Climate-Resilient Environmental Planning in the Awash River Basin, Ethiopia: A Geospatial Assessment of Environmental Change, Flood Hazard, and Nature – Based Solutions

Abayneh Tilahun Gebremichael

A Dissertation Submitted to the School of Built Environment, Department of Urban and Regional Planning of Addis Ababa University in Partial fulfillment of the Requirements for the Degree of Doctor of Philosophy in Environmental Planning

Supervisors: Ephrem Gebremariam, Ph.D.

: Hayal Desta, Ph.D.

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DECLARATION

I the undersigned, declare that this Ph.D. dissertation entitled " Climate-Resilient Environmental Planning in the Awash River Basin, Ethiopia: A Geospatial Assessment of Environmental Change, Flood Hazard, and Nature – Based Solutions'' is my original work under the professional guidance qnd supervision of Dr. Ephrem Gebremariam and Dr. Hayal Desta. It has not been presented for a degree or diploma in any other university and that all sources for materials used for this dissertation have been duly acknowledged.

Abayneh Tilahun Gebremichael ____________________________ ____________________________

Name of Student Signature Date

DISSERTATION APPROVAL

Doctoral Dissertation

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Abayneh Tilahun Gebremichael

Approval of the Board of Examiners

1. Supervisor

Name__Ephrem Gebremariam, Ph.D. Signature____________________Date_________________

Name__Hayal Desta, Ph.D.________ Signature____________________Date_________________

2. Internal Examiner

Name_________________________Signature____________________Date_________________

3. External Examiner

Name_________________________Signature____________________Date_________________

DEDICATION

To Mom!

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ABSTRACT

Flooding is a major environmental factor in the Awash River Basin (AWB) which is accredited by a concerted transformation of land-use change with climatic variability, topographical landscape, and soil degradation. The current dissertation has attempted to outline the flood prone area of the basin using the GIS and remote sensing as well as understand the etiology and the effects of floods, the dynamics of climatic changes, the future losses of the soil and prescribe some sustainable nature based methods of mitigation. The analysis of climatic trend by non-parametric techniques has shown that there is a remarkable reduction in annual and seasonal precipitation over the last forty years including the fact that temperatures are characterized by their continuously increasing pattern especially during spring and autumn. The decrease in vegetation cover and rise in surface temperatures are supported by satellite-based NDVI and land-surface temperature, thus worsening the situation of hydrological extremes. The long-term period in the range of 1990 to 2020 covering land-use and land-cover change (LULCC) show strong increment in the extent of the urban (by 160%), agricultural land (15%) and wetland areas, which are accompanied by considerable declines in bare land area and deep water bodies, which is mainly explained by the high population growth in the period. Such changes have altered surface runoffs pattern and vulnerability to flood significantly. The map of flood hazard susceptibility prepared with the help of multi-criteria decision-analysis framework which considers the elevation, slope, drainage density, precipitation, soil type, riverine proximity, and LULCC reveals that over half of the basin is at high to medium risk of floods, with the model validated by ROC-AUC evaluation. A soil erosion evaluation using the Universal Soil Loss Equation (USLE) indicates the strong spatial variability in soil erosion and subsidiary of sediment transportation with the majority of the erosive activity taking place in the upper basin areas thus highlighting the significance of land-management measures and rainfall erosivity. Lastly, suitability mapping of nature-based solutions reveals that vast areas (38%) of the basin are highly to extremely appropriate to interventions like afforestation, wetland restoration as well as sustainable land management. In general, it could be concluded that the findings offer a unified scientific foundation of the flood risk mitigation, soil protection, and nature based climate-resilient planning in the Awash River Basin as a means of sustainable development and informed decision-making. Keywords: Flood hazard, Climate Variability, Land use land cover change, Soil erosion, Soil Sedimentation, Nature Based Solutions, NDVI, LST, USLE

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ABBREVATIONS AND ACCRONYMS

ARB……………………………………. Awash River Basin

AHP……………………………………. Analytic Hierarchy Process

AGNPS……………………………….... Agricultural Nonpoint Source model

AST……………………………………. Adaptation Support Tool

AUC…………………………………….Area under the curve

BER……………………………………. Bale Eco-region

BM^3 …………………………………….Billion Cubic Meters

BMP…………………………………….Best Management Practices/Bitmap

CR……………………………………… Consistency Ratio

CREAMS……………….......................Chemical Runoff and Erosion from Agricultural Management Systems

CSA……………………………………..Central Statistics Agency

CSV……………………………………..Comma Separated Values

DEM…………………………………… Digital Elevation Models

DNs…………………………………….. Digital numbers

EEA……………………………………. European environmental agency

EMA………………………… ……….. Ethiopian Metrological Agency's

EPA…………………………………… Environmental Protection Authority

ERDAS IMAGINE……………………Earth Resources Data Analysis Systems

ESRI…………………………………….Environmental Systems Research Institute

ETM…………………………………….Enhanced Thematic Mapper

FAO …………………………………… Food and Agricultural Organization

FN……………………………………… False Negative

FPR…………………………………….. False Positive Rate

GCP……………………………………..Ground Control Points

GCS……………………………………..Geographic Coordinate System

GHG…………………………………….Greenhouse Gas

GIS……………………………………... Geographical Information Systems

GISP…………………………………….Green Infrastructure Spatial Planning

GLI……………………………………...Green Legacy Initiative

GPS…………………………………….. Global Positioning System
IPCC……………………………………. Intergovernmental Panel on Climate Change
ISDR……………………………………. International Strategy for Disaster Reduction
ISRIC………………………………….. International Soil Reference Information Center
ITAM…………………………………... Innovative Trend Analysis Method
IUCN……………………………………International Union for Conservation of Nature
LCR……………………………………..Land Consumption Rate
LST…………………………………….. Land Surface Temperature
LULCC………………………………… Land Use Land Cover Change
Mg ha−1 MJ−1 mm−1………………….Mega gram per Hectare Mega joule per Millimeter
MJ mm h−1 ha−1 year−1……………… Mega joule Millimeter per Hour per Hectare per Year
MCA……………………………………. Multi-criteria analysis
MCDA…………………………………. Multi-Criteria Decision Analysis
MEFCC…………………………………Ministry of Environment Forest, Climate Change
MK……………………………………... Mann-Kendall
MODIS………………………………… Moderate Resolution Imaging Spector Radiometer
MUSLE…………………………………Modified Universal Soil Loss Equation
NASA………………………………….. National Aeronautics and Space Administration
NBS……………………………………. Nature Based Solutions
NDVI……………………………………Normalized Difference Vegetation Index
NGOs………………………………….. Non-Governmental Organizations
OLI…………………………………….. Operational Land Imager
PGR……………………………………. Population growth rate
RI………………………………………. Random index
ROC……………………………………. Receiver Operating Characteristic
RS……………………………………….Remote Sensing
RUSLE………………………………… Revised Universal Soil Loss Equation
SDG……………………………………. Sustainable Development Goal
SFWMD………………………………...South Florida Water Management District
SNNPR………………………………… South Nation Nationality and People Region
SSANTO………………………………. Spatial Suitability Analysis Tool

STI……………………………………… Sediment Transport Index

T ha−1 year−1………………………….. Ton per Hectare per Year

TM……………………………………… Thematic Mapper

TP……………………………………… True Positive

TPR…………………………………….. True Positive Rate

TRMM…………………………………. Tropical Rainfall Measurement Mission

UN……………………………………… United Nation

UNDP………………………………….. United Nations Development Program

UNEA-5……………………………….. United Nations Environment Assembly

UNOCHA …………………………… United Nations Office for the Coordination of Humanitarian Affairs

USD……………………………………. United States Dollar

USEPA………………………………… United States Environmental Protection Agency

USGS…………………………………… United States Geological Survey

USLE…………………………………… Universal Soil Loss Equation

UTM……………………………………. Universal Transverse Mercator

WEPP…………………………………... Water Erosion Prediction Project,

WHO…………………………………… World Health Organization

WGS 84………………………………… World Geodetic System 84

WWAP………………………………… World Water Assessment Program

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CHAPTER ONE: INTRODUCTION

1.1. Background

Climate change refers to long-term changes in the average values of climate parameters. Among various factors, climate change is taking the lion shares as primary cause of flooding next to rapid land use land cover changes within study area, Awash River Basin (ARB). Moreover, the main consequences of climate change in the ARB are; high temperature, rainfall variability, high evapotranspiration, recurrent drought and severety, flood occurrence, stream flow changes, and water stress. Following thorough examination of consequences of flood hazard and heavy soil loss alongside sedimentations within ARB which is triggered by climate change, the main factors have to be discussed significantly. Climate change, which has been observed worldwide, is often associated with global warming. It is connected to both natural and man-made activities and has a direct or indirect effect on global warming (IPCC, 2007). The average world temperature has risen since 1850, rising by 0.6 degrees Celsius in the latter half of the 20th century. There is currently significant global warming (Kennedy, 2019). There are other changes than temperature; changes in precipitation features, increased air humidity, increased evaporation, and changes in soil moisture content and overflow have all resulted from the strong relationship between the hydrological process and climate dynamics and its components (Bates & Kundzewicz, 2008). Hence, Regional and local variations in yearly precipitation have been noted, though (IPCC, 2007; Basistha, 2009; Wang & Qin, 2017).

Similarly, variations in flooding and hydrodynamic extremes are greatly influenced by variations in temperature, precipitation, and other climatic factors (Wang & Xia, 2005). Asfaw (2018) states that by 2050, the hydrological regime in most parts of the world would alter significantly. Some of the main causes of climate change that have recently been connected to it include industrialization, farming, intense deforestation, and volcanic activity. Activities like burning fossil fuels, which are driven by rapid economic and population growth, increase greenhouse gas (GHG) emissions into the atmosphere (Yang & Lu, 2015). Ethiopia is one of the sub-Saharan countries most susceptible to climate-related natural disasters such droughts and floods (Ethiopian Red Cross Society, 2012; Awash Basin Authority, 2017).

Climate unpredictability already has a significant impact on the population and economic output in the Awash River basin. The severe droughts in the region have caused significant losses in crop yields and livestock mortality, which has increased food insecurity (Murendo, 2011). The Awash River basin, one of Ethiopia's 12 river basins, has experienced significant food insecurity as a result of recurring droughts, sporadic floods, and an extremely unstable climate (Edossa et al., 2010; Yang & Lu, 2015; Onyutha et al., 2015; Adeba et al., 2015).

In addition to multiple severe consequences of climate changes, land use land cover change induced by high population growth also has substantial impacts to flooding in study area. Numerous scientific research indicate that land use land cover change (LULCC) has a significant impact on flood dynamics and is closely related to floods (Dewan and Yamaguchi, 2009; Adnan et al., 2020; Roy et al., 2020). LULCC is one of the factors that contribute to flooding, which can be caused by both natural and human activity (Gan et al., 2018). Rahman et al. (2024), claim that dynamic changes in land cover made a region more susceptible to flooding. Human invasions, whether direct or indirect, can significantly alter land use and land cover (Etter et al., 2006; Manandhar et al., 2009). In nations such as Ethiopia, rapid population increase is a major contributing factor (Tekle and Hedlund, 2000). Overgrazing, urbanization, agricultural expansion, and population growth have all significantly changed Ethiopia's LULC in recent decades. Ethiopia's population, which probable as 108 million, is expanding rapidly at an estimated rate of 2.8%, which is comparable to that of most other sub-Saharan African countries (Andrew et al., 2019).

The Awash River Basin (ARB) is Ethiopia's most significant, highly developed, and heavily utilized basin. It supplies water to households, industries, hydropower plants, and large and small irrigation schemes, but it is also one of the country's most environmentally vulnerable basins (Bekele et al., 2018, Bekele et al., 2016; Edossa et al., 2010; Kinfe, 1999). The basin's strategic location, road access, arable land, and water supplies make it susceptible to human-induced issues such land degradation and high population density. Numerous Ethiopian scholars have studied changes in land cover and use within the Awash River Basin, and their findings indicate that there have been significant changes recently. The Awash River Basin (ARB) is confronted with a number of significant issues, such as urbanization, rapid human population rising, land degradation, and water resource depletion (Garedew et al., 2009; Haregeweyn et al., 2015; Tsegaye et al., 2010; Edossa et al., 2009; Taddese et al., 2003; Tiruneh et al., 2013).

The ARB is particularly susceptible to LULCC and flood hazards due to its unique climatic and hydrological characteristics, which include varying rainfall patterns and significant anthropogenic pressure from development and agriculture. The strategic economic importance of the basin exacerbates these problems by accelerating resource extraction and land change. Flooding threatens not just the sustainability of nearby communities but also long-term development goals; hence it is imperative that land-use planning initiatives take flood risk into account. Thus, it is crucial to comprehend the dynamics of land use and land cover at the basin level in order to establish and plan suitable environmental management policies and strategies (Hurni et al., 2010).

Significant effects of LULCC and climate change eventually result in runoff-induced soil loss and flood hazard threats. Zewde (2004) emphasized that the frequency and size of floods in the nation have rapidly increased in recent years due to changes in land use and climate. The impact is growing as a result of the enormous effects of climate change, the rapid population rise that coincides with an increase in land and forest degradation, and the influx of people who settle along riverbanks (Semu, 2007).

Numerous academics show that floods are a natural hazard brought on by a confluence of climatic and hydrological conditions. One of the most frequent and widespread natural disasters in the world, floods usually result in significant damage in many areas (World Bank, 2015). Demolition of agricultural soils, deterioration of various infrastructures like roads, bridges, canals, and other structures, transportation of solid waste into dam lakes, death of various organisms, including humans, destruction of urban communities, and waste of high-quality and suitable water are all significant losses (Shu et al., 1993). Additionally, floods are classified as river, coastal, urban, and flash floods based on their origins and locations. As a natural disaster that is exacerbated by human activities, floods can also be classified as socio-natural or unnatural hazards (ISDR, 2009). Floods occur when water, especially groundwater from heavy or prolonged rainfall, overflows a river's natural or manmade bounds, briefly flooding an area, typically on dry land. Among the most serious hazards to the environment, in addition to natural events, are human actions like pollution, deforestation, and continuous unsustainable development that modifies or affects the natural terrain (Wisner et al., 2003; Martini and Loat, 2007; Klijn 2009). Hence, unusual heavy rainfall is the primary cause of flooding in Africa. Surface land degradation, deforestation in catchment areas, excessive population density near river banks, poor land use planning, development zoning on the flood plain, inadequate drainage, and poor management of the river reservoir's expulsions are some additional human-induced causes of deterioration (Rakhi et al., 2008).

Ethiopia is one of the sub-Saharan countries that are vulnerable to droughts, floods, and other natural disasters (Ethiopian Red Cross Society, 2012). Flood is Ethiopia's second greatest threat, behind drought (Zewde, 2004). This is because important river lines in the lowland plains and highland ranges naturally produce drainage patterns. The severity and frequency of floods have sharply increased in recent years due to changes in the nation's climate and land development (Zewde, 2004). The impact of land and forest degradation is growing as the population increases and more people relocate to places close to rivers (Semu, 2007). Unexpected and erratic flooding posed a hazard to several regions of the nation.

Flooding event affects river basins and main urban areas severely in Ethiopia. Each year floods claim with them many lives and property in the country such as the flood events of year 2006 caused many losses, especially in South Omo and Dire Dawa where about 300 persons lost their lives. Making timely decisions and responding to emergencies is often compromised in turn, by the difficulty is finding appropriate and accurate information in time, leaving many affected populations at risk before a proper response can be considered.

The United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA, 2006) estimated the total number of people affected by the floods of 2006 at about 357,000 across the country, of which the number displaced was about 200,000; and economic losses were estimated at 40 million Birr. Similarly, World Bank (2019) reported that flood disasters in 2006 took an enormous toll in terms of lives lost in the country; with the Southern Nations, Nationalities, and Peoples' Region (SNNPR) losing more than 360 lives in South Omo alone. The floods also caused mass displacement, especially more than 16,000 persons were displaced in West Shewa Zone of Oromia Region. At Dire Dawa about 10,000 residents were forced to flee. These show the huge human, social and economic losses caused by flooding in Ethiopia. Half a million people nationwide were impacted. Over 3,000 people have died, 1.3 million have been homeless, and 10 million have been impacted by flooding in Ethiopia since 1991, according to the Desinventar database of catastrophe impacts. During that time, 280,000 livestock were destroyed and more than half a million hectares of crops were damaged.

The ARB, the study area, is now dealing with a number of environmental issues, including soil degradation, aridity, high salinity, dwindling natural water, high population density, and destruction of wetland areas (Hailemariam, 1999). Flooding is another significant problem that could worsen the environmental degradation of the ARB (Girma, 2010). Floods in the Gedabassa and Borkona wetland sections of Becho Plain caused water logging, according to a 2017 report by the Awash River Basin Authority. Additionally, possible risks from flooding in the basin area's downstream section were among the other hazardous events that are crucial to the region. In addition to being one of Ethiopia's most frequently flooded regions; the Awash River Basin is one of the country's main river basins in the rift valley (Wondim, 2016; Kefyalew, 2003).

Throughout the rainy season, particularly in August, there is significant discharge from the dams in Koka and heavy rainfall in the highlands of the ARB Ashenafi (2016) cause destruction to communities close to any part of the river and floods downstream (Abebe, 2007). According to the flood incidents that have occurred in the upper ARB, September 2017 was marked by severe floods in the woredas of Sebata Hawas, Walmera, and Ejere; Liben Chukuala and Bora in 2014, 2016, and 2017; Fentale in 2012, 2015, and 2017; and Ilu and Sebata Hawas in 2018 and 2019, respectively. Major cities in the Awash River Basin were often at risk of floods. For instance, Adama had catastrophic floods in 2008, 2009, and 2016, which resulted in large costs for numerous municipal areas (Dejene et al., 2017; Yonas et al., 2022).

Due to a number of reasons, including terrain, changes in land cover and use, steep slopes, extreme weather, population growth, rapid urbanization, and higher watercourse operations, the majority of metropolitan areas in the ARB are very vulnerable to floods. The principal consequences of flooding risks in city centers are largely caused by inadequate drainage systems, urban impermeable buildings, the types of building materials utilized, and the rapid illegal housing construction near riverbanks (World Bank, 2015).

Surface flooding is an inevitable consequence of urban growth since impermeable barriers can be built in urban areas to lessen runoff penetration. Following that, the potential and rate of runoff discharge increased downstream of urban areas (Rasul et al., 2018). Flood catastrophes in ARB have grown over time in terms of ecological, social, and financial aspects. In the end, many local administrations in the basin lack combined risk oversight and timely warning systems, which results in devastating flood damages. To prevent such recurrent issues, improvements in hazard analysis, remediation, and management are required (Ebert et al., 2009).

In addition to flood threats, in East Africa's highlands, soil erosion is a well-known problem that causes soil deterioration in larger areas of the region (Gachene, 1995; Tiffen, 1994). According to Gessesse et al. (2014), and Lanckriet (2014), Ethiopia has the highest rate of erosion. Ethiopia loses between 16 and 300 t hectare of soil annually as a result of heavy runoff. High precipitation intensity, the type and depth of land cover, and slope gradient are the main causes of this loss (Hawando, 1995; Tesfaye et al., 2014). Land degradation is also caused by ineffective soil conservation planning, extensive farming, farming on steep slopes, overgrazing, deforestation, rapid population growth, and urbanization (Bekele, 2019; Bayramin et al., 2003; Pimentel, 2013; Reusing et al., 2000; Schiettecatte et al., 2008; Nikonya et al., 2016). Soil erosion impacts agriculturally productive land in highland areas, which account for 45% of the country's total land area (Tiruneh, 2015).

Ethiopia currently has the lowest crop yield per plot of land when compared to other nations, according to Ma et al., (2014). This is the outcome of topsoil being removed by erosion, which reduces depth of root growth and diminishes nutrients.

Additionally, it lowers agricultural output by causing water loss and nutrient storage capacity (Bekele, 2019; Haileslassie et al., 2008; Sertsu, 2000). According to Desta (2000), the primary causes of soil erosion in Ethiopia are overgrazing, deforestation, farming on steep slopes, and rapid population growth. The diverse topography, climate, and land use characteristics of the Awash River watershed exacerbate soil erosion, endangering agricultural production and natural elements. High rates of deforestation, quick agricultural growth on steep slopes, and irregular rainfall patterns impacted by climate change are some of the particular problems the Awash River basin is currently confronting. It is therefore essential to ascertain the annual soil loss, the amount of soil lost due to runoff/water-induced erosion, the geographic distribution of soil erosion, and the degree of soil erosion triggered by catchment runoff. Furthermore, sediment yields are transported downstream by surface runoff following upstream soil erosion caused by high rainfall (Freebairn et al., 1996). Additionally, increased soil erosion and sediment transportation are being caused by climate change-related increases in annual precipitation and more complex showers (Mullan, 2018). Soil erosion can be made worse by a number of agent elements, such as wind, severe rainfall, and water flow. It is crucial to remember that sediments can be carried at comparatively high rates by strong water flow or runoff (Alhamid, 2002; Horton, 1945; Vanoni, 2006). Due to a variety of circumstances, including terrain, changes in land cover and use, steep slopes, extreme weather, population growth, rapid urbanization, and higher watercourse operations, the majority of metropolitan areas in the ARB are very vulnerable to floods, soil erosion and sedimentations. Therefore, it is imperative to create efficient flood control and mitigation strategies to minimize the effects. Hence, introducing a concept of Nature Based Solutions (NBS) to mitigate abovementioned effects are vital.

Considerable use of NBS, which are described as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience." NBS is defined by the IUCN as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham, 2016; UNEA-5, 2022). According to Liu et al. (2015), Dong et al. (2017), the European Commission (2016), and Neshover et al. (2017), NBS (such as forest regeneration, watershed/river re-naturation, and wetlands restoration) can address a variety of environmental issues, including natural disasters caused by urbanization and extreme climates.
Furthermore, opinions on whether NBS outperforms gray infrastructures differ (Thorne et al., 2015; Moreno et al., 2017). Several academics questioned NBS's overall efficacy in preventing floods during periods of severe rainfall when only green measures are employed (Zölch et al., 2017). NBS can also be viewed as an additional choice to be used in conjunction with existing techniques or grey infrastructures. According to Alves et al. (2019), integrating natural and gray infrastructure is therefore likely to produce greater results in terms of potential efficacy than any one measure taken unilaterally, especially after their many benefits are evaluated.

