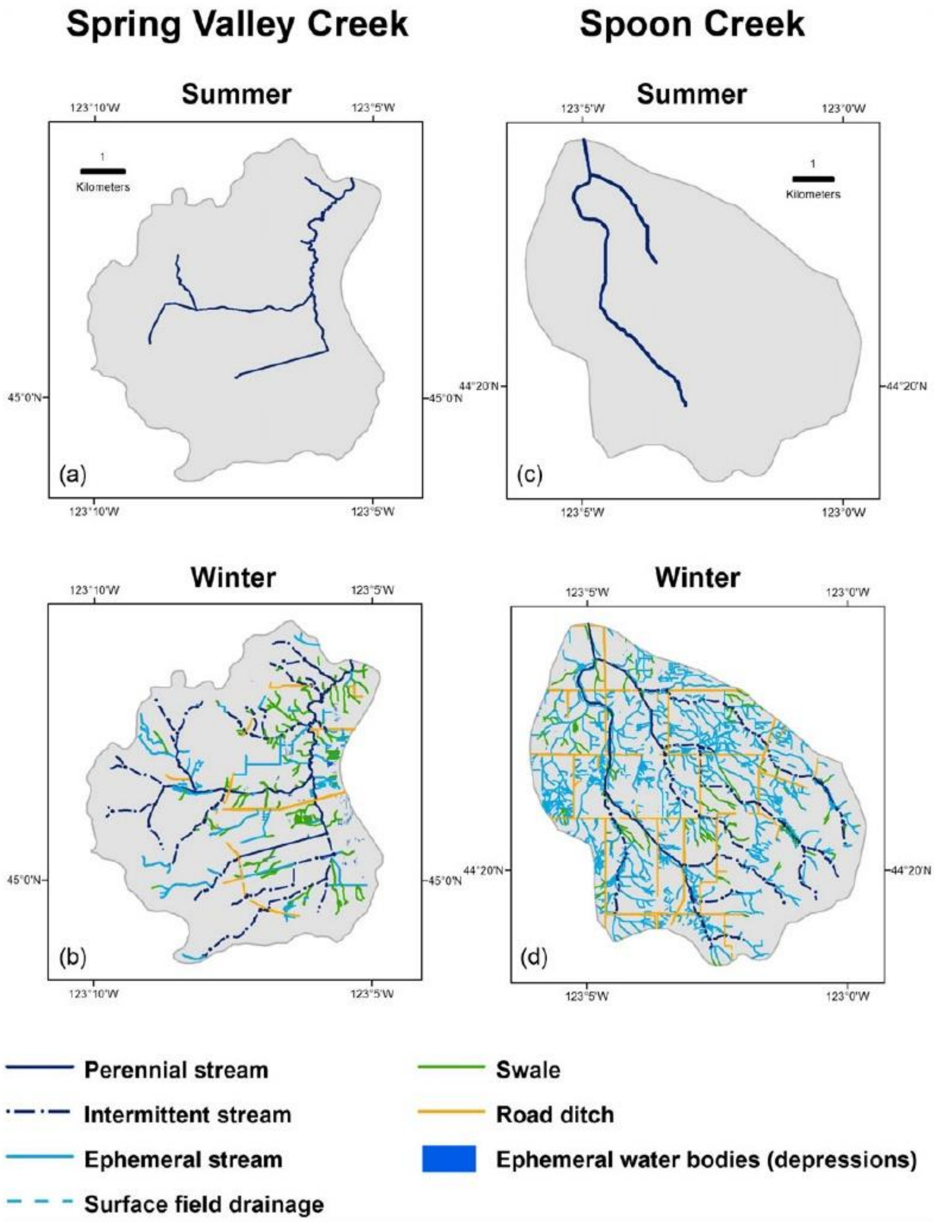


Figure 8. Examples of longitudinal expansion of river networks. Source: (a, b) USEPA (2015); (c) and (d) modified from Wigington (2005).

The fluctuation in the size of river systems can also influence the kind of hydrological connection (Rains et al. 2008; Leibowitz et al. 2016). When the outflow of water decreases due to a dry spell, hydrological connectivity can only take place through underground water sources (Rains et al. 2006; Rains et al. 2008).

Finally, as changes in the amount of water in channels can impact downstream waters, so too can the lack of water (i.e., isolation). When streambeds dry up temporarily, this provides a unique habitat for aquatic life adapted to wet and dry environments, and serves as a storehouse for eggs and seeds of aquatic invertebrates and plants (Steward et al. 2012). Additionally, a decrease in microbial activity, combined with increased oxygen levels and inputs of organic matter and nutrients from the land, can alter nutrient dynamics in these areas (Steward et al. 2012). During rewetting, these materials are carried downstream.

2.1.4.4. Factors that influence connectivity

Numerous components influence physical, chemical, and biological connectivity in river systems, operating at multiple spatial and temporal scales and interacting in intricate ways to determine the connectivity-isolation gradient at any given time (Schofield et al. 2018). This paper examines three key aspects: climate and watershed characteristics, the spatial patterns of water bodies, and human activities and alterations. Though not an exhaustive list of all factors, these illustrate how numerous elements can shape physical, chemical, and biological connectivity. It is necessary to explain these variables since they are essential to the framework.

i. Climate and Watershed Characteristics

The way in which water is transported and stored in watersheds is affected by the geographical, geological, topographical, and soil conditions of river systems (Winter 2001; Wigington et al. 2013). At a large scale, the climate determines the volume, timing, and duration of water available to the rivers and their basins. Factors that influence the degree of connectivity over different periods of time include the amount of precipitation surplus and the seasonality of the surplus during the year (Stieglitz et al. 2003), which is largely dependent on when and in what form the precipitation occurs (e.g., rain or snow); as well as the intensity of the precipitation (Gomi et al. 2008).

Rainfall intensity can have an effect on hydrologic connectivity in areas with surface layers that have limited infiltration in comparison to the intensity of the rain (Gomi et al. 2008).

When the intensity of rainfall surpasses the infiltration rate of the surface layer, infiltration-excess runoff can occur, providing a key means of delivering water to wetlands and river systems (Goodrich et al. 1997; Levick et al. 2008). In urban environments, where there are many impermeable surfaces, overland flow can develop in any scenario (Booth et al. 2002). The depth of the water table can have an impact on connectivity across a variety of hydrologic landscapes, particularly inside floodplains (Wigington et al. 2003; Wigington et al. 2005).

Within various hydrologic landscape structures, the permeability of soil and geological formations plays a crucial role in determining the direction of water flow (Wolock et al. 2004). Soils with high permeability facilitate infiltration, leading to groundwater flow paths, while the presence of impermeable soils with limited infiltration capacity encourages surface runoff. In scenarios where groundwater discharge from watersheds or landscapes prevails, the eventual path of the water partly relies on the permeability of the underlying geological layers.

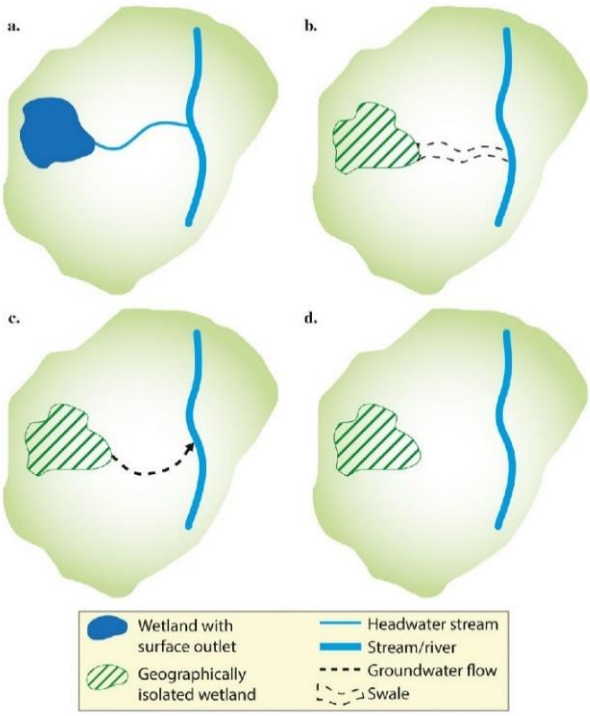


Figure 9. Types of hydrologic connections between no floodplain wetlands and streams or rivers. (Note that in a–c, flows connecting the wetland and river may be perennial, intermittent, or ephemeral). Source: USEPA (2015).

Fig. 9a: wetland connected to a river by surface flow through a headwater stream channel.
Fig. 9b: wetland connected to a river by surface flow through a non-channelized swale.
Fig. 9c: geographically isolated wetland connected to a river by groundwater flow.
Fig. 9d: geographically isolated wetland that is hydrologically isolated from a river.

ii. Spatial Distribution Patterns

Climate and watershed features have an effect on the timing and scope of waterway network extension and contraction (Wigington et al. 2005) and on the spatial division of water bodies within a catchment. These factors shape the spatial and temporal patterns of interconnectivity between streams, wetlands, and downstream waters (Tihansky, et all., 1999).

The connection between streams and rivers is largely dependent on the distance between them. Water from upstream reaches of lower order streams may be more altered or mixed with other substances when it reaches its destination than water from higher order streams due to the longer path it must take. However, because there are more low-order streams, collectively they are just as important to the overall hydrologic connectivity of a river network (Bracken and Croke 2007).

The distance between a riparian/floodplain wetland and downstream waters affects the connectivity between the two. Riverine wetlands that originate from the headwaters of a main river (e.g., first-order streams connected to fifth-order streams) have a stronger connection to that river than wetlands that start from higher up the drainage network (e.g., first-order streams connected to second-order streams). Similarly, riparian/floodplain wetlands that have direct surface-water connections to streams or rivers will have a greater influence on the incoming water than those wetlands that border higher order streams (Whigham et al. 1988). If geographically isolated non-floodplain wetlands have pathways that allow surface water to enter (e.g., depressions or groundwater seeps) (Fig. 9b), the amount of water that is able to infiltrate or be lost through evaporation decreases with increasing distance, and can vary significantly depending on the region (Cohen et al. 2016).

The distribution of distances between wetlands and rivers can vary significantly depending on different factors, such as drainage density, wetland density, climate, geological history, watershed characteristics, and human activities. The landscape settings of wetlands range from having a few rivers close by with a high density of wetlands (Fig. 10a–10c), to less spatially consistent wetlands (Fig. 10d), to areas with higher drainage density combined with either riparian wetlands (Fig. 10e) or larger, more extensive wetlands (Fig. 10f).

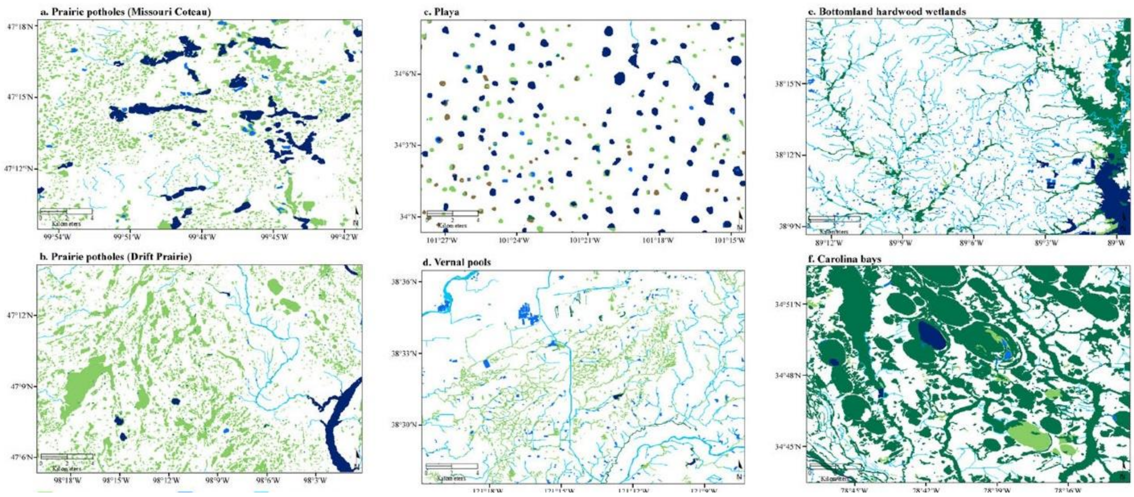


Figure 10. Examples of different landscapes showing interspersion of wetlands and streams or rivers, based on National Wetlands Inventory maps (http://www.fws.gov/wetlands)

These maps demonstrate how the environment can significantly influence the blending of wetlands and rivers, as well as the average gap between them. The distances between them can vary considerably, resulting in varying levels of connection.

Wetland connectivity to downstream waters is generally greater when they are located nearer to the stream network. However, other factors such as terrain, gradient, and soil absorption can alter this relationship and cause more distant wetlands to possess higher hydrological and ecological connectivity. In flat, open areas, small modifications in water levels can bring together wetlands that were once distant by more than a kilometer (Vanderhoof and Alexander 2016). The overall hydrologic function of a watershed depends on the continuity of wetland connection and detachment (Cohen et al. 2016).

iii. Human Activities and Artificial Alterations

Human activities frequently alter the connectivity between headwater streams, riparian/floodplain wetlands, non-floodplain wetlands, and downstream rivers, affecting the movement of energy and materials (Fullerton et al., 2010). While some interventions like dam construction, levee building, and water extraction can be detrimental, others such as wetland draining, irrigation, and basin transfers can be beneficial (Fullerton et al., 2010). The loss of headwater streams and wetlands due to human activity can impair river network conditions by reducing connectivity (Fullerton et al., 2010).

Landscape modifications can either decrease or increase hydrologic and biological connections, depending on the waterway's location. Channelization, for instance, accelerates water flow between river segments but may decrease flow to floodplain wetlands. Agricultural ditches and tile drainage facilitate rapid water transport to channels or wetlands but may reduce hydrologic connectivity by filling wetlands with soil and lowering the water table (De Laney, 1995; Blann et al., 2009). Furthermore, wetland loss increases mean distances between wetlands, reducing biological connectivity (Van Meter and Basu, 2014). Drainage enhances hydrologic connectivity between the landscape and downstream waters, leading to increased water runoff, sediment, pollutants, and organism dispersal (Wiskow and van der Ploeg, 2003; Blann et al., 2009; Babbitt and Tanner, 2000). However, drainage and ditching can decrease biological connectivity as the distance between wetlands increases, limiting organism dispersal between systems (Leibowitz, 2003).

2.1.4.5. Approaches for quantifying connectivity.

Quantifying connectivity serves several purposes, including establishing benchmarks for comparison, understanding watershed functions, and guiding rehabilitation efforts. The choice of assessment methods depends on factors such as the assessment's purpose, environmental context, type of connection, and available data (Calabrese and Fagan, 2004; Lexartza-Artza and Wainwright, 2009).

Water movement plays a crucial role in the transfer of chemical elements between upstream and downstream areas. Various techniques, including field measurements, topographical mapping, hydrological modeling, and satellite imagery, can be employed to assess hydrologic connectivity (Michalzik et al., 2001; Borselli et al., 2008; Golden et al., 2017).

Field-based approaches help understand linkages between water elements, assess water volume and material transport, and identify functional connectivity using water quality metrics (Johnston et al., 1990).

Topographic indices, alone or combined with other watershed characteristics, predict landscape features and estimate the spatial extent of hydrologic connectivity. These indices include the Topographic Wetness Index and quasi dynamic indices assessing effective contributing areas (Quinn et al., 1995; Creed and Beall, 2009).

Various models and indices, such as simulations of water or material fluxes and predictions of water movement based on topography, analyze functional and structural connectivity in watersheds (Chu et al., 2013). Geostatistical approaches are also used, primarily focusing on structural connectivity within stream networks (Fagan, 2002; Ganio et al., 2005).

There is no consensus on the most effective measures or models to evaluate hydraulic or chemical connectedness. Combining different assessment techniques and models is necessary for a comprehensive understanding of connectivity (Lexartza-Artza and Wainwright, 2009; Golden et al., 2017).

2.1.5. Urban green-blue infrastructure

Urban green-blue infrastructure plays a crucial role in mitigating the adverse effects of climate change, improving air and water quality, reducing noise pollution, providing recreational opportunities, and enhancing the aesthetic appeal of public spaces (Haase et al., 2017). However, the expansion and densification of urban areas, characteristic of urbanization, pose significant threats to natural infrastructure, as highlighted by a United Nations assessment (Ampatzidis, P. 2020). The repercussions of urbanization include vegetation degradation, water pollution, and biodiversity loss, which detrimentally impact the health and ecological functions of urban environments. Moreover, urban areas often exhibit lower levels of vegetation and water compared to surrounding regions, and existing green-blue infrastructure faces jeopardy due to population growth. Hence, it is imperative to study the impact of urban natural infrastructures, such as GBI, on urban climate (Ampatzidis, P. 2020).

Integration of blue infrastructure, such as wetlands and ponds, into urban landscapes offers various benefits, including the regulation of the urban heat island (UHI) effect. These features alter the land surface, enhancing sunlight absorption, reducing air convection cooling, and minimizing water evaporation. Additionally, city wetlands often create microclimates that are more temperate than surrounding areas, enhancing inhabitant comfort and environmental conditions (Ampatzidis, P. 2020). Many cities recognize the importance of conserving and restoring urban wetlands as part of urban design to enhance resilience against climate change impacts. However, urban expansion and development activities pose significant challenges to wetland preservation, leading to habitat destruction, water system alterations, contamination, and introduction of invasive species (Ampatzidis, P. 2020).

Improperly planned and uncontrolled urbanization threatens urban wetlands through population growth, resulting in wetland draining, contamination, and destruction due to housing, agricultural, and industrial development (Ampatzidis, P. 2020). Loss of natural wetlands and unsuccessful wetland creation and restoration projects diminish the landscape's ability to absorb pollutants, store floodwaters, and support dependent species. Recognizing the adverse impacts of urbanization on wetlands underscores the urgent need for effective conservation measures to safeguard urban ecosystems from the detrimental effects of climate change (Ampatzidis, P. 2020).

Urban Wetlands as Part of Green-Blue Infrastructure

Green-blue infrastructures (GBI) are proposed as a way to address climate change in urban areas (Alikhani, S. 2018). GBI optimizes land use, promoting sustainability while satisfying both human needs and environmental requirements (Sleegers, F. 2010). These infrastructures increase the biodiversity of urban areas, minimize the effects of global warming, connect ecological systems, and improve public health and welfare (Ingrao, C. 2020; and Well, F. 2020).

The existence of green infrastructure (GBI) in urban areas such as trees, rivers, and ponds can improve thermal comfort and create cities that are better equipped to handle the impacts of climate change (Perini, K. 2017). When the GBI covers over one hectare, the cooling effect is more pronounced, especially during summer (Yang, G. 2020). Additionally, GBIs provide positive health benefits and foster more positive emotions in cities (Chan, S. et al 2017). Moreover, access to these green areas encourages physical activity, social cohesion, and livable surroundings (Labib, S. 2020).

2.2. Methodological Review

2.2.1. Morphometric analysis

The flow of water through urban areas is influenced not only by soil structure, but also the landscape features, quantifying the water in the catchment difficult. To decide which modelling techniques to use, it is important to take into account the characteristics of the watershed such as climate, geology and soils. Geo-morphological analysis of a watershed can be used to create regional hydrological models to address hydrological issues in watersheds where data is unavailable. This is accomplished by examining the sub-watersheds in the area and determining the morphometric patterns and characteristics of the streams (Gajbhiye et al. 2014).

The morphometric analysis is an evaluation of a hydrological unit that is done through quantification. This is a widely used method for studying watersheds and their development, which involves stream segments, watershed length, basin area, altitude, volume, slope, profiles of the land. The arrangement of a drainage basin's stream system can be expressed numerically through stream order, drainage density, bifurcation ratio, and stream length ratio (Horton 1945). Horton's law of stream lengths suggested a geometric correlation between the lengths of channels in successive stream orders. Subsequently, the law of basin areas was developed, demonstrating a linear relationship between the mean basin area of successive stream orders. This was further refined by geomorphologists such as Strahler (1952 & 1964), Schumn (1956) and Gregory (1966, 1968) among other geoscientists.

Quantitative examination of the watershed, featuring elements such as stream segments, basin perimeter, basin area, height difference, slope and land profile, has been integral in the natural progress of the watershed (Horton 1945).

Table 1. Description of components computed in the method of morphometric analysis of watershed (the linear and areal aspects of morphometric parameter)

Component	Descriptions	equation
Streams Number (N_u)	Number of streams is also described as total counts of stream segments of different order separately and is inversely proportional to the stream order. Stream number is denoted by N_u.	total counts of stream segments using GIS
Total stream length (L_u)	The total stream length in a watershed is determined with the use of GIS by measuring the length of all ordered perennial streams. This is denoted by L_u.	total stream length in a watershed using GIS
Mean stream length ($L_{\bar{u}}$)	The mean stream length, denoted by $L_{\bar{u}}$, is calculated by dividing the total length of streams of a certain order by the total number of streams of the same order.	$L\bar{u} = \frac{Lu}{Nu} =$
Watershed perimeter (P_r)	The watershed perimeter is the total length of the outer edges of the watershed.	Computed Using GIS
Maximum length of the watershed (L_b)	It is the distance between the remotest point of the watershed and the outlet, as measured along the main watercourse.	Compute using GIS
Stream length ratio (R_L)	The stream length ratio (R_L) is the ratio of the mean length of the stream of a given order ($L_{\bar{u}1}$) to the mean length of the streams of the next smaller order ($L_{\bar{u}-1}$). In case the n+1 will be considered as number of stream orders. i.e., if 4, then n=3.	*Equation 1* $R_L = \frac{L_{\bar{u}1}}{L_{\bar{u}-1}} = \frac{\sum_i^n \left[\frac{L_1}{L_2}+\frac{L_2}{L_3}+\frac{L_3}{L_4}+\cdots+\frac{L_n}{L_{n+1}}\right]}{n}$
Bifurcation ratio (R_b)	The bifurcation ratio is an indication of the geology and tectonics of a watershed (Gajbhiye et al. 2014). It is calculated by dividing the number of streams at a lower order (N_u) by the number of streams at the next order (N_{u+1}). The value range of the R_b classifications varies among the researchers, there is even no statement about it. Based on most papers, it can be concluded that less than five (5) may be classified into low, and more than five (5) into high (Chandrashekar H, Lokesh K V, Sameena M, Roopa J and Ranganna G et all., 2015), (Yangchan J, Jain A K, Tiwari A K and Sood A 2015) Lower value of R_b indicates the partially disturbed watershed without any distortion in drainage pattern (Nag 1998). High value of R_b indicates the severe over land flow and low recharge for the sub-watershed.	*Equation 2.........* $R_b = \frac{N_u}{N_{u+1}}$
Form factor (R_f)	Most scholars have proposed that the form factor for a perfectly round basin should be less than 0.7854 (Rekha et al. 2011; Gajbhiye et al. 2014). The form factor is a measure of the shape of a basin, with a low value indicating a basin that is more	*Equatio 3......* $R_f = \frac{A_w}{L_b^2} =$ A_W: Area of watershed

	elongated and a higher value showing a basin that has a higher peak in a shorter amount of time. There are some different value ranges of form factor. The range values for form factor are <0.78 (elongated) and >0.78 (circular). (Abboud I A and Nofal R A 2017). The form factor of a watershed is determined by the proportion of its basin area (A_w) to the squared maximum length of the basin (L_b). A lower the value of form factor indicates a more elongated watershed, which will have higher peak flows of shorter duration (Horton 1932).	L_b : maximum length of watershed
Elongation ratio (R_e)	The elongation ratio (R_e) is determined by measuring the size of a circle with the same area as the watershed and comparing it to the longest dimension of the basin. Elongation ratio value is generally classified into three classes, less elongated (< 0.7), oval (0.8 – 0.9), and circular (>0.9), which is related to a variety of climate and geological factors (Strahler 1964).	*Equation 4.........* $R_e = \frac{d}{L_b} = \frac{2}{L_b}\sqrt{\frac{A_w}{\pi}}$, which is when diameter is written in terms of area: $d = \frac{2\sqrt{A_w}}{\sqrt{\pi}}$ Aw : Area of watershed
Circulatory ratio (R_c)	The circularity ratio is a measure that is comparable to the elongation ratio, which was initially formulated by Miller in 1953. It is expressed as the ratio of the area of the basin to the area of a circle with the same circumference as the perimeter of the basin (R_c). The circularity ratio is affected by the length and interval of the stream.	*Equation 5..........* $R_c = \frac{A_w}{\pi r^2} = \frac{4\pi A_w}{{P_r}^2} = \frac{\mathbf{12.57}A_w}{{P_r}^2}$, when radius is written in terms of circumference of the circle which is perimeter of the watershed as well. $r = \frac{P_r}{2\pi}$
Drainage density (D_d)	Drainage density is the linear parameter of morphometric analysis that is used to measure erosion by streams and the effect of the topography on the outflow. There are five classes of drainage density with the following value ranges, i.e., very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (>8) (*Chandrashekar H, Lokesh K V, Sameena M, Roopa J and Ranganna G 2015*), (*Vittala S S, Govindaiah S and Gowda H H 2004*). However, based on some definitions about D classes, it can be highlighted that there are two main classes, low/coarse and high/fine class. It is calculated by dividing the sum of the lengths of all streams in an area by the area of the basin. This figure gives an indication of the closeness of the channels and the amount of land in the watershed (Strahler 1964). The unit of	*Equation 6...........* $D_d = \frac{L_u}{A}$

	measurement for this density is km/km2 and is represented by (D_d).	
Stream or Drainage frequency (F_s)	Drainage frequency is determined by the number of streams per area of the watershed. This is strongly influenced by the geology of the catchment, which gives an indication of the type of drainage pattern. There is no mention about classifications and their value ranges. The relative value ranges of stream frequency sometimes make different implications of low and high class.	*Equation 7*......... $F_S = \frac{N_u}{A} = \frac{Total\ No\ of\ stream}{Area\ of\ watershed}$
Texture ratio (T)	The texture ratio of a basin is determined by several factors, including the properties of the lithology, soil infiltration capacity, climate, vegetation, and terrain relief (Vijith and Satheesh 2006). The classification of drainage texture is the same with the classification of drainage density. Classification of drainage texture mostly do not use a classification by applying certain values range for each class, but the classification tends to be more relative among studied watersheds by comparing one to another (Vittala S, Govindaiah S and Gowda H et all., 2004).	*Equation 8*........... $T = \frac{N_1}{P_r}$
Total Watershed relief (H)	Basin relief is a crucial element in determining the characteristics of a watershed. It is measured by the difference in height between the highest and lowest points within the given watershed. This has a huge impact on the formation of landforms, drainage patterns, and the permeability and erosive qualities of the terrain.	
Compactness coefficient (C_c)	The Compactness coefficient is a factor that measures the shape of a watershed and is calculated by dividing the perimeter of the watershed by the circumference of a circle with an area equal to the watershed. It is independent of the size of the watershed and rather based on the topography of the area, according to Horton (1945).	*Equation 9*........... $C_c = \frac{1}{2\sqrt{\pi}}(\frac{P}{\sqrt{A}}) = 0.2821(\frac{P}{\sqrt{A}})$

Relief ratio (R_h)	The relief ratio is the relationship between the elevation of the highest and lowest points of a watershed, and the length of the primary drainage line running through it (Schumm, 1956). No one mentioned about the value range of relief ratio (Vinutha D N and Janardhana M R 2014). Generally, the low value of relief ratio means low relief and the high value means steep slope and high relief.	*Equation 10*............ $R_h = \frac{H}{L_b}$
Length of overland flow (L_g)	The Length of Overland Flow (L_g) is the distance that water travels over the ground before it accumulates into streams and rivers, influencing the water cycle and landscape of a drainage basin. It is roughly equal to half of the inverse of the drainage density (Horton, 1945). There are three classes of L_g i.e., low value (< 0.2), moderate value (0.2 – 0.3), and high value (>0.3). Low value of Lg indicates high relief (Vinutha D N and Janardhana M R 2014) , short flow paths, more runoff, and less infiltration [2] which leads to more vulnerable to the flash flooding	*Equation 11*.............. $L_g = \frac{1}{2D_d}$

2.2.2. Graph Metrics analysis of hydrologic stream Network

Graphs serve as visual representations of real-world networks, offering insights into their complexity. To analyze these networks effectively, graph metrics are computed to quantify specific features based on the nodes and edges within the graph (Newman,

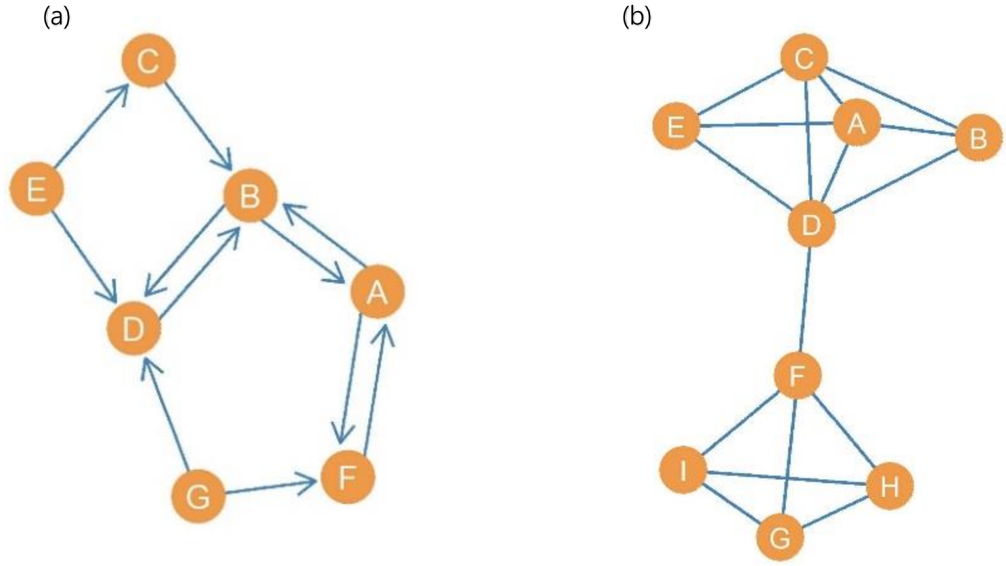


Figure 11*. Illustrative example of directed and undirected graph.* ***(a)****. directed graph,* ***(b)****. undirected graph*

2010). In the context of hydrologic stream connectivity analysis, it is essential to employ a graph that considers the number of indegree and outdegree streams along the water flux, as water typically flows downhill (Yang et al., 2020). Measuring connectivity provides a crucial benchmark for observing modifications, linking connectivity levels to watershed activities, and establishing standards for restoration and conservation efforts (Tockner et al., 2017). The directed graph average degree emerges as a robust tool for assessing connectivity between streams within a watershed. For instance, when comparing similar stream networks of equal size, significant variations in the average degree may indicate differing levels of connectivity. Understanding these connections enables insights into why one network may have failed while another maintained its connectivity, offering valuable guidance for watershed rehabilitation initiatives (Guo et al., 2019).