Integration of NBS and gray infrastructure has been recommended for sustainable urban flood control and storm water management (Alves et al., 2020; Jiang et al., 2018). NBS may bring together a wide range of parties and disciplines to produce ecosystem-based initiatives such as ecological engineering, ecosystem services, and green-blue infrastructure (European Environmental Agency, 2015). In contrast to gray infrastructures, NBS is considered a realistic sustainable solution since it makes use of ecosystem services that offer many benefits for both human well-being and the surrounding environment (Seifollahi-Aghmiuni et al., 2019).

The most crucial aspect of NBS implementation is its multi-functionality. For example, a specific flood plain area can effectively be used for a range of purposes, such as recreational, irrigation, or rice agricultural activities, while simultaneously retaining available water and lowering peak flows to mitigate flood hazard (Michielsen et al., 2016). This demonstrates the significant multi-functionality of eco-system-based mitigation or nature-based remedies. The multi-functionality of NBS must be highly appreciated in order to effectively improve human existence (Keesstra et al., 2018).

Henceforth, to mitigate flood hazards caused by recurrent impacts of worldwide warming, consideration of NBS is significantly important. Moreover, Geospatial Information Systems (GIS) based identification of suitable location for the implementation of NBS is a preliminary step to attain the target of mitigating the severe impacts of warming temperatures.

1.2. Statement of the Problem

The occurrence of natural hazards has recently increased dramatically due to climate change, fast population development, environmental degradation, and improper land use practices. Human settlements are harmed by these natural disasters in a number of ways, including social and economic losses, property and infrastructure losses, and fatalities and injuries. According to Arnine (2008), floods account for 31% of all natural disaster-related economic losses worldwide, making them one of the most expensive and common natural catastrophes in terms of both human and financial losses. Seasonal excessive rainfall is the primary cause of flooding in the Awash River Basin; however there are other causes of excess flows in water bodies (Abebe, 2007). In Ethiopia's Awash River Basin, the issue of river flooding brought on by heavy rainfall in a short period of time and the ensuing high river flow is a major worry. The Awash River's floodplain extends to specific places that are not typically submerged in water during the primary rainy season (June, July, August, and September).

Significant floods were reported in September 2017 in the upper Awash River basin woredas of Sebeta Hawas, Wolmera, and Egeria; in 2014, 2016, and 2017 at Liben Chukuala and Bora woredas; in 2012, 2015, and 2017 at Fentale; and in 2018 and 2019 at Ilu and Sebeta Hawasa woredas. The Teji River has been briefly flooded after intense or protracted rainfall storms, even though the downstream region is submerged for days or weeks each year during the rainy season. Most metropolitan areas in the middle Awash River basin are vulnerable to frequent flooding; in Adama, severe flooding occurred in 2008, 2009, and 2016, resulting in significant expenses in various portions of the city (Dejene et al., 2017).

The city is recently acknowledged as one of flood exposed city in Ethiopia, due to consequences of urbanization on hydrological features of the city is not well understood by the city government and sustainably managed (Sinha et al., 2016). Flood damage in the Awash River basin has been getting worse over time in terms of social, economic, and ecological issues. The lack of integrated early warning and risk management systems in many municipal administrations in the Awash River basin finally results in significant flood hazard impacts.

In addition to flood hazard impacts, soil erosion and removal of top soil due to heavy flow of waters triggered by heavy rain fall are also huge problem in Ethiopia, and study area Awash River basin. An estimated 100 to 300 t ha-1 year-1 of soil is lost annually from agricultural land alone in Ethiopia's highlands due to severe land degradation (Birhanu, 2014; Tiruneh, 2015). Approximately 2 million hectares of land are permanently lost from production, and 27 million hectares of the 60 million hectares of agriculturally productive land have the potential to erode (Birhanu, 2014; Tiruneh, 2015). Additionally, farmland soil disappears at an average rate of 42 tons ha-1 year-1, with losses of up to two billion tons ha-1 year-1, or $1 billion USD (Ma et al., 2014; Sonneveld et al., 1999).

Soil erosion impacts agriculturally productive land in highland areas, which account for 45% of the country's total land area (Tiruneh, 2015). Ethiopia currently has the lowest crop yield per plot of land when compared to other nations, according to Ma et al., (2014). This is the outcome of topsoil being removed by erosion, which reduces rooting depth and depletes nutrients.

Additionally, it lowers agricultural output by causing nutrient storage capacity and water loss (Bekele, 2019; Haileslassie et al., 2008; Sertu, 2000). According to Desta (2000), the primary causes of soil erosion in Ethiopia are overgrazing, deforestation, farming on steep slopes, and rapid population growth. Furthermore, according to Bizuwerk et al. (2003), soil loss in the Awash River Basin is projected to be about 37,684,000 t ha^{-1} $year^{-1}$ from 11.2 million hectares, with an average of 28.84 t ha^{-1} $year^{-1}$.

We may also list a few elements that can make the effects of flooding more severe. Rapid illegal building constructions along riverbanks, inadequate drainage systems, impermeable urban structures, and the kinds of materials used in home construction all contribute significantly to the serious effects of flood hazards in urban settings (World Bank, 2015).

Strategies for catastrophe planning and early warning are also improperly applied. Furthermore, flooding threatens a life of people in lower Awash Basin urban districts. Due to topography, changes in land use and land cover, severe slope variations, extreme weather events, population increase, fast urbanization, upper catchment activities, and other variables, the majority of urban areas in the ARB are extremely vulnerable to flooding. According to B. Ibrahim (2018), surface floods are inevitable as a result of urban growth since urban areas can be transformed into impermeable structures that might limit runoff infiltration. As a result, runoff capacity and flow rate rose downstream of metropolitan areas. The ARB low-lying, flat topographic features are typically where river or flash flooding occurs.

The ARB highlands experience heavy rainfall, which destroys communities along any portion of the river and causes flooding downstream (Abebe, 2007). Rainfalls in the highlands that flow through the main river's tributaries and heavy discharges from the Koka reservoirs during the wet season, especially in August, combine to cause flooding in the Awash River Basin, especially in the downstream portion (Ashenafi, 2016).

In the ARB, flooding has generally resulted in thousands of people leaving their homes and thousands of animals being slaughtered. Degradation of the environment and significant financial losses has also resulted from it. Infrastructure, healthcare, and educational facilities deteriorate year after year; health clinics are closed during the nation's rainy season, and schools in the basin often start late due to flooding. In addition to damaging many forms of infrastructure, floods brought on by excessive rainfall and the ensuing High River discharge also cause siltation and the movement of fertile soil.

Because of its serious effects on agricultural crop damage, productive soil loss, and human welfare losses, flooding has recently become a major concern in the ARB. For this reason, using geospatial models is essential to identifying and mitigating expected flood hazards and their major causes. In addition, the ARB requires regular flood control, timely forecasting, improving early warning capabilities, implementing a nature-based flood mitigation strategy, and mapping hazard-prone areas. Additionally, the lack of integrated early warning and risk management systems in many municipal administrations in the ARB finally results in significant flood hazard damages. Hazard analysis, mitigation, and management must be improved in order to prevent such recurring issues (Ebert et al., 2009).

Research Gaps

In this work, a number of major research gaps are identified and covered thoroughly to support the methodological framework and the findings of the whole research. As the main sources of the problem of flooding in the Awash River Basin are defined, it becomes evident that there was a lack of specific studies regarding the correlation of LULCC with the population growth and flood risks. In addition, in regard to trend analysis in the field of study, the majority of research studies conducted have used mainly data taken by meteorological stations and which often lack observations and therefore create inaccuracies or uncertainties in the datasets obtained. The lack of the shortcomings that were observed in the past is explicitly highlighted in the given work. To this effect, this study aims at filling the knowledge gap existing on long-term climate change trends especially in the Awash River basin where no proper study has been carried out using strict statistical trend analysis. Previous studies have mainly concentrated on variability in short term or have been limited on smaller spatial scales eliminating extensive long term geographically exhaustive knowledge. To overcome this gap the present study provides a 40-year and basin-wide evaluation of trends using non-parametric statistical tools to gain more insights into the effects of climate change in such a vulnerable area.

What is more, the combination of a complex method of analysis of climate trends is a rare characteristic in the literature to date, thus, this paper attempts to combine both statistical and geospatial methods to provide more valid results. Regarding the geospatial component, this study mainly used data on land surface temperature (LST) and normalized difference vegetation index (NDVI) data, which was found in the United States Geological Survey (USGS) and the Moderate Resolution Imaging Spector radiometer (MODIS) research data portals. LST and NDVI magnify a better result for chronological trend analysis in the study area, together with statistical approach.

Moreover, we have found certain gaps in the flood hazard area map and soil loss analysis after conducting a comprehensive examination of the causes of flood hazards and observing gaps in numerous scientific researches within the Awash River basin.

Therefore, utilizing geospatial models to map areas that are vulnerable to risks is necessary in order to identify and reduce expected flood dangers and their major causes. Additionally, where most studies fall short, the ARB will demand the application of nature-based flood mitigation techniques, consistent flood management, precise forecasts, and improved early warning capabilities. Additionally, in order to enhance conservation efforts in the research area, the study attempts to identify spatial hotspots for soil erosion in addition to estimating soil loss. Analysis of the sediment transport index (STI) along with soil erosion provides a substantial understanding of sediment dynamics within ARB systems, which is various erosion studies overlooked regularly, hence this study try to fill this gap.

Regarding flood hazard mitigation strategies various gaps can be seen in recent scientific studies, especially in preferences of either small scale or large scale NBS approach. In addition, combining strategies of both traditional engineering methods and NBS also not considered within such studies. Hence, there is a huge gap between the quantity of research undertaken upon small-scale NBS in urban settings and large-scale NBS across the watershed (river basin), suburban, and regional level. The main reason for this is that large-scale structures are more costly and complicated than small-scale ones. Additionally, small-scale NBS projects those are more concentrated along urban drainage system areas and buildings. This projects lack the determination to further enhance the experiences at larger scale in river basin, catchment, or watershed areas.

Furthermore, there is a large knowledge gap about evidence-based NBS performances; most of it is unbalanced and focuses mainly on specific ecosystem services that NBS offers (Pinto et al., 2021). Furthermore, no study examined the benefits of combining natural solutions with traditional engineering methods, such as using embankments, channel gates, and dams to enhance floodplain flood water retention (Acreman et al., 2021).

Henceforth, major research gaps that can be observed in Awash River basin flood hazard issues are considering of land use land cover change with correlation of population growth, climate change trend analysis based on integration of statistical and geospatial approach, flood hazard area mapping along with soil loss estimation and sedimentation analysis, lack of practicing of large scale Nature based flood hazard mitigation solutions, political determination and inconsistency of environmental planning strategies.

After many practical implementation plans & practices, still the people live desperately in adjacent to river banks and flood plain areas. In addition, most of the implementation strategies also lack significant public participation, that resulting eventually lacks permanent and consistent solution. In fact, mapping flood-prone areas, comprehending the potential of flood-triggering variables, and identifying sustainable solutions for flooding and other related issues are essential to an efficient and methodical approach to controlling periodic flood disasters (Dejene et al., 2017). Hence, this study tried to fill up all observed research gaps in numerous research works within the study area.

Therefore, this research aimed at analyzing the dynamics and correlation of land-use land cover change and human population growth with respect to flood hazards in the ARB using remote sensing and Geographic information system (GIS). Furthermore, helps to investigating land use changes and conservation efforts to protect ecosystems and biodiversity. Correspondingly, try to determine the patterns of climate change throughout the entire Awash River basin by analyzing temperature and precipitation trends statistically, and determine the patterns of climate change by analyzing the temporal trends as well as the connection between NDVI and LST, Geospatially.

The study's main goal, after a thorough consideration of the major elements that contribute to and effect floods in the ARB, is to construct a GIS-oriented flood hazard map. Similar to this, utilizing a GIS can help with emergency response plans, disaster preparedness, and the identification, planning, and prioritization of locations for flood hazard mitigation efforts. A crucial part of flood-prone land use planning and mitigation techniques is flood hazard mapping (Bhatt et al., 2014). Additionally, Using the Universal Soil Loss Equation Model (USLE) with the integration of GIS and remote sensing technology, this study was tried to estimate the severity level of soil erosion, estimate the average annual soil loss rate, compute the sediment transport index and identify and prioritize critical erosion prone areas for further environmental and conservation planning. Moreover, as environmental planning strategy this paper aimed to produce suitable locations for integrated/hybrid NBS implementation to overcome the impacts and devastating damages of flooding. Further, this study report plays a significant role by providing detailed suitable sites and types of nature-based mitigation measures to curb the risk and susceptibility of floods in the ARB.

Moreover, this research paper undertakes to explain the relative sustainability of integrated Nature-Based Solutions (NBS) and the conventional engineering methods, or grey infrastructure, and how they appeal to ecological services and biodiversity in the study area.

Hence, in summary, this work attempts to analyze major causes and impacts of flooding in Awash River basin and produce flood hazard area map, estimating soil loss and provide nature based suitable flood mitigation site selection map of the basin with high resolution images using GIS and RS techniques. In addition, this work will provide significant effort for scientific community, policy makers, as well as for societal benefits.

1.3. Objective of the Study

1.3.1 General Objective

The main objective of this study is to analyze flood hazards and their environmental impacts in the Awash River Basin (ARB) using Geographic Information Systems (GIS) and Remote Sensing techniques with the aim of taking action to manage flood hazard effectively and sustainably.

1.3.2 Specific Objectives

- To analyze trends of climatic variables (Temperature and Preciptation) of the study area over the past years.
- To identify land use land cover change dynamics and main causes of flood hazard in study area.
- To identify and mapping of the area that is prone or susceptible to flood hazards.
- USLE based soil loss estimation of the study area
- Provision of appropriate/suitable Nature based environmental planning solutions to overcome the impacts and damages of flooding.

1.4 Research Questions

- How are the trends of climatic variables in study area? (Temperature and Precipitation)
- How are the dynamics of land use land covers of study area?
- What are the main reasons for flood hazard in study area?
- Which parts of the study area are significantly vulnerable for flood hazards?
- How much is the estimated amount of soil loss in study area?
- What are significant mitigation solutions for flood hazard reductions?

1.5. Significance of the Research

- The research finally produces a high-resolution hazard map of flood-prone areas within the Awash River Basin along with a prediction of possible soil erosion and a sediment transport index. It also reports land-use and land-cover change analyses of the Awash River Basin, a climate-change trend analysis, and an appropriate place where nature-based solutions are applicable. Hence, it provides informed mitigation measures of the flood hazards on a sustainable basis.
- Employing a unified policy incorporating both the environmental conservation and urban planning of the Awash River Basin should therefore be a priority among the policy makers of the region. The relationship between population growth and urbanization and land-use/land-cover dynamic has been identified as one of the requirements in terms of reducing flood hazards. Additionally, the study will help in the attainment of Sustainable

Development Goal 15 by the year 2030. The findings, by spreading comprehensive details of the aspects of land-use and land-cover dynamics in the basin, assist in conserving biodiversity and also in managing terrestrial ecosystems in a sustainable way.

- The results highlight the need to become more active in developing the water management policies aiming at incorporating the trends in climatic conditions to develop an early warning mechanism and adopting the methods of water conservation and sustainable irrigation practices. The negative effects can be mitigated by enhancing climate resilience through creation of a diversified source of energy as well as adoption of adaptive farming methods. These climate insights have to be included in the regional planning to achieve improved food security and socioeconomic stability. The future studies can be enhanced with the use of greater resolution datasets, climate model predictions, and drought indices, which will take into consideration fewer limitations in data and better represent the spatial deviation and extremes. Climate models have the potential of enhancing prediction capacity as well as assisting in the development of overall adaptation strategies.

  Additionally, more detailed understanding of the vulnerability and resilience of the basin is provided through the combined studies of the annual socioeconomic variables and the climatic trends.

- Moreover, the results of the present study will provide useful information to policy makers, environmental planners, and authorities of the Awash River basin hence influencing the development of specific mitigation policies in the basin. Additionally, the paper explains how geospatial methods may be applied to promote sustainable and precise nature-oriented flood mitigation programs in the area, and by doing so, improve both theoretical and practical answers to environmental protection of areas facing floods.
- This paper evaluates the connection between transporting agents of sediment and soil erosion and reveals that there is a complex interaction system between water and sediment elements on water bodies and also on landforms. Failure to understand this interaction limits effective practices aimed at checking soil erosion and checking on the health of affected ecosystems.
- Furthermore, it provides scientific basis to the policymakers, agricultural and environmental specialists, political leaders and policy makers, enables their strategic

planning in localities affected by flooding. Finally, this paper highlights the possibility and effectiveness of large scale NBS as environmental friendly and sustainable flood-management treatments and biodiversity-enabling flood-management interventions in the Awash River basin. This type of approach could be a significant contribution to resilient landscape management, help reduce flood risk in Ethiopia and other flood-prone countries, and have considerable benefits in society.

- Contribute a lot for Environmental planning, hydrology and water management students, about how to manipulate and utilize GIS and RS as a tool in order to reduce flood hazards, risk and problems.

1.6. Scope of the Study

The current study aims at assessing flood risks and to develop sustainable mitigation strategies in the ARB, Ethiopia, by involving the combination of GIS, RS, and multi-criteria decision-making models. The breadth of the study is characterized in terms of spatial coverage, conceptualized approach, and subject matter to maintain the correspondence with the objectives and questions stated.

1.6.1. Spatial scope

The study is limited within the Awash River basin boundary. Every spatial analysis, such as flood hazard maps, land use/land cover change, climate trend evaluation, soil loss evaluation, and suitability mapping of NBS, is all done in this basin. Though spatial heterogeneity is recognized in the upstream, midstream and downstream segments, it is the basin that is regarded as the main unit of analysis.

1.6.2. Methodological and Thematic Scope

Flood hazard mapping is done through the use of Analytic Hierarchy Process (AHP) in a GIS environment. The essential flood-conditioning factors are based on the Digital Elevation Models (DEM) and thematic datasets of DEM - elevation, slope, drainage density, land-use/land cover, precipitation, and soil property- and the weight of key contributors are determined using the pairwise comparison matrices according to the AHP protocol. The overlaid layers are then used to produce a flood hazard susceptibility map thus classifying the basin into different flood-prone areas.

The change in land use/land cover are studied based on multi-temporal remote sensing databases in order to establish significant changes and their role in causing the enhancement of flood risks. The climate change analysis focuses on the trends of temperature and precipitations in the past based on the Mann-Kendall statistics and slope by Sen in order to explain the long-term that is relevant in the processes of flooding. The soil erosion and possible soil loss are measured through the Universal Soil Loss Equation (USLE) which is spatially done using GIS. The sedimentary indicators and soil loss obtained are assessed concerning the patterns of flood hazard to point to the areas of cumulative susceptibility in the environment.

To facilitate the mitigation planning of floods, the suitability evaluation of the NBS sites with the use of AHP-Fuzzy hybrid approach to the suitability assessment is applied in the study. AHP calculates the relative weight of the NBS suitability criteria, whereas fuzzy logic is used to control uncertainty, transition stages, as well as non-linear relationship between environmental factors. The AHP-Fuzzy model provides the integrated model, which provides a suitability map, which identifies the best areas to implement NBS interventions including floodplain restoration, wetland improvements, and other ecosystem-based solutions.

1.6.3. What the Study Includes

- Flood vulnerability mapping through an AHP based multi-criteria examination.
- Remote sensing data analysis- land use/ land cover change.
- Trend analysis of temperature and weather precipitation.
- Estimation of soil losses using the USLE model.
- The use of an AHP-Fuzzy hybrid technique is suitable to select the site for NBS.
- Co-integration of GIS and RS deliverables towards sustainable flood mitigation planning.

1.6.4. What has not been covered in the Study?

- Physical hydraulic/hydrodynamic flood simulations.
- River discharge records obtained as flood frequency or as return period analysis.
- Intensive socioeconomic damage/cost-benefit analyses.
- Future drought index or intensity and extreme-event indices or indices Climate projection/Future climate (IT series) or drought indices.

- RUSLE or other sophisticated erosion models haven't been used because of data inavelability.

To conclude, the research scope highlights a basin scope, geospatial study and decision-support applicative assessment of flood risks and reduction strategy of the Awash River Basin. The work provides a scientifically sound and practical framework of flood risk reduction which is environmentally sustainable through AHP based flood hazard mapping and an AHP-Fuzzy method of analyzing the suitability of NBS.

1.7. Limitation of the Study

Various constraints were experienced during implementation of this dissertation. Under the land-use and land-cover classification component, in as much as we obtained sound data to do the analysis based on the LULCC analysis through remote sensing, a number of limitations were observed.

The accuracy of the remote-sensing data was significantly affected by the atmospheric conditions and sensor opportunities as well as non-uniform terrain effects. Furthermore, in the classification, a spectral signature may overlap with varied terrain types thus biasing the classification results. As a result, the quality and accuracy of data in the future research can be significantly improved by the use of high-resolution imagery with ground-truth validation by field surveys.

Similarly, this research has limitations to the climate-change analysis owing to some restrictions when using the Mann-Kendall and Sen Slope test, despite them being good non-parametric techniques of determining trends in the climate data set. This analysis is based on historical climatic data, which is affected by gaps, inhomogeneity, and irregular measurements during the period of making the trend estimates (40 years) making the analysis inaccurate. Also, the existence of localized variance in the basin can be poorly represented by the spatial resolution of the climatic data used, hence capturing complicated spatial relationships too simplistically. In addition, the drought indices and other extremes of climate are not provided in the current research which is majored in the aspects of temperature and precipitation pattern. It is necessary to identify these limits of research to interpret the findings and to guide future research.

Moreover, during flood hazard mapping analysis we have ample information from remote sensing, but we must recognize that there are several limitations. The accuracy of the data from remote sensing was significantly impacted by a number of factors, including the air quality, sensor calibrations, and the different types of land cover. Additionally, some spectral signatures on different types of land cover overlap, which can lead to biases in the categorization and mislead the land use classification. Accordingly, high-resolution imagery combined with ground truth validation such as field surveys and Google Earth support can greatly enhance the high caliber and accuracy of the data provided by the confirmatory investigations.

We have decided to employ the USLE model for our soil erosion analysis due to a number of restrictions that prevent us from using the RUSLE model. Since the RUSLE model relies on continuous, reliable data for computation (Kim et al., 2005), such as maximum 30-minute rainfall intensity, rainfall kinetic energy, and soil erodibility (Renard et al., 1997), the majority of its enhancements and alterations are challenging to adapt to new sites. Due to a variety of technical problems, these crucial data are typically unavailable at different study sites.

1.8. Structure of the Dissertation

This dissertation is organized into seven chapters. Chapter one, which is the introduction part briefly describes background of the study, concise literature review which clearly describe about flood hazards, climate change impacts, concepts of nature based solutions, and outlines intensively the statement of the problem, general objective, specific objective, research questions, significance of the study, scope of the study, limitations of the study and finally provides the overview of the structure of the dissertations.

Chapter Two is prepared as a standalone research article entitled “Mapping Flood Hazard Area in the Awash River Basin (ARB), Ethiopia Using GIS and AHP Approach” this chapter has been published in journal of Geoscience Letters, by Springer.

Chapter Three written as a journal article entitled with “Assessment of Soil Erosion and Sediment Transport Index in the Awash River Basin, Ethiopia: An Application of the USLE Model and GIS Techniques” this chapter has been published in journal of Discover Sustainability, by Springer.

Chapter Four written as a journal article titled ‘’ Analysis of Land Use Land Cover Changes and Population Dynamics in Awash River Basin (ARB), Ethiopia Using GIS and Remote Sensing ‘’ this chapter has been published in Journal of Scientific Reports, by Springer.

Chapter Five written as a journal article entitled with ‘’Trend Analysis of Climatic Variables Using Statistical Approach in Awash River Basin (ARB), Ethiopia‘’ this chapter has been published in journal of Social Sciences and Humanities Open, Elsevier.

Chapter Six presents the article entitled “Analysis of Land Surface Temperature & NDVI Using Geospatial Approach to Determine Climate Change Patterns in Awash River Basin (ARB), Ethiopia “is currently under revision in journal of Geoscience Letters, Springer.

Chapter Seven presents the final article entitled “Mapping Suitable Sites For Nature Based Solutions To Mitigate Flood Hazards In The Awash River Basin Ethiopia Using A Hybrid Analytic Hierarchy Process And Fuzzy Approach “this chapter has been published in journal of Nature Based Solution, Elsevier.

Finally, chapter eight clearly synthesizes the key findings from all chapters depicts scientific and practical knowledge contributions of the dissertation, moreover discusses future research directions.

CHAPTER TWO: TREND ANALYSIS OF CLIMATIC VARIABLES USING STATISTICAL APPROACH IN AWASH RIVER BASIN (ARB), ETHIOPIA

2.1. Introduction

Global warming is frequently linked to climate change, which has been witnessed all across the world. Long-term variations in the average values of climatic parameters are known as climate change. It has a direct or indirect impact on global warming and is linked to both natural and man-made activities (IPCC, 2007). Since 1850, the average global temperature has increased, increasing in the second half of the 20th century by 0.6 degrees Celsius. Substantial global warming is currently occurring (Kennedy, 2019). Temperature is not the only change. The close connection between the hydrological process and climate dynamics and its components has led to changes in precipitation characteristics, elevated air humidity, enhanced evaporation, and modifications in soil moisture content and overflow (Bates & Kundzewicz, 2008). Hence, Regional and local variations in yearly precipitation have been noted, though (IPCC, 2007; Basistha et al., 2009; Wang & Qin, 2017).

Similar to this, changes in temperature, precipitations, and other climatic variables significantly affect changes in flooding and hydrodynamic extremes (Wang & Xia, 2005). According to Asfaw (2018), the hydrological regime of the majority of the world's regions will undergo substantial changes by 2050. Intensive deforestation, farming, volcanic activity, and industrialization are some of the primary reasons for changing the climate that have been lately linked to it. Green House Gases (GHG) emissions into the atmosphere are increased by activities like burning fossil fuels, which are fueled by fast economic and population expansion (Yang & Lu, 2015).

The human and livestock populations of the Awash River basin, one of Ethiopia's 12 river basins, have been severely impacted by the region's food insecurity due to its persistent droughts, periodic floods, and a very volatile climate (Edossa et al., 2010; Yang & Lu, 2015; Onyutha et al., 2015; Adeba et al., 2015). Poverty, fast population growth, drought, and flooding made many people susceptible to innumerable disasters. Ethiopia is among the sub-Saharan nation most vulnerable to natural disasters such as floods and droughts (Society, 2012; Awash Basin Authority, 2017). In the Awash basin, population and economic output are already severely impacted by climate unpredictability. Significant crop yield reductions and livestock deaths have resulted from the basin's severe droughts led to increasing food insecurity (Murendo et al., 2011). In addition, flooding in the Awash River basin has resulted in thousands of people having to leave their homes, thousands of animals being sacrificed, significant financial losses, and environmental degradation.

Few researches have been done on the basin as a whole or on specific areas. Awash River Basin areas have been included in a few station-based climate trend studies (Seleshi & Zanke, 2004; Alemayehu & Bewket, 2017; Mohammed, 2018; Rosell, 2011; Asfaw et al., 2018). Consequently, based on data from rainfall-simulating satellites, multiple research efforts have shown that the Awash River basin's hydro-climate has changed (Awash Basin Authority, 2017; Adeba et al., 2015; Peng et al., 2020; Jones, 1996; Kinfe, 1999). Just a small number of studies have covered the entire basin or important portions of the basin (Cheung et al., 2008; Viste et al., 2013; Bekele et al.,2017; Wagesho et al, 2013). Bekele et al., (2017) is the first one to look specifically at temperature and rainfall patterns over a number of sites in the Awash River Basins. It goes without saying that consequences of climate change are making it harder for society around the world to address issues with water and food security (Yang & Lu, 2015; Carter & Gulati, 2014; Holmatov et al., 2017). Furthermore, Valjarevic (2024) using hydrographic analysis, reported that climate extremes significantly impacts main rivers and their streams. Moreover, droughts and floods also witnessed due to this extremes. Moreover, the effects of floods are increased when urbanization is combined with the risk of altered rainfall patterns brought on by climate change and intense weather (Yousefi, 2022). Hence, the main drivers for flooding in study area are human induced land use land cover change and climatic variability.

Reducing natural hazards, droughts, and food insecurity requires an assessment and comprehension of previous climate changes. Temperature and precipitation trend analysis is crucial for studying how the changing climate is affecting society and developing mitigation strategies (Gedefaw, et al., 2018). Non-parametric tests have been favored in hydrological time series analysis due to their ease of use and suitability for data that contains abnormal values, according to trend analysis study. Even for consistently formed data, non-parametric tests are safer and preferred since they may be employed without assuming anything about the population distribution of the data (Chebana et al., 2013).

The two most commonly employed non-parametric statistical tests in trend analysis are the Mann-Kendall trend test and the slope test of Sen’s, which estimates the slope of a trend (Tesemma et al., 2003; Bekele et al., 2017). The Mann-Kendall (MK) test is a non-parametric technique for assessing the importance of monotonous trends in time series data, either they are linear or nonlinear (Ye et al., 2015). Additionally, the Mann-Kendall (MK) test is a popular non-parametric technique for evaluating trends, and the World Meteorological Organization strongly recommends to using it. It is widely used in hydro-meteorological time series trend analysis. Similarly, the slope of a time series' linear trend can be found using Sen's Slope estimator (Bekele et al., 2017; Asfaw et al., 2018; Degefu & Bewket, 2014; Wagesho et al., 2013; Rao & Solomon, 2013). Additionally, many researchers now consider it essential to analyze the temporal variability of climate variable changes, especially in river basins, as this is crucial for examining the hazards of drought and flooding as well as for managing water resources (Theobald et al., 2016; Lyon et al., 2017). Several studies for the Awash River Basin used linear regression to assess trends (Cheung et al., 2008; Viste et al., 2013; Seleshi & Zanke, 2004). Moreover, other scholars also employ innovative trend analysis method (ITAM) in various study area (Gedefaw et al., 2018; Abu Arra, 2025).

In order to comprehend and address the effects of the changing climate throughout the Awash River basin, it is crucial to evaluate the trends of climate variability using a non-parametric statistical approach. In order to look into possible signs of climate change that could have an impact on the sustainability of the entire Awash River basin, this study employed the Mann–Kendall (MK) test, and Sen’s slope estimator test methods to examine the changes over time of climate variables. Moreover, most trend analysis based studies conducted in ARB, mainly used data from meteorological stations which is mostly encountering missing data, and placed inaccuracy or uncertainty of registered data in various stations. The study has attempted to highlight issues with research gaps found in a number of earlier studies. Hence, this work aims to address the lack of knowledge regarding long-term climate change patterns, especially in the ARB, which has not been thoroughly examined using trustworthy statistical trend analysis. Previous research has often focused on short-term fluctuation or confined areas without include long-term, geographically complete data. To bridge this gap, our work provides a basin-wide, 40-year trend assessment using non-parametric statistical approaches, contributing to our understanding of the impacts of climate change in this highly susceptible region.

Hence, this study mainly collected data from NASA research data website for various coordinates placed within Awash River Basin (ARB), the coordinates points are represent about sixty (60) coordinated locations/ places and 2340 overall data points (1984 to 2022) which is significantly covered huge part of the basin than existing meteorological stations. Therefore, the primary goal of the present research is to determine the patterns of climate change throughout the entire Awash River basin by analyzing temperature and precipitation trends.

2.2. Materials and Methods

2.2.1. Study Area Description

2.2.1.1. Locations

The Awash River Basin lied between latitude 7°53' and 12° 0' and longitudes 37°57' and 43°25' (Figure 2.1). Its area is 112,000 km^2, its population is 10.5 million, and its yearly water surface area is around 4.9 BM^3. There is a range of 210 to 4195 meters above sea level. The 1250 km Awash River spans portions of the Oromia, Somali, Amhara, and Afar regions. The river rises in the mountainous area near Ginchi town on the west side of Addis Ababa, the capital of Ethiopia. After that, it travels through the Rift Valley into the Afar Triangle until draining into the saline Lake Abbe on the Djiboutian border (Tiruneh, 2013; Ministry of Environment, 2018; Sonder, 2008).

The Upper Awash, the Middle Awash, and the Lower Awash are the three parts of the ARB. The Upper Awash includes the areas above 1500 meters from Koka Dam, the Middle Awash includes the areas between Koka Dam and Awash station at elevations between 1000 and 1500 meters, and the Lower Awash includes the areas between 500 and 1000 meters as well as the Eastern catchment (Ministry of Environment, 2018; Edossa et al., 2010). There are two distinct rainy seasons in the Upper and Middle Awash: an infrequent one from March to May and a longer one from July to September. The upper Awash River Basin experiences humid weather, whereas the lower Awash River Basin experiences dry weather. Rainfall in the ARB averages between 940 and 1158 mm per year. Because of their high clay content, the soils of the basin are ideal for growing cotton. Cereals and sugarcane grow well in clay loam and sandy loam soils, whereas pasture with range grasses thrives in sandy soils (Ministry of Environment, 2018).

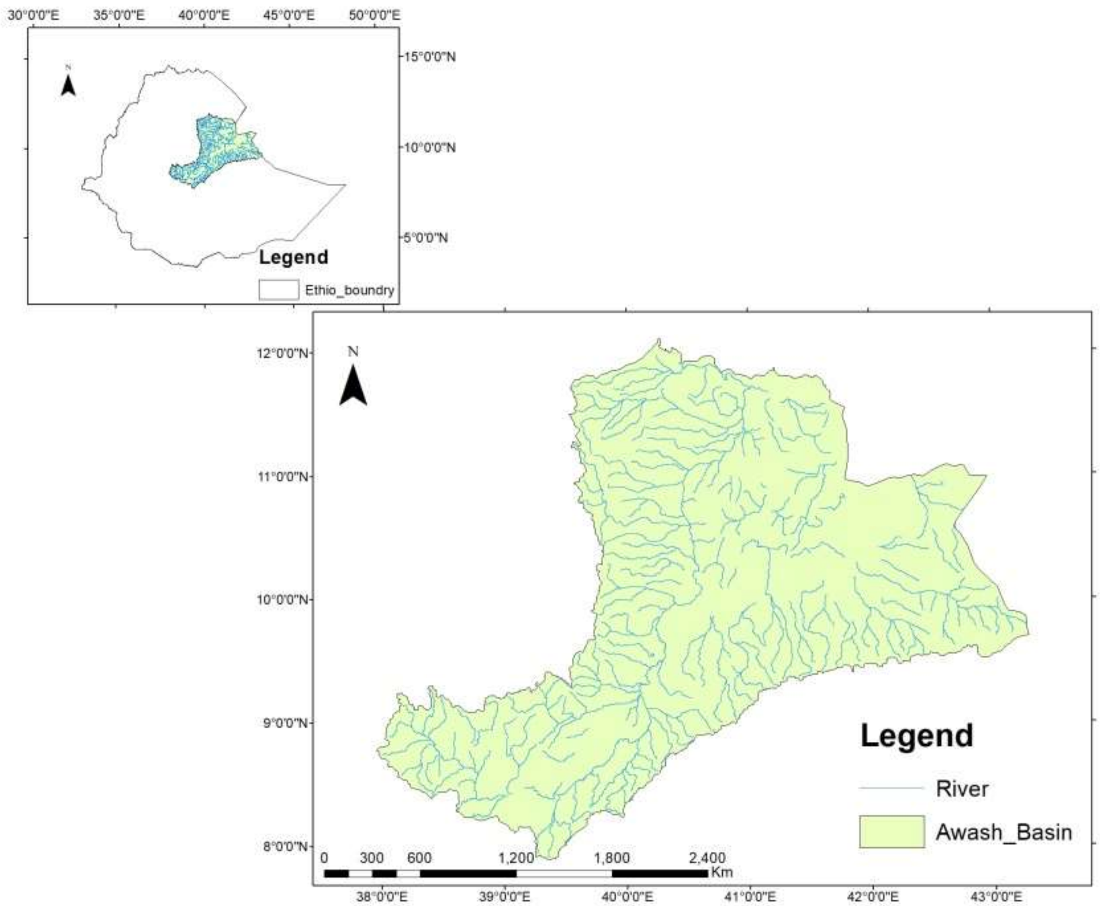

Figure: 2.1 Study area map; the figure generated with GIS software version 10.8 by the Authors. The link to the GIS software used can be found at https://www.arcgis.com/index.html Source: Authors

2.2.2. Data sources

For this study two climatic variables precipitation and temperature were incorporated, and trend analysis for these climatic variables was conducted. Statistical methods used to analyze the overall rise and fall in temperature and precipitation through time series. MK and Sen's Slope are well known statistical method used to climate change trend analysis. Hence, these methodologies were helpful to comprehend the dynamics of climate change within the designated time series in the study spot. Precipitation and temperature data of the last 40 years of the research spot were grasped from ministry of agriculture and metrological agency. Additionally, supplementary precipitation and earth skin temperature is also obtained from https://power.larc.nasa.gov/data-access-viewer/ website in CSV format.

2.2.3. Data Analysis

2.2.3.1. Mann–Kendall Trend Test (MK)

Both the past and projected patterns of climate change were evaluated using the Mann–Kendall trend test (MK). All stations had their minimum and maximum temperatures as well as precipitation trends examined. A nonparametric test called the MK is frequently used to identify monotonically growing or decreasing patterns in time series data related to climate and hydrology (Hirsch, 1984). Since the nonparametric MK test is less impacted by dataset deviations, it is appropriate for trend exploration (Asfaw, Simane, Hassen, & Bantider, 2018). For identifying trends in hydro-meteorological measurements, the MK test is simple to employ. In the current study, there were used to identify trends in the time series data for yearly temperature and precipitation. Furthermore, the MK test makes it possible to determine the statistical significance of an established trend. This is how the MK test statistic "S" is calculated (Equation 2.1):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(Xj - Xi) \qquad \text{Equation 2.1}$$

Where X_i and X_j denote sequential data values of the time series of j and I (j>i), and n is number of days in the data series. The sign function can be calculated as (Equation 2.2):

$$Sgn(Xj - Xi) = \begin{cases} 1\ if(xj - xi) & > 0 \\ 0\ if(xj - xi) & = 0 \\ -1\ if(xj - xi) & < 0 \end{cases} \qquad \text{Equation 2.2}$$

The S statistic is roughly a standard normal distribution with a mean of zero when the sample size is higher than or equal to 10 (n = 10). The variance is then computed using the following formula (Equation 2.3):

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} ti(ti-1)(2ti+5)}{18} \qquad \text{Equation 2.3}$$

Where ti is the number of data values in the m^{th} group, n is the number of data points, and m is the number of tied groups (sample data with the same value, where there is zero variation between the compared values).The following formula is used to calculate the Z-test (Equation 2.4):

$$Z = \begin{cases} \frac{s-1}{\sigma} if \;\; S > 1 \\ 0 \; if \;\; S = 0 \\ \frac{s+1}{\sigma} if \;\; S < 1 \end{cases} \qquad \text{Equation 2.4}$$

Where σ is the variance's square root and s represents the variance. A rising trend is indicated by a positive Z number, whilst a falling trend is shown by a negative Z value.

A rising trend is shown if Z > 0. At the crucial values of the Z-score, which are more than +/- 1.65, +/- 1.96, and +/- 2.58 at 0.1, 0.05, and 0.01, respectively, Z < 0 indicates a declining trend and a significance level.

Autocorrelation analysis, homogeneity, and nonparametric Mann-Kendall trend analysis criteria were taken into account. Few data were auto-correlated, and no homogeneity issues were anticipated. Within the hydro-climate data, the auto-correlated data were found. The effects of serial correlation are ignored in the original Mann-Kendall test. Devised the Modified Mann-Kendall test, took into account the autocorrelation effect, and scholars suggested the Modified Mann-Kendall trend analysis (Hirsch, 1984).

2.2.3.2. Sen's Slope

Nonparametric Sen Slope measures current statistical trends that are either rising or falling. Additionally, the magnitude of time series trend changes is assessed using the Sen Slope estimator (Endris, 2013) when it is assumed to be linear (Smith, 2001) (Equation 2.5 and

Equation 2.6). Furthermore, Sen's slope provides magnitude of trend estimation, present valuable quantification of changes over time within the study period. Hence, this method provides reliable means of trend identification without the influence of distributional assumptions, making them appropriate for trend analysis of climatic variables.

$$\mathrm{D}(t) = Q(t) + B \qquad \text{Equation 2.5}$$

Where B is intercepted (constant), Q is a slope, and D (t) is a growing or decreasing trend function of time. Consequently, each data pair's slope, Qi, is expressed

$$Qi = \frac{Xi - Xi}{j - i} \qquad \text{Equation 2.6}$$

Where, j > i, meaning that Xi is the data reading time series; Xj is a data reading time series j.

2.3. Result and Discussion

2.3.1. Trends of Annual Precipitation in the Awash River Basin

The minimum, mean, and maximum annual rainfall across the Awash River Basin range from 0 to 64.3 mm yearly, 6.607 to 168.786 mm, and 81.7 to 682.540 mm in a monthly pattern, respectively, according to the summary data for the annual rainfall time series (1984 to 2022) (Table 2.1 and Figure 2.2). According to (Table 2.2) Kendall's Tau (τ) test for spring and winter is -0.088 and -0.023 respectively, it shows that slight negative correlation or trend, the trend is weak because it's close to zero, but it indicates that still the values to decrease over time, but not strongly (Gedefaw M. W., 2018).

Negative value of S value for both spring (-240296) and winter (-62435) also support the idea of downward trend in precipitation data (Table 2.3 & Table 2.4). The finding of p-Value is 0.0001 for spring and 0.098 for winter. The p value of the spring season, which is much lower than the significance level (alpha) of 0.05, hence, the trend present in spring data is statistically significant, unlike of the trend present in winter data which is above the alpha level of 0.05 and insignificant. The Sen Slope for spring and winter is -0.798 and 0.132, respectively, indicating that the values of spring in precipitation data decrease by approximately 0.798 mm/ year and increased by 0.132 mm/year during winter time. Z value is -6.37 and -5.22, indication that the trend is significant and decreasing over time in spring time. Kendall's Tau (τ) test for summer is -

0.042, S (Test Statistic) value is -112525, p value 0.003, Z value approximately -2.98 and Sen Slope is 0.000, from the obtained data of summer season it can be interpret that, a very weak but statistically significant decreasing trend of precipitation over time. Despite the significant trend indicated by the Mann-Kendall test, no statistically meaningful change has occurred in the observed variable during the summer, because the Sen Slope value is 0.000 (Table 2.5) (Getahun, 2021).

The positive value of Kendall's Tau indicates an extremely weak positive and there is no statistically significant trend of precipitation in autumn season, because the p value (0.720) is higher than the alpha value (0.05). The Sen Slope of 0.312 suggests a slight increase of precipitation in mm per year, but this should not be overemphasized given the lack of statistical significance. The Z value is approximately 0.358, also supporting that the trend's strength is negligible (Table 2.6). Regarding annual value, there is a statistically significant decreasing trend of precipitation in the dataset over time, with a slope indicating that the observed values are declining significantly (approximately 1.172 mm/ year). The strong evidence (indicated by the very low p-value (0.000) and high absolute Z-value (-1.172) which is suggests that this trend is not due to random variation (Table 2.7). Various scholars reported that there is rainfall variability within the Awash river Basin (Gedefaw, 2018; Getahun, 2021; Duguma, 2021; Tadese, 2019). Significant downward trend of rainfall also reported in downstream part of ARB (Getahun, 2021). Other scholars also reported that, most of the rainfall stations in the upper awash basin showed downward trends of precipitation (Wagesho et al., 2013; Seleshi & Zanke, 2004; Jain, 2013).