Table 2. Description of the method of Graph metric analysis of the stream connectivity

Component	Descriptions	equation
Graph Order (the number of nodes in the graph, n)	The order of a graph (denoted by n) is the number of nodes in the graph, which is equal to the cardinality of the node set (n=|V|). Cardinality is a mathematical term that describes the number of elements in a set.	
Graph Size (number of edges in the graph, m)	The size of a graph (generally noted as m) is equivalent to the number of edges in the graph, which is the cardinality of the edge set m=|E|.	
The Directed Graph Degree Set (how many times the nodes are connected) number of edges. k)	Computing the degree of each node in the network produces a vector (called k) that shows the degree of each node. This vector has the same number of elements as the number of nodes in the network, meaning the size of the degree set is equal to the size of the node set. In other words, |k|=|V|.	

Minimum and Maximum Degree (the range of connectivity)	When studying a network, we are commonly interested in the degree of connectivity. The maximum degree ($K_{(max)}$) is the highest number of connections something has in the network, while the minimum degree (k(min)) is the least number of neighbors something has. Knowing the contrast between these values helps us comprehend the contrast in the connectivity between the best-connected and least-connected components in the graph.	
Sum of Degrees	The correlation between the total degree of all nodes and the number of edges in a directed graph is a direct one, meaning the sum of the degrees of each node is equal to the total number of edges. This can be expressed mathematically as equation 12: The cardinality of the edge set of a graph is often referred to as the first theorem of graph theory, which is equal to the number of edges (m) in the graph (Benjamin, Chartrand, and Zhang 2015, 20). Knowing the relationship between the total number of degrees of a graph and the number of edges it contains, we can start to compute other important graph metrics, such as the average degree.	*Equation 12* (in case of directed graph .... $\sum k_i = m$ (In the case of stream network, its one way, downflow)
Average Degree in directed Graphs	In this situation, it is not necessary to calculate the number of lines twice, as it would be with an undirected graph. We can simply figure out either the average indegree or the average outdegree for each node, and the result will be the same since each link only serves one purpose with regards to the indegree or outdegree of each node. Accordingly, the average degree in the directed case is:	*Equation 13……* $K_{(avg)} = \frac{m}{n}$

2.2.3. Analyzing Factor causing the stream disconnection using GIS overlay of Urban Hydrologic features and Infrastructures.

Several elements have an influence on physical, chemical, and biological interconnectivity in river systems. These elements act at multiple scales in both space and time, and the complexity of their interaction determines the level of connectivity or isolation of different parts of the system at any given moment. (Schofield et al. 2018).

Strong physical forces are actively affecting the energy, sediment, and life of a stream. Although streams are constantly changing, even with minimal human or natural influence, they still maintain their fundamental qualities. Knowing the right techniques for preserving or altering a graded stream is essential for having functional streams and watersheds.

Comprehending the characteristics of streams and how they evolve in a dynamic watershed is essential for successful stream and watershed preservation and restoration. Consequently, it is imperative for those engaged in stream and watershed monitoring, management, and restoration to possess a fundamental grasp of stream processes and their categorization in order to manage them effectively

Streams can be affected by a variety of factors, and shifts in these variables can cause instability. Urbanization, deforestation, construction of roads, and the withdrawal of groundwater can all lead to changes in the flow of a stream, potentially transforming it from a perennial to an intermittent or ephemeral waterway. Similarly, sediment loads can be altered by activities like urbanization, timber harvesting, mining, grazing, road construction, and wildfire.

In the analysis of factors contributing to stream disconnection, Geographic Information System (GIS) overlay techniques played a pivotal role by facilitating the integration of urban hydrologic features and infrastructures. Through this approach, a thorough exploration of the spatial interplay among different components influencing stream disconnection in urban settings was made possible. GIS overlay allowed for the simultaneous visualization and assessment of diverse elements such as impervious surfaces, drainage systems, land use patterns, and urban development, providing valuable insights into the complex dynamics affecting stream connectivity (Liu et al., 2017). By overlaying and analyzing these spatial datasets, patterns and correlations between urban infrastructure and hydrological features could be discerned, aiding in the identification of key factors driving stream disconnection and informing targeted management and mitigation strategies.

The importance of GIS overlay analysis in understanding the complex interactions between urban features and hydrological processes. By overlaying datasets representing urban infrastructure, such as roads, buildings, and drainage systems, with hydrological features like streams and watersheds, researchers can identify areas where these elements intersect, potentially leading to stream disconnection (Song and Li et al. 2016)

The significance of using GIS overlay techniques to assess the impact of urbanization on hydrological processes. By overlaying land use and land cover data with hydrological features, researchers were able to identify areas where changes in land use, such as urban expansion, contribute to alterations in hydrological connectivity (Peng et al. 2018).

The integration of GIS overlay analysis with urban hydrological features and infrastructures provides valuable insights into the factors influencing stream disconnection in urban areas. This approach enables researchers to identify specific urban features and land use patterns that contribute to stream disconnection, ultimately informing decision-making processes aimed at mitigating the negative impacts of urbanization on hydrological systems (Chen et al., 2020).

2.2.4. Analysis of the urban flood inundation extent and important water patches that require priority protection using ArcGIS Map Algebra.

Urban wetlands, often referred to as the "city's kidney" and "biodiversity library," play crucial roles in urban ecological infrastructure and contribute to the physical and mental well-being of city residents (Bhattarai & Hammitt, 2015). These ecosystems provide essential services such as flood prevention, water purification, air purification, and habitat conservation (Mitsch & Gosselink, 2015). Additionally, urban wetlands offer social and cultural amenities, including recreational and leisure activities for urban dwellers (Gould, 2015). However, the negative impacts of urbanization have led to the fragmentation and isolation of these wetlands, resulting in reduced biodiversity within urban areas (Kirkwood et al., 2019).

Flooding, characterized by the inundation of land due to an excess of water, is a phenomenon with significant implications for both human populations and natural ecosystems. According to the findings of the Intergovernmental Panel on Climate Change (IPCC), flooding events are becoming more frequent and severe due to climate change, exacerbating their impact on communities and infrastructure (IPCC, 2014). These events often result from heavy rainfall, storm surges, or the overflow of rivers and other water bodies, leading to widespread damage to property, disruption of essential services, and loss of life (Merz et al., 2010). Furthermore, flooding can have detrimental effects on agricultural productivity, water quality, and biodiversity, with long-lasting consequences for ecosystems and the economy (Winsemius et al., 2016). As such, understanding the mechanisms and drivers of flooding is essential for developing effective mitigation and adaptation strategies to minimize its adverse effects and enhance resilience in the face of changing climatic conditions.

In analyzing the extent of urban flood inundation and prioritizing water patches for protection, ArcGIS Map Algebra is utilized as a powerful tool. This method facilitated the comprehensive assessment of flood-prone areas and the identification of critical water patches in need of priority protection measures.

The effectiveness of ArcGIS Map Algebra in analyzing flood inundation extents by integrating topographic, hydrological, and land cover data. By applying spatial analysis techniques within ArcGIS, researchers were able to delineate flood-prone areas and identify vulnerable water patches that require immediate attention (Liu et al. 2019)

The utility of ArcGIS Map Algebra in prioritizing water patches for protection based on their ecological significance and vulnerability to urban development. By overlaying ecological data with flood inundation extents, researchers identified areas with high ecological value that are at risk of inundation, thus informing decision-making processes for conservation and management strategies (Yang et al. 2020)

The integration of ArcGIS Map Algebra with spatial analysis techniques enables researchers to accurately delineate urban flood inundation extents and prioritize water patches for protection. This approach provides valuable insights into the spatial distribution of flood-prone areas and helps identify critical water patches that play a crucial role in urban ecosystems (Xu et al., 2021).

CHAPTER THREE
MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Ethiopia Major River Basin Characteristics

A river basin is an area of land where all the runoff from rain and snowmelt drains into a single body of water, usually a river that drains into the sea. These areas are usually delineated by the tops of the highest points on the land, forming a physical boundary, as

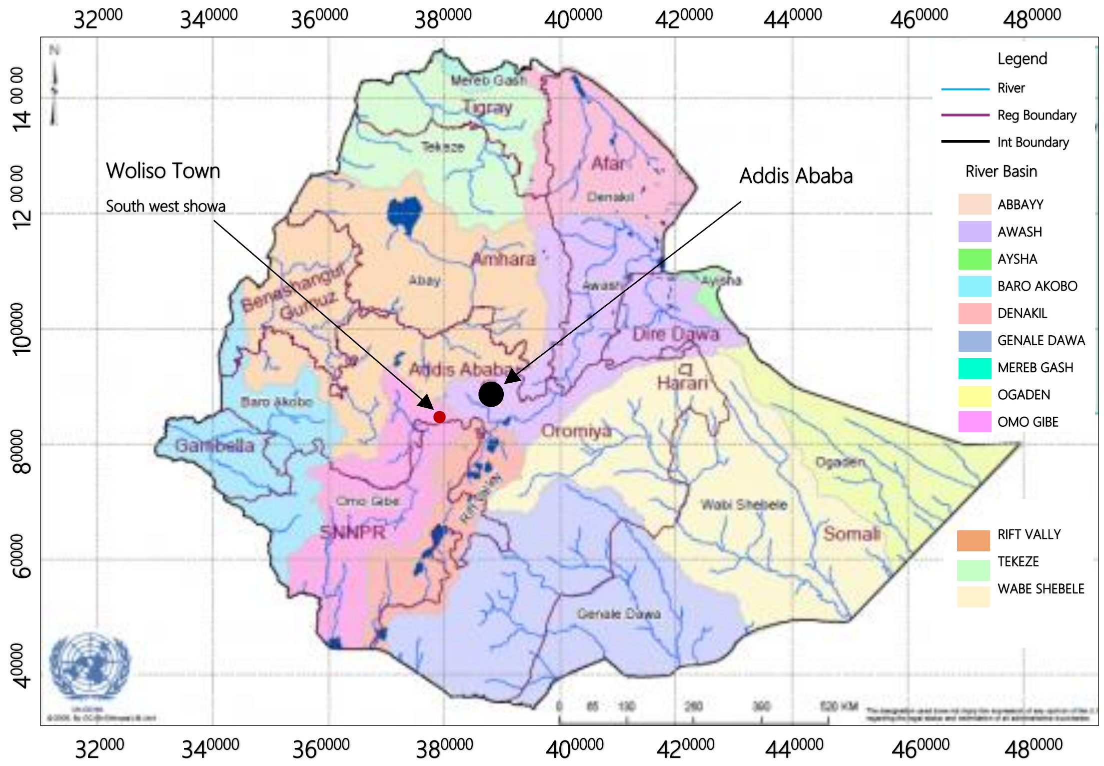


Figure 12. the 12 major Ethiopia River Basin map (source: UN OCHA, 2006

of the 12 major Ethiopian river basin (fig. 12).

The research site is located in Woliso, which is in the upper catchment of the Omo-Ghibe River basin among the 12 major river basins in the country.

3.1.2. The Omo-Ghibe Basin

The Omo-Ghibe River Basin, nestled in the southwestern corner of Ethiopia, extends from approximately 4°00' N to 9°22' N latitude and 34°44' E to 38°24' E longitude. This basin, the country's second largest, covers an expansive surface area of about 79,000 km2. It's fed by two significant rivers: the Ghibe River, meandering southwards, and the Gojeb River, which flows eastwards. Serving as an enclosed drainage area, it ultimately empties into Lake Turkana in Kenya, located at 3°35' N 36°7' E (Woodroof and associates, 1996).

3.1.3. The study area

The Ginfile sub watershed is among the upper catchment areas of the Omo-Ghibe Basin, situated within South West Shewa, Oromia. It occupies the eastern sector delineated by coordinates of 37° 58′ 18″ to 37° 59′ 40″ longitude and 8° 31′ 10″ to 8° 33′ 30″ latitude.

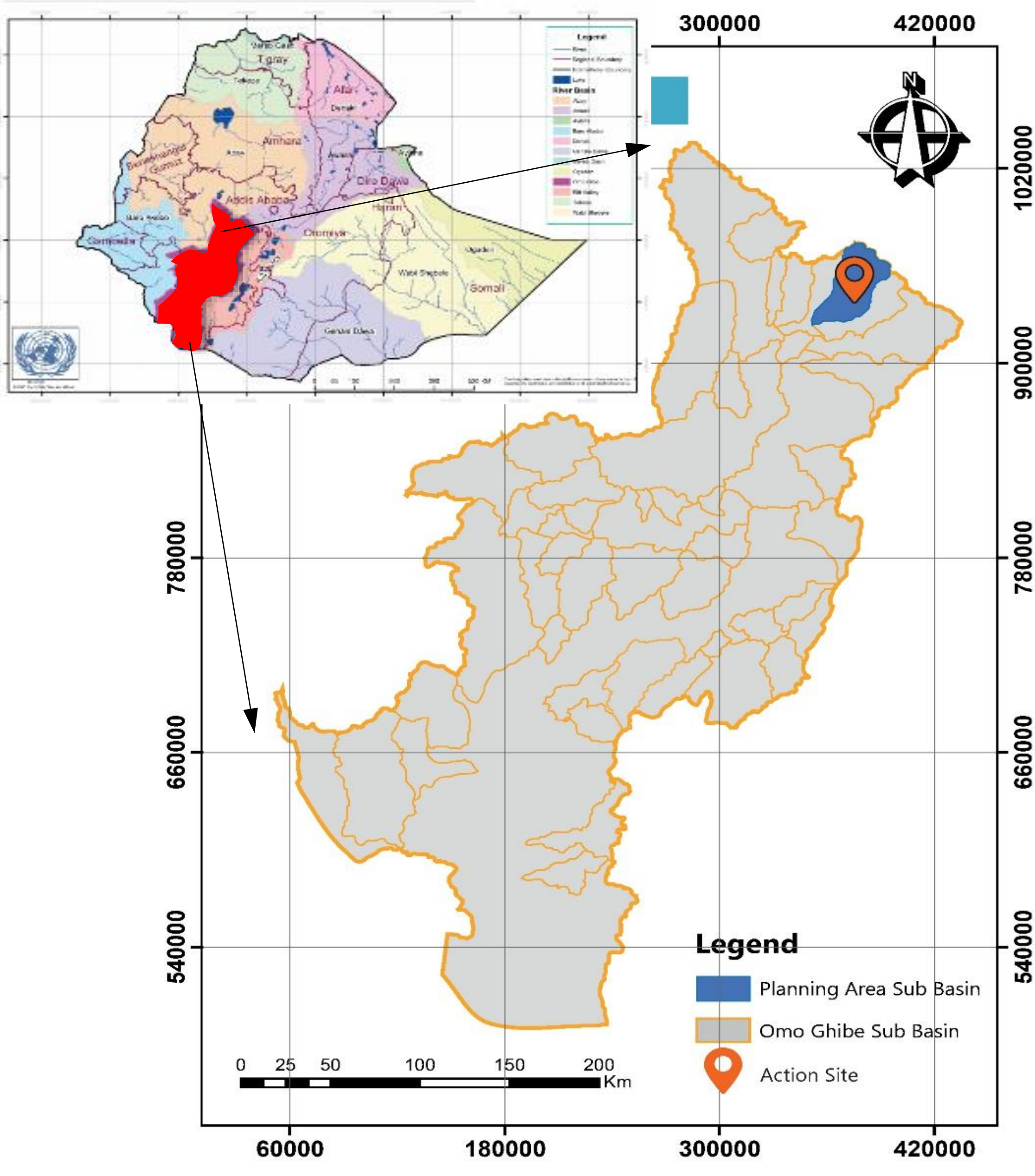


Figure 13. the Omo Ghibe Bain map (source: UN OCHA, 2006)

This watershed serves as the largest mixed residential hub southeast of Woliso, a burgeoning urban locale developing rapidly along the banks of the Ginfile River. Woliso, the focal point of this study, lies approximately 114 km to the south west of Addis Ababa, serving as the administrative capital of both the South West Shewa administrative zone and the Woliso district.

3.1.1. Historical background of the study area

The historical background of Woliso dates back to its establishment in 1923 (1919 EC), gaining urban status in 1930. Prior to the Italian invasion in 1935, the area was already urbanized, centered around "*Hora-Ayetu*" or "Filwuha" hot spring, featuring markets, small businesses, and a military station with the "*Abune-Gebremenfes-Qidus*" or "Abo" Church. The region encompassing Woliso is captivating due to its landscape and climate, with the hot spring serving as a popular leisure destination near the town center. Additionally, Woliso offers attractions like the Wenchi Crater Lake.

3.1.2. Sub watershed of the study Area

The primary drainage basin in the area of focus is particularly delineated for study as it is a hydrological unit that produces runoff due to rainfall.

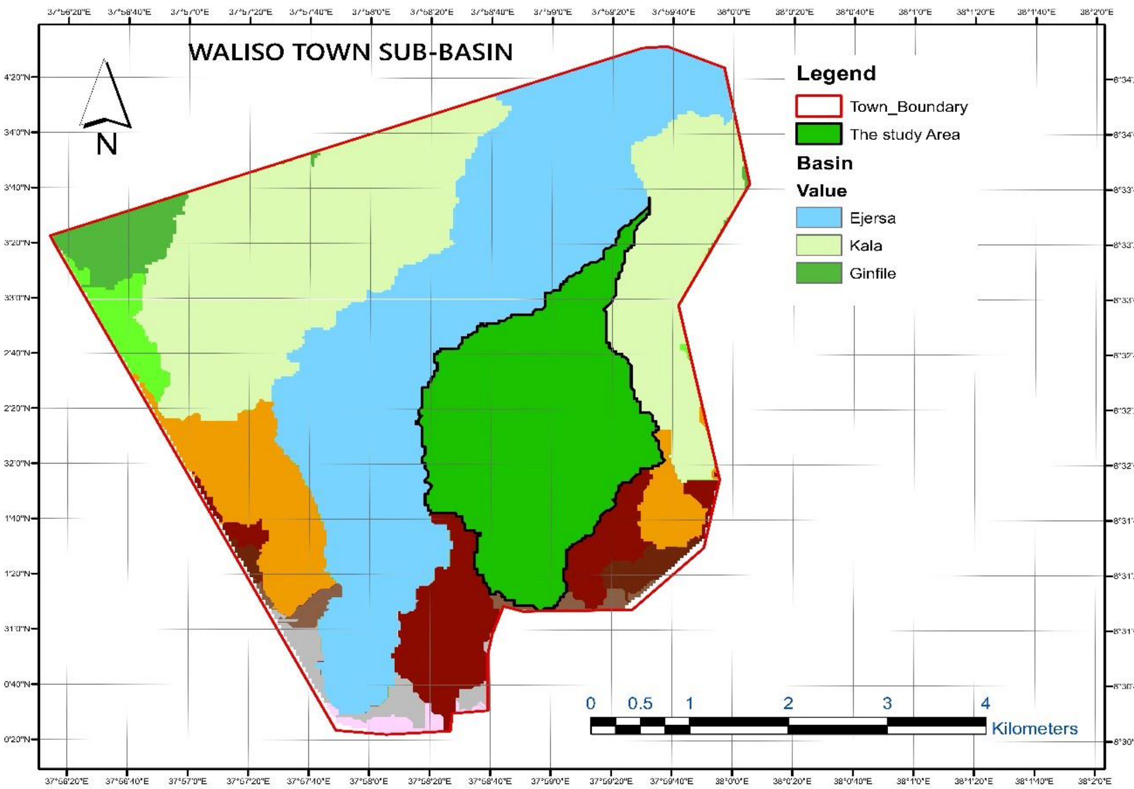


Figure 14. Basin map of the Woliso Province (the natural division along the three main high order streams in the town (source: the author)

3.1.3. Natural pattern and characteristics of Perennial and Intermittent streams of the study area

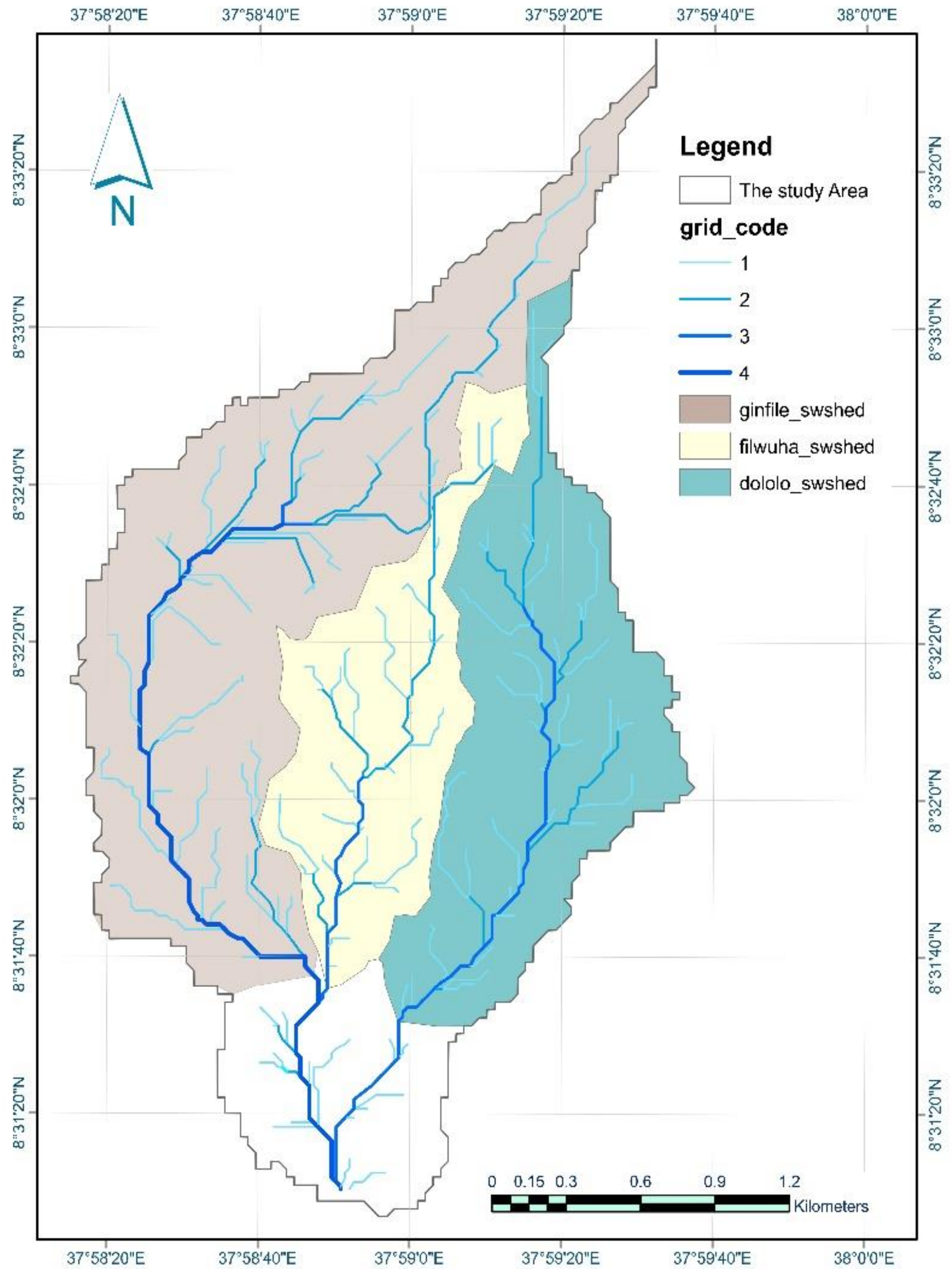


Figure 15. *the study area watershed spatial characteristics; in Woliso town (Ginfile, Filwuha and Dololo sub watershed) (source: the author)*

Stream networks has been delineated from the digital elevation model (DEM) using GIS (ArcMap) from the Flow Accumulation, which is the number of upslope cells that flow into each cell.

The array of local wet lands or blue spots creates a stream. The region is divided into three distinct watersheds. The area of the total planning region is 460ha, with the Ginfile, Filwuha, and Dololo sub-watershed measuring 252, 105, and 155 ha respectively.

The assemblage of individual streams into a drainage network is one of the defining features of stream ecosystems. Frequently termed hydrologic connectivity, this linkage between upstream and downstream reaches and defines many of the physical, biogeochemical, and biological attributes of a stream.

Each stream segment identified along the Natural stream order within the watershed are delineated from the flow accumulation raster cell, which is derived from a submeter resolution digital elevation model (DEM).

The drainage system was delineated using ArcMap 10.7, utilizing topographical maps sourced from the regional urban planning and development agency. Coordinates were aligned with NASA's ASTER Global Digital Elevation Model (GDEM) for each sub-watershed.

3.2. Data

3.2.1. Data Type

In this study, a diverse array of data types was employed to comprehensively analyze the hydrological characteristics and spatial dynamics of the study area. Both secondary and primary data have been used for this research. Central to this analysis was the utilization of a Digital Elevation Model (DEM), which provided crucial information about the topographical variations within the study area, including elevation, slope, and aspect. This DEM data facilitated the characterization of terrain steepness, which directly influences water flow energy and direction, thereby impacting surface runoff and erosion patterns. Furthermore, a Land Use/Land Cover (LU-LC) dataset, generated through supervised classification techniques, allowed for the assessment of spatial distribution of land use and land cover types, including surface permeability, vegetation cover, and impervious surfaces. Aerial photographs and real-time information supplemented quantitative data with qualitative insights obtained through aerial surveys, field observations, and interviews with local stakeholders. Moreover, a structural map sourced from the regional planning administration office provided detailed information about urban infrastructure, facilitating analysis of urbanization impacts on surface water dynamics.

Finally, drainage density metrics were calculated from spatial data to quantify the density of stream networks within the study area, aiding in the assessment of watershed connectivity and hydrological processes.

3.2.2. Source of Data and Method of Data Collection

Table 3. Source of Data and Method of Data Collection

Data Type	Source and Descriptions of Data Collection Method
Contour map	(Planning Administration office The Planning Administration office of the Woliso town has made available a contour map obtained from a ground survey to create a raster data set with the highest possible resolution. (Source: Planning Admin of the Woliso town)
Structural Map:	The structural map utilized in the research study was sourced from the zone planning administration office of Woliso. The map is DWG file format. Obtaining the structural map from the regional planning administration office ensures its reliability and accuracy, as it is likely to be based on official records and surveys conducted by municipal authorities. The use of this map in the research study provides valuable information about the structural layout and characteristics of the study area, facilitating a comprehensive analysis of urban development patterns and infrastructure planning considerations.
Digital elevation model (DEM)	Generated using "Topo to Raster" tool from the ArcGIS spatial analysis suite was used to generate hydrologically accurate digital elevation models (DEMs). It is based on the ANUDEM program developed by Michael Hutchinson and ensures a connected drainage system and accurate representation of ridges and streams from the input contour data through interpolation.