Table 2.1: Summary statistics of precipitation 1984 to 2022 Awash River Basin

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
JAN	2340	0	2340	0.000	81.700	6.607	11.357
FEB	2340	0	2340	0.000	226.760	17.940	27.769
MAR	2340	0	2340	0.000	326.430	43.968	44.985
APR	2340	0	2340	0.000	445.080	70.930	60.143
MAY	2340	0	2340	0.000	353.320	46.029	50.106
JUN	2340	0	2340	0.000	297.950	44.493	45.303
JUL	2340	0	2340	0.000	682.540	153.807	111.181
AUG	2340	0	2340	0.000	508.360	168.786	99.440
SEP	2340	0	2340	0.000	402.890	81.991	60.051
OCT	2340	0	2340	0.000	309.020	29.127	37.608
NOV	2340	0	2340	0.000	196.170	10.174	18.426
DEC	2340	0	2340	0.000	119.430	9.352	16.365
ANN	2340	0	2340	64.340	1748.230	683.205	346.306
Summer	2340	0	2340	0.000	254.710	33.900	36.428
Winter	2340	0	2340	10.540	1119.660	367.086	232.304
Spring	2340	0	2340	5.270	1071.030	160.927	116.986
Autumn	2340	0	2340	0.000	551.600	121.292	84.157

Table 2.2: Summary of MK and Sen Slope precipitation of Awash River Basin:

Series\Test	Kendall's tau	p-value	Sen's slope
JAN	-0.018	0.235	0.000
FEB	-0.040	**0.006**	0.000
MAR	-0.134	**<0.0001**	-0.410
APR	-0.036	**0.009**	-0.092
MAY	-0.025	0.072	0.000
JUN	-0.038	**0.006**	-0.009
JUL	-0.004	0.774	0.329
AUG	-0.033	**0.016**	-0.075
SEP	-0.038	**0.006**	-0.104
OCT	0.013	0.369	0.037
NOV	0.206	**<0.0001**	0.099
DEC	-0.004	0.772	0.000
ANN	-0.049	**0.000**	-1.172
Summer	-0.042	**0.003**	0.000
Winter	-0.023	0.098	0.132
Spring	-0.088	**<0.0001**	-0.798
Autumn	0.005	0.720	0.312

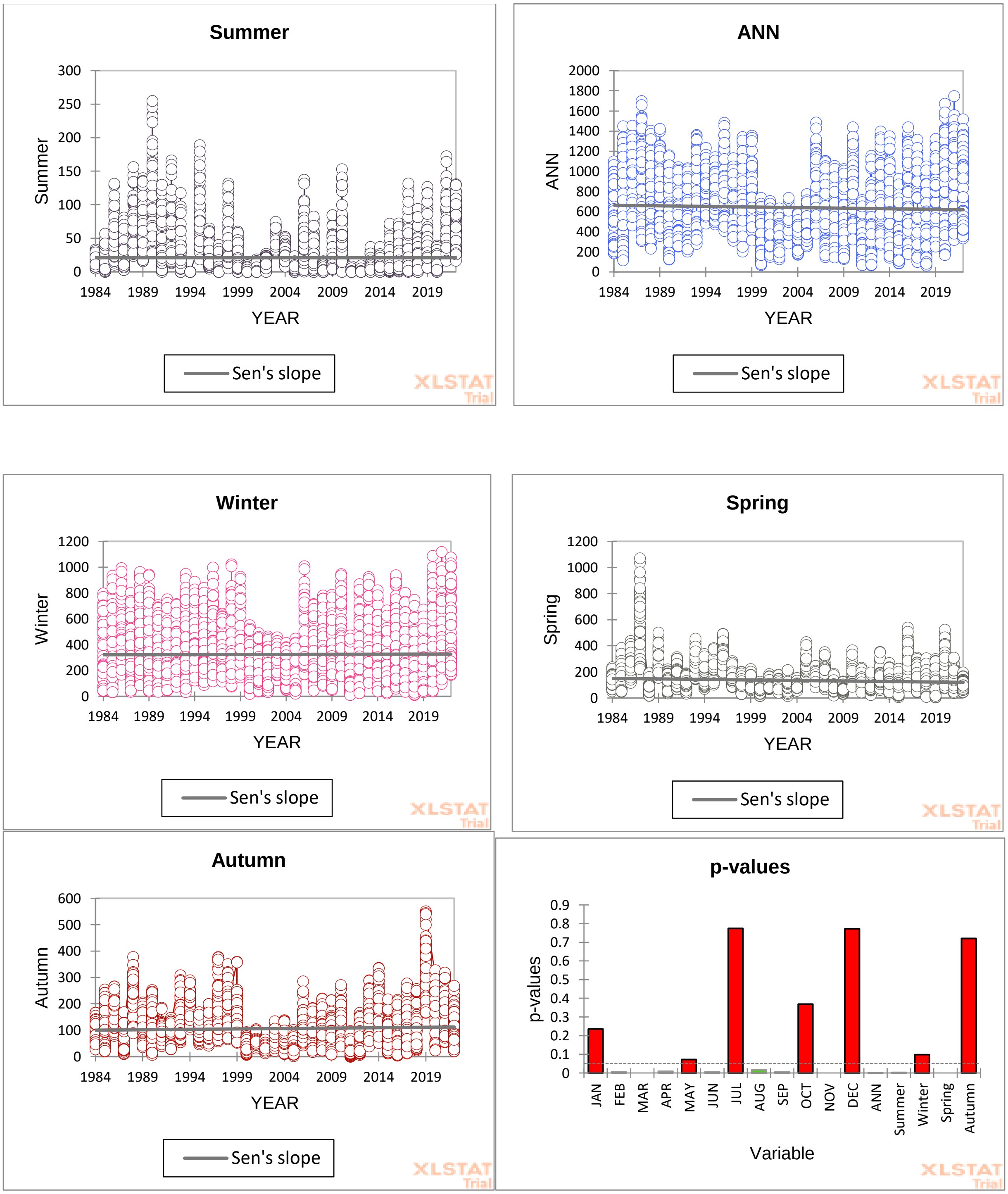

Figure 2.2: precipitation rate of Awash River Basin in four seasons, annually and the P-values (1984-2022) (Source: Authors)

Table 2.3: Mann-Kendall trend test / Two-tailed test (Spring): Precipitation of Awash River Basin (1984 – 2022)

Kendall's tau	-0.088
S	-240296
Var(S)	1424564319.333
p-value (Two-tailed)	<0.0001
alpha	0.05

Sen's slope: Spring

	Value
Slope	-0.798
Intercept	1732.568

Table 2.4: Mann-Kendall trend test / Two-tailed test (Winter): Precipitation of Awash River Basin (1984 – 2022)

Kendall's tau	-0.023
S	-62435
Var(S)	1424566866.333
p-value (Two-tailed)	0.098
alpha	0.05

Sen's slope: winter

	Value
Slope	0.132
Intercept	60.503

Table 2.5: Mann-Kendall trend test / Two-tailed test (Summer): Precipitation of Awash River Basin (1984 – 2022)

Kendall's tau	-0.042
S	-112525
Var(S)	1421378714.333
p-value (Two-tailed)	0.003
alpha	0.05

Sen's slope: summer

	Value
Slope	0.000
Intercept	21.371

Table 2.6: Mann-Kendall trend test / Two-tailed test (Autumn): Precipitation of Awash River Basin (1984 – 2022)

Kendall's tau	0.005
S	13509
Var(S)	1424562435.333
p-value (Two-tailed)	0.720
alpha	0.05

Sen's slope: Autumn

	Value
Slope	0.312
Intercept	-517.666

Table 2.7: Mann-Kendall trend test / Two-tailed test (ANN): Precipitation of Awash River Basin (1984 – 2022)

Kendall's tau	-0.049
S	-134448
Var(S)	1424566260.667
p-value (Two-tailed)	0.000
alpha	0.05

Sen's slope: ANN

	Value
Slope	-1.172
Intercept	2987.648

2.3.2. Trends Analysis of Annual Temperature in the Awash River Basin

The overall temperature of Awash River basin of minimum, maximum and mean annual temperature ranges from 11.280 – 16.201, 29.810 - 39.470, and 21.777 - 28.024 respectively as described in (Table 5.8) According to (Table 5.9) a statistically significant increasing pattern over time may be shown in the annual temperature trend study. The magnitude of this trend is weak (Sen Slope value shows that 0.040 degree Celsius increment per year), but it is statistically significant, suggesting that there is a reliable increase in the values being analyzed. The results indicate that despite the small size of the trend, it is meaningful and consistent across the data (Gedefaw, 2018; Tadese, 2019).

There is a very weak positive trend of temperature in the data as indicated by the slope (0.076) and Kendall's Tau (0.024), it is not statistically significant. The p-value (0.082) indicates that there is not enough proof to claim that a meaningful trend exists. Hence, while the results suggest a slight upward movement in the summer values, it is statistically inconclusive and may be attributed to random fluctuations rather than a true trend (Table 2.10).

Kendall's value indicates a very weak positive but statistically significant trend of temperature in the data over time and more concordant pairs than discordant pairs. The Z value (2.16) reinforces the finding; stipulate the trend is not from random fluctuations. And the slope value (0.120) indicates that the temperature in winter time increased by an average of 0.120 degree over time (Table 2.11).

The analysis of the results suggests the increase tendency of positive values in the autumn dataset is statistically significant. The Z statistic aligns to this result, meaning that it is not random fluctuation that caused such tendency to be observed. Interpreting the slope value of 0.151, which indicates that autumn temperature conditions are in the process of rising on average by 0.151-degree Celsius, which would be a very big change in the long run in Awash River basin (Table 2.12) (Legass, 2025).

Even if the temperature trend of spring season is weak positive, it is statistically significant and unlikely to be due to random chance. The Z high value of 4.38 reiterates that the trend is significant. The Sen Slope value of 0.156 indicates a noticeable upward temperature change over time (Table 2.13). The Annual temperature trend shows statistically significant trend increasing at 0.040 degree Celsius. The result indicated a very gradual upward trend in study area with minimal magnitude of change (Table 2.14). Numerous scholars depict that there is consistent rises of temperature registered within the Awash River Basin (Legass, 2025; Gedefaw, 2018; Getahun, 2021). In addition, Getahun (2021) reported that a significant increasing trend of annual and seasonal temperature in Awash River Basin. Similarly, substantial upward trend of maximum temperature also observed in upper awash river basin (Shawul, 2020; Wagesho et al., 2013; Jain, 2013; Seleshi & Zanke, 2004).

Table 2.8: Summary statistics of temperature (1984 - 2022) of Awash River basin

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
JAN	2340	0	2340	13.430	30.110	22.681	3.723
FEB	2340	0	2340	15.150	31.510	24.448	3.633
MAR	2340	0	2340	16.210	35.260	25.926	3.976
APR	2340	0	2340	16.060	35.320	26.253	4.503
MAY	2340	0	2340	15.510	38.460	27.258	5.455
JUN	2340	0	2340	16.190	39.070	28.024	6.338
JUL	2340	0	2340	15.040	39.470	25.584	6.568
AUG	2340	0	2340	14.710	37.290	24.386	6.211
SEP	2340	0	2340	14.480	37.050	24.759	6.435
OCT	2340	0	2340	12.430	34.470	23.393	5.958
NOV	2340	0	2340	11.280	31.370	22.236	5.080
DEC	2340	0	2340	11.940	29.810	21.777	4.299
ANN	2340	0	2340	15.550	33.370	24.722	5.030
Summer	2340	0	2340	43.400	88.620	68.906	11.408
Winter	2340	0	2340	47.380	112.680	77.994	18.912
Autmun	2340	0	2340	40.160	101.370	70.388	17.291
Spring	2340	0	2340	48.280	105.610	79.437	13.629

Table 2.9: Summary MK and Sen Slope temperature result of Awash River basin:

Series\Test	Kendall's tau	p-value	Sen's slope
JAN	0.010	0.462	0.019
FEB	0.041	**0.003**	0.034
MAR	0.051	**0.000**	0.043
APR	0.069	**<0.0001**	0.059
MAY	0.052	**0.000**	0.057
JUN	0.036	**0.010**	0.046
JUL	0.027	0.054	0.041
AUG	0.019	0.160	0.033
SEP	0.036	**0.009**	0.048
OCT	0.048	**0.000**	0.055
NOV	0.050	**0.000**	0.050
DEC	0.016	0.234	0.025
ANN	0.046	**0.001**	0.040
Summer	0.024	0.082	0.076
Winter	0.030	**0.031**	0.120
Autmun	0.048	**0.001**	0.151
Spring	0.060	**<0.0001**	0.156

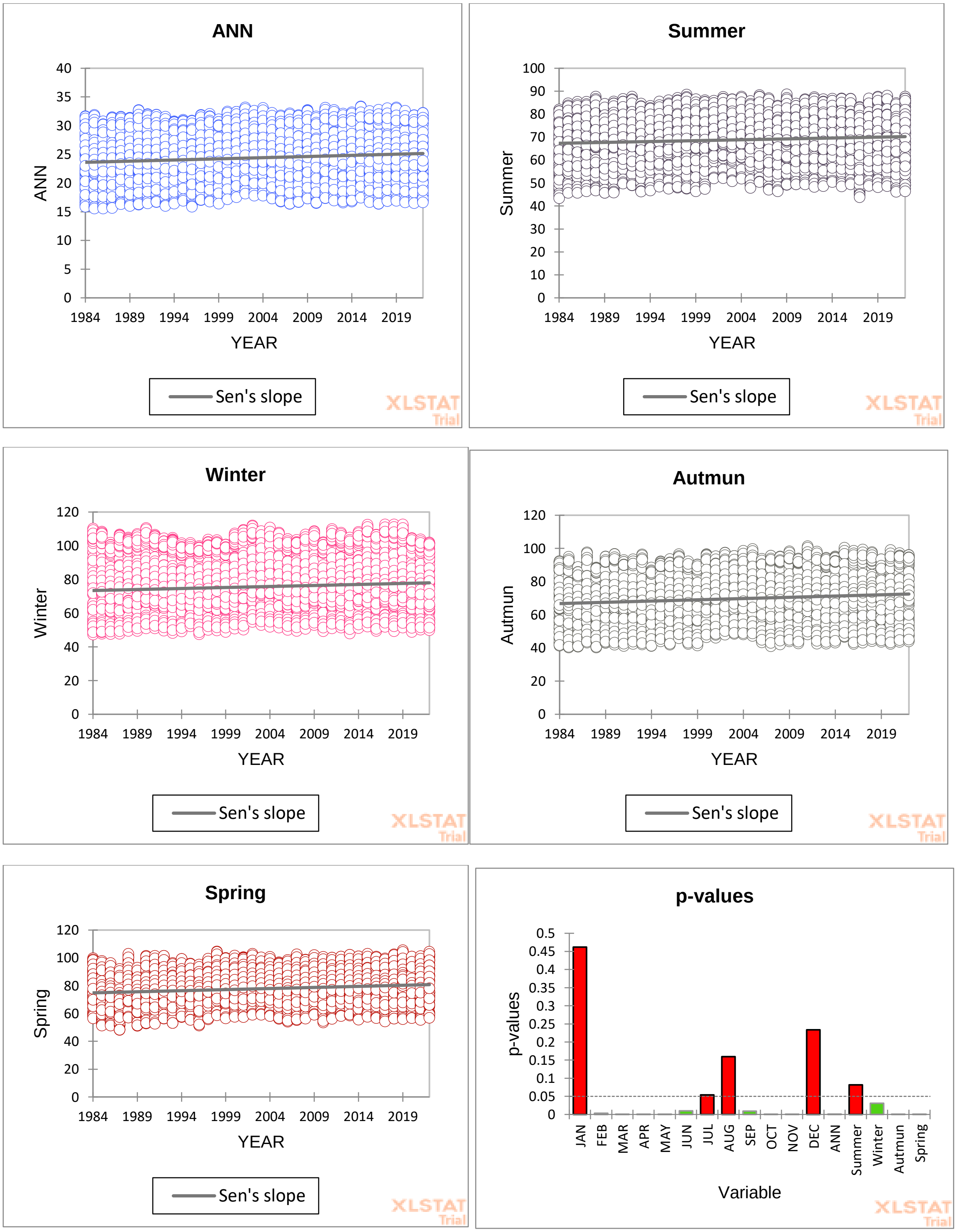

Figure 2.3: Trends of Temperature Awash River basin and P-values (1984 – 2022) (Source: Authors)

Table 2.10: Mann-Kendall trend test / Two-tailed test (Summer): Temperature of Awash River Basin (1984 – 2022)

Kendall's tau	0.024
S	65714
Var(S)	1424567366.667
p-value (Two-tailed)	0.082
alpha	0.05

Sen's slope: Summer

	Value
Slope	0.076
Intercept	-84.147

Table 2.11: Mann-Kendall trend test / Two-tailed test (Winter): Temperature of Awash River Basin (1984 – 2022):

Kendall's tau	0.030
S	81486
Var(S)	1424567582.667
p-value (Two-tailed)	0.031
alpha	0.05

Sen's slope: Winter

	Value
Slope	0.120
Intercept	-164.391

Table 2.12: Mann-Kendall trend test / Two-tailed test (Autumn): Temperature of Awash River Basin (1984 – 2022)

Kendall's tau	0.048
S	130475
Var(S)	1424567609
p-value (Two-tailed)	0.001
alpha	0.05

Sen's slope: Autumn

	Value
Slope	0.151
Intercept	-232.552

Table 2.13: Mann-Kendall trend test / Two-tailed test (Spring): Temperature of Awash River Basin (1984 – 2022)

Kendall's tau	0.060
S	165053
Var(S)	1424567498.333
p-value (Two-tailed)	<0.0001
alpha	0.05

Sen's slope: Spring

	Value
Slope	0.156
Intercept	-233.735

Table 2.14: Mann-Kendall trend test / Two-tailed test (ANN) of Temperature of Awash River Basin (1984 – 2022)

Kendall's tau	0.046
S	124828
Var(S)	1424565514.667
p-value (Two-tailed)	0.001
alpha	0.05

Sen's slope: ANN

	Value
Slope	0.040
Intercept	56.629

2.3.3. Socioeconomic and Hydrological Implications

The water resources and socioeconomic stability of the Awash River basin are significantly impacted by the observed decrease in annual and seasonal precipitation, especially in the spring, when combined with rising temperatures. Water scarcity problems are made worse by decreased rainfall, which directly jeopardizes the supply of water for industrial, agricultural, and residential uses. As a result, crop yields are reduced; endangering food security, which further affects agriculture, the foundation of the basin's economy. The productivity of agriculture can be strained by rising evapotranspiration rates, which further deplete soil moisture and water availability. According to Abu Arra (2025) because of the effects of climate change, integrated surface and ground water management must be carefully taken into account when precipitation is insufficient.

Furthermore, livelihoods reliant on small-scale industries, agriculture, and pastoralism are in danger due to these climate changes, which could lead to socioeconomic displacement and increased vulnerability. In order to improve resilience, it is critical to incorporate climate trend data into agricultural management and water resource planning. Moreover, Irregular distribution of rainfall across the basin brought severe flood hazards.

2.3.4. Methodological Limitations

There are some drawbacks to using the Mann-Kendall and Sen's slope tests, even though they provide reliable non-parametric methods for identifying trends in climate data. The analysis is based on historical climate data that is currently available, which could be impacted by gaps, inhomogeneity, or inconsistent measurements over the 40-year period. The interpretation of trend estimates may be impacted by such data limitations. Furthermore, localized variability within the basin might not be adequately captured by the spatial resolution of the climate data used, which could oversimplify intricate spatial patterns. Furthermore, drought indices and other climate extremes which are essential for fully comprehending the effects of climate change are not included in the current study, which mainly concentrates on temperature and precipitation trends. In order to interpret the results and determine future research directions, it is imperative to acknowledge these limitations.

2.4. Conclusion and Recommendation

In order to determine the trends of climate change across the entire Awash River basin, the study examines at temperature and precipitation changes. According to the findings, there has been a noticeable drop in annual rainfall and only a slightly less noticeable rise in temperature over the last four decades. Precipitation is decreasing, mainly in spring, but temperature keeps rising in every season, especially during autumn and spring. Practicing afforestation actions and strengthen sustainable land use to boost the amount of vegetation, reduce the surface temperature, and combat climate problems. Non-parametric statistic trend analysis provides a stronger mechanism to describe the impacts of climate change in the Awash River basin. This approach, statistically validating the results for different periods of time, allows for accurate pinpointing of areas with distinct climatic changes in study area. By employing this methodology, these studies not only improve our comprehension of the temporal patterns of climate change, but they can also provide information on specific mitigation initiatives, like afforestation, sustainable land management, and the creation of early warning climate systems, directed towards effective policy adaptation tools that help mitigate the adverse effects of warming temperatures on the basin. Setting up early warning systems can assist communities and the environment in preventing climate-related calamities like flooding and drought. Encourage initiatives to enhance climate trend assessment and inform appropriate policy choices. The findings bring out the need to go on the proactive in terms of establishing water management policies that employ climate trend data to design early warning mechanism as well as water conservation and sustainable irrigation methods. The adverse impacts can be mitigated by equipping climate resilience through energy diversification and adaptive farming techniques. To achieve increased food security and socioeconomic stability, these climatic insights will have to be determined in regional planning. Future studies would benefit from using finer resolution datasets, climate model projections and drought indices in order to minimize data limitations and better reflect spatial variability and extremes. Climate models can be used to not only improve predictive skills but able to contribute to the development of overall adaptation strategies. Moreover, a joint inference on annual socio-economic variables and climatic trends can provide a deeper understanding of the basin's vulnerability and resilience. Additionally, strengthen cooperation with neighboring areas to efficiently manage the basin as climatic conditions evolve. All things considered, prompt and suitable action is needed to mitigate the adverse effects of climate change and safeguard the ecology and inhabitants of the Awash River Basin. Concisely, Proved by using rigorous non-parametric analytical tools, the study illustrates that the basin temperature is rising with diminished distribution of rainfall. Hence, future researches should include finer-scale climatic data, forecasting projections and socio-economic drivers to better capture the variability and resilience.

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CHAPTER THREE: ANALYSIS OF LAND SURFACE TEMPERATURE & NDVI USING GEOSPATIAL APPROACH TO DETERMINE CLIMATE CHANGE PATTERNS IN AWASH RIVER BASIN (ARB), ETHIOPIA

3.1. Introduction

Global warming is frequently linked to climate change, which has been witnessed all across the world. Long-term variations in the average values of climatic parameters are known as climate change. It has a direct or indirect impact on global warming and is linked to both natural and man-made activities (IPCC, 2007). Since 1850, the average global temperature has increased, increasing in the second half of the 20th century by 0.6 degrees Celsius. Substantial global warming is currently occurring (Kennedy, 2019). Temperature is not the only change; the close connection between the hydrological process and climate dynamics and its components has led to changes in precipitation characteristics, elevated air humidity, enhanced evaporation, and modifications in soil moisture content and overflow (Bates & Kundzewicz, 2008). Similar to this, changes in temperature, precipitations, and other climatic variables significantly affect changes in flooding and hydrodynamic extremes (Wang & Xia, 2005). According to Asfaw (2018), the hydrological regime of the majority of the world's regions will undergo substantial changes by 2050. Intensive deforestation, farming, volcanic activity, and industrialization are some of the primary reasons for changing the climate that have been lately linked to it. Green House Gases (GHG) emissions into the atmosphere are increased by activities like burning fossil fuels, which are fueled by fast economic and population expansion (Yang & Lu, 2015).