Land Use/Land Cover dataset (LU-LC):	In the absence of a detailed LULC map with sufficient resolution, an Interactive Supervised Classification feature in ArcGIS was employed, utilizing high-resolution Google Earth imagery as the data source. This feature expedites the maximum likelihood classification process and allows for rapid visualization of the classification result, eliminating the need for the Maximum Likelihood Classification tool.
Stream Order map	Calculated from spatial data, drainage density metrics quantify the density of stream networks within the study area, aiding in the assessment of watershed connectivity and hydrological processes.
Aerial Photographs & Real-Time Information	These data sources offer valuable visual and qualitative information obtained through aerial surveys, field observations, and interviews with local stakeholders. They supplement quantitative data with qualitative insights into land use changes, infrastructure development, and community perceptions.

3.3. Sampling technique

For this research study, the sampling technique will involve a comprehensive approach to address the unique challenges presented by the flood-prone and water-logging characteristics of the study area. Initially, the study area will be thoroughly assessed through physical observation to understand its specific morphological features and flood dynamics. Subsequently, a stratified random sampling technique will be adopted to ensure the representation of different strata within the Ginfile sub watersheds. The study area, encompassing various morphological characteristics within the sub watersheds, will be stratified based on geo-morphological attributes such as elevation, slope, and land use dynamics identified through satellite imagery and GIS data.

In the sampling procedure, the Ginfile sub watersheds will be stratified into distinct strata based on these geo-morphological characteristics. Data collection will involve a combination of field surveys, remote sensing techniques, and GIS analysis to collect comprehensive information on the geo-morphological characteristics, stream disconnectedness, land use dynamics, and urban flood inundation within the selected samples.

After data collection, rigorous analysis will be conducted to characterize geo-morphological features, identify stream disconnectedness, assess the impact of land use dynamics on stream connectivity, and spatially evaluate urban flood inundation, to finally propose alternative planning solutions. This comprehensive approach will address research objectives, offering valuable insights for managing flood-prone areas and guiding sustainable planning strategies.

3.4. Research Framework

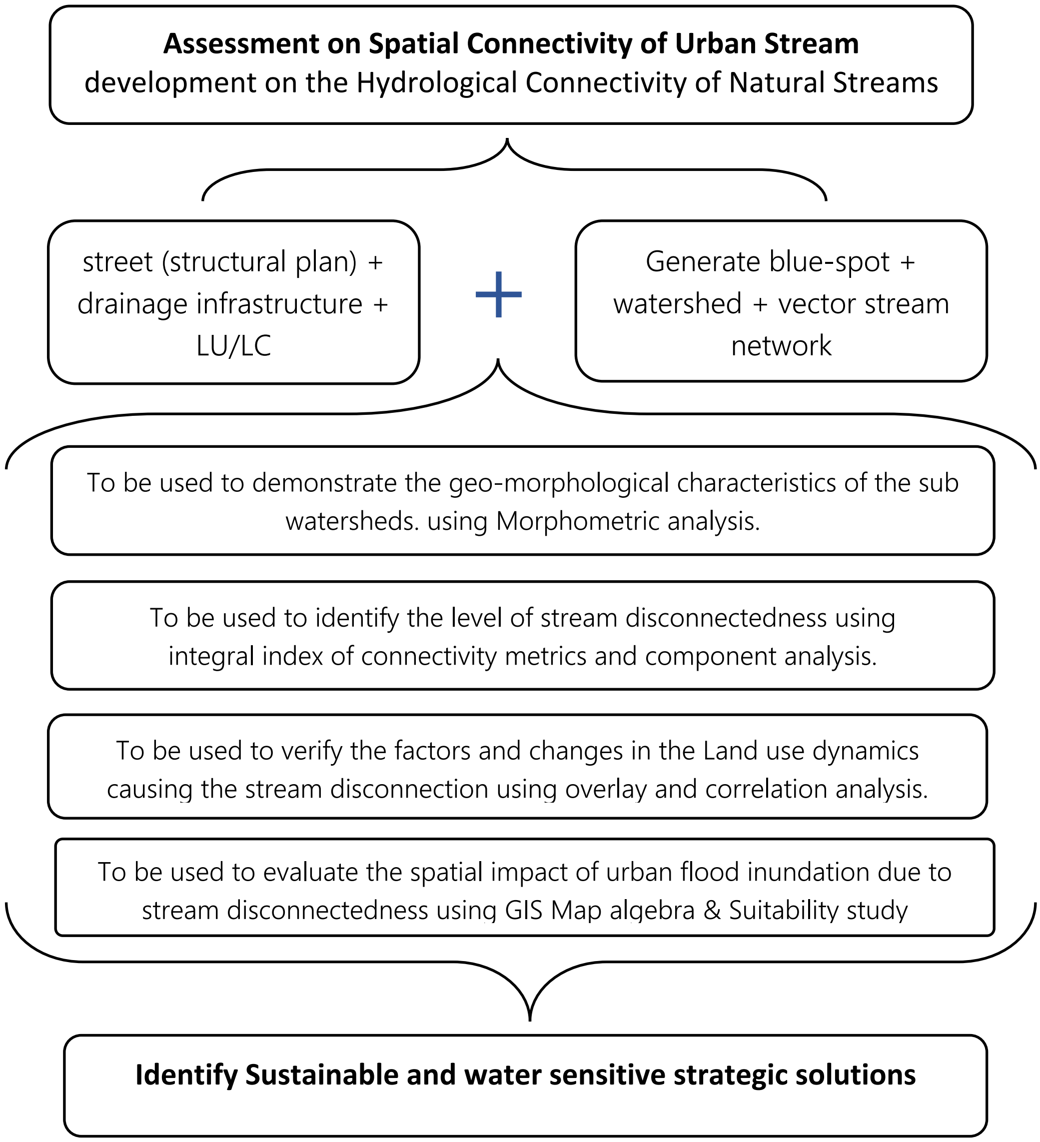


Figure 16. *Graphic Illustrations of the Research framework*

Figure 16 illustrates the research framework for assessing the spatial connectivity of urban stream development on the hydrological connectivity of natural streams. It combines street plans, drainage infrastructure, and land use/land cover (LU/LC) with blue-spot generation, watershed delineation, and vector stream networks. These components help demonstrate the geomorphological characteristics of the Ginfile sub-watersheds, identify stream disconnectedness using connectivity metrics, verify factors causing disconnection through overlay and correlation analysis, and evaluate the impact of urban flooding using GIS. The goal is to identify sustainable and water sensitive strategic solutions.

3.5. Research Design

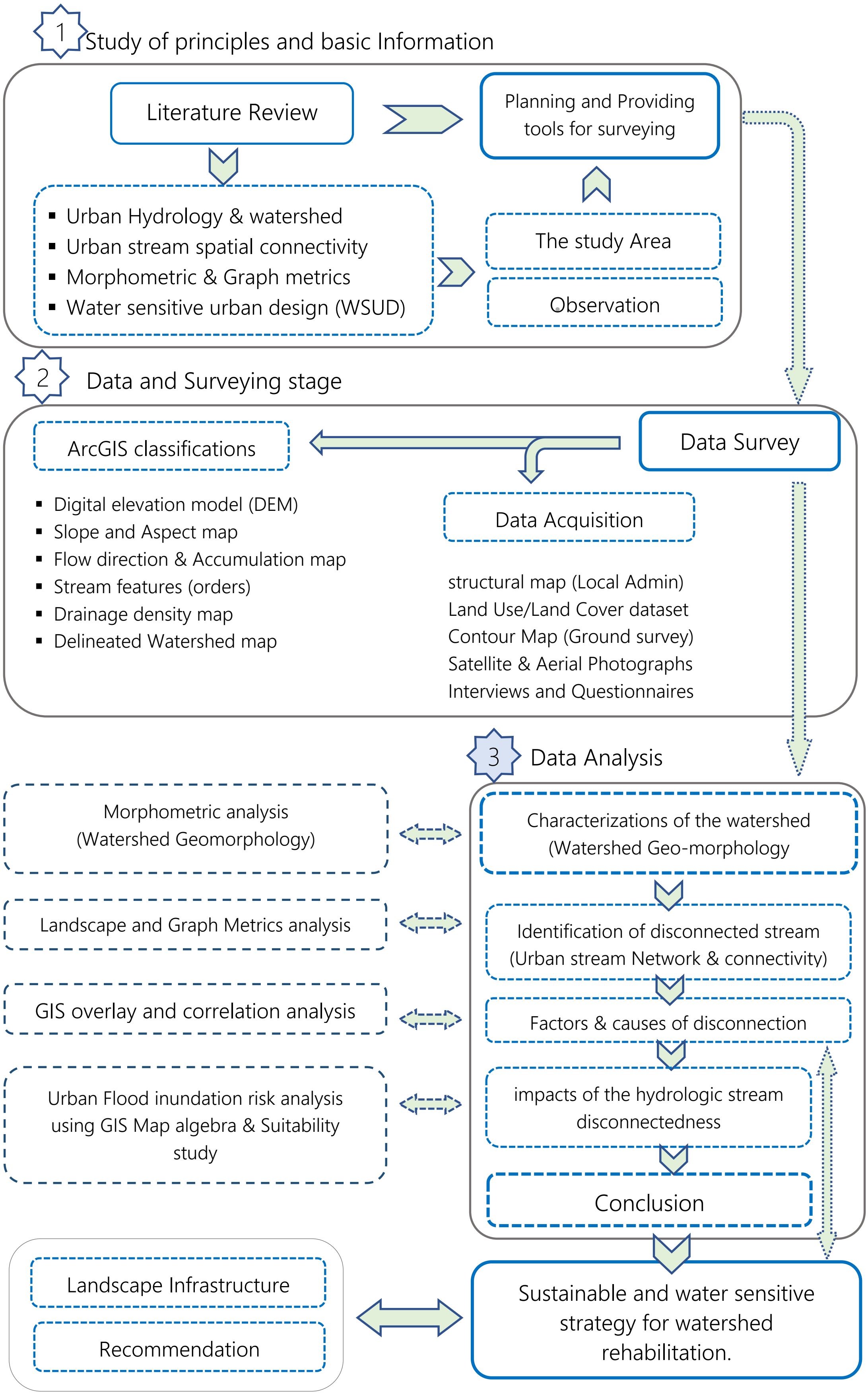


Figure 17. Graphic illustration of research design.

3.6. Methods of data analysis

The following are the data analysis methods employed in the study to respond to each thematically interdependent research objectives.

3.6.1. The geo-morphology and natural characteristics of the sub watershed using Morphometric analysis. (Obj. I)

To characterize the sub-watershed, morphometric analysis was conducted. This analysis provided a means to measure the current water circulation and erosion within the catchment area. Erosion occurred as a result of obstructions to the natural stream channel and water flow, primarily caused by man-made impediments. This phenomenon was closely associated with stream connectivity (Gregory and Walling, 1973; Langbein et al., 1947). ArcGIS was utilized (using 1mx1m resolution DEM generated form ground survey contour map) for the analysis, offering precise and reliable data for characterizing watersheds and their physical behavior, including stream segments, watershed length, basin area, altitude, volume, slope, and land profiles.

The spatial arrangement of the drainage basin's stream system was quantified using stream order (fig. 19), drainage density, bifurcation ratio, and stream length ratio (Horton, 1945). Horton's law of stream lengths proposed a geometric relationship between the lengths of channels in successive stream orders, while the law of basin areas demonstrated a linear relationship between the mean basin area of successive stream orders.

Sub-watersheds were evaluated by assigning ranks to their respective values. Linear parameters, (such as *bifurcation ratio, drainage density, texture ratio, length of overland flow,* and *stream frequency*), showed a direct correlation with erodibility. Conversely, shape parameters, (such as *circularity ratio, form factor, elongation ratio,* and *compactness coefficient*), exhibited an inverse relationship with erodibility (Biswas et al., 1999; Ratnam et al., 2005; Javed et al., 2009).

A compound parameter was derived by averaging all individual parameters within each sub-watershed. The resulting highest value signified the highest degree of erosion vulnerability, while the lowest value indicated the least vulnerability. Subsequently, sub-watersheds were ranked based on their parameter values. Linear parameters such as *bifurcation ratio*, *drainage density, texture ratio, length of overland flow*, and *stream frequency*, directly associated with erodibility, were ranked highest to lowest (highest value was attributed rank 1, the second highest rank 2, and the least rank 3). Conversely, shape parameters including *circularity ratio, form factor, elongation ratio*, and *compactness coefficient*, inversely related to erodibility, were ranked lowest to highest (the lowest value was assigned rank 1, the next lower rank 2, and the highest rank 3) (Biswas et al., 1999; Ratnam et al., 2005; Javed et al., 2009). Finally, the compound parameter was calculated by averaging all parameters, with the highest value denoting the greatest erosion vulnerability and the lowest value representing the least vulnerability.

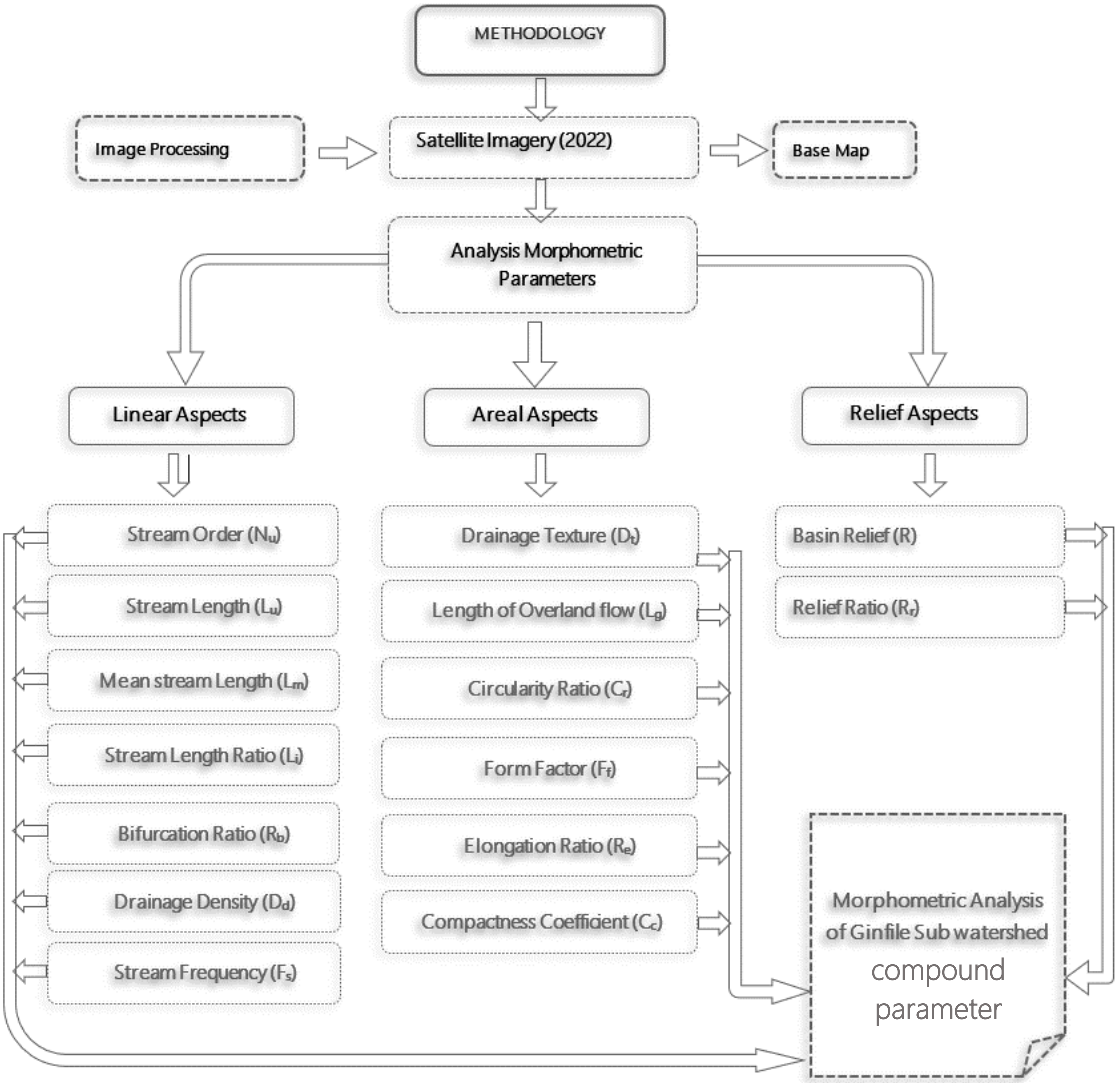


Figure 18. Method of Morphometric analysis.

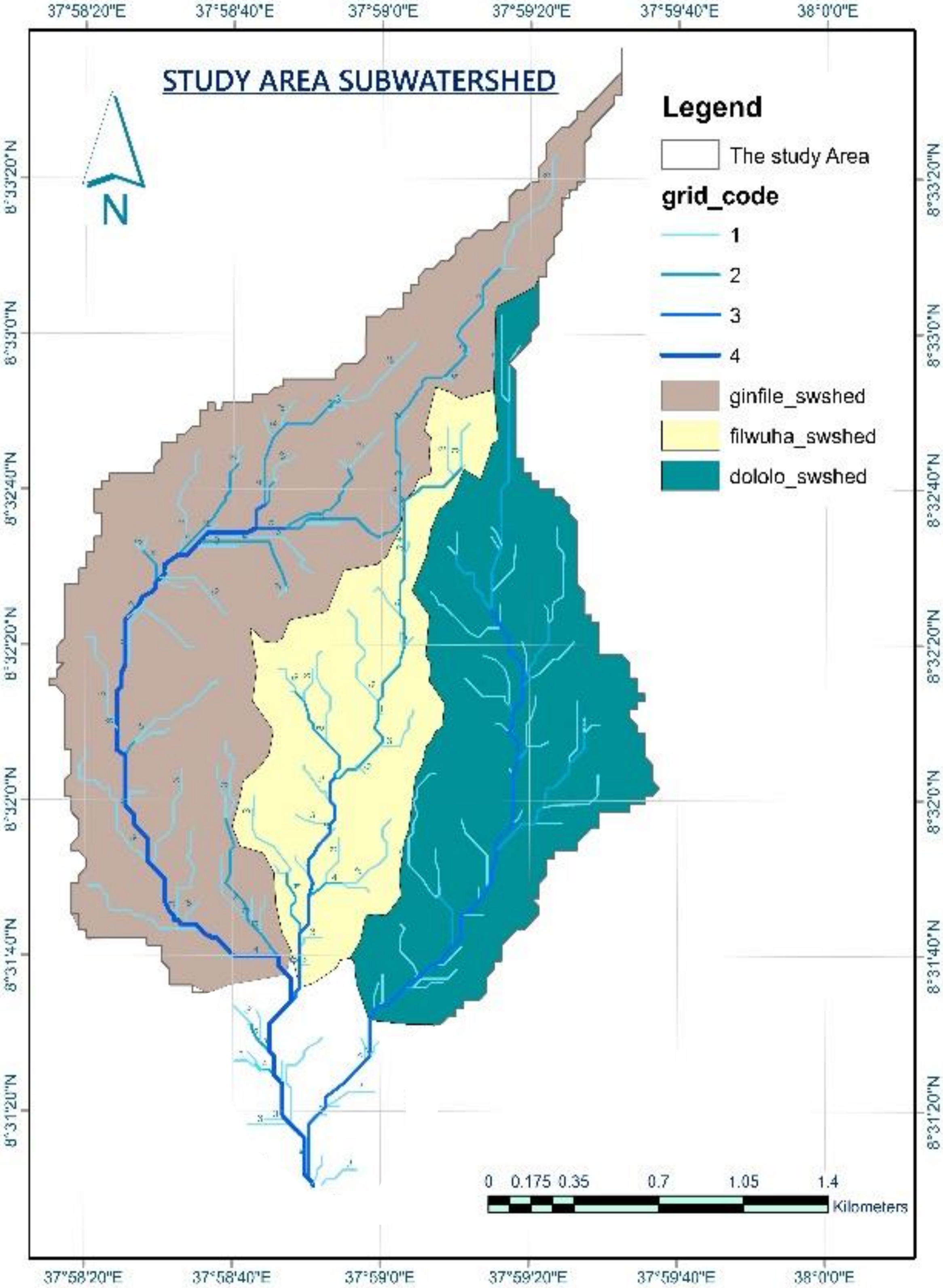


Figure 19. Watershed characteristics. Stream order of sub-watersheds.

3.6.2. Stream connectivity analysis using graph metrics. (*Obj II*)

Connectivity was assessed by examining structural elements, such as watershed topography or the spatial arrangement of habitat patches, and functional metrics, which consider how processes and interactions affect hydrological flows or biological dispersal.

Directed Graph metrics (fig. 20) were employed to establish the distance limits between interconnected habitats, identify hubs and stepping stones, and pinpoint water sources requiring special attention for protection or development.

Initially, the maximum possible number of edges in a stream network graph was determined by considering the natural flow of every stream in the network (complete graph). This provided insight into the potential connections within the network of order n.

Subsequently, comparisons among several similar stream networks of the same size within the sub-watersheds revealed significant variations in the average degree. This discrepancy indicated that some networks had more connections than others. Analyzing these connections shed light on why certain networks had failed while others maintained their connectivity, offering valuable insights for further watershed investigation and rehabilitation approaches.

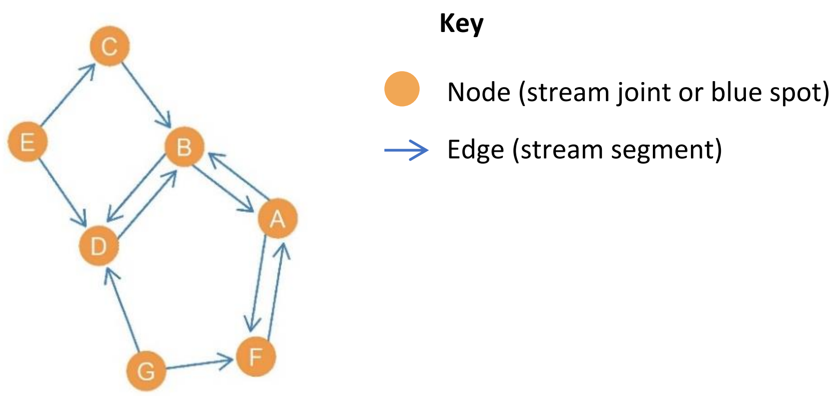


Figure 20. *Illustrative sample of directed graph*

The graph size in this study focuses on the second, third, and fourth stream orders. The key node that is taken for the connectivity analysis can be found at the beginning of the second order stream and also where the stream order changes. Additionally, this is where the depth of the third layer blue spot has been discovered.

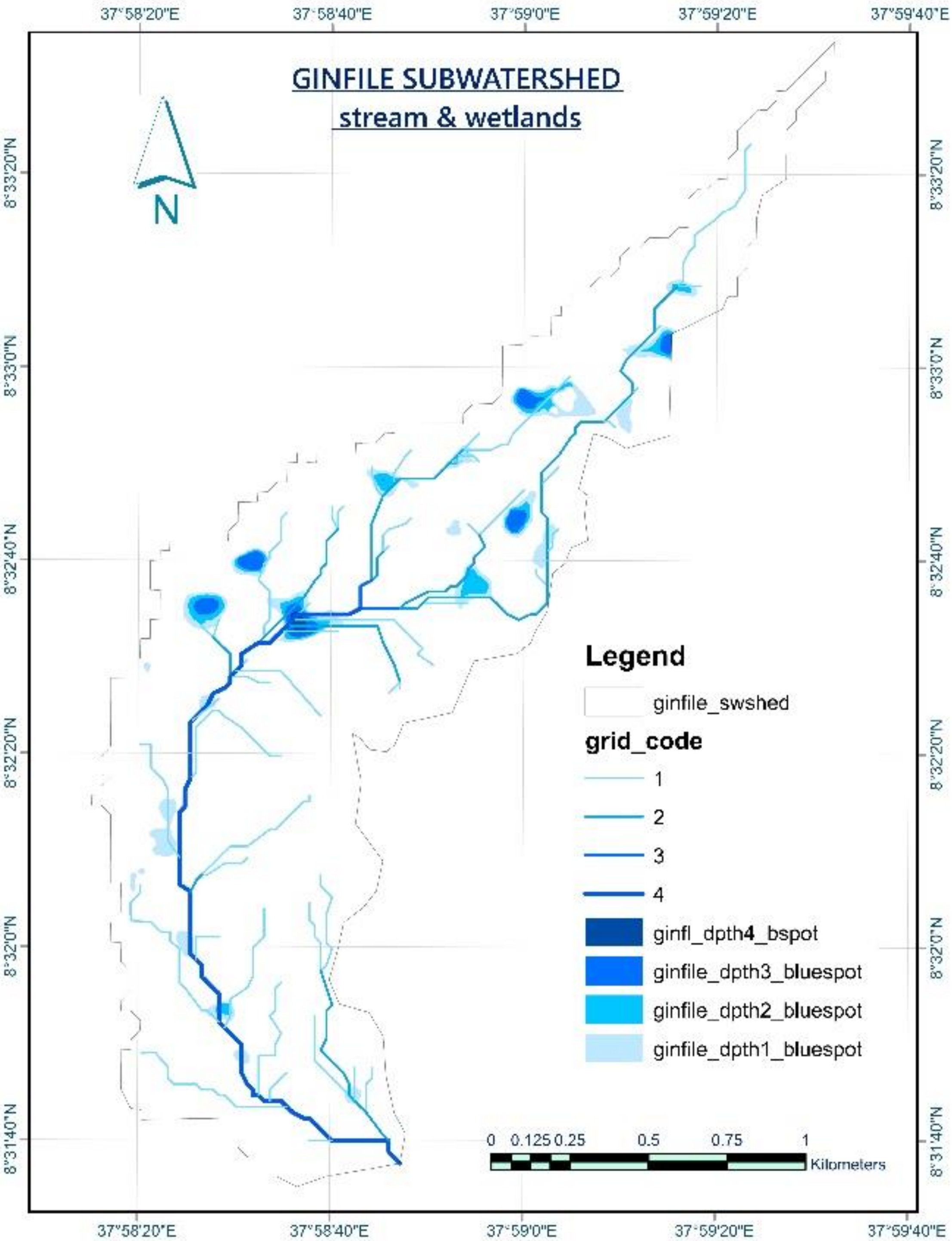


Figure 21. Woliso town Ginfile sub watershed stream and wetland map (GIS generated)

The connection between the stream segment and the wetland location to the stream network has been evaluated with the application of remote sensing and GIS overlay tools (fig. 21), along with satellite imagery. Factors such as the imperviousness of the land and any natural obstructions to water flow are taken into account when determining the connection status.

3.6.3. Factors causing the stream disconnection using GIS overlay and correlation analysis. (*Obj III*)

In order to determine the origins of the hydrological spatial connectivity problem, a GIS overlay technique was employed. This involved analyzing man-made impediments and the land use and land cover (LULC) in regions that might serve as water features, particularly wetlands and waterways. Subsequently, the collected data was examined to determine the underlying cause of the issue.

i. Spatial analysis of Artificial impediments using GIS overlay

The process of combining multiple maps to obtain new information can be used to determine the source of stream spatial disconnection. By overlaying the existing Urban infrastructure (street and drainage layout) with generated full graph stream network data, new spatial elements are created (fig. 22). GIS is used to perform this operation, and the spatial distribution of the land cover in the affected area is analyzed. The potential cause (which has been called factor) of specific disconnections within the area was then identified. The structure of the raster data is particularly appropriate for this kind of analysis, as all the maps have the same geographical reference.

ii. Analysis of the spatial distribution of LULC over the potential wetlands

This process began with the identification of all prospective wetlands within the study area (see fig. 21). Next, a supervised image classification approach was employed to digitize and analyze the land cover and imperviousness associated with the anticipated wetland areas. The first step in this analysis was to partition and digitize the feature space where the potential wetlands were located. This was achieved by defining the spectral characteristics of the classes and identifying sample areas for training purposes. Each sample, representing a specific class, consisted of several training cells to form a representative dataset for the given class. The selection of these clusters ensured diversity within the class while also meeting a minimum threshold of observations per cluster.