The human and livestock populations of the Awash River basin, one of Ethiopia's 12 river basins, have been severely impacted by the region's food insecurity due to its persistent droughts, periodic floods, and a very volatile climate (Edossa et al., 2010; Yang & Lu, 2015; Onyutha et al., 2015; Adeba et al., 2015). Poverty, fast population growth, drought, and flooding made many people susceptible to innumerable disasters. Ethiopia is among the sub-Saharan nation most vulnerable to natural disasters such as floods and droughts (Ethiopia Red Cross Society, 2012). The summertime water shortfall has been noted by the Awash Basin Authority as a hindrance to several activities, including agriculture and domestic water delivery, and the region is vulnerable to notable intra-annual fluctuations (Awash Basin Authority, 2017). In the Awash basin, population and economic output are already severely impacted by climate unpredictability.

Significant crop yield reductions and livestock deaths have resulted from the basin's severe droughts led to increasing food insecurity (Murendo et al., 2011). In addition, flooding in the Awash River basin has resulted in thousands of people having to leave their homes, thousands of animals being sacrificed, significant financial losses, and environmental degradation. It goes without saying that consequences of climate change are making it harder for society around the world to address issues with water and food security (Yang & Lu, 2015; Carter & Gulati, 2014; Holmatov et al., 2017).

Reducing natural hazards, droughts, and food insecurity requires an assessment and comprehension of previous climate changes. Furthermore, we must have a better knowledge of their possible influence on climatic variables or parameters and how it will affect the basin as a whole, since these extremes of climate variability could worsen due to alterations in the climate. Hence, better understanding of temperature and vegetation cover temporal trends and correlation is significantly crucial to study climate changes. Trend analysis is critical for studying how the changing climate is affecting society and developing mitigation strategies (Gedefaw et al., 2018). Satellite image-based analysis of vegetation cover and land surface temperature has great significance in analyzing and alleviating effects of climate change. The technology of remote sensing appears as a very appropriate and important way of mapping land surface temperature (LST) and vegetation cover (NDVI).

Remote sensing has availed a wide range of useful applications across many study areas, such as the social, economic, and environmental sciences. Among many applications, remote sensing is very useful in geological and soil mapping, agriculture, forestry, hydrology, wildlife ecology and environment, assessment of natural disasters, land appraisal and conservation, archeology, land use and land cover studies, and urban and regional planning (Lillesand, 2015). Several previous researchers used the normalized difference vegetation index (NDVI) and land surface temperature (LST) to extract temperature and vegetation data (Arif, 2020; Liu, 2015; Moisa, 2022; Ahmed, 2022). NDVI is a biophysical metric that correlates with photosynthetic activity in vegetation (Xie, 2008). The land surface temperature (LST) is determined by the balance of the earth's uppermost energy, ambiance, thermodynamic characteristics of the earth's surface, and ground-surface objects identified by remote sensing.

In order to comprehend and address the effects of the changing climate throughout the Awash River basin, it is decisive to evaluate the trends of climate variability using LST and NDVI analysis. In order to look into possible signs of climate change that could have an impact on the sustainability of the entire Awash River basin, this study employed the correlation of LST and NDVI to examine the changes over time of climate variables. Moreover, most trend analysis based studies conducted in ARB, mainly used data from meteorological stations which is mostly encountering missing data, and placed inaccuracy or uncertainty of registered data in various stations. Hence, this study mainly collected LST and NDVI data from USGS and MODIS research data websites. Moreover, LST and NDVI magnify a better result for chronological trend analysis in the study area.

Therefore, the primary goal of the present research is to determine the patterns of climate change throughout the entire Awash River basin by analyzing the temporal trends as well as the connection between NDVI and LST.

3.2. Materials and Methods

3.2.1. Study Area Description

3.2.1.1. Locations

The Awash River Basin lied between latitudes 7^{o}53’ and 12^{o} 0’ and longitudes 37^{o}57’ and 43^{o}25’ (Figure 3.1). It has a population of 10.5 million people, covers an area of 112,000 km^{2}, and has an annual water surface area of about 4.9 BM^{3}. The elevation above sea level varies from 210 to 4195 meters. Parts of the Oromia, Somali, Amhara, and Afar areas are covered by the 1250 km long Awash River. On the west side of Ethiopia's capital, Addis Ababa, the river originates on the mountainous region close to Ginchi town. It then runs into the Afar Triangle via the Rift Valley until discharging into the brackish Lake Abbe on the Djiboutian border (Tiruneh, 2013; Ministry of Environment, 2018; Sonder, 2008).

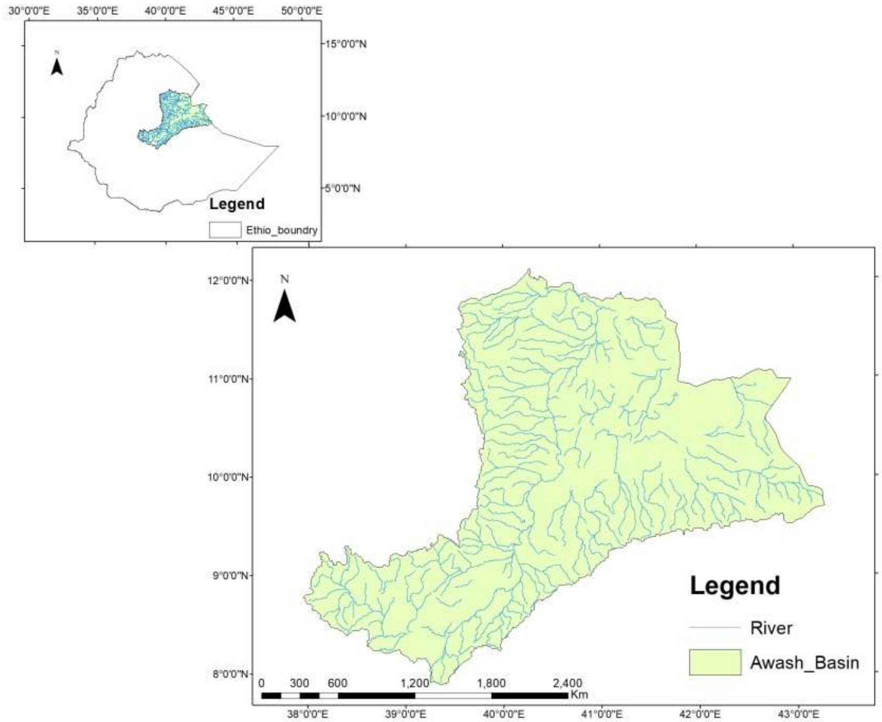

Figure: 3.1 Study area map; the figure generated with GIS software version 10.8 by the Authors. The link to the GIS software used can be found at https://www.arcgis.com/index.html

3.2.2. Data sources

For this study geospatial methods were used to analyze the overall rise and fall in temperature and vegetation greenness through time series. LST and NDVI are geospatial method used to determine climate change trend within the study area. Hence, these methodologies were helpful to comprehend the dynamics of climate change within the designated time series in the study spot. Data from satellites for LST and NDVI analysis obtained from USGS and MODIS websites free of charge.

3.2.3. Data Analysis

3.2.3.1. Land surface temperature (LST)

Because of the change of land cover land use, the LST is rising globally. A significant upward trend in LST was confirmed by studies carried out in various regions of Ethiopia (Moisa, 2022). The single channel mono-window algorithm Qin (2001) was developed using OLI/TIRS, ETM+, and Landsat TM data (Jimenez-Munoz, 2003). LST were calculated using the mean and difference in land surface emissivity, as well as the brightness temperature of the two Thermal Infrared (TIR) bands (Cheng, 2017).

Step I: Conversion of DN in to radiance.

The mono window technique transformed the digital input into an at-sensor radiance sensor prior to computing the brightness of the temperature (Equation 3.1). The DN values of TM and ETM+ fall between 0 and 255.

$$L\lambda = \left(\frac{LMAX\lambda - LMIN\lambda}{QCALMAX - QCALMIN}\right) \times (DN - QCALMIN + LMIN\lambda) \qquad \text{Equation 3.1}$$

Where:

QCLA= quantized calibrated pixel value in Digital Number (DN).

LMINλ = spectral radiance scaled to QCALMIN in watts/ (meter squared*ster* μm).

LMAXλ = spectral radiance scaled to QCALMAX in watts/ (meter squared*ster* μm).

Watts (W): the SI unit of power, representing energy transfer per unit time

Meter squared (m^2): the area over which the radiation is emitted or measured.

Steradian (sr): the SI unit for solid angle, measuring the three-dimensional angle over which the radiation is emitted or observed.

Micrometer (μm): The unit of wavelength, representing the spectral dimension. 1 μm = 10^{-6} meters.

QCALMIN = minimum quantized calibrated pixel value corresponding to LMINλ in DN.

QCALMAX = maximum quantized calibrated pixel value corresponding to LMAXλ in DN= 255.

Step II. Conversion of Radiance to brightness temperature (In kelvin)

It is also possible to convert the spectrum radiance of TM and ETM+ Band 6 imaging into a more physically useful quantity, as was previously described. The following is the conversion formula (Equation 3.2):

$$\boldsymbol{T} = \frac{\mathrm{K2}}{\ln\left(\frac{K1}{L\lambda} + 1\right)} \qquad \text{Equation 3.2}$$

Where:

T = Effective at-satellite temperature in Kelvin.

K2= Calibration constant 2.

K1= Calibration constant 1.

Lλ = Spectral radiance in watts/(meter squared * ster * µm).

Step III. Conversion of temperature from degree kelvin to degree Celsius

Lastly, 273.15 were subtracted from the results of the Landsat TM, ETM+, and OLI/TIRS LST values to convert them to degrees Celsius. The temperature was converted from degrees Kelvin (K) to degrees Celsius (°C) using the formula below (Equation 3.3).

$$℃ = K - 273.15 \qquad \text{Equation 3.3}$$

Where: °C= LST result in degree Celsius;

K = LST result in degree Kelvin.

3.2.3.2. Normalized difference vegetation index (NDVI)

The amount of vegetation covering the earth's surface was determined using this index. Landsat imagery' multi-spectral bands were used to determine the NDVI. The effects of land use conversion and the resulting temperature changes on plant structure and coverage were shown by NDVI. Near-infrared bands on Landsat 5 and 7 was measured using band 4, and Landsat 8 was measured using band 5. Band 4 for Landsat 8 and Band 3 for Landsat 5 and 7 were used to measure the red band of the Landsat data. This index's formula is as follows (Equation 3.4).

$$NDVI = \frac{NIR - R}{NIR + R} \qquad Equation\ 3.4$$

The range of the NDVI magnitude is -1.0 to 1.0. The NDVI values for dense and healthy vegetation are consistently in the range of 0.2 to 0.9 (Bustos, 2015). Following the completion of the LST and NDVI results for the study region, correlation analysis were performed to examine the inverse relationship between the two variables, which was reportedly utilized to amplify the overall impact of climate change on the study area.

3.3. Result and Discussion

3.3.1. Analysis of LST

For the years 2000, 2010, 2020, and 2024, the LST were computed for month of May. Generally speaking, the downstream section of the basin exhibits higher LST values than the upper stream section. The lowland area downstream of the basin is primarily occupied by shrubs and bare land; the amount of vegetation has also decreased. Furthermore, covered with sands; sands absorb a lot of sunlight, which raises the warmth of the ground surface. The research area's upper basin, on the other hand, had the lowest LST due to the amount of substantial forest shield and sparse bare ground coverage.

The research area's maximum LST values were 56.85C^{o}, 57.29, 60.31, and 52.27 in the years 2000, 2010, 2020, and 2024, respectively. In the study region, the highest LST was recorded in 2020. In the years 2000, 2010, 2020, and 2024, the minimum values of LST noted in the Awash River Basin were 19.25, 19.6, 20, and 16.29, respectively. The year 2024 saw the lowest LST recorded (Figure 3.2). The LST increased from the year of 2000 to 2020 by the temperature from 56.85 to 60.31 by 4 degree Celsius and declined in 2024. The temperature may decline due to cloud covers, effect of precipitation, high evapotranspiration, cooling effect of vegetation, high surface shading and altered surface energy balance. Numerous studies revealed that significant role of vegetation cover by providing shade, presence of wetland area, and riverside flood plains area contributes to reduce the surface temperature in study area (Saha, 2024; Speak, 2020; Sresto, 2022; Yu, 2024; Li et al., 2023).

Hence, these bio-physical processes are significantly observed in a place where there is high NDVI. The highest LST in study area also expected due to global warming, urbanization and declining of vegetation. Rasul et al., (2012) predicted that the temperature would have risen 1.40 °C to 5.80 °C by the 21st century, which corroborated the current study. The Awash River basin's high surface temperature is a result of both the growing urbanization and the presence of barren terrain. Bare land effectively absorbs and retains heat, according to several authors. However, urbanization leads to raise impermeability, such as highways and neighborhoods. This makes the research area's surface temperatures raise significantly (Debele, 2024; Patel, 2024; Bala, 2024 ;Khan, 2022; Rahaman, 2022; Zhang, 2022; Gebremichael et al., 2025a; Gebremichael et al., 2025b).

3.3.2. Analysis of NDVI

The NDVI result in the period of 2000, 2010, 2020 and 2024 shows the positive value of (0.808, 1, 1 and 0.886) and the negative values (-01965, -0.2,-0.2&-0.1996) respectively (Figure 3.3). The NDVI result ranges from 1 to -0.2, in 2024 the highest area coverage of the study area shows significant greenness compared to other periods consequently lead to declining of the LST. In Awash River basin due to their high quantities of green biomass, crops, fruit trees, and forests are exemplified by high NDVI values, whereas urban areas and bare soil are represented by low NDVI values. Higher NDVI values imply more dense greenery, whereas lower values suggest water bodies. Insufficient precipitation and regional droughts also influence lower NDVI levels.

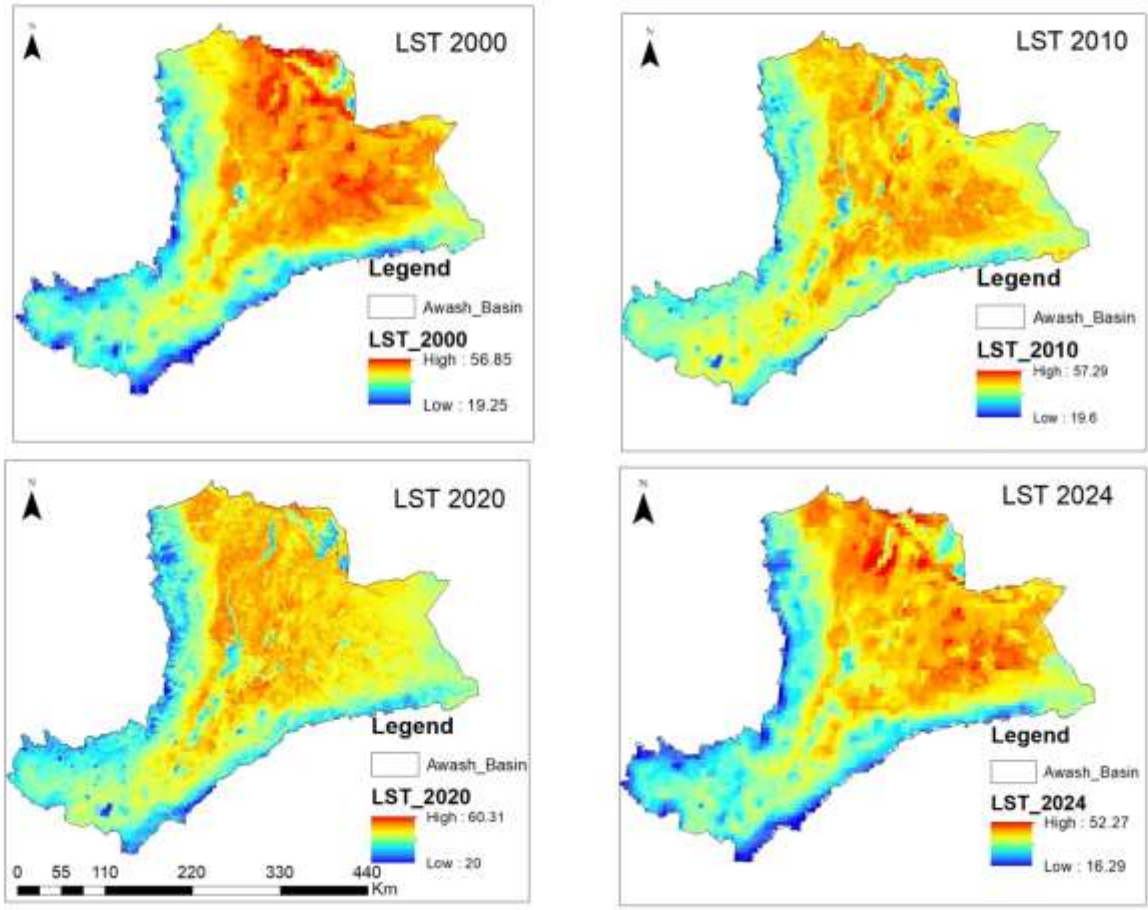

Figure 3.2: Land surface temperature (LST)

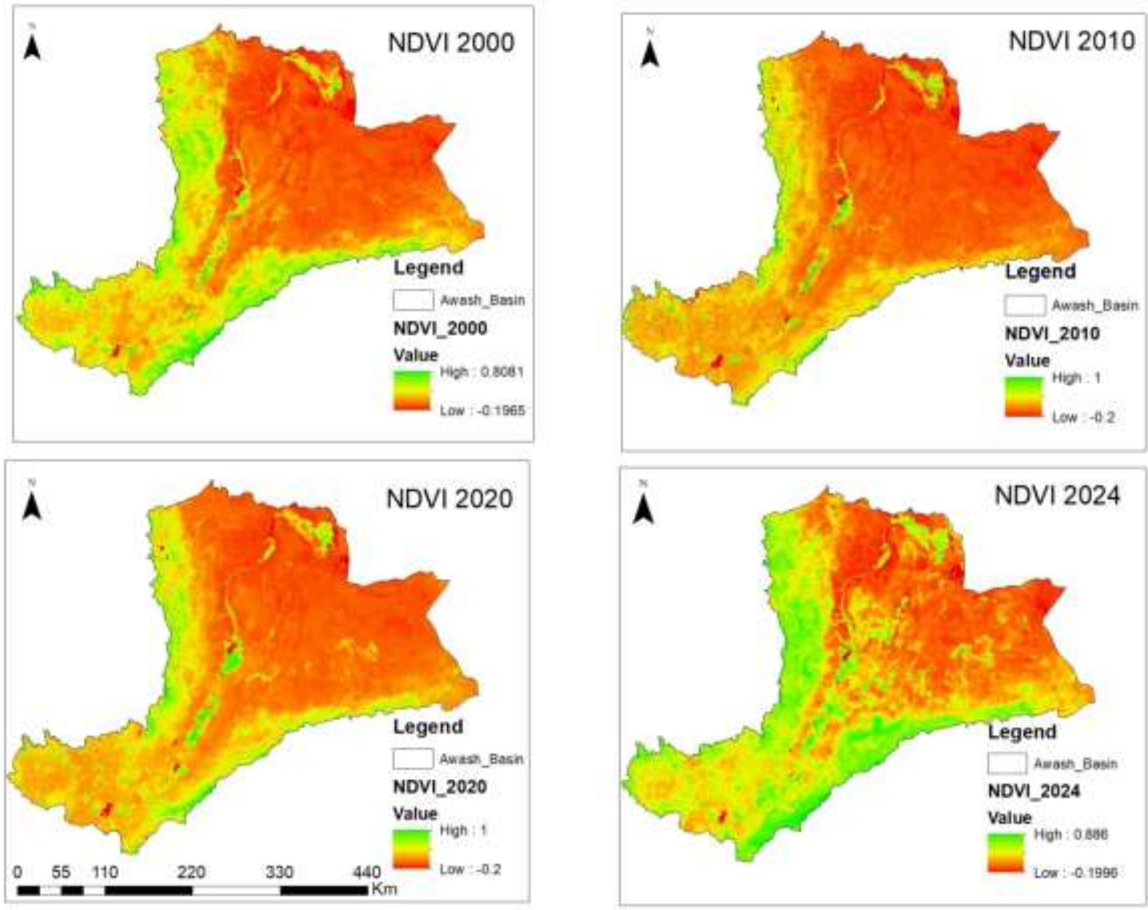

Figure 3.3: Normalized Difference Vegetation Index (NDVI)

3.3.3. Correlation between LST and NDVI

Within the research area, the highest and lowest recorded LST values are 60.31 and 52.27, respectively. In contrast, the study area's highest and lowest NDVI values are 1 and -0.2, respectively. In the Awash River Basin, the correlation finding indicates a strong negative relationship between LST and NDVI, meaning that high LST is linked to low NDVI values and vice versa. Because of the low NDVI value, dispersed vegetation in some areas of the research area also has a higher LST (Figure 3.4). Various scholars report the strong negative correlation of LST and NDVI (Alemu, 2019; Wedajo, 2019; Merga, 2022; Wolteji, 2022; Nemani, 1995; Sun, 2007; Getu, 2024; Guha, 2022; Roy, 2022; Sharma, 2022; Yue, 2007).