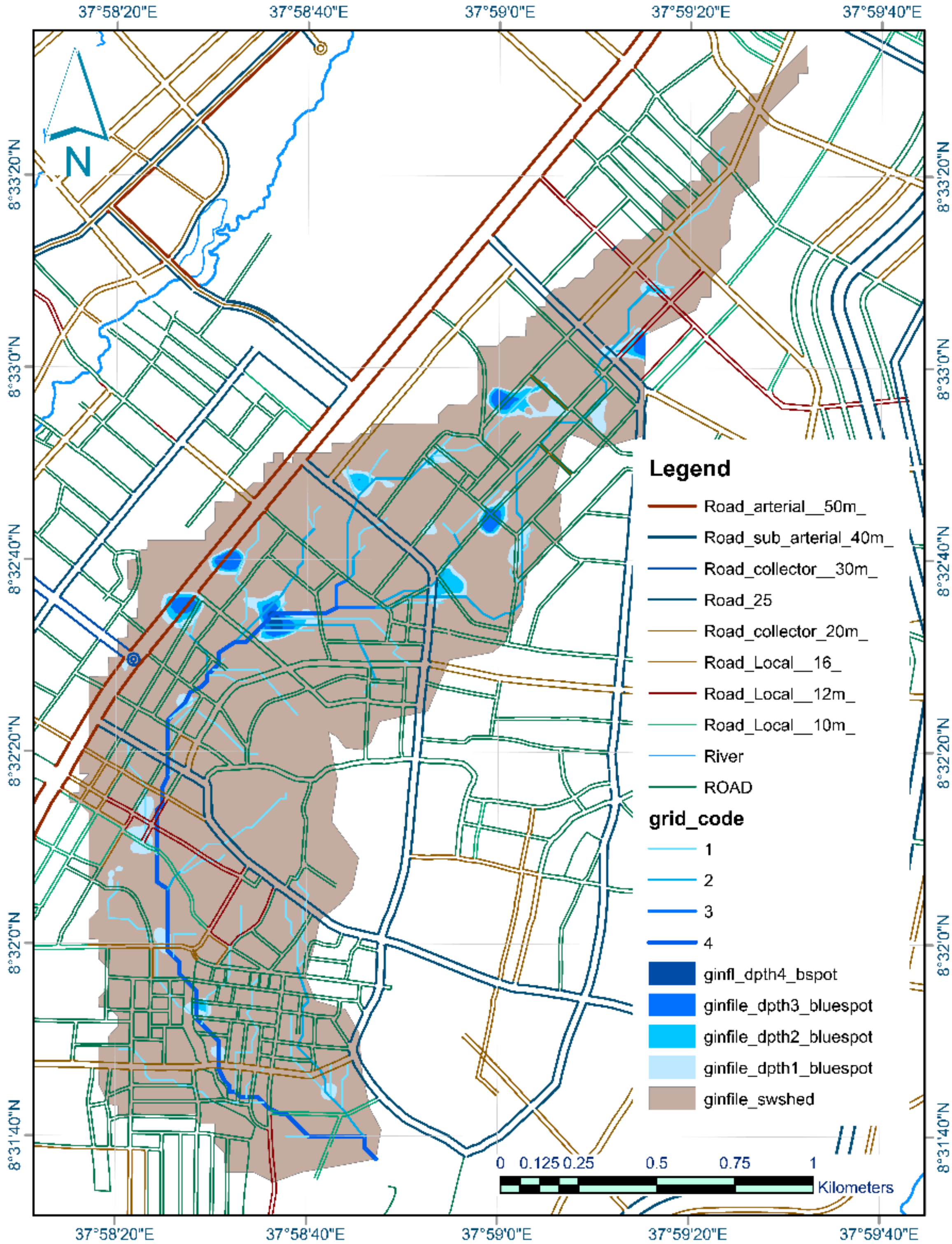


Figure 22. wetland and stream overlay with existing built urban infrastructures

3.6.4. Assessing the risk of urban flood inundation and stream disconnectedness using GIS Map algebra & flood venerability study. (Obj Iv)

Flooding takes place when a large quantity of water fills an area and submerges it. The GIS spatial analysis is used to generate the attribute of areal coverage for blue spot

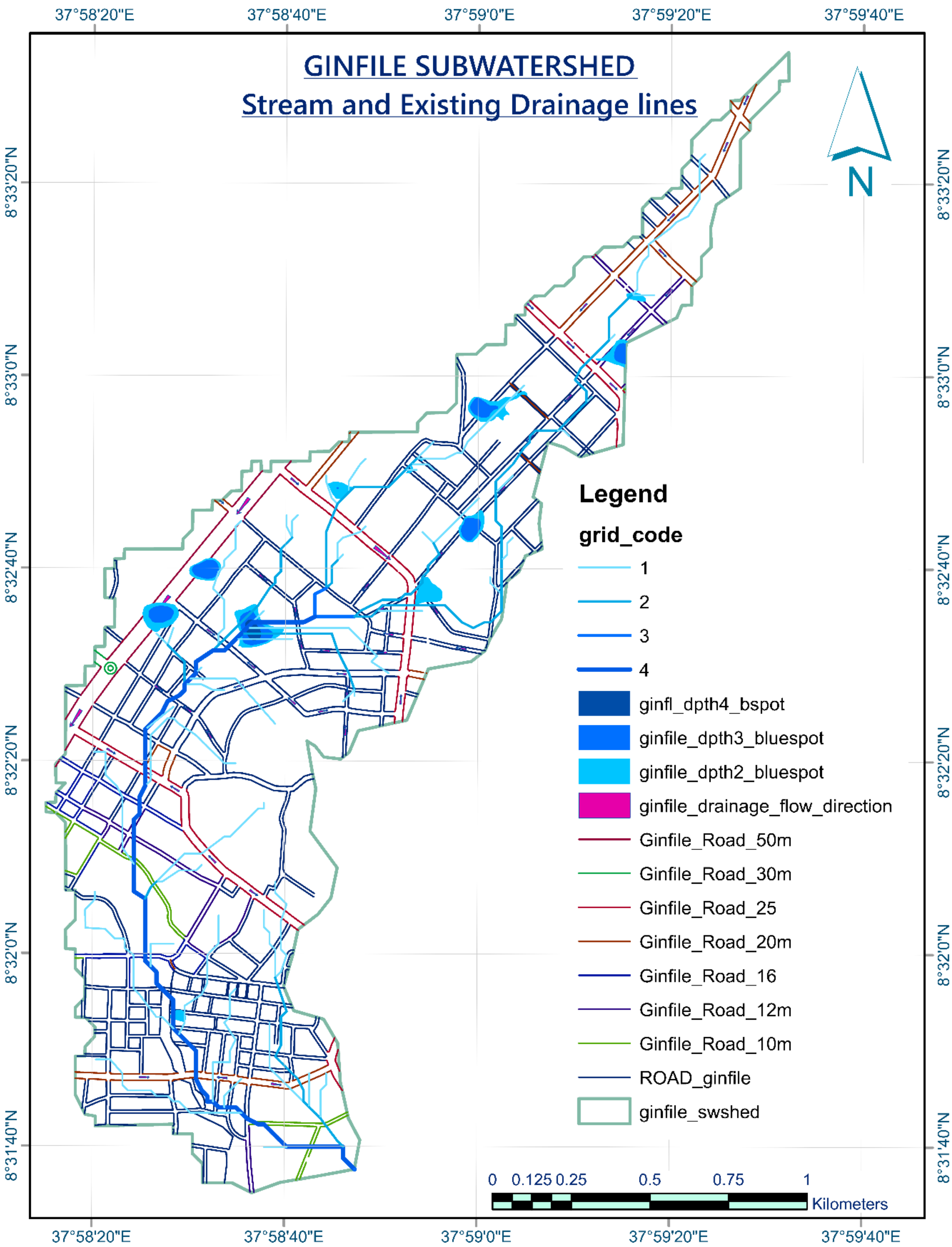


Figure 23. wetland and stream overlay with existing built environment.

dataset and the supervised classification of land use within the prospective wetlands.

The method of Assessment for evaluating the spatial impacts and consequences of hydrologic stream disconnectedness involved employing GIS Map Algebra techniques and conducting a flood vulnerability study. To begin, GIS Map Algebra was utilized to analyze the spatial distribution of urban wetlands and their connectivity status across the study area. This analysis involved overlaying various spatial datasets, including land cover, land use, hydrological features, and urban infrastructure, to identify areas of wetland disconnection and fragmentation caused by urbanization.

Subsequently, a flood vulnerability study was conducted to assess the susceptibility of identified wetland areas to flooding events. This study considered factors such as rainfall intensity, surface water connectivity, and land use modifications to determine the potential inundation extent, depth, and damage in the study area. By integrating the results of the GIS Map Algebra analysis with the findings from the flood vulnerability study, a comprehensive understanding of the spatial impacts of hydrologic stream disconnectedness on urban wetlands was obtained.

Furthermore, the analysis quantified the extent of urban wetland fragmentation and its implications for biodiversity loss and flood risk management. Areas of high flood vulnerability within disconnected wetlands were identified. Additionally, the social and cultural amenities provided by urban wetlands, such as recreational opportunities and ecosystem services, were considered in the analysis to highlight the importance of preserving and restoring these valuable urban ecosystems.

CHAPTER FOUR
RESULT AND DISCUSSION

The study successfully examined various stream characteristics and their responses to changes in the watershed. The subsequent sections present the outcomes and discussions corresponding to the specific objectives outlined in the research.

4.1 Geo-morphological characterizations of the Ginfile Sub watershed.

The results for morphometric analysis of various characteristics of the three sub watersheds have been summarized below.

Table 4. Results of linear morphometric analysis for Ginfile sub watershed in Woliso town

		Area	Perimeter	Number of streams			
S. No	Sub Watershed name	(Km2)	(Km)	1	2	3	4
1	Ginfile sub watershed I	2.5254	11.5951	49	9	2	1
3	Filwuha sub watershed	1.0529	6.2934	27	4	1	0
4	Dololo Sub watershed	1.5553	8.0779	36	8	1	0
	Total watershed	5.13		112.00	21	4.00	1
		Area	Perimeter	Streams Length in km			
S. No	Sub Watershed name	(Km2)	(Km)	1	2	3	4
1	Ginfile sub watershed I	2.5254	11.5951	10.0268	4.6798	0.2380	2.5885
3	Filwuha sub watershed	1.0529	6.2934	3.8660	2.4148	0.9038	0.0000
4	Dololo Sub watershed	1.5553	8.0779	4.7526	1.4926	2.1477	0.0000
	Total watershed	5.13		18.68	8.59	3.29	2.59

As depicted in Table 4, the analysis reveals the presence of three sub-watersheds. Among these, the Ginfile sub-watershed stands out with four ordered streams, while the remaining two sub-watersheds each possess streams of third order. The bifurcation ratio is found to be influenced by both stream order and the total number of streams present within each sub-watershed. Across all orders, the total number of streams amounts to 138, with a cumulative stream length of 33.11 km

Table 5. Analytic result of the Morphometric parameter (cont.. table)

Morphometric Parameter					
S. No	Sub Watershed name	Area	Elevation (m)		Perimeter
		(Km 2)	Max	Min	(Km)
1	Ginfile sub watershed I	2.5254	2,110.00	2,009.00	11.5951
3	Filwuha sub watershed	1.0529	2,065.00	2,009.00	6.2934
4	Dololo Sub watershed	1.5553	2,072.00	2,010.00	8.0779

Morphometric Parameter					
S. No	Sub Watershed name	Watershed Length (Km)	Watershed relief (m)	Total No of stream	Total Stream length in Km
1	Ginfile sub watershed I	3.8004	101.0000	61	17.53
3	Filwuha sub watershed	2.9309	56.0000	32	7.18
4	Dololo Sub watershed	2.6700	62.0000	45	8.39

Table 6. morphometric analysis calculation result (Using formulas in the data analysis)

S. No	Sub Watershed name	Bifurcation ratio	Drainage density	Stream frequency	Circulatory ratio	Form factor
1	Ginfile sub watershed	3.9815	6.9427	24.1546	2.7377	0.1749
3	Filwuha sub watershed	8.7500	6.8236	30.3922	2.1030	0.1226
4	Dololo Sub watershed	8.5000	5.3964	28.9341	2,4201	0.2182

S. No	Sub Watershed name	Elongation ratio	Texture ratio	Compactness coefficient	Relief ratio	Length of overland flow
1	Ginfile sub watershed	0.4717	4.2259	2.0583	0.0266	0.0720
3	Filwuha sub watershed	0.3950	4.2902	1.7302	0.0191	0.0733
4	Dololo Sub watershed	0.5269	4.4566	1.8272	0.0232	0.0927

Table 7. Descriptions of the morphometric finding

Characteristic component	Study Result (Finding)	Description and Analytic Implications
Bifurcation ratio:	Lower value Dololo: 3.98 Higher value Ginfile: 8.75	The study has showed the mean bifurcation ratio varied from 3.98 to 8.75 Lower value of Rb indicates the partially disturbed watershed without any distortion in drainage pattern. On the other hand, a high Rb value points to a large amount of surface runoff and low groundwater recharge for the sub-watershed.
Drainage density:	Lower value Dololo: 5.39 Higher value Ginfile: 6.94	The amount of drainage in a watershed is determined by both climate and the physical characteristics of the region. The drainage density values of entire sub-watersheds are above 5 revealing that the subsurface strata are impermeable characteristic feature. (See Table 6.)
Stream frequency:	Ginfile lowest frequency value: 24.15 Filwuha: highest frequency value: 30.39	The drainage frequency, or the number of channels per unit area of the watershed, is closely linked to the stream population in that area. The higher the frequency, the greater the runoff. In this study, the Filwuha sub-watershed had the highest runoff rate
Circulatory ratio:	Filwuha Lowest (R_c) value: 2.1030 Ginfile Highest (R_c) value: 2.7377	Circulatory ratio (Rc) is influenced by the length and frequency of the stream, geological structures, land use land/cover (LULC), climatic variability, relief and slope of the sub-watersheds
Form factor:	Lowest form factor: 0.1226 highest form factor: 0.2182	Most scholars have proposed that the form factor for a perfectly round basin should be less than 0.7854. The form factor is a measure of the shape of a basin, with a low value indicating a basin that is more elongated and a higher value showing a basin that has a higher peak in a shorter amount of time. In this study, the form factor was found to range from 0.1226 to 0.2182, indicating that the Dololo sws is more elongated than the other two and creating higher peaks over a shorter period.
Elongation ratio (R_e):	Lowest (R_e): 0.395 Highest (R_e): 0.5269 (all are less elongated watershed (< 0.7))	Generally, the elongation ratio (Re) of a watershed can range from zero (most elongated shape) to one (circular shape), which is related to a variety of climate and geological factors. The values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are followed with high relief and steep

		ground slope. The study found elongation ratio varies between 0.3950 (Filwuha sws) and 0.5269 (Dololo sws), both max and min lies in the category of 'less elongated (<0.7)' group. Therefore, in this case the Ginfile sws, which relatively has high relief ratio, is elongated.
Texture ratio:	Lower texture ratio: 4.22 Highest texture ratio: 4.45	The texture ratio of the sub-watersheds in this study ranges from 4.2259 (Ginfile sws) to 4.4566 (Dololo sws). This indicates that the basin is mostly flat and has a lower degree of slopes.
Compactness coefficient:	Highest value: 2.0583 Lowest value: 1.7302	A circular basin is the most hazardous from a drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin
Relief ratio:	Highest value: 0.0266 Lowest value: 0.0191	The relief ratio values across the studied sub-watersheds vary from 0.0191 in the Filwuha sub-watershed to 0.0266 in the Ginfile sub-watershed. These values signify the steepness of each basin and serve as indicators of the erosion intensity within the watershed's slopes. Higher relief ratio values suggest a more pronounced topographical variation and potentially greater erosion activity within the watershed's terrain.
Length of overland flow:	Highest value: 0.0927 Lowest value: 0.0720	The length of overland flow factor, which inversely correlates with the average slope of the channel and is akin to the length of sheet flow, exhibits variability across the sub-watersheds. Specifically, the values range from 0.0720 in the Ginfile sub-watershed to 0.0927 in the Dololo sub-watershed. These values provide insight into the distance over which water travels across the surface before entering the channel network, with lower values indicating steeper slopes and potentially shorter overland flow distances.

The results of the analysis of the three sub-watersheds are presented in a bar graph (Fig 24) demonstrating the characteristics of the drainage pattern.

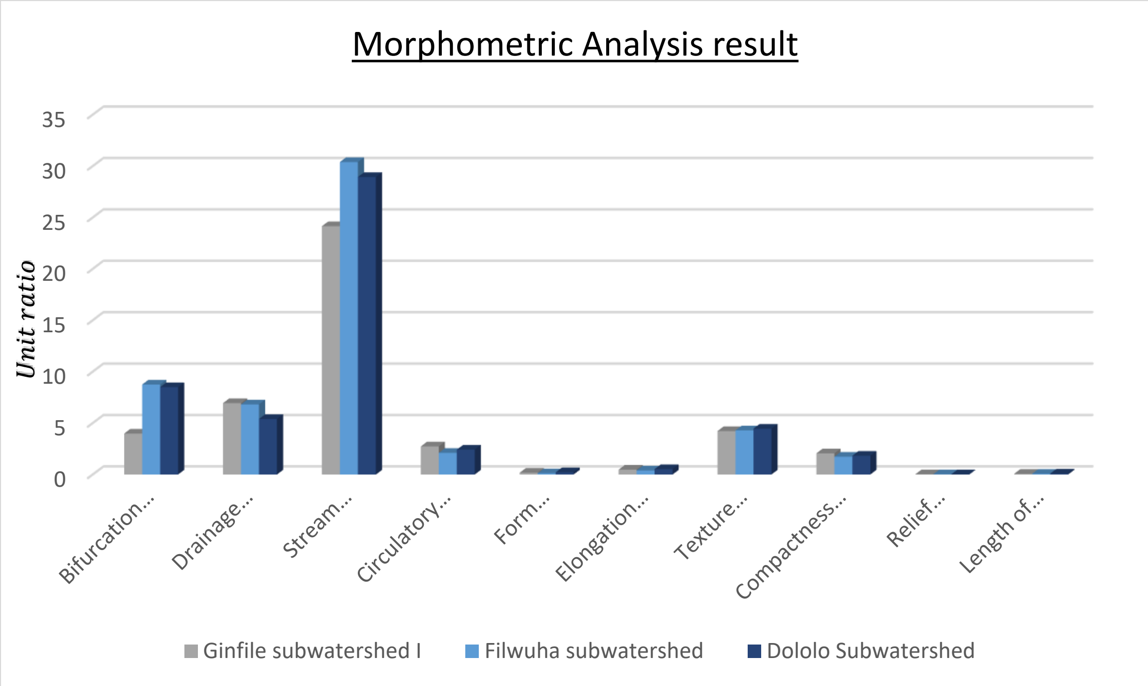


Figure 24. graphic illustration of morphometric analysis result

The highest value of the compound parameter represents the greatest degree of erosion vulnerability, while the lowest value is the least degree of erosion vulnerability. The scores of the sub-watersheds analysis, from maximum to minimum compound parameter value,

Table 8. the compound parameter (CP) result of the morphometric analysis

S.No	Sub Watershed name	Bifurcation ratio	Drainage density	Stream frequency	Circulatory ratio	Form factor
1	Ginfile sub watershed	3	1	3	3	2
3	Filwuha sub watershed	1	2	1	1	1
4	Dololo Sub watershed	2	3	2	2	3

S. No	Sub Watershed name	Elongation ratio	Texture ratio	Compactness coefficient	Relief ratio	Length of overland flow	Average (Degree of erosion)
1	Ginfile sub watershed I	2	3	3	1	3	2.40
3	Filwuha sub watershed	1	2	1	3	2	1.50
4	Dololo Sub watershed	3	1	2	2	1	2.10

were found to be 2.40 (Ginfile SWS), 1.50 (Filwuha SWS), and 2.10 (Dololo SWS) respectively (figure 25).

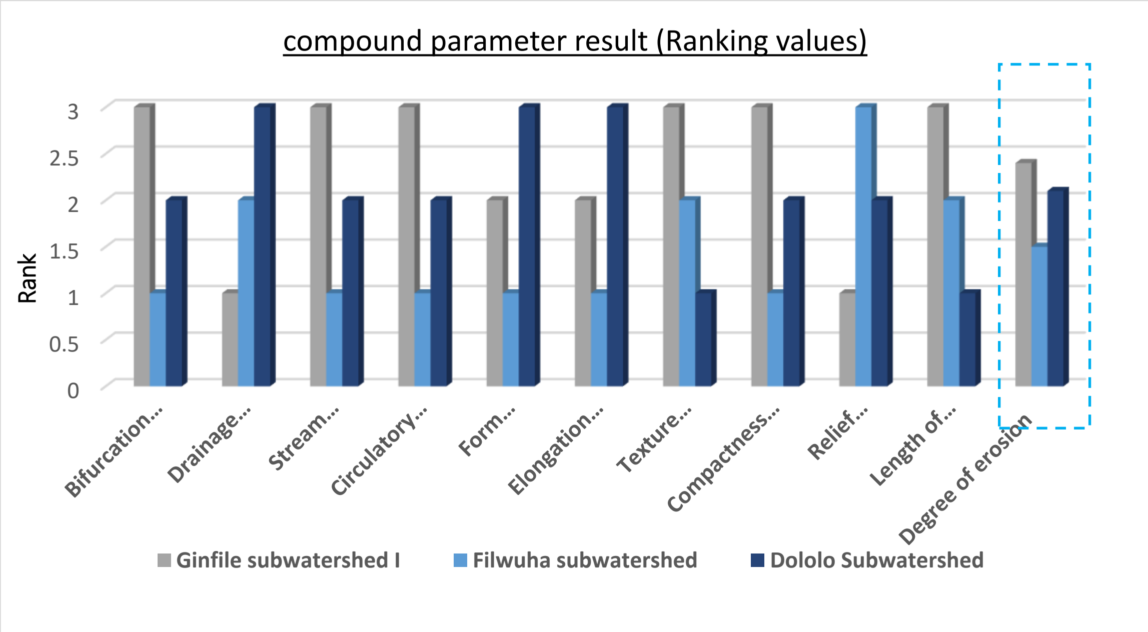


Figure 25. Graphic illustration for the compound parameter results of the Morphometric Analysis

The rehabilitation practices and measures urban hydrology should be tailored to the degree of erosion vulnerability based on the final assessment. Runoff peak, speed, and volume are all factors which can be used to calculate erosion. Drainage density, a linear parameter, is a key indicator of this, as it links the form of the watershed to the processes in the course (Gregory and Walling 1973). Langbein (1947) suggested that drainage density played a role in determining the time that water takes to travel within the watershed. The drainage density values of entire sub-watersheds are above 5, and the Ginfile sub-watershed is the highest value (6.9427) in particular revealing that the subsurface strata are impermeable characteristic feature. Meanwhile, erosion occurs when the natural stream channel and water flow are obstructed by various physical, primarily man-made impediments. This is closely related to stream connectivity. In this study, it was determined that the Ginfile sub-watershed had the highest degree of erosion (2.40), indicating that it is a highly vulnerable area. Consequently, prioritizing comprehensive investigation and remedial action in the Ginfile sub-watershed is imperative to address erosion challenges effectively.

4.2 Level of Stream Disconnection.

i. Spatial positions of important nodes and edge of hydrologic stream

The spatial analysis conducted through GIS revealed the presence of six significant wetlands along the Ginfile tributaries within the sub-watershed area (fig. 26). Among which, five (5) wetlands, which constitute 71.85% of the entire wetland area, were located in privately-owned parcels with public access. These wetlands are not completely protected from most anthropogenic disturbances, and they are entirely surrounded by impervious land cover such as asphalt streets, buildings, and pavements. The remaining wetland, with a high degree of connectivity value, is situated in a grassy/loamy and undeveloped area with swampy characteristics. Additionally, the study identified a total of 49 first-order stream segments, 9 second-order, 2 third-order, and 6 fourth-order streams were identified. Among these, the second, third, and fourth-order streams (subdivided into six segments due to nodal junctions) were considered for the connectivity analysis. However, five second-order streams and two nodal segments of the fourth-order stream reaches are at risk of increased stress or alteration due to the lack of protection and exposure to anthropogenic disturbances and potential development in the contributing area.

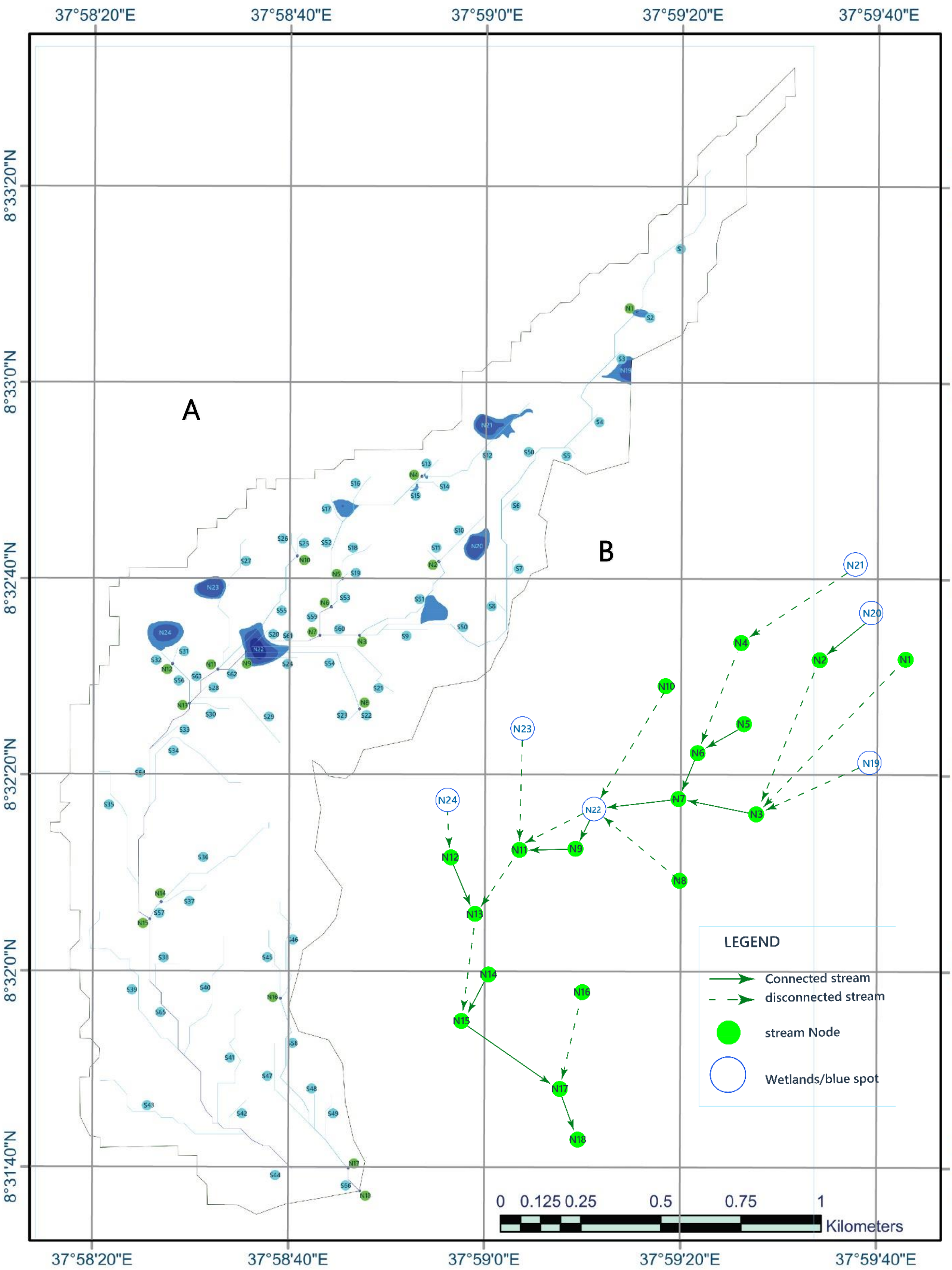


Figure 26. (A). graphic illustration of spatial positions of important nodes and edge of hydrologic stream and wetland of the study area, Ginfile sub watershed. (B). Node spatial connectivity graph.

ii. The Directed Graph Network Components

Degree Measures in a Weighted, and Directed stream Network

By modeling node degree, the places in the graphed network with the highest (area and depth) local cumulative wetland influence were highlighted. The study has identified 24 Nodes, which are associated with the longest and highest quality stream and wetland and were directly connected to neighbors with large, high-quality wetlands had the highest in- degree scores. i.e., node 'N22, N3, and N11' had the highest in-degree score in the case of assumed directed full graph scenario, because they have high quality wetlands

Table 9. second, third and fourth order hydrologic stream and important wetland node label and their existing connectivity status of the Ginfile sub watershed.

Stream Labele	stream order	from Node	to node	stream length (m)	connection Status
S50	2	N1	N3	1786.0800	spatialy disconnected
S51	2	N2	N3	406.5318	spatialy disconnected
S52	2	N4	N6	587.9914	spatialy disconnected
S53	2	N5	N6	104.8068	spatialy connected
S54	2	N8	N9	481.8583	spatialy disconnected
S55	2	N10	N11	459.9098	spatialy disconnected
S56	2	N12	N13	148.2192	spatialy connected
S57	2	N14	N15	65.6394	spatialy connected
S58	2	N16	N17	638.8039	spatialy disconnected
S59	3	N6	N7	112.1371	spatialy connected
S60	3	N3	N7	125.8741	spatialy connected
S61	4	N7	N9	252.9079	spatialy connected
S62	4	N9	N11	112.2552	spatialy connected
S63	4	N11	N13	151.6599	spatialy disconnected
S64	4	N13	N15	770.2993	spatialy disconnected
S65	4	N15	N17	1214.0331	spatialy connected
S66	4	N17	N18	87.3095	spatialy connected

wetland as node	wetland lebel	from Node	to node	wetland Area	connection Status
N19	wetland 1	N19	N3	4,324.1818 sq.m	disconnected wetland
N20	wetland 2	N20	N2	7,983.4677 sq.m	spatialy connected
N21	wetland 3	N21	N4	5,688.3314 sq.m	disconnected wetland
N22	wetland 4	N22	N9	12,358.1629 sq.m	spatialy connected
N23	wetland 5	N23	N11	5,522.9898 sq.m	disconnected wetland
N24	wetland 6	N24	N12	8,028.7969 sq.m	disconnected wetland

(N22), covering 28.15% of the entire wetland area coverage and directly connected neighbor that contained a high-quality stream (2nd and 4th order). Node N6, N7, N13, N15, and N17 have the second highest in-degree score in case of fully connected network graph. The other 16 node has the third indegree value. According to the existing graph indegree measure, 22 out of the 24 nodes in the network carried 62.85% of all the attribute weight in the connected network.

The graph in Figure 27 illustrates the interpretations of the graph metric analysis result of

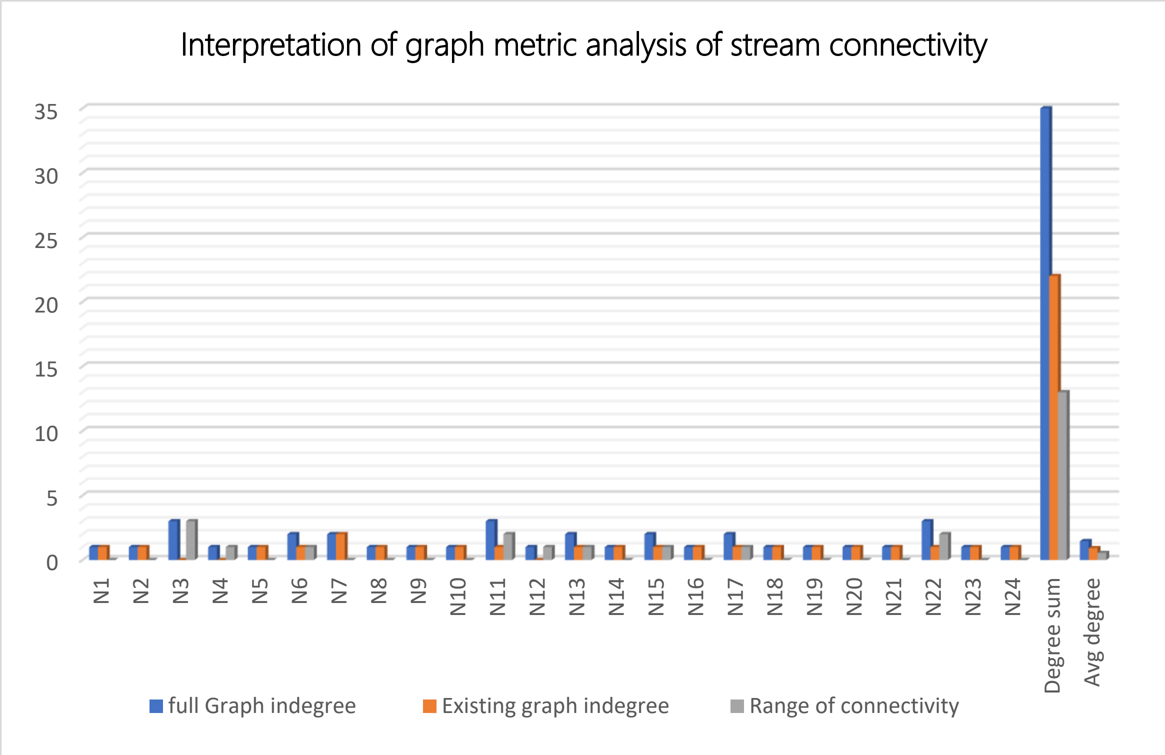


Figure 27. Graphic illustration for the graph metric analysis result of Ginfile stream connectivity

stream connectivity. The blue bar shows the degree of stream connectivity when each stream maintained it natural flow within the watershed. Whereas, the orange bar reveals the existing scenario which shows 37.14% of stream and wetland disconnection. It's a serious sense of heterogeneity or range of stream disconnectedness, which needs an intervention to restore the stream richness and boost the ecological value and the biodiversity.

iii. Statistical Analysis of Functional Connectivity Metrics

The Statistical Analysis of Functional Connectivity Metrics of complete/full directed graph revealed the indegree sum of 35 whereas, with the existing urban environment (physical scenario) is 22. (See table 9) This figure shows 37.14% sense of heterogeneity or range of stream connectivity within the watershed.

Table 10. The graph metric analysis result of hydrologic stream and wetland connectivity of Ginfile sub watershed

No	Node	full Graph indegree	Existing graph indegree	Range of connectiv ity	Remark
1	**N1**	1	1	0	No change
2	**N2**	1	1	0	No change
3	**N3**	3	0	3	significant impact
4	**N4**	1	0	1	Impacted
5	**N5**	1	1	0	No change
6	**N6**	2	1	1	Impacted
7	**N7**	2	2	0	No change
8	**N8**	1	1	0	No change
9	**N9**	1	1	0	No change
10	**N10**	1	1	0	No change
11	**N11**	3	1	2	Impacted
12	**N12**	1	0	1	Impacted
13	**N13**	2	1	1	Impacted
14	**N14**	1	1	0	No change
15	**N15**	2	1	1	Impacted
16	**N16**	1	1	0	No change
17	**N17**	2	1	1	Impacted
18	**N18**	1	1	0	No change
19	**N19**	1	1	0	No change
20	**N20**	1	1	0	No change
21	**N21**	1	1	0	No change
22	**N22**	3	1	2	Impacted
23	**N23**	1	1	0	No change
24	**N24**	1	1	0	No change
	Degree sum	35	22	13	**sense of heterogeneity of the two directed**
	Avg degree	1.4583	0.9167	0.5417	

Overall, the implications of these findings highlight the need for holistic approaches to urban watershed management that prioritize the preservation and restoration of wetland-stream connectivity. Urban areas can better mitigate the impacts of urbanization, support biodiversity, and ensure the long-term sustainability of watershed health.

4.3 Factors causing stream disconnection.

The examination of drainage density within the study area revealed elevated values exceeding 5, indicating impermeable subsurface strata and implying potential hindrances

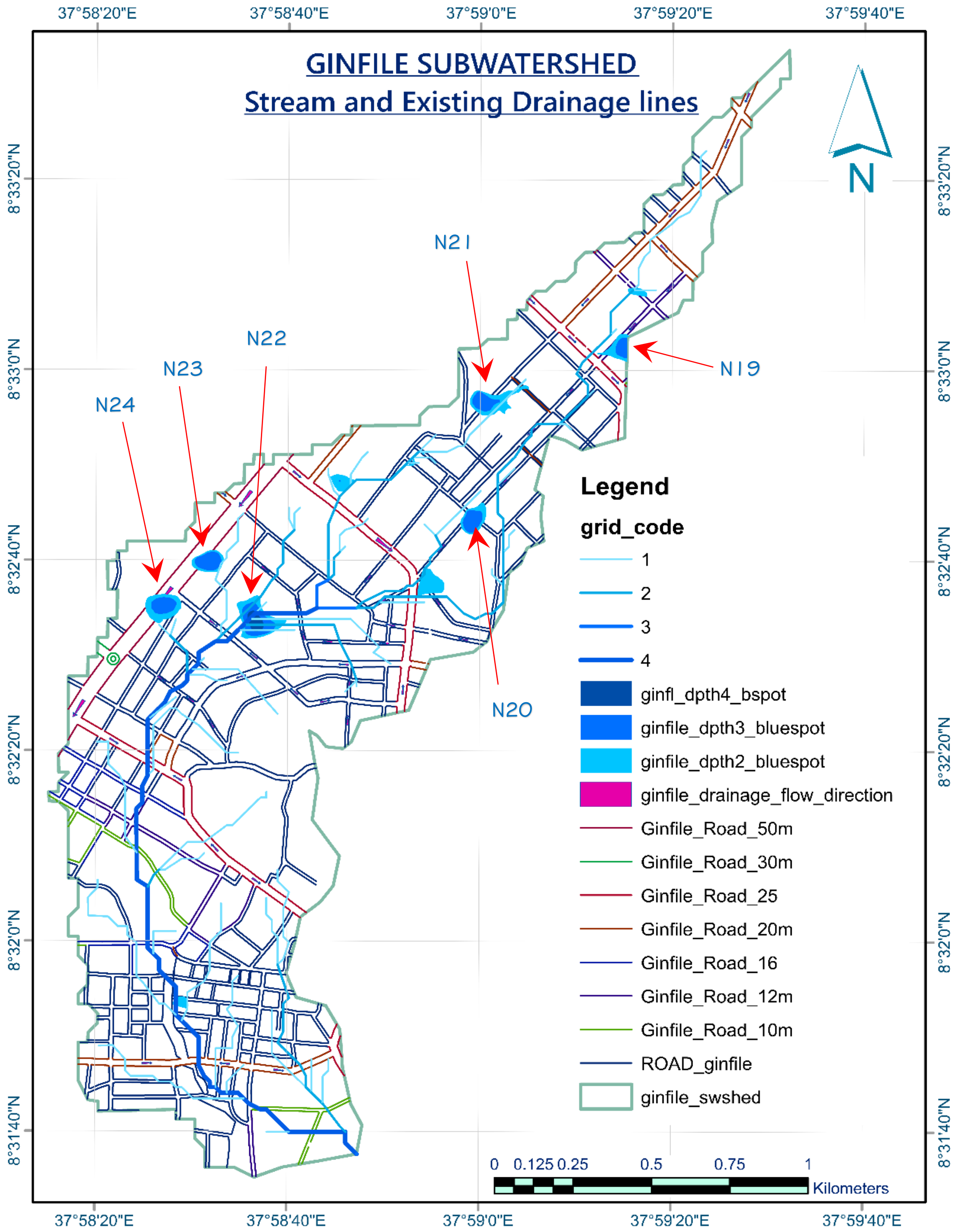


Figure 28. the overlayed hydrologic stream, street and existing drainage lines of Ginfile sub watershed.

to natural water flow along stream lines. This observation underscores three key contributing factors: the watershed's characteristics, the spatial arrangement of waterbodies, and the influence of human activities and alterations in land cover and artificial impediments. Together, these factors provide valuable insights into the intricate interplay among various components impacting physical, chemical, and biological connectivity. While many of these factors align with fundamental hydrological and

Table 11. illustration of factor causing the stream disconnection

Stream Labele	stream order	from Node	to node	stream length (m)	Number of disconnected edge	Disconnecting Factors
S50	2	N1	N3	1786.08 m	13	Factor 1
S51	2	N2	N3	406.5318 m	4	Factor 2
S52	2	N4	N6	587.9914 m	4	Factor 3
S54	2	N8	N9	481.8583 m	1	Factor 4
S55	2	N10	N11	459.9098 m	3	Factor 5
S58	2	N16	N17	638.8039 m	7	Factor 6
S63	4	N11	N13	151.6599 m	1	Factor 7
S64	4	N13	N15	770.2993 m	7	Factor 8
N19	wetland 1	N19	N3	4,324.1818 sq.m	2	Factor 9
N21	wetland 3	N21	N4	5,688.3314 sq.m	2	Factor 10
N23	wetland 5	N23	N11	5,522.9898 sq.m	2	Factor 11
N24	wetland 6	N24	N12	8,028.7969 sq.m	1	Factor 12
	total impacted stream length			5283.1344 m	47	12
	Total of impacted wetland			23,564.2999 sq.m		

biological principles, it is essential to recognize that they represent only a subset of the myriad elements influencing connectivity within the ecosystem.

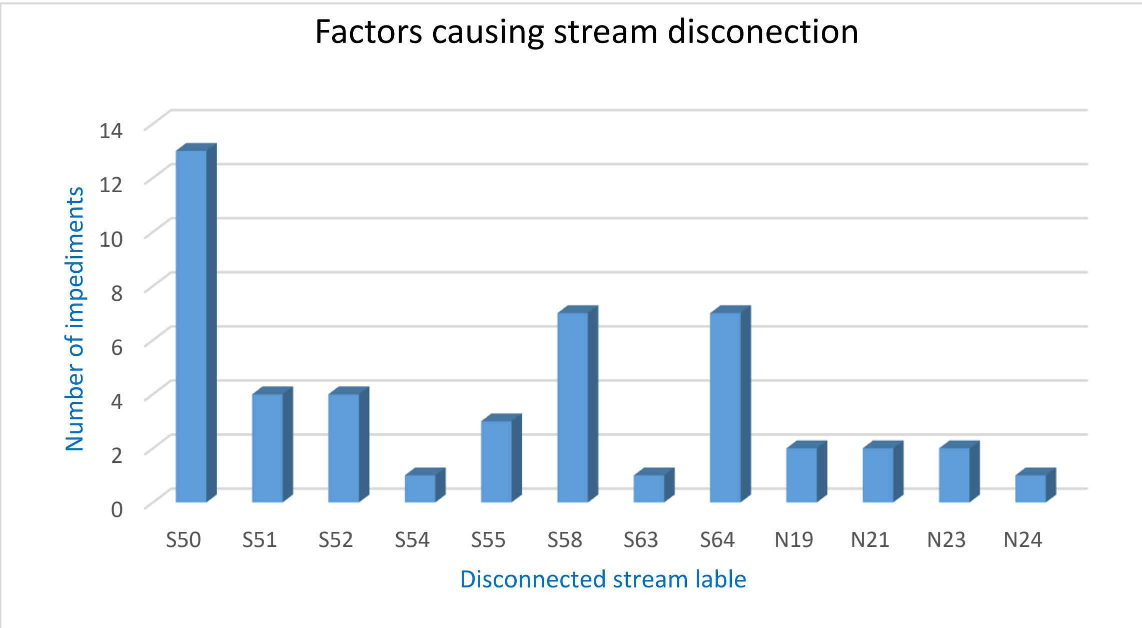


Figure 29. Graphic illustrations of disconnected stream and number of physical impediments observed.

As illustrated on table 11, it has been identified 47 case circumstances that cause stream spatial disconnection. Among these 13 is on the stream line S50 between the two node N1 and N3, two stream lines (S58 and S64) with 7 disconnection and so on (see table 11).

Table 12. Description of the spatial phenomenon of the factors causing disconnection between important nodes.

Factor label	Description of the spatial phenomenon of labeled factors ***(see table 7.)***
Factor 1	The water flow along Stream line (S50) was revealed to be interrupted by roadways and redirected 13 times before it reached at its destination (N3).
Factor 2	The second order stream (S51) connects nodes N2 and N3, which appear to align the artificial drainage line along the street and traverse about four streets without a culvert.
Factor 3	This second order stream accumulates in the residential neighborhood above St. Lukas Hospital and runs towards a tiny wetland on the condominium site near the hospital, where the stream must flow down to pass the hospital compound. However, the hospital complex is surrounded by an HCB wall fence, which completely impairs surface water movement and creates a barrier or stream disconnection.
Factor 4	The stream route between nodes N8 and N9 has been disturbed and imposed by the street drainage line, resulting in a lengthier course before joining the wider marsh (N22).
Factor 5	The stream emanates from the St. Lukas Hospital compound and intercept built up and impervious surfaces before it hits the swampy area wetland (N22).
Factor 6	It begins at the 04-Kuteba neighborhood village on the NE side and runs through the Panafric residences on the right side. Its natural flow is interrupted seven times before it hits the next large stream order at (N17)
Factor 7	Short considerable stream segment disturbed and dislocated its channel owing to cut and fill of the ground surface for housing construction. We

	also discovered through interviews that the natural stream route was previously filled by earth debris dumped from nearby settlements.
Factor 8	A lengthier fourth-order stream segment and extensions to the stream S63 that have been influenced by factor 7. The stream dislocation is still an issue for the same reason.
Factor 9	An isolated/disconnected wetland and completely impacted due to land use change and introductions of impervious land cover. The wetland is covered with the 26.40% built up, 44.97% street, 27.53% of grass cover and generally the wetland is found severely impacted (71.37% impact)
Factor 10	prospective blue spots are totally sealed with an impervious surface cover which is leading to isolation and disconnection of wetland. The wetland is covered with the 63.57% built up, 31.05% street, 51.53% of grass cover and generally the wetland is found seriously impacted (94.63% impact)
Factor 11	The wetland (N23) is physically situated on the Addis to Jimma highway road passing the town center. And since the street is relatively elevated at this particular spot, the wetland magazine which supposed to retain the storm water rush the runoff to the commercial buildings at the side of the road mainly in the form of flash floods and water logging of streets due to high intensity short spell rainfall. The wetland is covered with the 24.40% built up, 22.66% street, 5.34% of grass cover and generally the wetland is found significantly impacted (94.40 % affected)
Factor 12	the same physical scenario as of the N23 wetland. The wetland is covered with the 29.39% built up, 38,35% street, 10.28% of grass cover and 20.38% of paved surface. generally, the wetland is substantially impacted (88.14 % impacted)

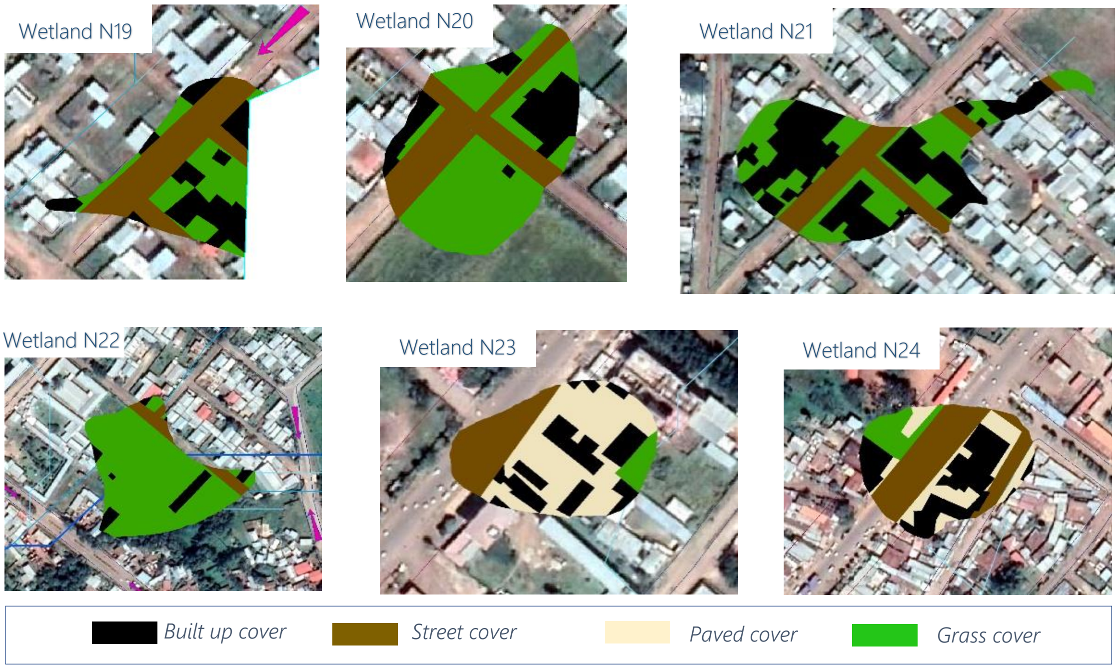


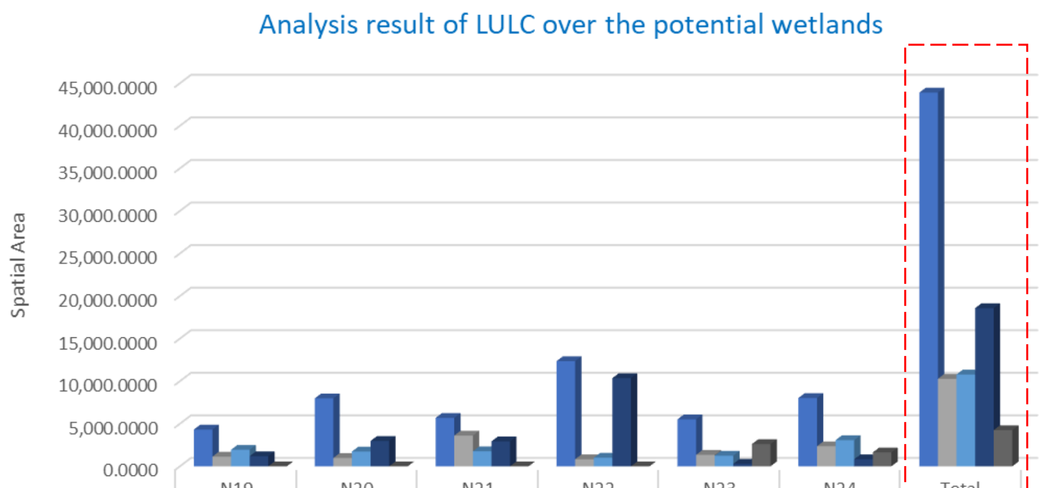
***Figure 30**. the existing LULC dominating the six potential wetlands taken within the watershed*

The analysis of existing land use and land cover areas has revealed significant impacts on the potential wetlands within the watershed. Wetlands labeled N19, N20, N21, N22, N23, and N24 exhibit varying degrees of impact from built-up areas, streets, and paved cover, with percentages ranging from 14.93% to 94.63%. Notably, wetlands N19, N21, N23, and

***Table 13**. the existing land use land cover areal analysis of potential wetlands within the watershed*

wetland Lable	Wetland Area (Sq.m)	wetland Builtup cover	wetland street cover	wetland Grass cover	Wetland Paved surface	Impact in percent (%)	Connectivity status
N19	4,324.1818	1141.5720	1944.5405	1190.5212	…	71.37	disconnected wetland
N20	7,983.4677	980.0497	1738.4264	2980.5144	…	34.05	spatialy connected
N21	5,688.3314	3616.2222	1766.3885	2931.3171	…	94.63	disconnected wetland
N22	12,358.1629	835.0838	1010.3186	10359.5908	…	14.93	spatialy connected
N23	5,522.9898	1348.1266	1251.5342	296.2796	2613.8968	94.40	disconnected wetland
N24	8,028.7969	2360.3567	3079.3260	825.3565	1636.50894	88.14	disconnected wetland
Total	**43,905.9305**	**10281.4109**	**10790.534**	18583.5796	4250.4057	57.67	

N24 are particularly affected, with percentages of impacted areas exceeding 70%. Overall, approximately 57.67% of the total blue spot, representing potential wetlands, has been impacted by land use and cover changes. These alterations have contributed to the disconnection of wetland areas within the watershed, highlighting the significant influence of human activities on the landscape and loss of wetland habitats.



	N19	N20	N21	N22	N23	N24	Total
Wetland Area (Sq.m)	4,324.1818	7,983.4677	5,688.3314	12,358.1629	5,522.9898	8,028.7969	43,905.9305
wetland Builtup cover	1141.5720	980.0497	3616.2222	835.0838	1348.1266	2360.3567	10281.4109
wetland street cover	1944.5405	1738.4264	1766.3885	1010.3186	1251.5342	3079.3260	10790.53425
wetland Grass cover	1190.5212	2980.5144	2931.3171	10359.59079	296.2796	825.3565	18583.5796
Wetland Paved surface	0	0	0	0	2613.8968	1636.50894	4250.4057

Wetlands Lable

Wetland Area (Sq.m) · wetland Builtup cover · wetland street cover · wetland Grass cover · Wetland Paved surface

Figure 31. Analytical result of land use land cover over the potential wetland across the strudy area watershed.

The study ascertains that human-made obstructions to the natural stream network, such as those caused by urban development, along with the topography of the area, play a major role in determining the water flux and the degree of its interconnectedness. Additionally, the lack of maintenance and utilization of the organic water flow has an effect on the pattern of the streams

The graph (figure 32) illustrates the different land cover types in six wetlands in the study area. The amount of impervious area blocking the infiltration of stormwater after it has been held in the wetland is seen as an effect.

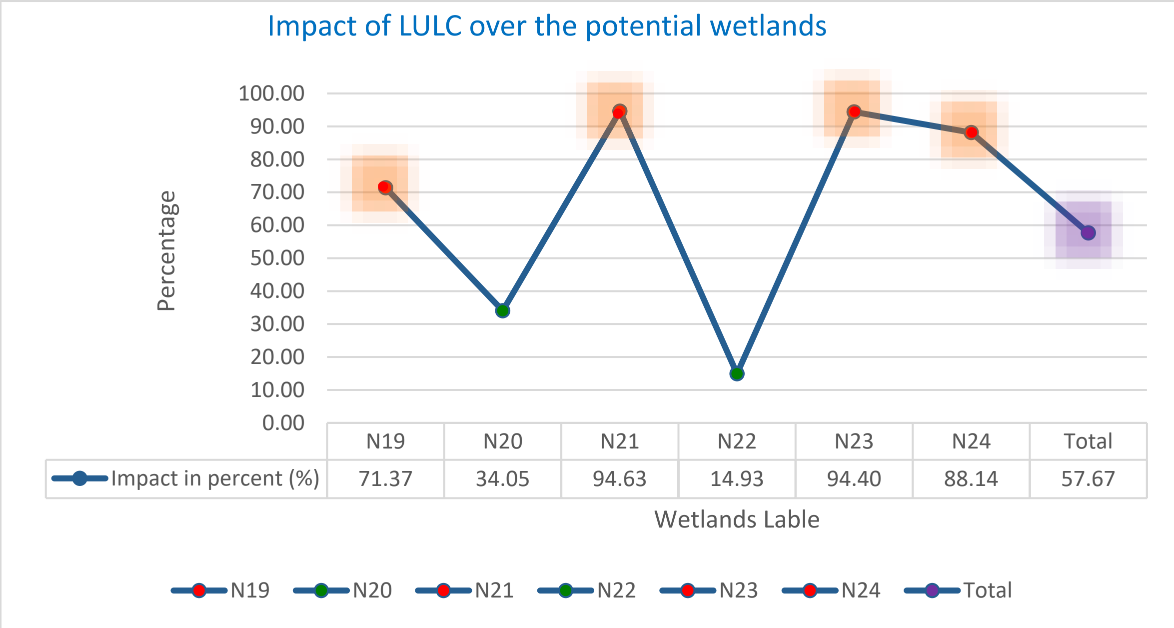


Figure 32*. imperviousness impact of prospective wetlands within the study area watershed.*

Approximately 57.67% of the wetland area has been affected by impermeable surfaces, resulting in a prolonged period of flooding due to the low absorption rate of the magazine. The chart illustrates how the potential wetlands are affected and the lack of hydrological connection through ground water when the amount of water added surpasses the storage capacity of the wetlands (fill).