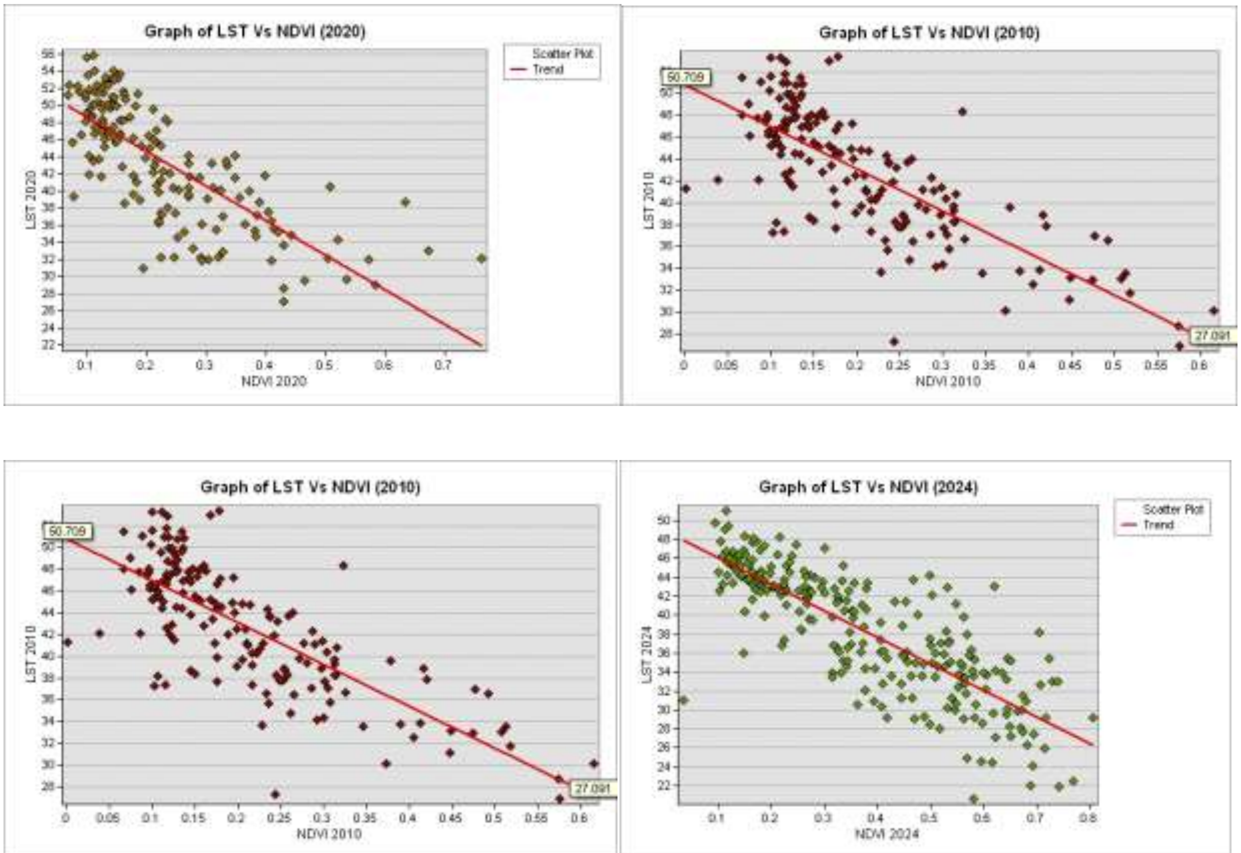

Figure 3.4: interaction between NDVI and LST

3.4. Conclusion and Recommendation

The paper examines temporal trends and correlation of NDVI and LST to stipulate the trends of climate change of the entire Awash River basin. According to the findings, there has been a noticeable rising values of LST from 2000 to 2020, based on satellite analyses, are mainly attributed to increased urbanization, different land uses, and fewer vegetation areas, which NDVI data also confirms by showing a decline in vegetation in some places. A strong link shows that fewer shades in plants make the surface warmer when the sun is rise. Practicing afforestation actions and strengthen sustainable land use to boost the amount of vegetation, reduce the surface temperature, and combat climate problems. Implementing the geospatial methods provides a stronger mechanism to describe the impacts of climate change in the Awash River basin. This approach, spatially visualizing changes in land use, vegetation dynamics and surface temperature based on satellite information for different periods of time, allows for accurate pinpointing of areas with distinct climatic changes in study area. The substantial inverse link between rising land surface temperature and declining plant cover indicates that changes in land use are the primary causes of regional climate variability.

Such geospatial approach not only increases our understanding of climate change spatial and temporal patterns, but as well can inform of targeted mitigation efforts, such as afforestation, sustainable land management, and the development of early warning climate systems, towards sound policy adaptation instrument help counteract the negative effects of rising temperatures on the basin. Establishing early warning system to help communities and the environment to curb climate relate disasters such as drought and flooding. Stimulate efforts to blend satellite observations with measurements made on earth to improve assessment of climate trends and guide proper policy decisions. Moreover, Increase collaboration with other regions to manage the basin effectively as climate situations change. All in all, early and appropriate steps are required to control negative impacts of climate change and protect the environment and people living in the Awash River Basin.

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CHAPTER FOUR: ANALYSIS OF LAND USE LAND COVER CHANGES AND POPULATION DYNAMICS IN AWASH RIVER BASIN (ARB), ETHIOPIA USING GIS AND REMOTE SENSING

4.1. Introduction

Alongside population expansion and global warming, land use land cover change (LULCC) is a crucial component of environmental change on a worldwide scale. LULCC has recently gained international attention. Therefore, taking into account land use and land cover dynamics is a crucial component in achieving sustainable development with proper land use management and regional development (Das & Sarkar, 219). All man-made and natural structures that encircle certain areas, such as flora and water bodies, are referred to as land cover. However, human activities that involve the soil can be used to determine land use. LULC change is one among the factors contributing to ecological changes at the local, regional, and global levels (De Paulo Rodrigues da Silva, et al., 2018). Over the past few decades, there has been a notable rise in the area of grassland, woodland, and forest that has been turned into farmland and grazing land (Güler, 2007; Houghton, 1994). On a typical year, 16 million hectares of the forests are destroyed worldwide and the trend is continually steady over time (FAO, 2010).

In most of developing nations, land use land cover dynamics are rapidly rising, and the key factors to be cited are high economic growth and population increase coupled with globalization. As an illustration, drastic changes of natural landscapes took place in the eastern part of Africa due to human activities (Twisa & Buchroithner, 2019), and Woodlands, grasslands, and vegetated spots have now been converted to agricultural land (Panel., 2005). Unfavorable hydrological processes like runoff, infiltration, evapotranspiration, and rainfall patterns are also influenced by changes in land cover and land use brought on by urbanization, deforestation, and the growth of crop fields (Bradshaw, 2007; Houghton J.T., 1995; Liverman, 2008; Loveland, 2014; Scanlon, 2005). Soil moisture is also significantly influenced by the form and quantity of groundwater and surface discharge (Setyorini A., 2017).

Many scientific researches show that LULCC is deeply connected to the phenomenon of flooding and significantly affects flood phenomena dynamics (Adnan, 2020; Dewan, 2009; Roy, 2020). Both natural and man-made factors may result in floods, and one of these factors is changes in land use and cover (Gan et al., 2018). Dynamic changes in land cover made an area more susceptible to flooding. Human invasions, whether direct or indirect, can significantly alter land use and cover (Etter, 2006) (Manandhar, 2009) and rapid population increase is a major contributing factor, particularly in nations like Ethiopia (Tekle K., 2000). The LULC of Ethiopia has occurred in great distinction over the past decades due to overgrazing, urbanization, agriculture growth, and population expansion. The Ethiopian population is currently increasing rapidly with the population currently standing at 108 million people whose growth rate has been estimated to average 2.8 percent same as many other sub-Saharan African countries (Andrew et al., 2019).

The most important basin is the ARB, which is heavily used and provides water for industry, hydropower plants, households, and large and small-scale irrigation schemes. Despite this, Ethiopia's Awash River Basin is environmentally endangered (Bekele, 2018; Bekele, 2016; Edossa, 2010; Kinfe, 1999). Because of its strategic location, accessibility to roadways, and the availability of land and water resources, the basin is susceptible to human-induced effects such as land degradation and high population density. Many Ethiopian scholars have studied changes in land use and land cover within the ARB, and their results lately revealed that there are significant changes in the area. Land degradation, water resource depletion, urbanization, and rapid population expansion are some of the primary issues facing the ARB (Edossa, 2010; Garedew, 2009; Haregeweyn, 2015; Taddese, 2003; Tiruneh, 2013; Tsegaye, 2010).

Land use and land cover change entails some of the challenges such as land degradation, urbanization, and water depletion as closely interconnected as knots, which strongly affect both the environment and population dynamics. Increased urban uses such as population growth often results in expansion of urban areas encroaching upon previously undeveloped land, which results in habitat loss, fragmentation, and land degradation. Although this expansion usually means that more resources are being extracted, especially water concentrated in urban centers, urban centers need significant supplies for drinking, sanitation, and industrial use. This can cause depletion of aquifers and surface water bodies, over extraction of water resource can also result in further degradation of the land and increase deterioration of the ecosystem. Furthermore, the change from natural landscapes to urban infrastructure affects local climate, reduces biodiversity, and affects the health of soil. A critical point of knowledge regarding these interactions is critical to the development of sustainable land use policies between urban development interest and environmental conservation as well as resource management. Therefore, it is crucial to comprehend the basin-level LULC dynamics and driving forces in order to establish and plan effective environmental management policies and strategies (Hurni, 2010).

The most popular technique for producing comprehensive land use classification maps is the use of remote sensing and geographic information system techniques, which are utilized to explore modifications in LULCC (Alqurashi & Kumar, 2013; Hassan et al., 2016; Madden, 2004; Rwanga & Ndambuki, 2017; Van Lynden & Mantel, 2001). The rates, extents, and patterns of land-use dynamics can be ascertained by mapping land use changes using remote sensing techniques, which offer a quantitative description of land transformation. Numerous unique remote sensing categorization techniques have been developed and are frequently used to map changes in land cover and use (Aplin, 2004). One of the most popular classification techniques is supervised classification (Kibet Langat, 2019; Kogo, 2019; Rawat, 2015). Maps of land use, land cover change, forest and other natural resource inventories, and other topics were produced in numerous studies using GIS and remote sensing technology (Alemu, 2015; Bekele, 2019; Bekele, 2018; Dinka, 2012; Garedew, 2009; Kidane, 2015; Mango, 2011a; Mango, 2011b; Melesse, 2007; Melesse, 2005).

However, in the case of the Awash River Basin, the relationships between LULCC, population expansion, and flood dangers are rarely examined and discussed in detail. There is also a lack of understanding and practice regarding the introduction of nature-based solution (NBS) approaches. Hence, this study expected to examine the dynamics and relationship between land-use land cover change and population growth in relation to flood hazards in ARB through remote sensing and Geographic Information Systems. Moreover, suggest a sustainable nature-based solution to reduce the consequences of unexpected floods and rapid land use changes.

Furthermore, this research helps to achieve the Sustainable Development Goals for 2030: Goal 15 encompasses investigating land use changes and conservation efforts to protect ecosystems and biodiversity.

4.2. Materials and Methods

4.2.1. Study Area Description

4.2.1.1. Locations

The Awash River Basin is located between 7º53’-12º 0’ latitude and 37º57’-43º25’ longitude (Figure 4.1). It is home to 10.5 million people and occupies an area of 112,000 km2, with an annual water surface area of about 4.9 BM^3 (Ministry of Environment, 2018). The elevation above sea level varies from 210 to 4,195 meters. Parts of the Oromia, Somali, Amhara, and Afar regions are embraced by the 1,250 km long Awash River (Tiruneh, 2013). Originating on a high plateau close to Ginchi town, west of Addis Ababa, Ethiopia's capital, the river runs across the Rift Valley into the Afar Triad until spilling into the filthy Lake Abbe at the Ethiopian border with Djibouti (Sonder, 2008).

Based on physical and socioeconomic characteristics, the Awash River Basin is separated into three sections: the Middle Awash, which includes areas between Koka Dam and Awash Sebat station (areas between 1000 and 1500 m); the Lower Awash, which includes areas between 500 and 1000 m and the Eastern catchment; and the Upper Awash, which includes areas upstream from Koka Dam (areas above 1500 m) (Edossa, 2010; Ministry of Environment, 2018). In upper and middle Awash, the rainfall pattern is bimodal, with the major rainy season occurring from July to September and an irregular wet season from March to May. The higher and lower regions of the Awash River Basin experience different climates, ranging from humid to desert. The Awash River Basin's soil is classified as high clay soils that are good for cultivating cotton, clay loam and sandy loam for growing cereals and sugarcane, and sandy soil for range grass pasture (Ministry of Environment, 2018).

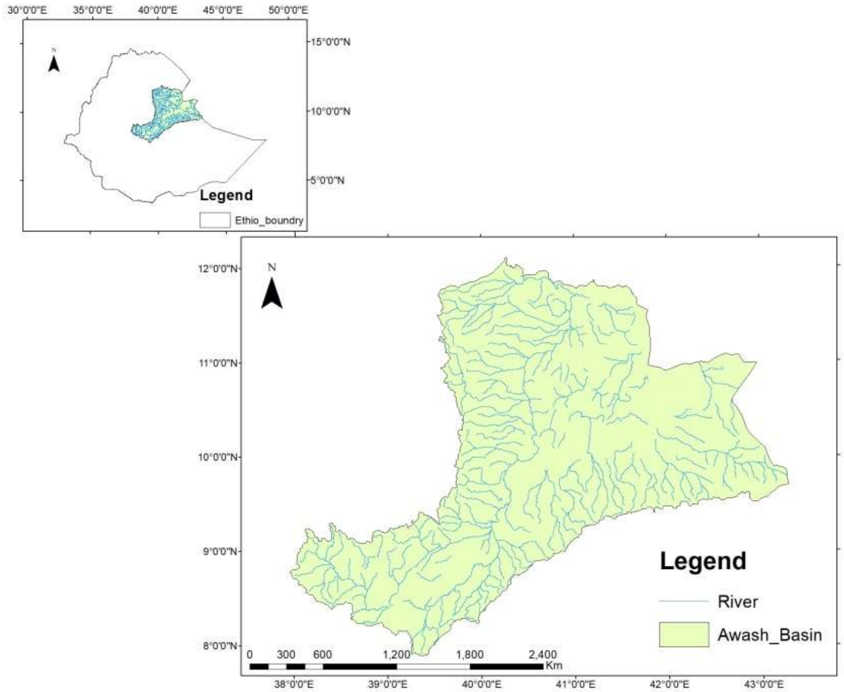


Figure: 4.1 Study area map; the figure generated with GIS software version 10.8 by the Authors. The link to the GIS software used can be found at https://www.arcgis.com/index.html

4.2.2. Data Collection and Sources

For 1990, 2000, 2010, and 2020, four cloud-free Landsat TM and ETM images were obtained and thoroughly analyzed (Table 4.1). The patterns and trends of land use land cover changes in the study area were quantitatively measured and observed. All image bands 1- 7 have a spatial resolution of 30 m. The images were obtained from the United States Geological Survey (USGS) through http://glovis.usgs.gov free of charge; they were geo-referenced to the Universal Transverse Mercator (UTM) map projection (Zone 37), WGS 84 datum. To observe clear changes in land use land cover, all satellite images from 1990 - 2020 were clipped or extracted from the same recent boundary shape file of the study area. During data collection for image classification and verification, we utilized GPS data to ensure accurate geo-location of agricultural areas and other land use types. Google Earth images provided high-resolution visual references for validating classifications, while field observations offered on-the-ground insights to enhance data quality and correct discrepancies. This comprehensive approach helped us to ensure the accuracy and reliability of our land-use classifications.

Table 4.1: Description of satellite data

Year	Data Types	Sensors	Pixel Resolution (m)
1990	Landsat 4–5 TM	Thematic Mapper (TM)	30
2000	Landsat 7 ETM	Enhanced Thematic Mapper (ETM)	30
2010	Landsat 8 OLI	Operational Land Imager (OLI)	30
2020	Landsat 8/9 OLI	Operational Land Imager (OLI)	30

Source: USGS data portal https://earthexplorer.usgs.gov/

4.2.3. Data Analysis

4.2.3.1. Image Classification

Determining the LULC classification algorithm is the most crucial stage in creating LULC maps. Six distinct LULC classes—urban area, agricultural land, forest cover, deep water bodies, bare land, and wetland—are defined for this study based on the standard classifications established by the US Geological Survey (Table 4.2). All satellite pictures are examined using spectral and spatial profiles prior to classification operations in order to verify the digital numbers (DNs) of various LULC classes. The training regions were selected using reference data and terrain maps. In ArcGIS 10.8, every satellite image is supervised and classified using a maximum likelihood approach. To compare supervised and unsupervised image classifications, according to D. Lu, (2007) Choosing pixels that correspond to land cover classifications that the analyst is aware of are known as supervised classification. The classification of unsupervised images is more computer-automated. The use of unsupervised categorization may not produce satisfactory results because grass, crop, and shrub areas have similar spectral features and were previously identified as distinct classes. Consequently, supervised image classifications were employed in the data extraction procedure.

The reference data used in classifying the satellite images were the existing topographic maps, Google earth images and GPS coordinates of ground information. The classified images were used to obtain the areas of each of the LULC classes respectively in accordance with that of LULC scheme.

Table 4.2 Description of the land use land covers (LULC) types.

LULCC Type	Description
Agricultural Land	Land used for growing crops, vegetables, fruits, areas currently under crop, fallow and land under preparation; it also includes grazing lands
Urban/Built-up	All types of developed land, including commercial, residential, industrial, and other infrastructure infrastructures
Deep Water bodies	Lake, ponds, lagoon, river and small dammed water fed by rainfall and small streams
Forest cover	Areas covered with various planted forest tree species, and it include natural forests
Wetland	Swampy land, marsh land, muddy land, Bump land, deposited land, river bank
Bare land	Infertile area with little or no vegetation dominantly covered with desert sand, rocks, volcanic ashes and open land with dispersed shrubs and bushes.

4.2.3.2. Accuracy Assessment

By evaluating commission and omission errors in a confusion or error matrix, the overall accuracy level is evaluated. In order to enhance classification methods and increase the quantity of overlooked misclassified cells, ArcGIS also uses classification and post-classification processes. It goes without saying that the anticipated errors in image classification may arise during the classification phase or earlier in the image processing step. Consequently, accuracy evaluation should be taken into consideration once classification concludes in order to raise the degree of reliability for image classification. (Lillesand T. M., 2004), Classification remains incomplete until accuracy assessment is done.

An error matrix or confusion matrix is one of the realistic widely used methods for evaluating classification accuracy (Congalton, 1991). Google Earth authentication and the collection of some GPS data were used to analyze the image classification accuracy. Sample points were collected from GPS coordinates and classified images corresponding to specific years. These points were converted into point features in ArcGIS environment and then visualized in Google earth by adjusting the time span to match the years of the classified images. Afterward, the points were compared against the respective images in Google earth for those specified years. This allows us to count and analyze the points that correspond accurately to the designated land use classes in the classified images over different time periods. The purpose of the confusion matrix is to examine and compare the ground truth points with the classification outcomes that were attained throughout the classification procedure (Lillesand T. K., 2015). A confusion matrix, which primarily uses various accuracy types, such as overall accuracy, user accuracy, producer accuracy, and the kappa coefficient (Equation 4.1), was used to authenticate the categorized image in terms of percentage. The formulas that are briefly shown here were obtained from (Congalton, 1991; Jennes, 2007; Jensen, 1996; Landis, 1977).

$$\text{Kappa coefficient (T)} = \frac{(TS*TCS) - \sum (\text{column total} * \text{Row total})}{TS^2 - \sum (\text{column total} * \text{Row total})} \times 100$$

$$\text{Overall Accuracy (\%)} = \frac{\text{Total number of correctly classified Pixels (diagonal)}}{\text{Total number of reference pixels (sample)}} \times 100$$

$$\text{Users Accuracy (\%)} = \frac{\text{Number of correctly classified Pixels in each category}}{\text{Total number of classified pixels in that category (the row total)}} \times 100 \quad \text{(Equation: 4.1)}$$

$$\text{Producers Accuracy (\%)} = \frac{\text{Number of correctly classified Pixels in each category}}{\text{Total number of reference pixels in that category (the column total)}} \times 100$$

Where: TS = Total sample and TCS = Total Correctly classified Sample

4.2.3.3. Change Detection

Various methods have been employed to identify changes in land cover and land use using remote sensing imagery. It ranges from detailed quantitative techniques to visual comparisons (Wickware, 1981).This paper incorporates post classification accuracy assessment, which is acknowledged as the most widely used and popular system (Weismiller, 1977). From 1990 to 2020, changes in the research area were identified and examined. Determine which land use types have changed, to what extent, and in what percentages as compared to the state of the specified land use type in the prior year in order to assess the degree and scope of the changes. This kind of change study is crucial for figuring out how much change occurs. To determine the LULC %, subtract the initial LULC area from the final LULC area, divide the result by the original LULC area, and then multiply the result by 100 (Equation: 4.2) (Garai, 2018).

$$\text{Change percentage} = \frac{(\text{Final LULC area} - \text{Initial LULC area})}{\text{Initial LULC Area}} * 100 \qquad \text{(Equation: 4.2)}$$

The results of this matrix, which show a decline or rise in areal coverage in the study area, can be interpreted as negative as well as positive percentage values.

4.2.4. Methodological limitations

We had acquired vigorous data for LULCC analysis from remote sensing, but various limitations were recognized. The precision of remote sensing data was strongly impacted by atmospheric variables, sensor measurements, and varying terrain features. Moreover, during classification because of intersection in spectral signatures amid different terrain type possible biases may happen, consequently distort the classification. Hence, integration of high-resolution imagery and verification of ground truth comprising surveys in the field can significantly enhance the quality and data accuracy of future studies.

4.2.5. Population Change Analysis

Analyzing the study area's population patterns was a crucial component for determining the primary source of flood threats in the region with regard to LULCC assessment.

The Central Statistics Agency (CSA) and the Awash River Basin Authority provided the population census and projection statistics that served as the basis for the population data (Table 4.3). The population data for the years 1984, 1994, and 2007 were obtained from the Ethiopian Population and Housing Census (CSA, 2007) and the literature (Mahtsente Tadese, 2020). The populations of the Awash River Basin in 1990, 2000, 2010 and 2020 were estimated via the population trend line from 1990 - 2020. In order to evaluate the effects of rising population on the dynamics of urbanization and land use change, the population also correlates with the pace of urban growth. The years that were chosen depended on the demographic data's accessibility and ability to accurately depict changes in the population during the previous 30 to 40 years. A population's change over a given time period is referred to as its population growth rate. According to the UN (2014) Ethiopia's population is expected to rise by 2.3% annually, whereas urban regions' average is 4.2%. The Ethiopian Central Statistical Agency's equation (Equation 4.3) is employed to generate projections (CSA, 2007).

$$P_t = Po\, e^{r*t} \qquad \text{(Equation: 4.3)}$$

Where:

Pt : population projected at a given time,

Po : population size of a base year,

e : natural logarithm base,

r: average annual population growth rate, and

t: the time interval between the base year and the projected year.

Equation (4.3), obtained from the Ethiopian Central Statistics Agency, is used to get the estimated population in the Awash River basin, as seen in (Table 4.3).