4.4 Spatial impacts and consequences of the hydrologic stream disconnectedness

The analysis reveals that approximately 43,905.93 m^2 of the studied region qualifies as a potential wetland. Among these wetland areas, 23.42% is composed of built-up cover,

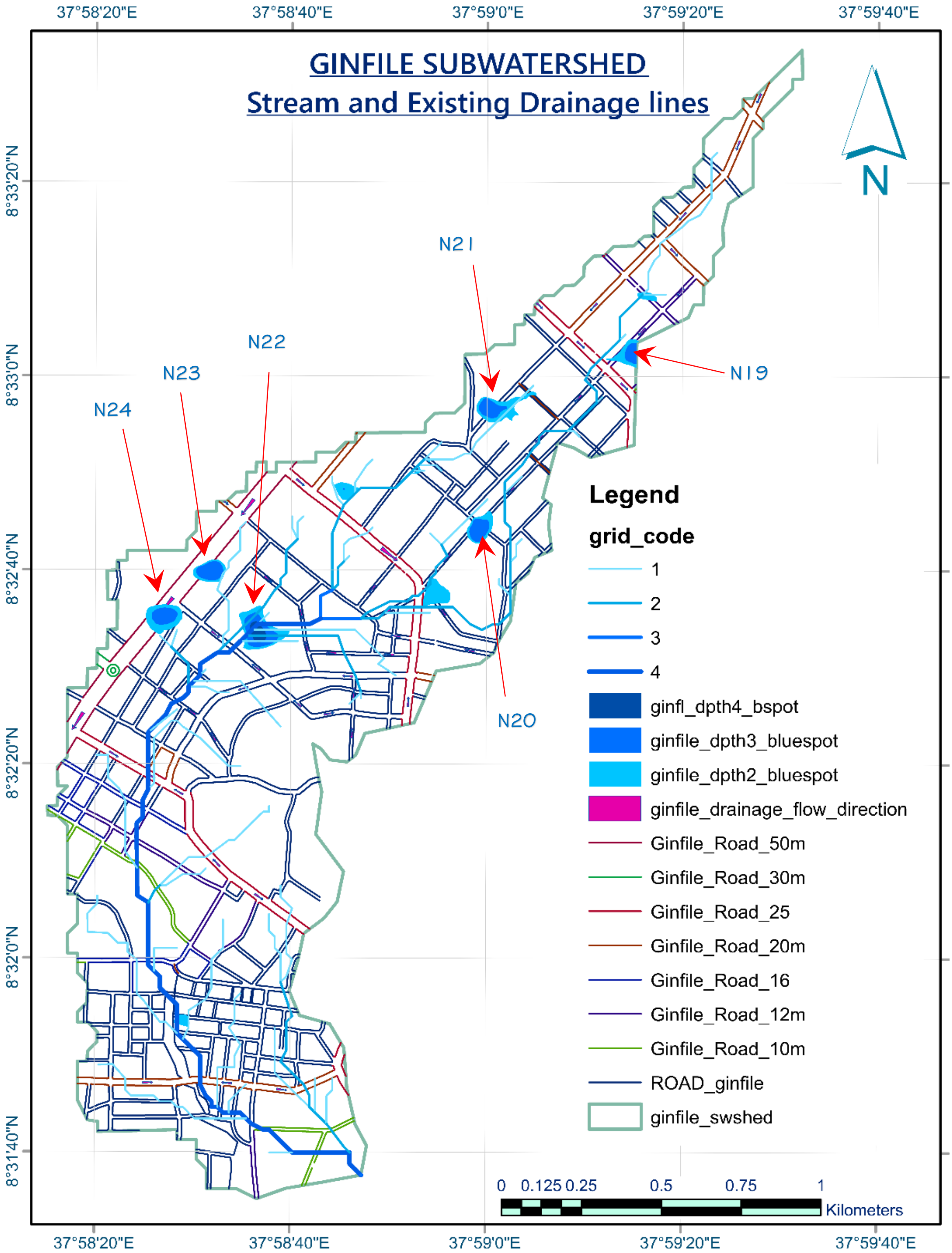


Figure 33. the overlayed hydrologic stream, street and existing drainage lines of Ginfile sub watershed.

24.58% is made up of streets, 42.33% is grass cover, and 9.68% is paved surfaces, amounting to 57.67% of the wetland area which is susceptible to heavy precipitation. These potential wetlands are also impacted by modifications in land utilization.

The findings of the study indicate that urban flooding has affected an area spanning 25,322.35 square meters, comprising built-up infrastructure, streets, and paved surfaces, over the years 2020 to 2022. This observation is corroborated by photographic evidence (Figure 34A, C, and D), which captures instances of urban flooding occurring at identical spatial locations as identified through GIS analysis.

Figure 34. The urban flood inundation impact observed across the study area watershed. @Woliso, photo: on May 20- 2020.

(A): (N24) venerable 'Amin bakery' on the main road, (B): surviving 2nd order stream around Irsha sebil. Mazoria, (C): flood victim in the hospital condominium ground-floor, (D): Heavy rainfall occurred at the condominium residential zone

The destruction of buildings, mostly commercial and residential, was widespread in the affected area. Areas within the designated blue spot circle faced the highest levels of destruction to properties and households. According to socio-economic data of the Woliso town, the household dwellings have mud as predominant material for wall. Such materials generally may not be able to endure the strong flood inundation when heavy rains experienced during the rainy seasons. Exposure to more risks of structural damage, wearing out, and aging quickly, thus increasing maintenance and replacement costs. This has caused major damage to urban infrastructure, socioeconomic systems, and those living in the area, thus creating a serious concern.

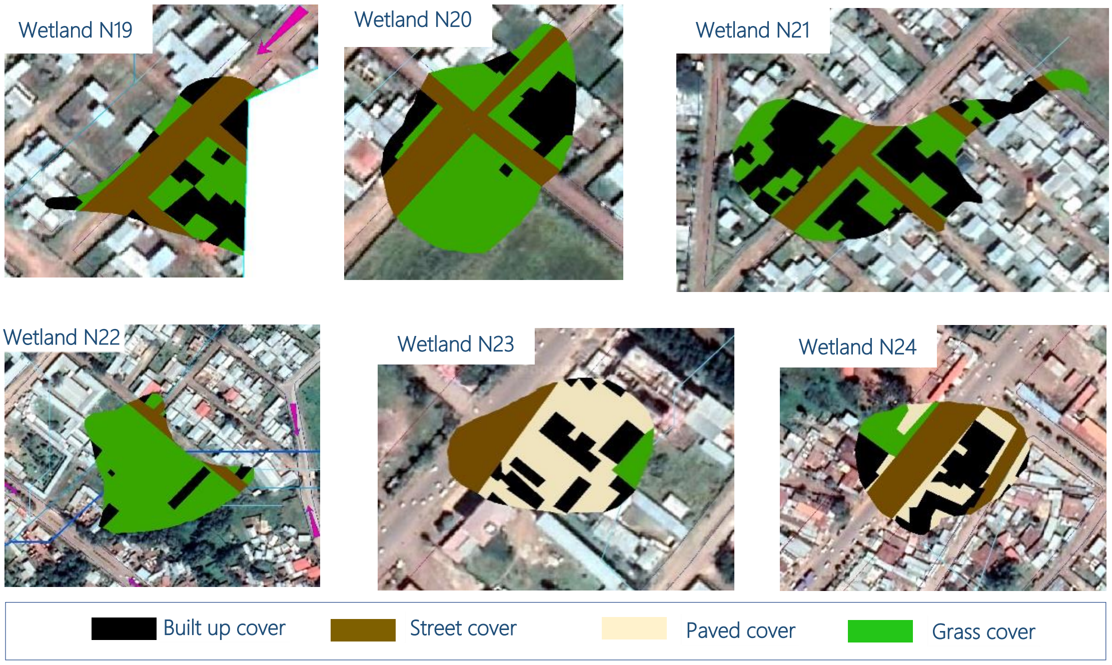


Figure 35*. the existing LULC dominating the six potential wetlands taken within the watershed*

Meanwhile, species richness and plant abundance in soil were positively related to inundation and negatively related to intense historic land use. The abundance of native species was significantly higher in more frequently inundated areas. Abundances of exotic and ruderal species were higher in areas of intense prior land use.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

This study characterized the case area watershed and the hydrologic stream connectivity in Woliso using multiple methodologies (GIS spatial analysis, and graph metric of connectivity).

In this research, it was found that the Ginfile sub-watershed was the most affected by erosion and soil loss, correlating to the obstruction of natural stream channels and water flow, primarily due to man-made impediments. Therefore, it is imperative that further studies be conducted on the Ginfile sub-watershed to fully understand the erodibility.

The analysis of the stream and wetlands revealed that the wetland features were situated in a private plot with open access to the public, leaving them vulnerable to human-caused disturbances. The presence of hard surfaces such as asphalt roads, buildings and pavements have further increased the risks, as these areas are not safeguarded from flooding during the rainy season. This has had a serious negative effect on urban infrastructure, economic systems and the people who live in the city, raising widespread concerns.

Generally, it is evident that unplanned growth of cities within a watershed has a detrimental effect on the watershed's hydrology, groundwater recharge, stream geomorphology, climate, bio-geochemistry, and stream ecology. As a result, those involved in urban planning, construction, the public, and government officials are held accountable for not correctly anticipating the calamities that might arise due to any changes in the constructed environment and should therefore put into practice integrated watershed planning and management (IWM).

5.1. Recommendation

Based on the research finding, exploring integrated approaches to urban planning and management that prioritize the protection and enhancement of water systems. This could involve incorporating watercourse spatial requirements into urban planning procedures at both regional and local levels, acknowledging their social and ecological importance. To address the impacts of urban stream disconnectedness, potential solutions could include implementing green infrastructure projects such as bioswales and rain gardens to promote hydrological connectivity, restoring riparian habitats to facilitate streambank stabilization and wildlife corridors, and employing innovative stormwater management techniques to reduce runoff and pollution. Additionally, fostering community engagement and collaboration among stakeholders can enhance the effectiveness of these solutions and promote sustainable urban water management practices. By adopting a comprehensive and proactive approach, cities can work towards mitigating the adverse effects of urbanization on water systems while simultaneously promoting resilience and sustainability.

To address the impacts of urban stream disconnectedness, the following Recommendations have been proposed:

a) **Develop an integrative and proactive land use planning and management system** at both regional and local levels. This system should incorporate sustainable water resource management principles to preserve and enhance the natural hydrologic functions of streams and wetlands.
b) **Prioritize the restoration and rehabilitation** of the most affected streams and wetlands. Focusing on the areas with the highest degree of erosion vulnerability, such as the Ginfile sub-watershed, will help optimize resource allocation and achieve the most significant improvements.
c) **Implement green infrastructure solutions,** including permeable pavements, rain gardens, and bioswales, to reduce impervious surfaces and enhance stormwater infiltration. This will help mitigate flooding risks and improve water quality in urban streams.

d) **Establish buffer zones along streams and wetlands to protect riparian habitats** and maintain ecological connectivity. These zones should be free of development, and native vegetation should be encouraged to grow to provide habitat for wildlife and stabilize stream banks.

e) **Raise public awareness and engage local communities in the preservation and restoration of urban streams and wetlands.** Community participation can foster a sense of stewardship and promote sustainable land use practices that benefit both people and the environment.

f) **Conduct regular monitoring and assessment of urban stream connectivity** to track progress and inform adaptive management strategies. This will help identify emerging threats and ensure that management interventions remain effective and responsive to the evolving urban landscape.

5.1.1. Proposed Alternative Planning Solutions and Indicated Potential Strategy.

Given the impermeable nature of the subsurface strata and the elevated drainage density values, particularly observed in the Ginfile sub-watershed, urgent action is needed to address erosion vulnerabilities and mitigate flooding risks. To achieve this, a comprehensive approach to urban watershed management is essential, with a focus on preserving and restoring wetland-stream connectivity. The following recommendations are proposed:

a) Develop an Integrative and Proactive Land Use Planning and Management System:

- This system should operate at both regional and local levels, incorporating sustainable water resource management principles to preserve and enhance the natural hydrologic functions of streams and wetlands.

b) Prioritize Restoration and Rehabilitation:

- Focus on the areas with the highest degree of erosion vulnerability, such as the Ginfile sub-watershed, to optimize resource allocation and achieve significant improvements.

c) Implement Green Infrastructure Solutions:

- This includes the creation of permeable pavements, rain gardens, and bioswales to reduce impervious surfaces and enhance stormwater infiltration. These interventions will help mitigate flooding risks and improve water quality in urban streams.
- Additionally, increasing vegetative cover and permeable surfaces, such as parks and green roofs, will help absorb and infiltrate stormwater.

d) Establish Buffer Zones:

- Buffer zones should be established along streams and wetlands to protect riparian habitats and maintain ecological connectivity. These zones should remain free of development, and native vegetation should be encouraged to provide habitat for wildlife and stabilize stream banks.

e) Raise Public Awareness and Engage Local Communities:

- Engaging local communities in the preservation and restoration of urban streams and wetlands can foster a sense of stewardship. Community participation is vital for promoting sustainable land use practices that benefit both people and the environment.

f) Conduct Regular Monitoring and Assessment:

- Regular monitoring and assessment of urban stream connectivity will track progress and inform adaptive management strategies. This will help identify emerging threats and ensure that management interventions remain effective and responsive to the evolving urban landscape.

g) Strategic Land Use Planning and Zoning Regulations:

- Implementing strategic land use planning and zoning regulations can limit the encroachment of built-up infrastructure and impervious surfaces into wetland areas. This includes establishing buffer zones around wetlands and implementing regulations to restrict development in flood-prone areas.

- Incentivizing sustainable development practices, such as low-impact development techniques and stormwater management systems, can minimize the impact of urbanization on wetland ecosystems and reduce the risk of flooding.

Overall, a multifaceted approach that integrates green infrastructure, land use planning, and sustainable development practices is essential for addressing the challenges posed by urbanization. By prioritizing the preservation and restoration of wetland-stream connectivity and implementing strategic interventions, communities can enhance resilience to flooding and safeguard valuable ecosystem services for future generations.

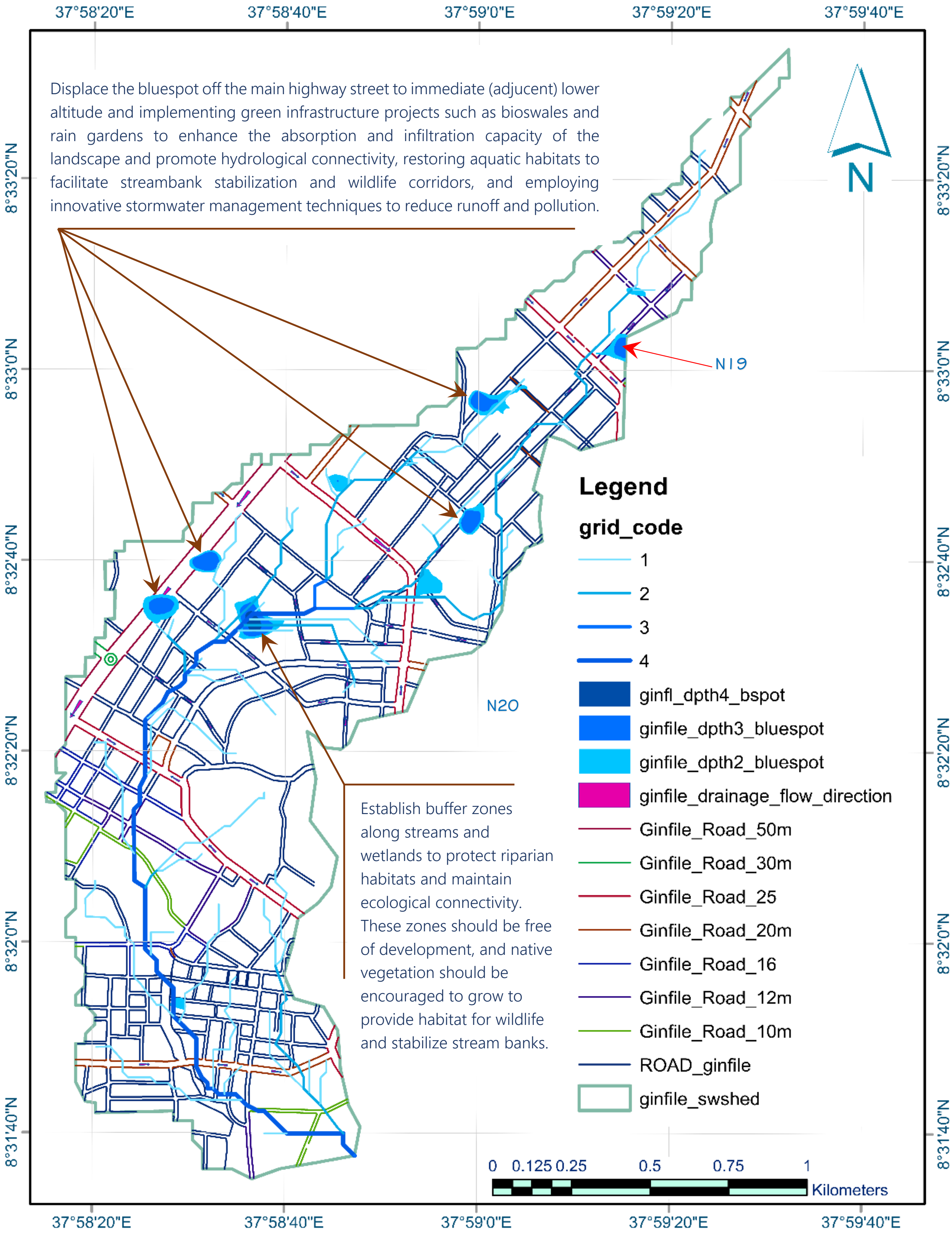


Figure 36. Proposed watercourse spatial planning solutions for the Ginfile sub watershed.

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ANNEX 1

Addis Ababa University
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SEEK WISDOM, ELEVATE YOUR INTELLECT AND SERVE HUMANITY !

Assessment on Spatial Connectivity of Urban Hydrologic Streams for Rehabilitation of Ginfile sub-watershed in Woliso Town, Ethiopia.

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- *Postgraduate Program Office in Partial Fulfillment of the Requirement of Master of Science in Urban Design and Development.*
- *Demelash Geremew (Author). Email: eyos.tamrt@gmail.com, Adviser: Alazar A (PhD)*

K E Y W O R D S

Graph Metrics,
morphometric,
stream connectivity,
watersheds,
wetlands/blue-spot,
Woliso town;

A B S T R A C T

Woliso town is renowned for its natural resources, including the hot spring (Filwuha), "*Hora Ayetu*", and abundant yearly water sources. However, due to increasing population and expansion of the town, the delicate balance of the natural atmosphere is being disrupted. This study seeks to evaluate spatial and temporal connectivity of urban streams in relation to wider natural stream network, explore how land use and land cover might affect this connectivity, and heighten awareness of surface water management within urbanized catchments of the Omo Gibe sub-basin area. GIS and remote sensing technologies, morphometry, graph metrics, GIS spatial analysis, and correlation analysis were used to measure surface water patterns and connectivity, and explore correlation between surface water bodies and urban land use. Uncontrolled urban growth can significantly damage surface water and surrounding ecosystems, leading to decreased value of water bodies and increased chances of floods and pollution. Comprehensive and proactive land management and planning is necessary to restore and improve surface water systems. Urban planning policies should take into account the spatial requirements of water bodies and riparian areas through considering water sensitive urban design and planning strategies.

1. Introduction

The amount of water on Earth is the same as it has been since its inception. This volume is approximately 1.386 billion cubic kilometers, with most of it being in the ocean (97%), and the rest being fresh water. This includes all forms, such as liquid, vapor, and solid forms. The global hydrologic cycle is made up of three subsystems: *atmospheric water*, *surface water*, and *subsurface water*. Surface water flows through rivers and eventually reaches the ocean, and ground water moves laterally until it reaches the rivers and then the ocean. Rivers and streams provide a major source of water for people, supplying it for different activities. Streams and rivers are not pipes (Bencala 1993; Bencala et al. 2011); they are dynamic systems that interact with their environment and alter material fluxes along the way. Connectivity between streams can enable material and energy to be altered in sequence as it moves downstream, which can change the overall proportion and form of the material reaching its destination (Newbold et al. 1981; Ensign and Doyle 2006).

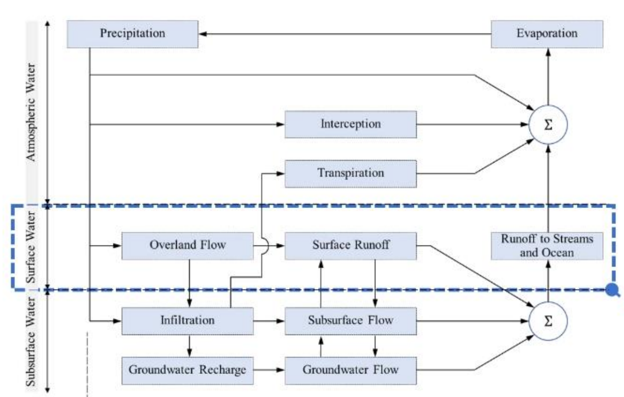

Figure 1. The three subsystems of hydrologic cycle adapted from Mays (2005, p. 229).

Urban Expansion in a broad sense means, increasing in imperviousness or in other word imperviousness is a direct measure of urbanization.

***Corresponding author**: E-mail eyos.tamrt@gmail.com (Demelash G.J)*

The expansion of a city, both in terms of area and density, is affects the natural infrastructure and disrupt its natural process (Ampatzidis, P. 2020). This increase in urbanization typically results in an increase in the number of impervious surfaces, blocking the free flow of water along connected stream networks and into the ground surface (Snyder et al. 2005).

1.1. Urban Stream

Streams are small waterways that join together to form larger rivers, characterized by water flowing through a channel and descending to lower elevations. Streams are usually shallow and turbulent, with powerful erosive force and narrow banks. Types of streams include headwater, year-round, seasonal, and rain-dependent.

Springs, seeps, and other small flows from the highlands are assigned an order of one. When two of these streams join, they form a stream of order two, and when two of those join, they form a stream of order three. Fourth to sixth order watercourses make up the middle stretches of streams, which are wider than the upstream counterparts and allow more sunlight to reach the water, creating habitats for periphyton. Lower reaches of seventh order or higher are even larger, with drainage basins spanning thousands to millions of square miles, and are characterized by FPOM from upstream, providing an energy source for the river.

Figure 2. *Stream order classification systems and numerical designations that indicate the particular stream segments (according to Strahler, 1952.)*

Much of the recent research done on cities and metropolitan areas has been devoted to examining the impacts of spatial development patterns on quality of life. One particular area of interest is the measurement of the hydrologic connectivity of streams, which looks into the connections between upstream parts of urban streams and their downstream tributaries. This is of paramount importance because of its relevance to the Clean Water Act (CWA) which seeks to restore and maintain the chemical, physical, and biological integrity of the country's waters (Wohl, 2017).

1.2. Recent Studies on Aquatic Connectivity

Aquatic sciences have progressed from analyzing singular ecosystems (Valiela and Teal 1979) to understanding connections between multiple ecosystems and their role in larger-scale landscape operations (Cohen et al. 2016). Connectivity between wetlands (McIntyre et al. 2014; Uden et al. 2014; Hayashi et al. 2016; Leibowitz et al. 2016; Vanderhoof et al. 2016), hillslopes and streams (Jencso et al. 2010; Jencso and McGlynn 2011; Bracken et al. 2013; Reaney et al. 2013; Janzen and McDonnell 2015), rivers, floodplains, and floodplain wetlands (Rooney et al. 2013; Vilizzi et al. 2013; Wolf et al. 2013; Zilli and Paggi 2013; Scott et al. 2014; Jones et al. 2015; Reid et al. 2015), non-floodplain wetlands and rivers (McLaughlin et al. 2014; McDonough et al. 2015; Cohen et al. 2016; Evenson et al. 2016; Fossey et al. 2016; Golden et al. 2016; Rains et al. 2016), and other components of river systems (Giblin et al. 2014; Harvey and Gooseff 2015; Moore 2015; Hauer et al. 2016) is essential for understanding interactions between components. This connectivity also provides ecosystem services (Mitchell et al. 2013; Jordan and Benson 2015) and is essential for watershed and aquatic ecosystem management (Uden et al. 2014; Crook et al. 2015; Moore 2015; Creed et al. 2017). Research into cities and metropolitan areas has specifically examined how space configuration affects water sources and downstream areas, to preserve water integrity according to the Clean Water Act (US). Studies have looked into the full connectivity-isolation gradient of aquatic ecosystems, including ephemeral and intermittent streams, and isolated wetlands.

1.3. Hydrologic connectivity of urban stream and wetland

Urban stream connectivity is important for the health and functioning of urban ecosystems, as it allows for the movement of water, nutrients, and organisms. Factors that can impede stream connectivity include barriers such as roads and buildings, as well as the amount of impervious surface cover in the surrounding landscape. To improve connectivity, land use planning, stormwater management, and habitat restoration should be combined with green infrastructure, such as rain gardens, bioswales, and green roofs, to reduce the amount of impervious surface and promote infiltration. These steps are necessary for creating sustainable and resilient urban ecosystems.

1.3.1. Connectivity and Transport of Materials to and from Streams and Wetlands

Connectivity in river systems is the linkages between components and their interaction. The River Continuum Concept looks at the river from source to mouth as a gradient of hydrologic structure and function, while the Spiraling Concept evaluates and measures material circulation. Additionally, the Flood Pulse Concept considers the lateral connectivity of river channels to floodplains. Ward (1989) proposed four dimensions of connectivity in running water ecosystems: longitudinal, lateral, vertical, and temporal connections. Euliss et al. (2004) added the Wetland Continuum Concept, which explains wetland changes due to dynamic climate changes.

1.3.2. Spatial and Temporal Variability of Connectivity

Connectivity of a system varies over time and distance (Ward 1989; Leibowitz et al. 2003/16). This generates a connection-isolation continuum impacting the hydrologic operation of watersheds (Cohen 2016). Variation in hydrological connection comes from longitudinal, lateral, and vertical extension and contraction of the river network (fig. 15), as well as short-term connections (e.g. temporary and sporadic) (Poff et al. 1997). Exchange between rivers, wetlands and downstream waters is affected by seasonal or high-flow events (Wigington et al. 2005, Fig. 18). Expansion and contraction of rivers also affects magnitude of connectivity (Fritz et al. 2018).

Goodrich et al. (2018) showed that changes in hydrologic linkages, such as length, intensity, and timing of precipitation, can affect the timeframe and sequence of flows along different streams, including intermittent and ephemeral streams, as well as the connection between wetlands and downstream waters.

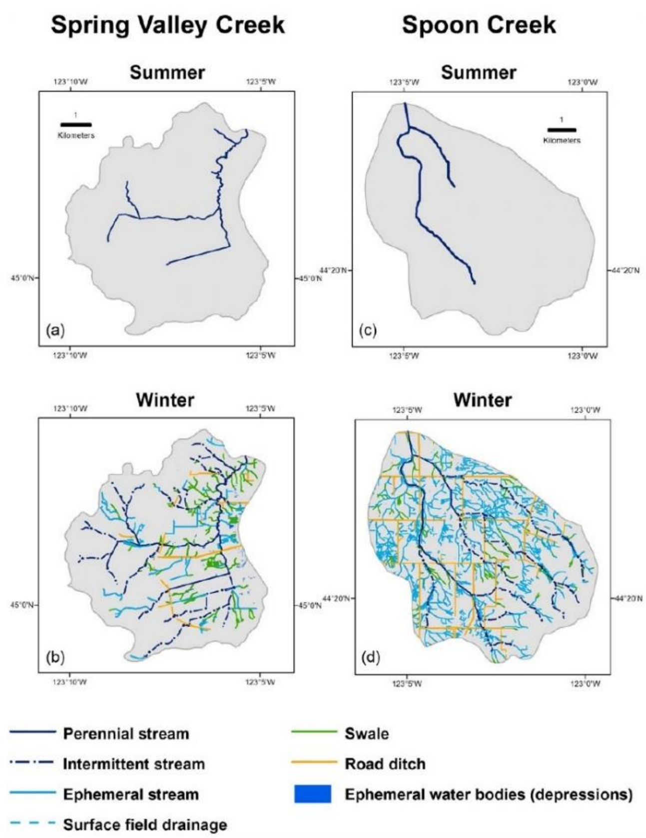

Figure 3. . Examples of longitudinal expansion of river networks. Source: (a, b) USEPA (2015); (c) and (d) modified from Wigington (2005).

Fluctuations in river systems can impact the type of hydrological connection (Rains et al. 2008; Leibowitz et al. 2016). Dry spells can reduce outflow and have the potential to connect only through underground waters (Rains et al. 2006; Rains et al. 2008). These temporary dry environments can provide an unusual habitat for aquatic life adapted to dry and wet conditions, as well as store eggs and seeds of aquatic invertebrates and plants (Steward et al. 2012). Decreased microbial activity, along with increased oxygen and organic matter, can alter nutrient dynamics (Steward et al. 2012). Upon rewetting, materials are carried downstream.

1.3.3. Factors that influence connectivity

Climate and watershed characteristics, the spatial arrangement of water bodies, and human activities and modifications are three key aspects that influence physical, chemical, and biological connectivity in river systems (Schofield et al. 2018). These factors, operating at multiple spatial and temporal scales, interact to determine connectivity-isolation gradients.