Table 4.3: Awash River Basin population estimates (in millions)

Year	1985	1988	1990	2000	2002	2007	2010	2014	2018	2019	2020
Population	7.6	8.25	8.638	10.87	11.84	12.85	13.77	14.9	15.95	16.43	16.8

The relationship between land-use/land-cover dynamics and population growth was quantitatively examined using the Pearson correlation coefficient (r). Finding the linear relationship between these two variables is the main goal of this analysis. A perfect positive correlation is represented by a coefficient (r) value of +1, a perfect negative correlation by a value of -1, and no association by a value of zero (Ahlgren, 2003).

Thus, this approach enables us to understand the connections between shifts in land use patterns, including urbanization, agriculture, and deforestation, and shifts in population density and growth rates. The Pearson correlation can be used to find important connections and insights that help legislators, environmental managers, and urban planners better understand the relationship between ecological change and human activity. Equation (4.4) displays the Pearson correlation formula, which is frequently used.

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}} \quad \text{(Equation: 4.4)}$$

Where

r = Pearson coefficient

n = number of pairs of the variables

$\sum$***xy*** = sum of products of the paired variables

$\sum$***x*** = sum of the x variables

$\sum y$ = sum of the y variables

$\sum x^2$ = sum of the squared x variables

$\sum y^2$ = sum of the squared y variables

4.2.6. The Land Consumption Rate (LCR)

The LCR is a measure of a city's degree of compactness that captures the city's progressive spatial expansion. While a low value of LCR indicates the existence of open spaces, a high number suggests a high degree of crowdedness (Laxmikant Sharma, 2012). Researchers can comprehend the full effects of urban sprawl on cities' socioeconomic and environmental conditions by combining LCR analysis with land-use dynamics. The approach assists experts in urban planning and policy in identifying trends that govern sustainable development, quality of life, and the management of natural resources.

Because metropolitan regions have more impermeable surfaces as a result of infrastructure development and urbanization, rainwater cannot rapidly sink into the ground after rainfall. Flooding follows from this. Therefore, assessing and understanding the rate of land consumption requires an understanding of land use-land cover change and flooding brought on by urbanization and growing population (Astuti, 2019; Irham, 2022; Lacher et al., 2019; Naikoo, 2020). The land consumption rate, which was used as an indicator to measure how rapidly an urban area progressed geographically in relation to its population, was computed using equation (4.5).

$$\text{Land consumption rate} = \frac{\text{Built−up area}}{\text{Population}} \qquad \text{(Equation: 4.5)}$$

4.3. Results and Discussion

4.3.1. Accuracy Valuation

The kappa coefficients for the same year image classifications were 0.92, 0.97, 0.99, and 0.95, respectively, while the overall accuracies for the 1990, 2000, 2010 and 2020 classifications were 94, 97.6, 99, and 96, respectively (Table 4.4). The accuracy of both the producer and the user in classifying the entire image met scientific requirements. According to Anderson et al., (1976) if the kappa coefficient (K) value falls between 0.81 and 1.00, it's nearly perfect, and the minimum total accuracy result should be 85%. As a result, this paper's accuracy assessment level fulfills the necessary image classification threshold.

4.3.2. Land Use Land Cover Change Rate

As is evident from Table 4.5 and Figure 4.2, in 1990, bare land made up the largest area coverage, accounting for 8,770,185 ha (74.7%) of the land use class. This was followed by agricultural land, which made up 2,768,467 ha (24%). During the 1990–2020 study periods, agricultural land increased and eventually made up 27% of the land use class in 2020, while bare land slightly decreased and made up 71% of the land use class's overall area coverage in 2020. Between 1990 and 2020, there was a notable and steady growth in the coverage of urban areas; for instance, in 1990, urban areas made up 0.22% of the land use class; in 2000, 2010, and 2020, that percentage rose to 0.26%, 0.3%, and 0.6 %, respectively. The amounts of forest cover growing minimal between 1990 and 2020. Forest cover made about 0.7% of the study area in 1990 and rose dramatically to 1.5% of the river basin in 2000. The amount of forest cover rapidly decreased from 0.5% in 2010 to 0.8% in 2020. Wetland and water bodies had the lowest area coverage, making up 0.5% and 0.12% of the total area coverage in 2020, respectively. Regretfully, this kind of urbanization of barren and agricultural land can also result in a sufficient increase in impervious surfaces to raise the risk of flooding and runoff elsewhere.

The hydrology of the basin may be affected by the changes, putting society at risk for more frequent and severe floods that would weaken community resilience and sustainability. By improving water quality through natural filtration, expanding wetlands can boost biodiversity and serve as a buffer against the effects of flooding. However, there are significant negative effects of such metropolitan growth, including the potential for habitat fragmentation and pressure on local resources. The goal of this study is to give readers a more nuanced understanding of the interactions that occur within the ecosystem of the basin and the extent to which these interactions affect the communities that surround it.

Table: 4.4 Accuracy assessment results for 1990, 2000, 2010 & 2020

1990	Urban area	Agricultural area	Deep water	Wetland	Forest cover	Bare land	Total (User)	User Accuracy (%)
Urban area	75	5	0	0	3	8	91	82
Agricultural area	0	82	0	0	0	0	82	100
Deep water	0	0	56	6	0	0	62	100
Wetland	0	1	0	41	0	0	42	100
Forest cover	0	0	0	0	92	2	94	97
Bare land	0	0	1	0	0	48	49	100
Total (Producer)	75	88	57	47	95	58	420	98
Producer Accuracy (%)	100	93	98	87	97	83		
Overall Accuracy (%) = 94%			Kappa coefficient= 0.92					
2000	Urban area	Agricultural area	Deep water	Wetland	Forest cover	Bare land	Total (User)	User Accuracy (%)
Urban area	77	14	0	0	0	0	91	84.6
Agricultural area	0	146	0	0	0	0	146	100
Deep water	0	0	103	0	0	0	103	100
Wetland	0	0	0	83	0	0	83	100
Forest cover	0	0	0	0	87	0	87	100
Bare land	0	0	0	0	0	90	90	100
Total (Producer)	77	160	103	83	87	90	600	
Producer Accuracy (%)	100	91	100	100	100	100		
Overall Accuracy (%) = 97.6%				Kappa coefficient= 0.97				

2010	Urban area	Agricultural area	Deep water bodies	Wetland	Forest cover	Bare land	Total (User)	User Accuracy (%)
Urban area	169	0	0	0	0	0	169	100
Agricultural area	0	59	0	0	0	0	59	100
Deep water	0	0	103	0	0	0	103	100
Wetland	0	4	0	40	0	0	44	91
Forest cover	0	0	0	0	74	0	74	100
Bare land	0	0	0	0	0	61	61	100
Total (Producer)	169	59	103	40	74	61	510	
Producer Accuracy (%)	100	100	100	100	100	100		

Overall Accuracy (%) = 99% Kappa coefficient= 0.99

2020	Urban area	Agricultural area	Deep water bodies	Wetland	Forest cover	Bare land	Total (User)	User Accuracy (%)
Urban area	81	17	0	0	0	6	104	78
Agricultural area	3	121	0	0	0	0	124	97.6
Deep water	0	0	133	0	0	0	133	100
Wetland	0	1	0	54	0	0	55	98
Forest cover	0	0	0	0	102	1	103	99
Bare land	0	0	0	0	0	180	180	100
Total (Producer)	84	139	133	54	102	187	699	
Producer Accuracy (%)	96	87	100	100	100	96		

Overall Accuracy (%) = 96% Kappa coefficient= 0.95

Table: 4.5 Total area coverage of land use classes

Landuse_Class	Area_1990 _ha	Percent	Area_2000 _Ha	Percent	Area_2010 _Ha	Percent	Area_ 2020_Ha	Percent
Agricultural_land	2,768,467	24	4,668,237	40	3,215,528	27.5	3,193,068	27
Bare_land	8,770,185	74.7	6,687,484	57.6	8,285,017	70.8	8,262,189	71
Deep_water_bodies	24,836	0.2	30,823	0.26	33,514	0.3	14,117	0.12
Forest_cover	83,055	0.7	176,351	1.5	58,835	0.5	94,435	0.8
Urban_area	25,701	0.22	30,481	0.26	35,529	0.3	66,907	0.6
Wetland	21,693	0.18	44,896	0.4	65,519	0.6	63,221	0.5
Grand Total	11,693,938		11,638,273		11,693,942		11,693,936	

With reference to the change rate dynamics briefly described in (Table 4.6), there was a notable rise in agricultural land by 69% from 1990 – 2000. In contrast, bare land drastically declined by a 24% rate of change over the same year span. From 2000 – 2010 and 2010 – 2020, agricultural land significantly declined by 31.1% and 0.69 %, respectively. In general, from 1990 – 2020, agricultural land increased by 15.3%; in contrast, bare land declined significantly, with a 6% rate of change within the same year range (1990 - 2020). This can be highly linked with an increasing rate of urbanization and population growth in the Awash River basin. Unfortunately, such conversion of bare land to urban areas can also increase impervious surfaces enough to enhance the potential for runoff and increased flood risk elsewhere. The changes could have an impact on the hydrology of the basin and place us at risk for more frequent and more severe flood events, which in turn would erode community resilience and sustainability.

Based on the findings of this paper, the primary reason for the increasing in agricultural land is the conversion of bare land areas into agricultural and urban development, driven by significant population growth that has resulted in rapid urbanization. Additionally, environmental stresses such as climate change, drought, and soil degradation have negatively impacted agricultural productivity. As a result, there has been an expansion in the amount of arable land within the basin to secure food security. According to Foeken (2006) (Foeken, 2006), food demand and food insecurity in cities are likely to rise in tandem with urbanization and population growth. Hence, to secure the existence of an urban community, urban irrigation practices, and intensive agricultural production take place as immediate remedies.

In 2018, more than 250,000 ha of agricultural land were cultivated with extensive irrigation projects, which potentially increased during the coming decades (Ministry of Environment, 2018). As a result, in the future, we can expect a significant increase in agricultural land and a notable decline in bare land within densely populated and heavily utilized river basins in the country. This shift is driven by the high demand for food and the rising levels of food insecurity caused by population growth in urban areas.

The forest cover percentage rate significantly increased from 1990 - 2000 (112%) and declined by 66.6%. This reduction can be attributed to the unprecedented rate of deforestation, which has become a global issue. According to the FAO (2010), Africa lost most of its forest between 1980 and 2000. Furthermore, Dessu (2020) reported that rapid urban expansion was accompanied by a severe decline in green vegetation cover. In addition, a slight increase of 60.5% from 2010 – 2020 occurred because of the expansion of afforestation and reforestation programs designed by the government. In general, from 1990 – 2020, the forest coverage change rate registered a positive value of 13.7%. The Green Legacy Initiative (GLI) of Ethiopia seeks to advance sustainable land management and reforestation. Implemented in the Awash River basin in Ethiopia, the GLI attempts to address environmental issues such as climate change, land degradation, and deforestation. Although the initiative's overarching objectives are evident, its concrete effects on LULC changes and land surface temperature (LST) regulation are less clear. Moreover, in line with consideration of NDVI analysis, according to Gebremichael et al. (2025), the NDVI result in 2024 ranges from 1 to -0.2. The highest area coverage of the study area within this year shows significant greenness compared to other periods. In the Awash River basin, due to their high quantities of green biomass, crops, fruit trees, and forests are represented by high NDVI values, whereas urban areas and bare soil are represented by low NDVI values. More dense vegetation is indicated by higher NDVI values; this may have a strong relation with GLI, the reforestation program that started in 1999.

Another noteworthy shift pertains to the land use class of deep-water bodies, which experienced a 24% increase between 1990 and 2000, an 8.7% decline between 2000 and 2010, a significant decrease to 58% between 2010 and 2020, and a significant 43% reduction in deep water bodies of the Awash River basin between 1990 and 2020. Many studies have shown that urbanization results in changes in micro climates with large impacts on hydrological process, thermodynamic and solar radiation (McCarthy, 2010). Moreover, some scholars have reported that the extraction of water from deep water bodies is highly practical in the Awash River Basin. According to Elleni (2009) small- and large-scale agricultural activity and the extensive activities of different industry developments are practiced in the Awash River Basin. Moreover, towns such as Awash and Adama received their water supplies from the Awash River (Gedion, 2009). In addition, intensive water extraction from Lake Beseka (Metehara) and Haramaya for irrigation and the nearby city water supply has been highly demonstrated. Sonder (2016) stressed that, in the Afar region, lakes and swamps have been fragmented in to small size spots. Moreover, since the 1930s, the extent of salty Lake Abbe has decreased by 67%.

Conversely, the wetland class has shown a significant increase of 191% during the previous thirty years (1990 – 2020). The wetland in the research area are mostly filled with floods and are susceptible to a possible increase in wetland coverage because of the frequent flash floods that occur in the basin riverbank area. In contrast, Alemu (2015) reported that intensive utilization of wetland for irrigation practices would affect the sustainability of the basin. Furthermore, Sonder (2016) argued that patches of wetland are converted into agricultural lands and that large water banks are renewed for hydroelectric power production or irrigation projects.

Another land use class that demonstrates notable and consistent changes is the urban area. From 1990 – 2000, the urban area change rate increased by 19%, and within the following two decades, significantly increased by 160% change rate. In the last three decades, rapid population growth has led to the extension of the development of urban areas and settlements in the study area. Many scholars agree with the link between population growth and urban expansion. In the basin of the Awash River from a socioeconomic standpoint, as the population and urban area grew, so did settlement areas and infrastructural development. Roba et al. (2025) report that settlement areas increased gradually, adding 30.1 km^2 between 1993 and 2003 and then increasing by 3.1 km^2 after that, for a total gain of 33.1 km^2.

With a modest 6.0 km^2 rise in the first ten years and a more substantial 35.4 km^2 expansion in the following ten, sugarcane plantations gradually grew, reaching a total increase of 41.4 km^2. In general, the upper Awash River basin saw modest growth in settlement areas and sugarcane plantations (Asmamaw, 2011; Bewket, 2013; Garedew, 2009; Miheretu, 2018). In other hand, regarding both land use class; wetland and urban area shows a substantial increment within the basin, expanding wetlands can increase biodiversity, improve water quality by natural filtration, and act as a buffer against flood influence. On the other hand, however, such expansions of urbanization have very huge consequences that can cause habitat fragmentation and put strain on nearby sources.

Ethiopia's annual population growth rate is 2.3%; it is a higher rate than the developing countries, whose average rate is (2.2%), and this set Ethiopia as the second most populous country in Africa (UN, 2014). Eventually, rapid population growth accelerated the rate of urban expansion. Consequently, urbanization has a major influence on the abiotic environment (E. Simon, 2013) and the whole living components of urban area (T. Magura, 2010). Hence, this contributes to land use and land cover class changes, changes in the microclimate, surface temperature and rate of rainfall in the study area. Furthermore, owing to the high rate of population growth, the need for the consumption of natural resources has increased and has become a key challenge for the sustainable management of agriculture and forestland. The intensive consumption of forest resources and small patches of watersheds resulted in soil erosion in the lower stream of the Awash River Basin (Kinfe, 1999).

In order to magnify the significant interrelation of LULCC, population growth, and flood hazard, the flood hazard map of the Awash River Basin was illustrated (Figure 4.3). ArcGIS 10.8 was used to create, reclassify, and weight flood-causing elements, including slope, rainfall, elevation, LULC, drainage density, proximity to a river, and soil type, in order to create a flood hazard map. Lastly, utilizing AHP techniques, a flood hazard area map of the Awash River Basin (ARB) was created after weighted overlay. Additionally, the results of the classification of the flood hazard map produced in this work are quantitatively validated using a widely used validation technique: the area under the curve (AUC) of the Receiver Operating Characteristic (ROC) methods. The AUC score of 0.92 indicated an outstanding validation outcome. Population growth and general land use changes, including increased agricultural output, increased overflow, and created a high flood hazard zone in the downstream regions of Awash River basins. Recurrent floods have therefore increased in frequency each year in the Awash River Basin, causing large financial losses as well as associated societal effects. The primary cause of this is the climate and other associated factors. Additionally, Gebremichael et al.

(2025), emphasize that the majority of the basin, or 5,855,130.12ha (51.4%), is at high risk of flooding, while the second-highest area coverage, or 4,625,378.51ha (40.6%), of the entire Awash River Basin area coverage, is at moderate risk of flooding.

Table 4.6 Land use class change detection percentage rate

Landuse_Class	1990-2000	2000-2010	2010-2020	1990-2020
Agricultural_land	69	-31.1	-0.69	15.3
Bare_land	-24	23.8	-0.27	-6
Deep_water_bodies	24	8.7	-58	-43
Forest_cover	112	-66.6	60.5	13.7
Urban_area	19	16.6	60.2	160
Wetland	107	45.9	-3.5	191

4.3.3. Relationship between Population Growth and LULCC Using Pearson Correlation

The Pearson correlation calculation indicates that the r values (Table 4.7 and Annex 4.1) for bare land, deep water bodies, agricultural land, and forest coverage (-0.75, -0.49, -0.28, & -0.25, respectively) have a negative interaction with population growth. Thus, while the population of the Awash River basin is increasing at an astonishing rate, the aforementioned land use groups are seeing a sharp decline. Specifically, we can state with simplicity that when population growth increased significantly, the study area's bare land transitioned significantly into different land use groups. In contrast, urban areas and wetlands are positively correlated with population growth (r values of 0.94 and 0.89, respectively). We can demonstrate how urbanization and population growth are substantially correlated. As a result, rural and semi-urban regions grew into urban areas, which in turn caused considerable changes in land use and cover. The strong positive correlation of urban and population growth shows that, the area of the urban tends to increase as the population increases that could add more stress on the already existing infrastructure and resources. Unsurprisingly, this could create problems like traffic congestion, higher demand for public services and heightened pressures on housing markets.

They can help urban planners set the baselines for analyzing the sustainable strategies of growth determined by the scenario of projected population dynamics. For instance, it could entail focusing on the development of green spaces, the best land use strategy to avoid urban sprawl, and guaranteeing people’s access to essential services that will respond to their increasing requirements. Results and influence of the correlation on decision making processes concerning the development and management of resources in the region is highly significant.

According to (Ganaie et al., (2021) and Rimba et al., (2021) the increase in the number of people and built-up patterns has caused alterations in land use–land cover and regularly results in flooding. This finding is also supported by Mahtsente Tadese (2020), who revealed that urbanization significantly correlates positively with population growth in the Awash River Basin. According to (EEA, 2004) climate change, population growth and urbanization are among the driving forces behind floods.

On the other hand, the expansion of irrigation activities along the river line of the Awash River basin has also strongly increased, and the development of irrigation activities in the area led to the creation of various small patches of wetlands. The small wetlands in the study area were created due to natural processes, such as sedimentation, erosion and, changes in water flow patterns. Moreover, frequent flash floods on the river side line are extremely common and contribute to the creation of patches of wetlands. Hence, these factors caused the wetland coverage in the Awash River basin to account for significantly greater coverage in association with population growth.

Table 4.7: Pearson correlation between different classifications of land use

Landuse_Class	r Value
Agricultural_land	-0.28
Bare_land	-0.75
Deep_water_bodies	-0.49
Forest_cover	-0.25
Urban_area	0.94
Wetland	0.89

4.3.4. Land Consumption Rate (LCR)

In 1990, 2000, 2010, and 2020, the Awash River Basin's estimated land consumption rates (LCR) were 0.29, 0.28, 0.26, and 0.34, respectively (Table 4.8). Given the strong correlation between urbanization and the LCR, the rate has been gradually declining over the last thirty years, suggesting that the Awash River Basin has a low development density.

However, the LCR decline rate in the studied area from 1990 to 2010 indicates that urban area growth is not keeping up with population increase. In the research area, there were still modest rates of population increase and urban area increment, nonetheless. According to Laxmikant Sharma (2012) the primary drivers of land use change and the increase of built-up land are population growth and developmental activity.

On the other hand, the LCR has risen sharply since 2020, which has somewhat accelerated the rise in progressive urbanization that is, the growth of urban areas has outpaced the rate of population expansion. According to Nesru (2021) there have been instances of extremely high LCR in certain cities, which can occasionally exceed double the population growth rate (PGR). Resulting in a high LCRPGR index, this demonstrates notable inefficiencies in urban land utilization and poor land resources management. Hence, the maximum urban area expansion was registered during 2020, and the trend also indicated that the rate will increase in the near future. This is considered urban extension or urban sprawl (Hasse, 2003). This finding is also supported by the finding from the Pearson correlation analysis of this study, which illustrates a positive association between land consumption rate and urban expansion.

The Awash River basin saw the fastest rate of LCR from 2010 to 2020, with significant LCR recorded throughout that time despite a very slow pace of population expansion. Inefficient urban land use and inadequate land resource management in the basin's urban and peri-urban zones may be the primary cause of this. According to Nesru (2021) between 2007 and 2014, a rapid pace of LCR occurred in certain cities, including Addis Ababa. Others saw significant growth following 2014. While population growth rate (PGR) is extremely low, a notable increase in LCR could be a hint of a rush by state or non-state entities to seize Peri-urban territory. In a similar vein, the cities' LCRPGR index, this gauges urban land use efficiency.

From 2014 to 2019, the majority of regional cities had high LCRPGR. Conversely, between 2007 and 2014, Addis Ababa's outlying cities had a higher LCRPGR index.

Table: 4.8 Land Consumption Rate for Awash River basin

Year	LCR (ha per person)
1990	0.29
2000	0.28
2010	0.26
2020	0.34

This could suggest that Addis Ababa and the surrounding area experienced rapid urbanization and extensive rural land conversion before the regional cities were affected. Moreover, the majority of Ethiopian cities have low urban land use efficiency. Addis Ababa's urban land efficiency is poorer than that of its regional peers, with an LCRPGR rating of 1.2: Nairobi (0.9), Dares Salaam (0.2), Khartoum (0.9), Kampala (0.4) and Kigali (0.6) (Melchiorri, 2019).