1.3.4. Human Activities and Artificial Alterations

Human interventions often modify the connection between headwater streams, riparian/floodplain wetlands, non-floodplain wetlands, and downstream rivers, impacting the transmission and movement of energy and materials. These interventions can be detrimental (e.g. dams, levees, water extraction) or beneficial (e.g. draining wetlands, irrigating, paving over, basin transfers). Loss of headwater streams and wetlands can lead to impaired conditions due to decreased connectivity. Channelization and agricultural ditches/tile drainage can both increase and decrease hydrologic and biological linkage. Loss of wetlands can decrease water storage, leading to increased runoff, stormflows, and flooding risk; and reduced dispersal of organisms. This can also lead to increased sediment and pollutant delivery to downstream waters, and transport of water-dispersing organisms (Fullerton et al. 2010; De Laney 1995; Blann et al. 2009; Wiskow and van der Ploeg 2003; Leibowitz 2003; Babbitt and Tanner 2000).

1.4. Urban green-blue infrastructure as a water sensitive planning strategy

Urban green-blue infrastructure (GBI) helps reduce the impacts of climate change by improving air and water quality, reducing noise pollution, providing recreational opportunities, and creating attractive public spaces. It also regulates the urban heat island (UHI) by altering the land surface to absorb sunlight, reduce air convection cooling, and lower evaporation. However, urban expansion and development can lead to habitat destruction, alterations to the water system, contamination, and the introduction of alien species, which puts wetland preservation at risk. According to Ampatzidis (2020), the rising trend of urbanization is harming and disrupting natural infrastructure and negatively impacting the urban environment's health and ecological functions. Thus, it is important to protect wetlands and incorporate GBI into urban design to make cities more resilient to the effects of climate change.

1.5. Objective/Aim of the study

The objective of the study is to assess the spatial connectivity of urban hydrologic streams and its relationship to the general stream network. Additionally, explore the effect of changes to land use and land cover patterns on the spatial connectivity of urban streams, and bring enhanced focus to surface water management issues in the spatial planning of Woliso town.

2. Materials and methods

2.1. Study area

The study area for the Ginfile watershed, located in Woliso town, is limited to 460 hectares and stretches between 37° 58′ 18″ and 37° 59′ 40″ east longitude and between 8° 31′ 10″ and 8° 33′ 35″ north latitude. This area falls within the suggested range of 200-500 hectares for watershed planning as suggested by CPWD.

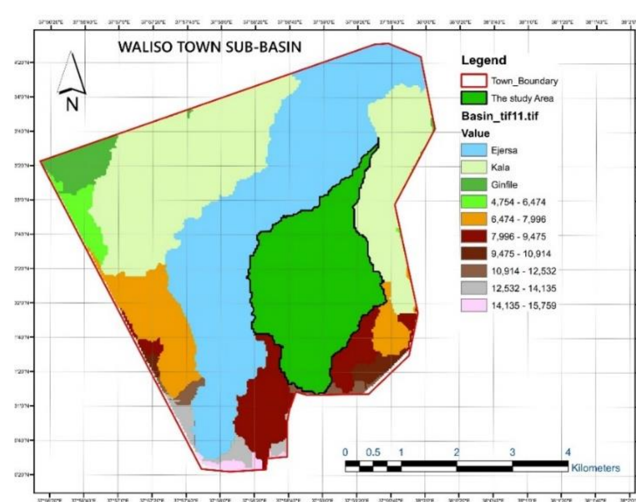

Figure 4. Basin map of the Woliso Province (the natural division along the three main high order streams in the town (source: the author)

In regards to the scope and size of the research area, the region is divided into three distinct watersheds. The area of the total planning region is 460 hectares, with the Ginfile sub-watershed measuring 252.54 hectares, the Filwuha sub-watershed at 105.29 hectares, and the Dololo sub-watershed at 155.52 hectares.

2.2. Spatial analysis

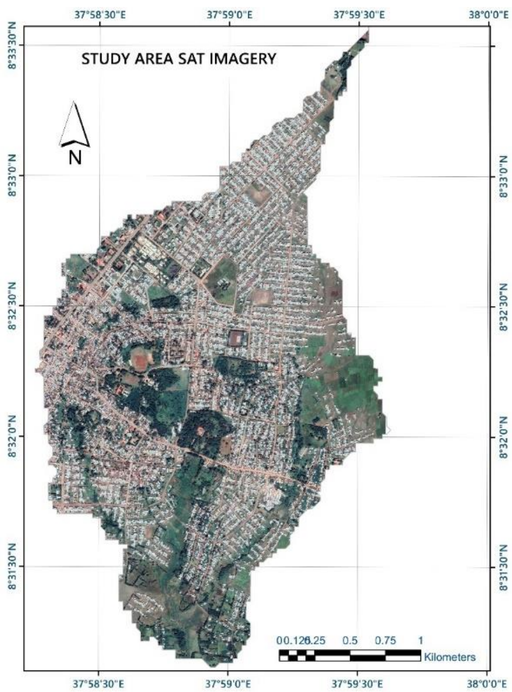

Figure 5. google imagery of the study area delineated watershed using ArcGIS.

2.3. Data collection

A strategy combining Geographic Information System (GIS) and remote sensing techniques has been commonly adopted in many studies to gain insight into the stream connectivity and hydrologic characteristics of the research area (Ravagnani et al. 2009).

2.3.1. Methods of data collection and tools

Interviews and Questionnaires

Direct Observation and aerial photography

Maps from local and regional planning administration

Hydrometeorological (satellite data Acquisition, local inventory)

Maps & Satellite Images (satellite data Acquisition, local inventory)

GIS Classification of the raw data

2.4. Data analysis

ESDA facilitated by GIS is often utilized to generate Decision Support Systems (DSS) and GIS Hydrology specifically for hydrologic data analysis. This study used GIS-based calculation of MCE and ReFH2 storm surge modelling to analyze the effective connectivity and flood inundation of an urban stream in a suburban watershed. Data analysis methods were used to answer the research objectives.

2.4.1. Morphometric analysis of watershed

Flow of water in urban areas is influenced by soil structure and landscape features, making quantifying the water difficult. Morphometric analysis can identify the patterns and features of streams, helping to develop regional hydrological models (Gajbhiye et al. 2014; Horton 1945).

Morphometric analysis is a method of evaluating a hydrological unit via quantification. It is used to study watersheds and their development, by measuring elements such as stream segments, length, area, elevation, quantity, inclination, landscape profiles, etc. (Horton 1945). Horton's law of stream lengths suggested a geometric correlation between lengths of channels in successive stream orders, and the law of basin areas demonstrated a linear relationship between mean basin areas of successive stream orders. This was refined by geomorphologists such as Strahler, Schumn and Gregory.

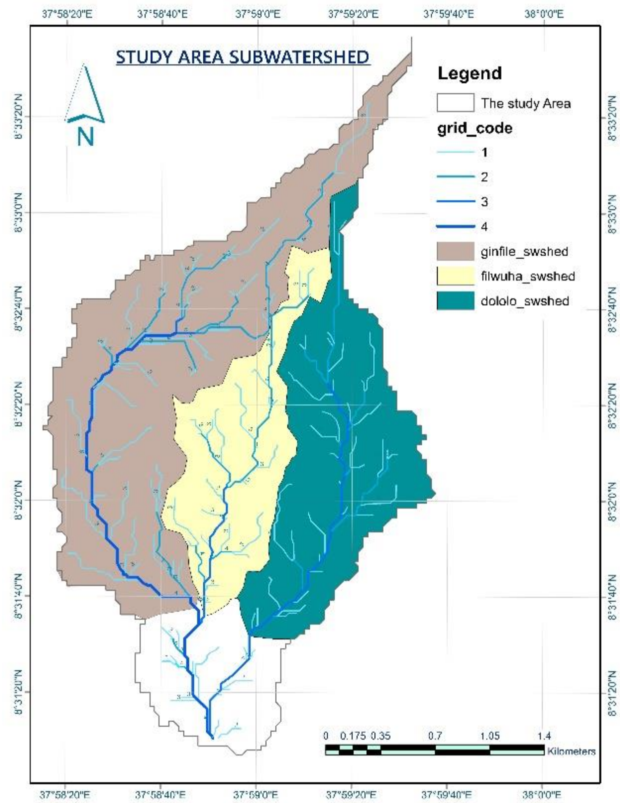

Figure 6. Stream order of sub-watersheds

A morphometric analysis of three sub-watersheds was conducted to determine parameters such as *stream order, stream length, bifurcation ratio, drainage density, stream frequency, circulatory ratio, form factor, elongation ratio, texture ratio, compactness coefficient, length of overland flow, watershed area, perimeter, elevation difference, basin length, total relief, number of streams* and *total stream length.*

2.4.2. Graph Metrics analysis

Measuring connectivity is important as it provides a baseline to observe changes, connects watershed activities to connectivity levels, and sets standards for restoration and protection. Structural elements such as watershed shapes and habitat layouts, and functional metrics considering water flow and animal dispersal are used to set limits on the distance between connected habitats, identify hubs and stepping stones, and determine important water sources that require special attention for protection or development.

The directed graph average degree is a useful metric for analyzing hydrologic stream connectivity, as it allows comparison between

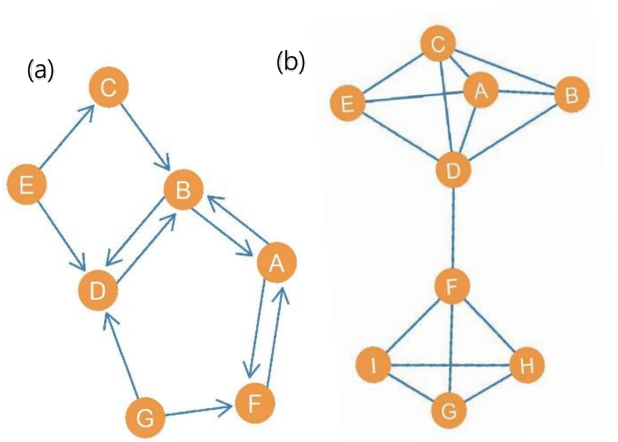

Figure 7. Illustrative example of directed and undirected graph. (a). directed graph, (b). undirected graph

similar stream networks of the same size to identify differences in connectivity. By understanding the connections between streams, insights can be gained into causes of network failure and maintained connectivity, which can aid in watershed rehabilitation.

The correlation between the total degree of all nodes and the number of edges in a directed graph is a direct one, meaning the sum of the degrees of each node is equal to the total number of edges. This can be expressed mathematically as:

Equation .... in case of directed graph: ... $\sum k_i = m$ (In the case of stream network, its one way, downflow)

The cardinality of the edge set of a graph is often referred to as the first theorem of graph theory, which is equal to the number of edges (m) in the graph (Benjamin, Chartrand, and Zhang 2015, 20).

Knowing the relationship between the total number of degrees of a graph and the number of edges it contains, we can start to compute other important graph metrics, such as the average degree.

Average Degree in directed Graphs

The average degree in a directed graph can be found by calculating either the average indegree or the average outdegree for each node; the result will be the same since each link only serves one purpose with regards to the indegree or outdegree of each node (Fischer, 2020).

Equation ...... $K_{(avg)} = \frac{m}{n}$

2.4.3. overlay and correlational analysis.

The hydrologic connectivity of a river system is determined by the flow of water, which transports physical, chemical and biological components. Factors that influence connectivity include characteristics of the watershed, spatial configuration of waterbodies, and impacts of human activities and changes (Fullerton et al. 2010; Newbold et al. 1981; Ensign and Doyle 2006; Pringle 2001; Schofield et al. 2018). GIS overlay is used to analyze any man-made impediments and the land use and land cover (LULC) that could be water sources. This data is examined

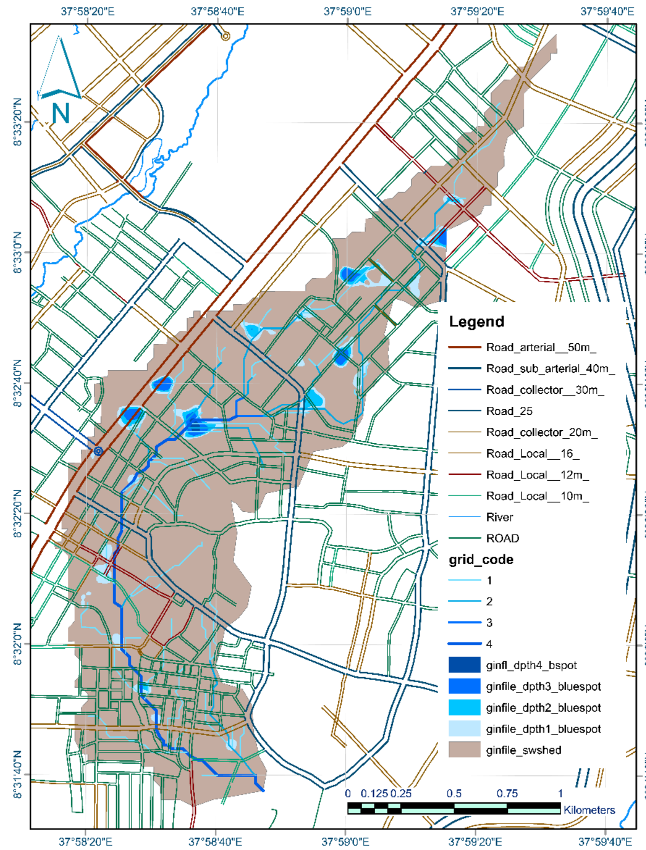

Figure 8. wetland and stream overlay with existing built environment.

to identify the cause of the hydrologic spatial connectivity issue.

Spatial analysis of Artificial impediments using GIS overlay

GIS can be used to determine the source of stream spatial disconnection by overlaying street and drainage layout with natural stream network data, creating new spatial elements and analyzing the land cover in the affected area (raster data structure is particularly suitable).

2.4.4. Map algebra & flood venerability study.

Flooding takes place when a large quantity of water fills an area and submerges it. Geographic Information System (GIS) analysis can be used to determine the size of the area impacted and the type of land use in the potential flooded zone.

Urban wetlands provide a variety of social and cultural amenities, including recreational and leisure activities for city dwellers. However, urbanization has had a negative impact on these wetlands, causing them to become disconnected and physically isolated. As a result, urban wetlands have become scattered and discontinuous, resulting in a reduction of biodiversity in urban areas.

Figure 9. the existing LULC dominating the six potential wetlands taken within the watershed

3. Result/finding

3.1. Result of the Morphometric Analysis.

A morphometric analysis of three sub-watersheds was conducted to determine parameters such as stream order, stream length, bifurcation ratio, drainage density, stream frequency, circulatory ratio, form factor, elongation ratio, texture ratio, compactness coefficient, length of overland flow, watershed area, perimeter, elevation difference, basin

Table 1. morphometric analysis calculation result (Using formulas in the data analysis)

Morphometric Analysis

Result of morphometric analysis for the four sub-watersheds of Ginfile watershed in Weliso

S. No	Sub Watershed name	Bifurcation ratio	Drainage density	Stream frequency	Circulatory ratio	Form factor
1	Ginfile subwatershed I	3.9815	6.9427	24.1546	2.7377	0.1749
3	Filwuha subwatershed	8.7500	6.8236	30.3922	2.1030	0.1226
4	Dololo Subwatershed	8.5000	5.3964	28.9341	2.4201	0.2182

S. No	Sub Watershed name	Elongation ratio	Texture ratio	Compactness coefficient	Relief ratio	Length of overland flow
1	Ginfile subwatershed I	0.4717	4.2259	2.0583	0.0266	0.0720
3	Filwuha subwatershed	0.3950	4.2902	1.7302	0.0191	0.0733
4	Dololo Subwatershed	0.5269	4.4566	1.8272	0.0232	0.0927

length, total relief, number of streams and total stream length. The results of this analysis are summarized in the tables below.

A morphometric analysis is an effective way to measure the current water circulation and erosion in the catchment area. The traditional methods of this analysis can be laborious and prone to mistakes, so GIS techniques can be used to provide precise and reliable data. The results of the analysis of the three sub-watersheds are presented in a bar graph (Fig 36) demonstrating the characteristics of the drainage pattern.

3.2. Result from connectivity Analysis

Analysis of the sub-watershed wetlands revealed six significant wetland locations on private land with public access, as well as a grassy/loan area unbuilt and swampy. The connectivity analysis considered 49 first-order, 9 second-order, 2 third-order, and 1 fourth-order streams (with six nodal divisions). Five second-order streams and two fourth-order nodal segments were at risk of human development due to lack of protection.

3.3. Result from Overlay and correlational study

The urban flood inundation impact observed across the study area watershed. (A). (N24) venerable Amin bakery on the main road, (B). surviving 2nd order stream around *Irsha sebil. Mazoria*, (C). flood victim in the hospital condominium ground-floor, (D). Heavy rainfall occurred at the condominium residential zone @Woliso.

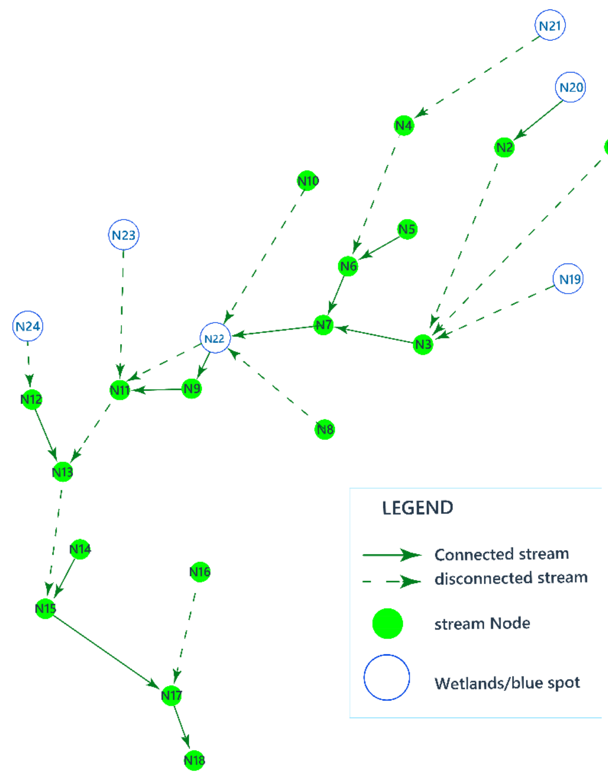

Figure 10. graphic illustration of spatial positions of important nodes and edge of hydrologic stream and wetland of the study area, Ginfile sub watershed

3.4. *Result from flood inundation study*

This investigation reveals an understanding of how to manage flood risks, create urban flood prevention techniques, and construct flood avoidance measures. Urban wetlands are commonly known as a "city's kidney" and "biodiversity library" due to their part in Urban wetlands provide numerous benefits for cities, including flood prevention, water purification, air purification, and habitat conservation, as well as social and cultural amenities. However, urbanization has led to fragmentation of these wetlands, resulting in decreased biodiversity.

Table 2. the graph metric analysis result of hydrologic stream and wetland connectivity of Ginfile sub watershed

The connectivity graph metric analysis

No	Node	full Graph indegree	Existing graph indegree	Range of connectivity	Remark
1	N1	1	1	0	No change
2	N2	1	1	0	No change
3	N3	3	0	3	significant impact
4	N4	1	0	1	Impacted
5	N5	1	1	0	No change
6	N6	2	1	1	Impacted
7	N7	2	2	0	No change
8	N8	1	1	0	No change
9	N9	1	1	0	No change
10	N10	1	1	0	No change
11	N11	3	1	2	Impacted
12	N12	1	0	1	Impacted
13	N13	2	1	1	Impacted
14	N14	1	1	0	No change
15	N15	2	1	1	Impacted
16	N16	1	1	0	No change
17	N17	2	1	1	Impacted
18	N18	1	1	0	No change
19	N19	1	1	0	No change
20	N20	1	1	0	No change
21	N21	1	1	0	No change
22	N22	3	1	2	Impacted
23	N23	1	1	0	No change
24	N24	1	1	0	No change
	Degree sum	35	22	13	sense of heterogeneity of the two directed graphs
	Avg degree	1.4583	0.9167	0.5417	

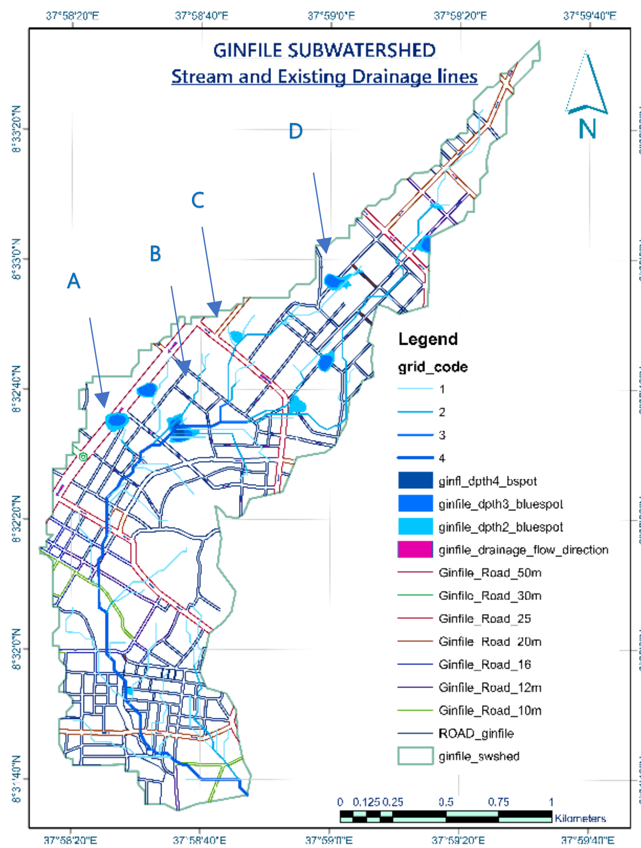

Figure 11. spatial distribution and relative position of wetlands thought out the study are.

4. Summary of Finding

4.1. Morphometric

A morphometric analysis can be used to measure water circulation and erosion in a catchment area using GIS techniques, providing precise and reliable data. The analysis results of three sub-watersheds are presented in Fig 12 and Table 1, showing the drainage pattern characteristics.

The sub-watersheds were evaluated by assigning ranks to their respective values. Linear parameters such as bifurcation ratio, drainage density, texture ratio, length of overland flow and stream frequency had a direct correlation with erodibility, so the highest value was attributed rank 1, the second highest rank 2, and the least rank 3. Conversely, shape parameters like circularity ratio, form factor, elongation ratio and compactness coefficient had an inverse relationship with erodibility, so the lowest value was assigned rank 1, the next lower rank 2, and the highest rank 3.

The compound parameter was calculated by averaging all parameters in the sub-watersheds; the highest value of the compound parameter indicates the greatest degree of erosion vulnerability, while the lowest value is the least degree of erosion vulnerability. Scores of sub-watersheds analysis, from highest to lowest compound parameter value, were 2.40 (Ginfile SWS), 2.10 (Dololo SWS), and 1.50 (Filwuha SWS). To manage the issue of erosion, appropriate rehabilitation practices and measures should be tailored to the degree of erosion vulnerability. As the Ginfile sub-watershed had the highest degree of erosion (2.40), extra attention should be given to this area. (Langbein, 1947).

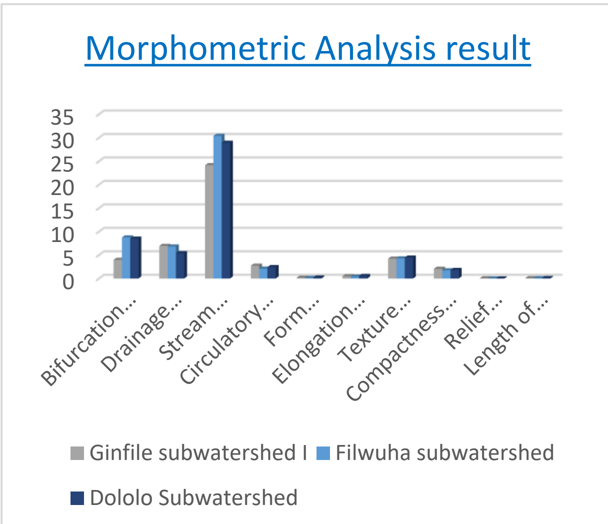

Figure 12. graphic illustration of morphometric analysis result

4.2. Graph Metrics

Evaluating connectivity levels is important to identify variations, relate them to basin activities, and create standards for rehabilitation and conservation.

The graph in Table 2 shows a 37.14% disconnection of streams and wetlands compared to their natural state, highlighting the need to restore streams for increased ecological value and biodiversity.

4.3. Overlay and correlational study

Streams may be affected by urbanization, deforestation, construction of roads, withdrawal of groundwater, timber harvesting, mining, grazing, road construction, and wildfire, potentially transforming them from perennial to intermittent/ephemeral watercourses. To effectively manage streams and watersheds, it is important to understand stream processes and their categorization. Therefore, those involved with stream and watershed surveillance, administration, and rehabilitation must possess a basic knowledge of stream dynamics and how to preserve or alter a graded stream

Human-made obstructions and topography affect the movement of water and its interconnectedness, resulting in a changed stream network due to lack of maintenance and utilization.

The key factor which the study identified for the phenomenal cause are illustrated in the above tables. These are the descriptions of factors causing the stream disconnection.

The graph (figure 9) illustrates the different land cover types in six wetlands in the study area. The amount of impervious area blocking the infiltration of stormwater after it has been held in the wetland is seen as an effect

57.67% of wetlands affected by impermeable surfaces, leading to prolonged flooding due to low absorption rate. Chart illustrates potential wetlands affected and lack of hydrological connection when water surpasses storage capacity.

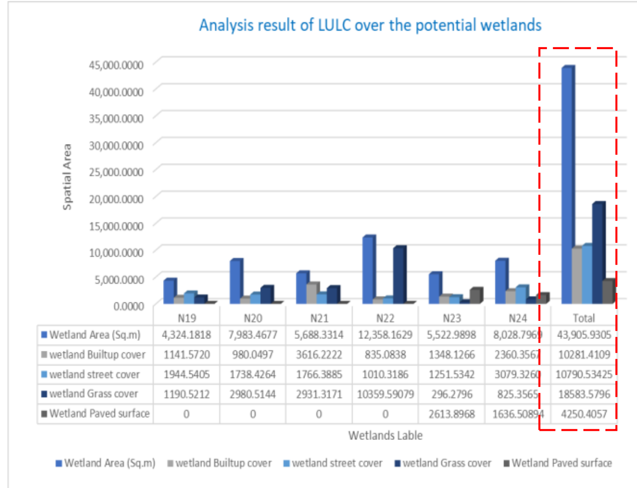

Figure 13. Analytical result of land use land cover over the potential wetland across the strudy area watershed.

4.4. flood venerability study

25,322.35 m2 of built-up infrastructure, streets and paved surfaces have been affected by floods from 2020-2022. Woliso Town data shows that most houses have mud walls, which are not strong enough to withstand the flooding. Soil diversity and plant quantity were positively impacted by flooding, but negatively affected by prior land use. Native species had higher presence in frequently flooded areas, while exotic and ruderal species had higher presence in intensively used land.

5. Conclusions & Recommendation

This research examined the watershed in the area of Woliso, revealing that the Ginfile sub-watershed is most affected by erosion and soil loss due to man-made impediments obstructing natural stream channels and water flow. Wetland features are situated in a private plot with open access, leaving them vulnerable to human-caused disturbances. Unplanned growth of cities within a watershed has a detrimental effect on the watershed's hydrology, groundwater recharge, stream geomorphology, climate, bio-geochemistry, and stream ecology. As a result, IWM (integrated watershed management) should be put into practice to anticipate calamities that may arise due to changes in the constructed environment.

5.1. Research Recommendation

Wetlands provide many ecosystem services, such as water efficiency, biodiversity, flood control, and climate regulation, and can be used as nature-based solutions to tackle environmental, social, and economic issues (McInnes, R.J. 2014). Sustainable urban growth and planning are necessary to maximize the benefits of wetlands to an expanding population. To protect and enhance water systems, land use planning and management must be done proactively at both regional and local levels (Song, F. 2020). Urban planning should take into account the needs of watercourses and their surrounding areas for their social and ecological significance.

To address the impacts of urban stream disconnectedness, the following solutions have been proposed:

- Develop an integrative and proactive land use planning and management system at both regional and local levels.

- Prioritize the restoration and rehabilitation of the most affected streams and wetlands.
- Implement green infrastructure solutions, including permeable pavements, rain gardens, and bioswales, to reduce impervious surfaces and enhance stormwater infiltration.
- Establish buffer zones along streams and wetlands to protect riparian habitats and maintain ecological connectivity.
- Raise public awareness and engage local communities in the preservation and restoration of urban streams and wetlands.
- Conduct regular monitoring and assessment of urban stream connectivity to track progress and inform adaptive management strategies.

Acknowledgements

I am immensely grateful to my advisor Alazar Assefa (Ph.D.) for his dedicated support, direction, and insightful advice which enabled the successful completion of this research. My thanks also go to the architects, Municipality of Woliso town, and my family for their wisdom, knowledge, sensitivity, and perspective. Lastly, I am thankful to have an incredible source of strength in my life, my beloved wife Feven K. (Architect), and my sons. I am thankful to the Almighty Lord God for His guidance and blessings.

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ANNEX 2

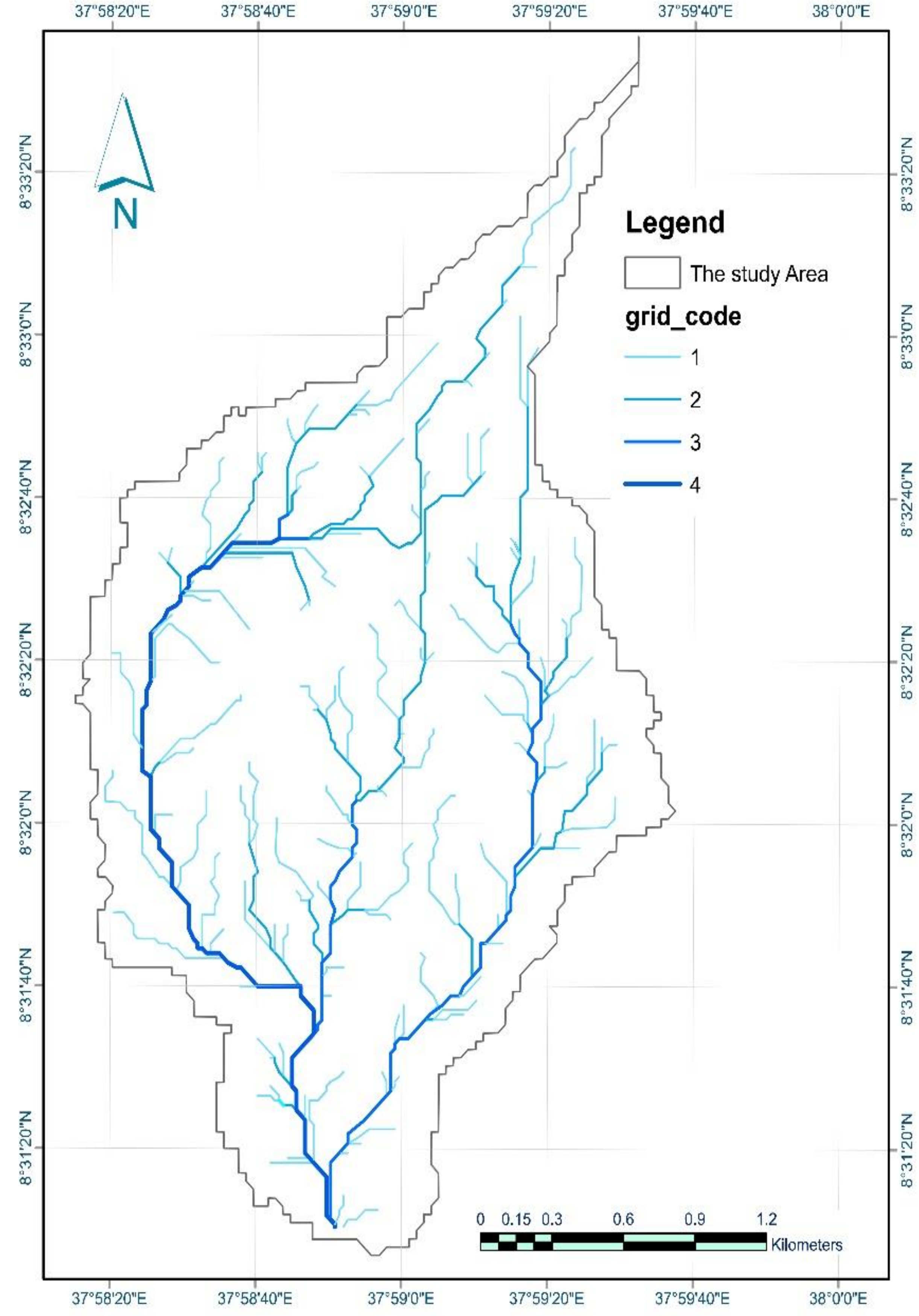
Stream Labele	stream order	from Node	to node	stream length (m)	connection Status	Remark
S1	1	initial	N1	552.6688	Null	1st ord stream segment
S2	1	initial	N1	71.9280	Null	1st ord stream segment
S3	1	initial	S50	25.4305	Null	1st ord stream segment
S4	1	initial	S50	25.4305	Null	1st ord stream segment
S5	1	initial	S50	43.4124	Null	1st ord stream segment
S6	1	initial	S50	76.2912	Null	1st ord stream segment
S7	1	initial	S50	86.8248	Null	1st ord stream segment
S8	1	initial	S50	68.8428	Null	1st ord stream segment
S9	1	initial	S50	143.8561	Null	1st ord stream segment
S10	1	initial	N2	203.4432	Null	1st ord stream segment
S11	1	initial	N2	50.8608	Null	1st ord stream segment
S12	1	initial	N4	442.614	Null	1st ord stream segment
S13	1	initial	N4	76.2912	Null	1st ord stream segment
S14	1	initial	S52	485.0312	Null	1st ord stream segment
S15	1	initial	S52	35.964	Null	1st ord stream segment
S16	1	initial	S52	126.2295	Null	1st ord stream segment
S17	1	initial	S52	100.2765	Null	1st ord stream segment
S18	1	initial	N5	161.6709	Null	1st ord stream segment
S19	1	initial	N5	25.4304	Null	1st ord stream segment
S20	1	initial	S61	50.8608	Null	1st ord stream segment
S21	1	initial	S61	541.0936	Null	1st ord stream segment
S22	1	initial	N8	17.982	Null	1st ord stream segment
S23	1	initial	N8	50.8608	Null	1st ord stream segment
S24	1	initial	S61	179.8201	Null	1st ord stream segment
S25	1	initial	N10	79.3765	Null	1st ord stream segment
S26	1	initial	N10	76.1731	Null	1st ord stream segment
S27	1	initial	S55	450.661	Null	1st ord stream segment
S28	1	initial	S61	25.4304	Null	1st ord stream segment
S29	1	initial	S61	335.0074	Null	1st ord stream segment
S30	1	initial	N13	130.1191	Null	1st ord stream segment
S31	1	initial	N12	56.8641	Null	1st ord stream segment
S32	1	initial	N12	50.8608	Null	1st ord stream segment
S33	1	initial	S61	115.141	Null	1st ord stream segment
S34	1	initial	S61	516.9411	Null	1st ord stream segment
S35	1	initial	S61	423.9424	Null	1st ord stream segment
S36	1	initial	N14	452.106	Null	1st ord stream segment
S37	1	initial	N14	162.1934	Null	1st ord stream segment
S38	1	initial	S61	143.856	Null	1st ord stream segment
S39	1	initial	S61	623.2484	Null	1st ord stream segment
S40	1	initial	S61	429.88	Null	1st ord stream segment
S41	1	initial	S61	443.6169	Null	1st ord stream segment
S42	1	initial	S61	112.2552	Null	1st ord stream segment
S43	1	initial	S61	556.4548	Null	1st ord stream segment
S44	1	initial	S61	71.9281	Null	1st ord stream segment
S45	1	initial	N16	230.6809	Null	1st ord stream segment
S46	1	initial	N16	341.3238	Null	1st ord stream segment
S47	1	initial	S58	296.4385	Null	1st ord stream segment
S48	1	initial	S58	107.892	Null	1st ord stream segment
S49	1	initial	S58	151.3044	Null	1st ord stream segment

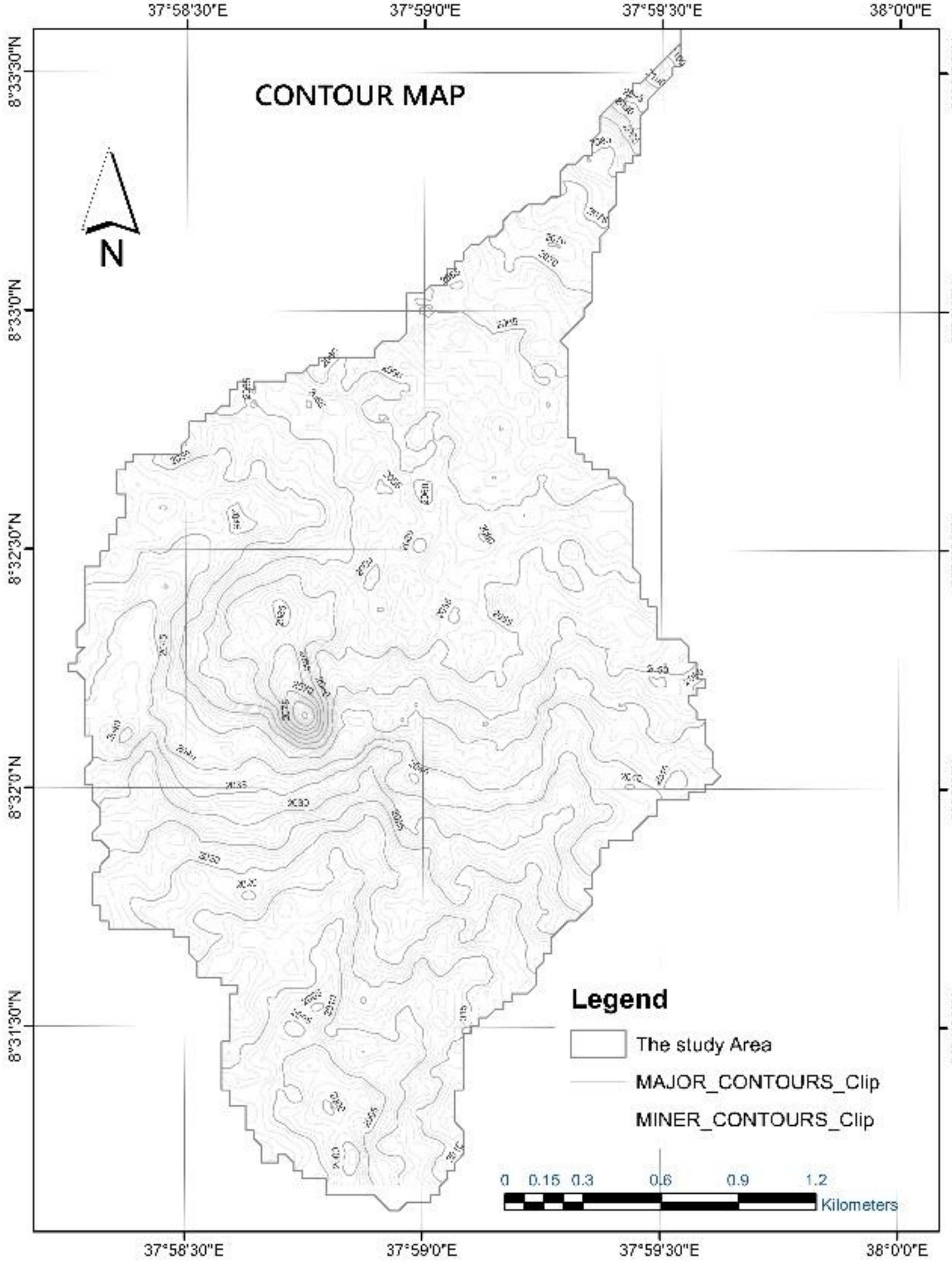
S50	2	N1	N3	1786.0800	spatialy disconnected	Physical impediment
S51	2	N2	N3	406.5318	spatialy disconnected	Physical impediment
S52	2	N4	N6	587.9914	spatialy disconnected	Physical impediment
S53	2	N5	N6	104.8068	spatialy connected	Pervious
S54	2	N8	N9	481.8583	spatialy disconnected	Physical impediment
S55	2	N10	N11	459.9098	spatialy disconnected	Physical impediment
S56	2	N12	N13	148.2192	spatialy connected	Pervious
S57	2	N14	N15	65.6394	spatialy connected	Pervious
S58	2	N16	N17	638.8039	spatialy disconnected	Physical impediment
S59	3	N6	N7	112.1371	spatialy connected	Pervious
S60	3	N3	N7	125.8741	spatialy connected	Pervious
S61	4	N7	N9	252.9079	spatialy connected	Pervious
S62	4	N9	N11	112.2552	spatialy connected	Pervious
S63	4	N11	N13	151.6599	spatialy disconnected	Physical impediment
S64	4	N13	N15	770.2993	spatialy disconnected	Physical impediment
S65	4	N15	N17	1214.0331	spatialy connected	Pervious
S66	4	N17	N18	87.3095	spatialy connected	Pervious
wetland as node	**wetland lebel**	**from Node**	**to node**	**wetland Area**	**connection Status**	**Remark**
N19	wetland 1	N19	N3	4,324.1818 sq.m	disconnected wetland	Artificially isolated
N20	wetland 2	N20	N2	7,983.4677 sq.m	spatialy connected	in and outgoing stream
N21	wetland 3	N21	N4	5,688.3314 sq.m	disconnected wetland	Artificially isolated
N22	wetland 4	N22	N9	12,358.1629 sq.m	spatialy connected	in and outgoing stream
N23	wetland 5	N23	N11	5,522.9898 sq.m	disconnected wetland	Artificially isolated
N24	wetland 6	N24	N12	8,028.7969 sq.m	disconnected wetland	Artificially isolated

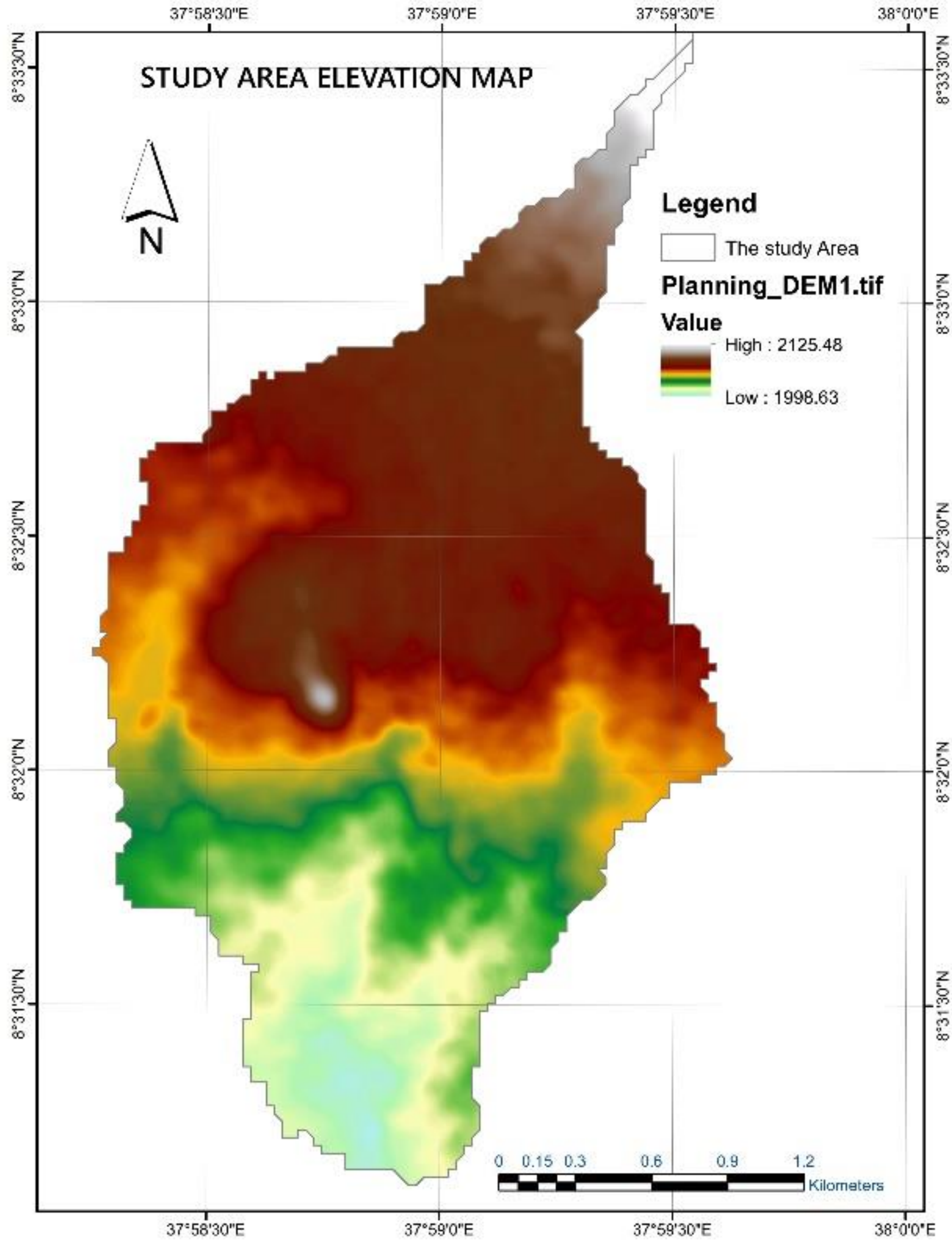
Stream Labele	stream order	from Node	to node	stream length (m)
S1	1	initial		194.71687
S2	1	initial		25.4304
S3	1	initial		205.250487
S4	1	initial		58.191003
S5	1	initial		167.360994
S6	1	initial		50.8608
S7	1	initial		61.394418
S8	1	initial		441.572481
S9	1	initial		17.982009
S10	1	initial		251.580973
S11	1	initial		17.982009
S12	1	initial		43.412409
S13	1	initial		393.678716
S14	1	initial		140.770845
S15	1	initial		17.982009
S16	1	initial		194.716869
S17	1	initial		158.467516
S18	1	initial		25.4304
S19	1	initial		94.273209
S20	1	initial		202.165263
S21	1	initial		387.508264
S22	1	initial		122.788834
S23	1	initial		79.376426
S24	1	initial		220.989423
S25	1	initial		115.340443
S26	1	initial		35.964017
S27	1	initial		140.770843
S28	2			1566.531363
S29	2			419.060159
S30	2			162.193488
S31	2			267.000316
S32	3			903.777369

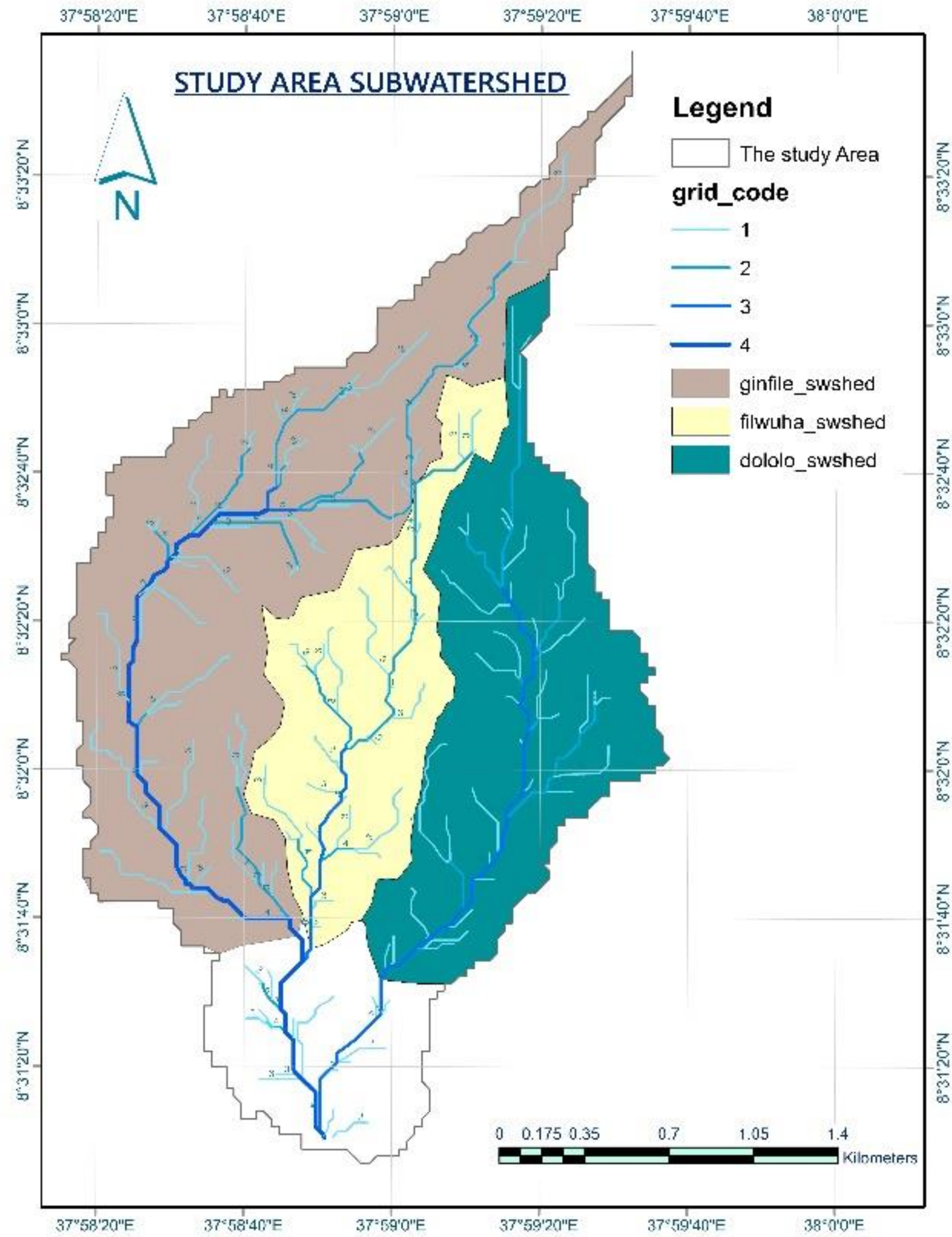
Stream Labele	stream order	from Node	to node	stream length (m)
0	1			184.07
5	1			25.43
9	1			64.84
19	1			127.15
12	1			89.91
8	1			50.86
43	1			71.93
28	1			381.22
40	1			79.38
44	1			79.38
60	1			128.79
56	1			236.20
63	1			254.50
78	1			235.04
94	1			68.84
86	1			208.17
103	1			94.16
110	1			25.43
117	1			65.64
122	1			107.89
125	1			50.86
127	1			309.89
159	1			53.95
166	1			71.93
109	1			606.57
156	1			17.98
181	1			119.70
170	1			286.95
192	1			209.61
199	1			133.32
204	1			133.32
202	1			110.81
213	1			68.84
7	2			317.10
14	2			296.44
54	2			307.33
91	2			40.21
105	2			68.84
121	2			206.53
158	2			220.15
197	2			35.96
39	3			2147.66

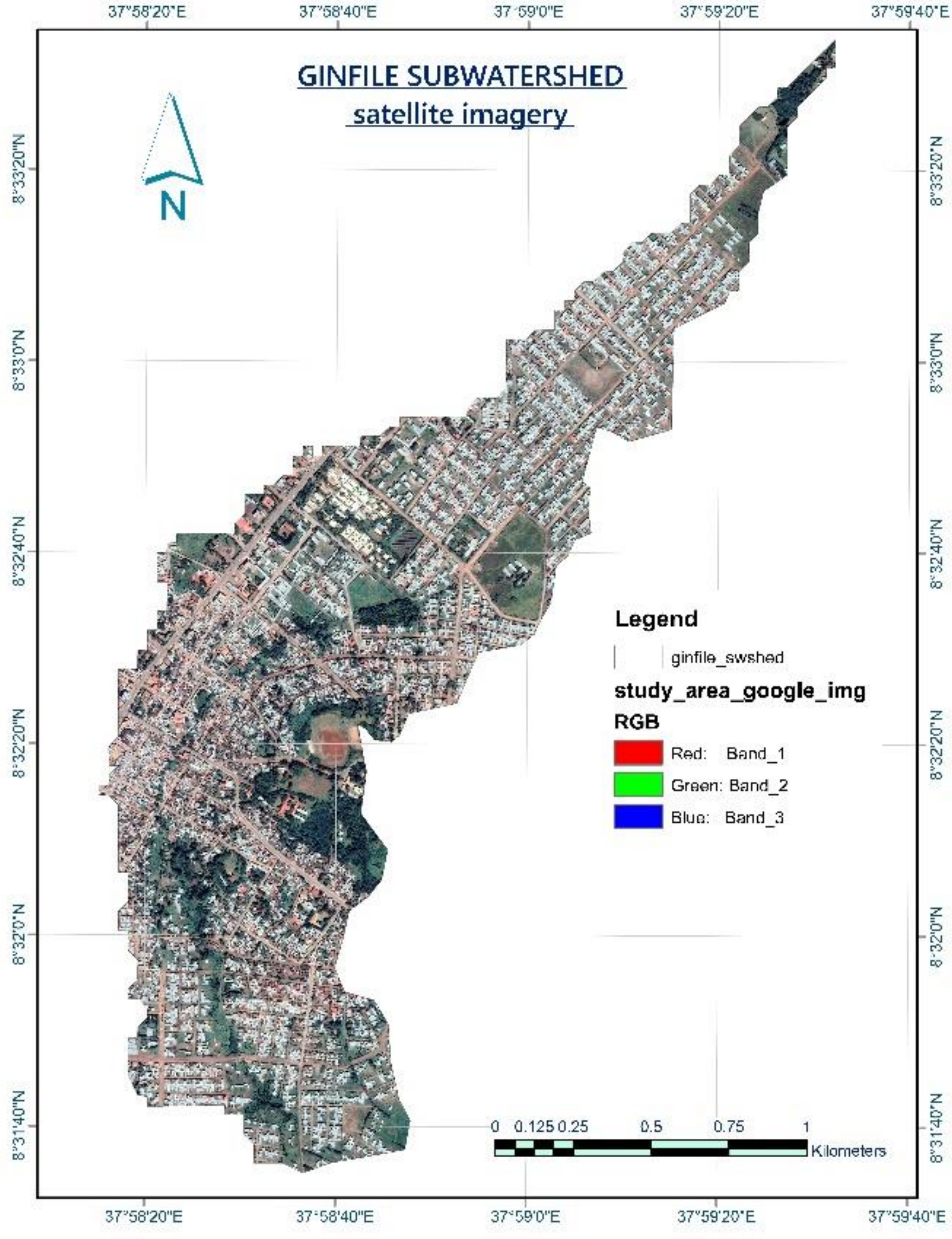
ANNEX 3


37°58'20"E
37°58'40"E
37°59'0"E
37°59'20"E
37°59'40"E
38°0'0"E
8°33'20"N
8°33'0"N
8°32'40"N
8°32'20"N
8°32'0"N
8°31'40"N
8°31'20"N
N
Legend
The study Area
grid_code
1
2
3
4
0 0.15 0.3 0.6 0.9 1.2
Kilometers


CONTOUR MAP
N
37°58'30"E
37°59'0"E
37°59'30"E
38°0'0"E
8°33'30"N
8°33'0"N
8°32'30"N
8°32'0"N
8°31'30"N
Legend
The study Area
MAJOR_CONTOURS_Clip
MINER_CONTOURS_Clip
0 0.15 0.3 0.6 0.9 1.2
Kilometers


STUDY AREA ELEVATION MAP
N
Legend
The study Area
Planning_DEM1.tif
Value
High : 2125.48
Low : 1998.63
0 0.15 0.3 0.6 0.9 1.2
Kilometers
37°58'30"E
37°59'0"E
37°59'30"E
38°0'0"E
8°33'30"N
8°33'0"N
8°32'30"N
8°32'0"N
8°31'30"N


STUDY AREA SUBWATERSHED
N
Legend
The study Area
grid_code
1
2
3
4
ginfile_swshed
filwuha_swshed
dololo_swshed
0 0.175 0.35 0.7 1.05 1.4
Kilometers
37°58'20"E
37°58'40"E
37°59'0"E
37°59'20"E
37°59'40"E
38°0'0"E
8°33'20"N
8°33'0"N
8°32'40"N
8°32'20"N
8°32'0"N
8°31'40"N
8°31'20"N


GINFILE SUBWATERSHED
satellite imagery
N
Legend
ginfile_swshed
study_area_google_img
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
0 0.125 0.25 0.5 0.75 1
Kilometers
37°58'20"E
37°58'40"E
37°59'0"E
37°59'20"E
37°59'40"E
8°33'20"N
8°33'0"N
8°32'40"N
8°32'20"N
8°32'0"N
8°31'40"N