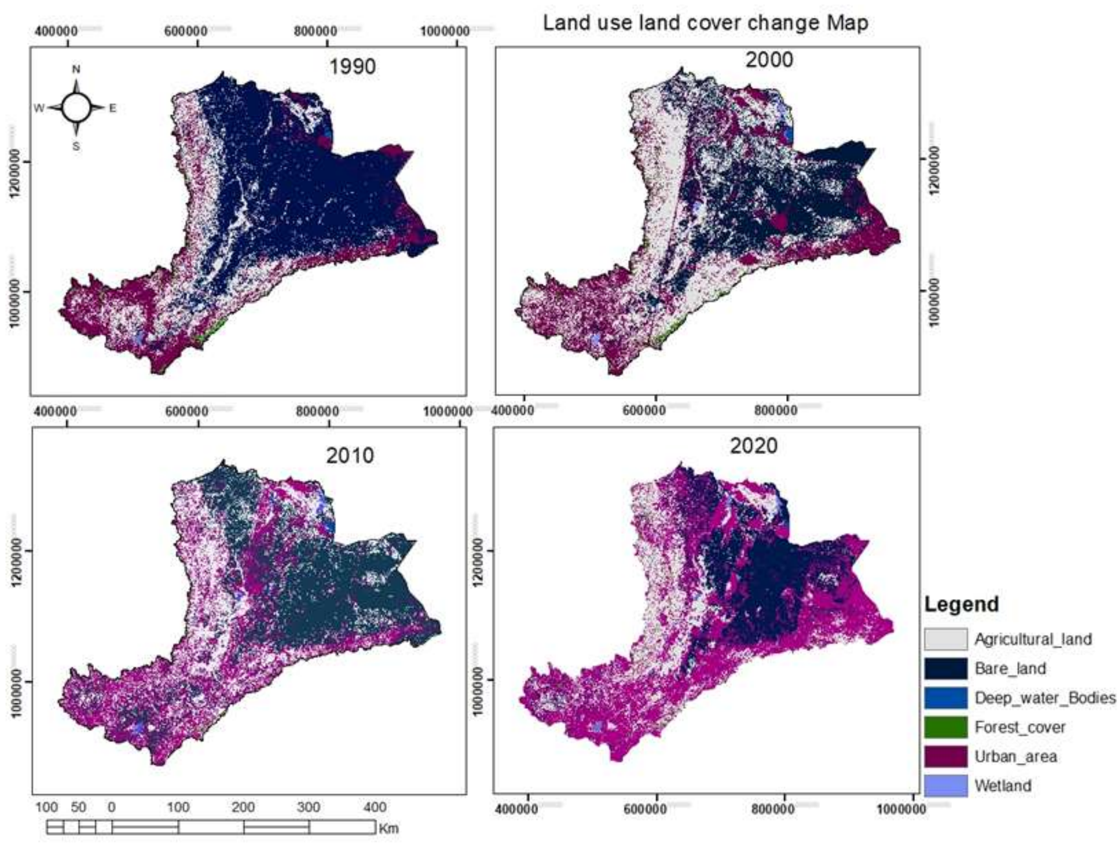


Figure: 4.2 LULCC of Awash River Basin; the figure generated with GIS software version 10.8 by the Authors. The link to the GIS software used can be found at https://www.arcgis.com/index.html

4.3.5. Sustainable Development Goal: Goal 15

Our research identifies critical factors influencing biodiversity and ecosystem health in the context of changing land use patterns. By analyzing the interactions between human activities and ecological systems, our findings reveal areas where conservation efforts can be most effectively focused to protect and restore biodiversity. This alignment with Sustainable Development Goal: Goal 15 is paramount, as it aims to protect, restore, and promote sustainable use of terrestrial ecosystems and manage forests sustainably in Awash River Basin. Moreover, our study suggests the need for integrating ecological considerations into land use planning processes to mitigate detrimental impacts on habitats and species. By advocating for sustainable practices such as agro-ecology, habitat preservation, and the restoration of ecological corridors, we aim to provide actionable recommendations that contribute toward achieving Sustainable Development Goal: Goal 15.

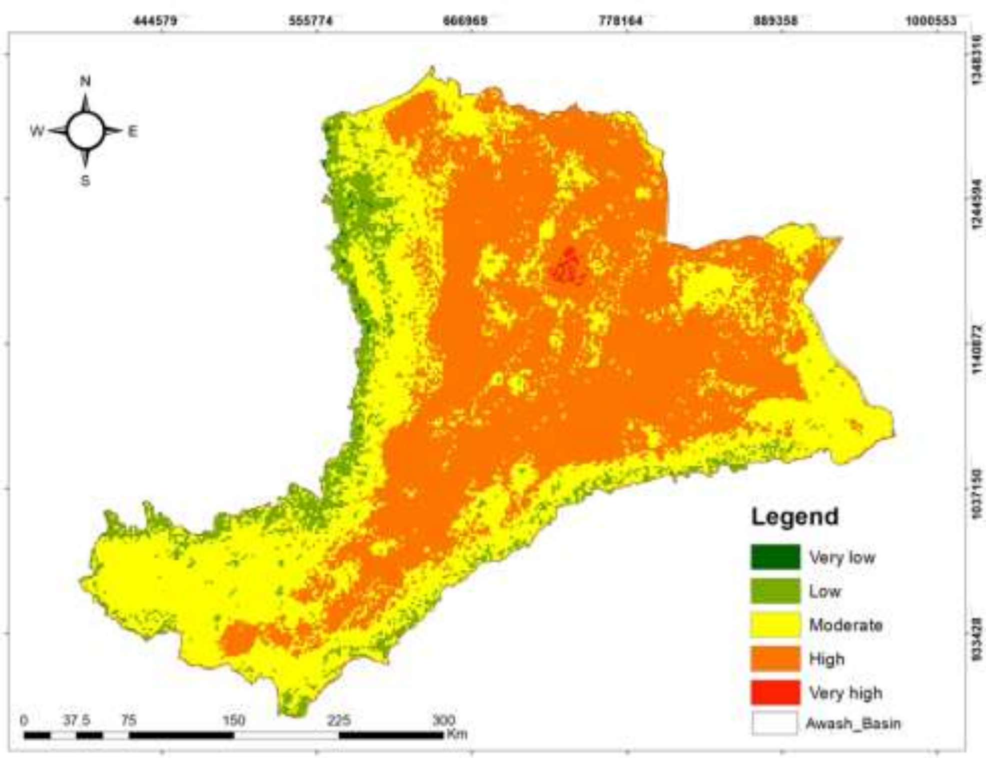


Figure 4.3: Flood hazard map of Awash River basin: the figure generated with GIS software version 10.8 by the Authors. The link to the GIS software used can be found at https://www.arcgis.com/index.html

4.4. Conclusion and Recommendations

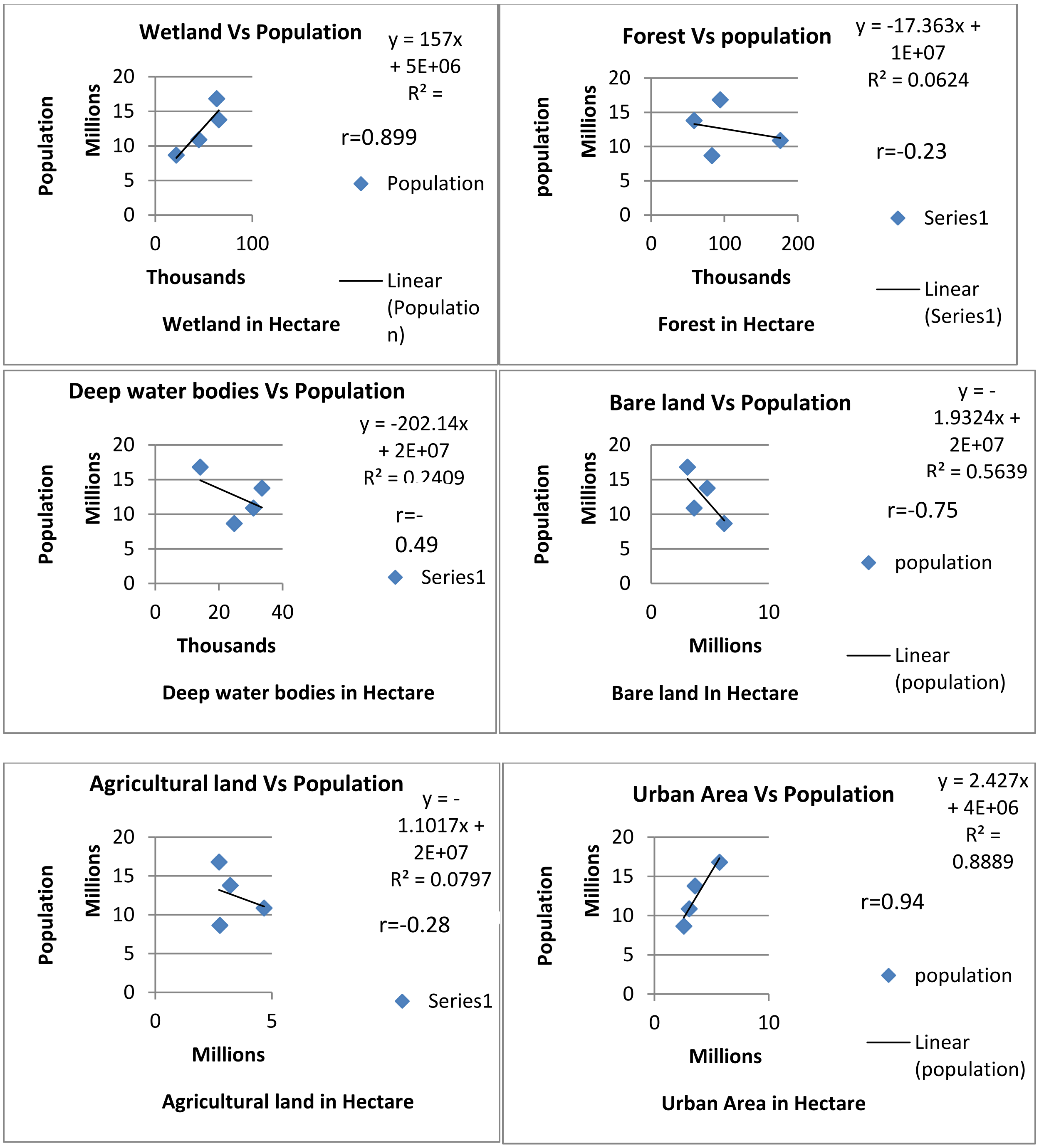
The main objective of this research paper is to analyze the dynamics of land-use land cover change and population growth with respect to flood hazards in the Awash River Basin using remote sensing and Geographic information system (GIS). Supervised classification for image from 1990, 2000, 2010 and 2020 was accurately conducted, and the results were effectively discussed. According to the findings from the land use land cover classifications, in the year 1990 in ARB, the area with highest coverage was bare land, followed by agricultural land. Bareland drastically transformed into different land use types. In contrast, urban area coverage significantly and consistently increased from 1990 - 2020, which was strongly linked with increasing rates of urbanization and population growth in the Awash River basin.

The findings of the Pearson correlation analysis indicate a favorable association between the expansion of the human population and both urban areas and wetlands. This connection might show the strong relationship between population growth and urbanization. Furthermore, the study demonstrates that while urban and population growth has expanded dramatically, the rate of land consumption in terms of density has remained negligible. In 2020, there was a noticeable increase in the study area's population, urbanization, and land consumption rate. Since then, the growth of the population in conjunction with urban regions has the ability to impact land use land cover, which has led to flooding. Considering sustainable nature-based solutions to mitigate spontaneous rapid land use changes and flood impacts is invaluable. Some nature-based solutions that can be implemented in the region to improve the effectiveness of our recommendations are proposed. Wetland restoration is a very important aspect of improving natural habitat modification as it can help to both increase natural water retention and decrease flood risks and improve biodiversity. Additionally, reforestation can offer a huge pool to stabilize soil and regulate water. Enhanced watershed management and reduced surface runoff by increasing the forested areas of strategic locations mean that flood risks can be minimized. Promoting agro-forestry practices, such as triangular farming that combines agricultural productivity with ecological benefits through the establishment of resilient landscapes for the purpose of supporting local communities and environmental health would also be beneficial. The effect of incorporating these nature-based solutions does not only address immediate concerns had with land use changes and flooding but also greatly aligns with broader sustainability goals for the region and achieve long term resiliency in the region.

Sustainable stakeholder actions can be proactively adopted by adopting the pragmatic, nature based ways of addressing social and economic needs while safeguarding ecological integrity.

The paper concludes that this study has significant implications for policy makers, urban and environmental planners. They highlight the importance of addressing the correlation between population growth, urbanization, and land-use land-cover changes to mitigate flood hazards. Reforestation initiatives, such as Ethiopia's GLI, are successful in improving local microclimates, reversing land degradation, and restoring ecosystem services, all of which improve human health and agricultural output. This study also emphasizes the need for sustainable solutions that prioritize nature-based approaches to mitigate the impacts of severe land use land cover change and flood events. Overall, this research provides valuable insights into the complex relationships among land use land cover changes, population growth, and flood hazards in the Awash River Basin. Moreover, this research helps to succeed Sustainable Development Goal number 15 by 2030.

Annex 4.1. Pearson correlation graph (r value)



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CHAPTER FIVE: MAPPING FLOOD HAZARD AREA IN THE AWASH RIVER BASIN (ARB), ETHIOPIA USING GIS AND AHP APPROACH

5.1. Introduction

5.1.1. Background Information

According to Martini and Loat (2007) and Ward (1978), a flood is defined as a body of water that is not submerged or as a phenomenon that occurs when silt and/or water are present in areas that are not typically thought of as water bodies. Nevertheless, several scholars demonstrate that floods are a threat that occurs naturally and is caused by a combination of hydrological and climatic factors. Floods are one of the most common and widely distributed natural disasters in the world and typically cause great damage in many regions (World Bank, 2015). They can result in significant yearly losses in both financial and human terms (Shu et al., 1993). In addition, floods are divided into four categories according to their causes and locations: river, coastal, urban, and flash floods. Floods can also be categorized as socio-natural or unnatural hazards, which means that they are a natural disaster that is made worse by human activity (ISDR, 2009).Floods happen when water overflows at river's natural or artificial limits, including groundwater from heavy or protracted rains, momentarily flooding an area, usually on dry land.

In addition to natural occurrences, human activities like pollution, deforestation, or ongoing unsustainable development that alters or impacts the natural terrain are among the most significant environmental hazards (Wisner et al., 2003; Martini and Loat, 2007; Klijn, 2009). Unusual heavy rainfall is the primary cause of flooding in Africa. Surface land degradation, deforestation in catchment areas, excessive population density near river banks, poor land use planning, development zoning on the flood plain, inadequate drainage, and poor management of the river reservoir's expulsions are some additional human-induced causes of deterioration.

Ethiopia is among the sub-Saharan nations that are susceptible to floods and other natural calamities and droughts (Ethiopian Red Cross Society, 2012). After drought, flood is Ethiopia's second worst threat (Zewde, 2004). This is due to the natural drainage patterns created by key river lines in the highland ranges and lowland plains. Changes in the country's climate and land use have led to a sharp increase in floods' severity and regularity happening recent years (Zewde, 2004).

As the population grows and more people move into areas near riverbanks, the impact is increasing due to land and forest degradation (Semu, 2007). Flooding of unexpected and irregular intensity threatened several parts of the country. River basins and metropolitan areas are particularly affected; for example, flooding in 2006 killed 300 people in South Omo and Dire Dawa. As a result, many individuals are impacted before the relevant decision makers receive the actual facts. In addition, flooding in 2006 affected about 357,000 people, resulting in 40 million Eth. Birr in losses, 600 fatalities, and 200,000 displaced people (UNOCHA, 2006).

The Awash River Basin (ARB) is currently experiencing an array of environmental problems, notably aridity, high level of acidity, declining of natural water, soil degradation, high human density, and ruining of wetland regions (Hailemariam K., 1999). Another major issue that might aggravate the ARB's environmental deterioration is flooding (Girma, 2010). According to assessment by the Awash River Basin Authority (2017) Water logging was caused by floods in the Gedabassa and Borkona swamp areas of Becho Plain. Furthermore, the other dangerous occurrences that are vital to the area were potential hazards from flooding in the downstream section of the basin area. Within Ethiopia's primary river basins in the rift valley is the Awash River Basin, besides one of its most frequently flooded areas (Wondim, 2016; Kefyalew, 2003). Heavy rainfall in the ARB's highlands and substantial release from the dams in Koka throughout the season of rains, especially in August (Ashenafi, 2016) result in floods downstream and devastation to communities near any portion of the river (Abebe, 2007).

On the basis of the flood incidents that have taken place in the upper ARB, September 2017 was noted to have been a year of severe floods in the Sebata Hawas, Walmera, and Ejere woredas; 2014, 2016 and 2017 in Liben Chukuala and Bora woredas; 2012, 2015 and 2017 in Fentale; plus at the woredas of Ilu and Sebata Hawas in 2018 and 2019, respectively. In the Awash River Basin, major cities were frequently in risk of flooding. For example, Adama experienced a severe flood in 2008, 2009 and 2016, which caused significant expenses in many city districts (Dejene et al., 2017; Yonas et al., 2022).

Most metropolitan spaces in the ARB are very susceptible to flooding due to a variety of factors, including terrain, alterations in land cover and use, sharp slopes, severe weather, rise in population, swift urbanization, plus upper watercourse operations.

Inadequate drainage systems, urban impermeable buildings, the kinds of materials used to build dwellings, and the quick illegal housing constructions near riverbanks all have a major impact on the serious repercussions of flooding dangers in city centers (World Bank, 2015). Since impermeable barriers can be erected in metropolitan areas to reduce runoff penetration, surface flooding is unavoidable as a result of urban expansion. After that, the runoff's potential and rate of discharge grew downstream of the cities (Rasul et al., 2018). Over time, flood damages in ARB increased regarding ecological, social in nature and financial factors. Ultimately, catastrophic flood damages are caused by the absence of combined risk oversight and prompt warning mechanisms within many city governments in the basin. Improvements in hazard analysis, mitigation, and management are necessary to stop such recurring problems (Ebert et al., 2009). For this reason, identifying and reducing predicted flood hazards and their primary causes requires mapping areas that are prone to hazards using geospatial models. Furthermore, the ARB will require the implementation of nature-based flood mitigation strategies, consistent flood management, accurate forecasts, and enhanced early warning capabilities.

Recent research demonstrates that NBS can be used to persistently address a variety of problem areas. Nature based practice mainly entails protecting and repairing of natural systems, like as regenerating natural forests, avoiding exotic species, interlinked floodplains with their rivers and constructed interventions, together with installing of green roofs and artificial wetlands (M Acreman et al., 2021). Furthermore, reduction of flood hazard (Song et al., 2018), runoff infiltration and storage, lowering erosion and particle movement, as well as postponing and decreasing runoff from surfaces Loperfido et al. (2014), increasing of aquifers recharge, reducing contamination of surface water Donnell et al. (2018), enhancing of absorption of nutrients Loperfido et al. (2014), preserving wetness in the soil, and improving emergence of flora are main contribution of Nature Based solutions. Nature Based Solutions have potential to deal with various environmental issues including natural disasters caused by urban development and climate fluctuations (Dong et al., 2017; European Commission, 2016; Liu et al., 2015; Nesshöver et al., 2017). Various scholars also stress that, NBS practicing for sustainable reduction of flooding, resilience to and abatement of climate change, and enhancement of urban habitats (Cohen-Schacham et al., 2016; Denjean et al., 2017). Henceforth, flood hazard mapping should be used in planning and limiting for areas subject to flooding (Bhatt et al. 2014). Numerous scholars (Kebede, 2012; Getahun et al, 2015; Yonas et al, 2022) indicates GIS based flood hazard mapping as an important way of prevention from severe flood hazards. In addition, Alkema (2004) states that geospatial technics remain important to measure the threat of flooding whenever there has been obsolete data availability.

Furthermore, mapping flood hazard areas significantly contributes to achieving Sustainable Development Goals derived via UN in 2015. Floods have a severe effect on water resource sectors and infrastructures, consequently leading to an impact on SDG 6: Clean Water and Sanitation. In addition to that destruction by floods, expensive economic expenditures are needed to reconstruct this eventually imposed effect on SDG 8: Decent Work and Economic Growth. Moreover, severe flood hazards impact crop production and food security, which consequently impact SDG2: Zero Hunger. Hence, sustainable spot identification and mitigation of flood hazard substantially value SDGs. Likewise, to achieve SDG 13: climate action, mapping of climate-induced flood hazard areas has a significant role to play in combating climate impacts. Addressing these challenges requires a concerted effort from governments, communities, and organizations to implement effective flood management strategies. By investing in resilient infrastructure and sustainable agricultural practices, we can not only protect vulnerable populations but also enhance our overall capacity to adapt to climate change (WHO, 2015; UN, 2017; UN-Water, 2017).

Indeed, critically important to map out areas that are sensitive to flooding, comprehend the possible causes of flooding, and identify long-term fixes for floods and associated problems (Dejene et al., 2017). Therefore, the study discusses the main factors that contribute to and effects of floods in the ARB and aim to create a GIS-oriented flood hazard area map. Additionally, the paper attempted to incorporate nature-based solutions to reduce high peril of floods in the ARB.

5.2. Research Methodology and Materials

5.2.1. Study Area Description

5.2.1.1. Locations

ARB is sited between $7^0$53'- 12^0 latitude and $37^0$57'- $43^0$25' Longitude (Figure 5.1). And covered an area of 112,000Km^2, comprises 10.5 million people and annual surface water accounts around 4.9 BM^3 (MEFCC, 2018). The elevation is fluctuating between 210 to 4,195m above sea level. The Awash River's whole length is accounts 1,250 km and cover portions of the Amhara, Afar, Somali, and Oromia states (Tiruneh et al., 2013). The river originates from the elevated land next to Ginchi town on the west side of Addis Ababa, Ethiopia's capital. It then travels into the Afar Triad via the heart of the Rift Valley until draining into the briny Lake Abbe on the Djiboutian border (Sonder and Peden, 2008).

The Upper Awash, the Middle Awash, and the Lower Awash are the three parts of the ARB. The Upper Awash includes the areas above 1,500 meters from Koka Dam, the Middle Awash includes the areas between Koka Dam and Awash station at elevations between 1000 and 1500 meters, and the Lower Awash includes the areas between 500 and 1000 meters as well as the Eastern catchment (MEFCC, 2018; Edossa et al., 2010; Hailemariam, 1999). There are two distinct rainy seasons in the Upper and Middle Awash: an infrequent one from March to May and a longer one from July to September. The upper and middle Awash River Basin experiences humid weather, whereas the lower Awash River Basin experiences dry weather. Because of their high clay content, the soils of the basin are ideal for growing cotton. Cereals and sugarcane grow well in clay loam and sandy loam soils, whereas pasture with range grasses thrives in sandy soils (MEFCC, 2018).

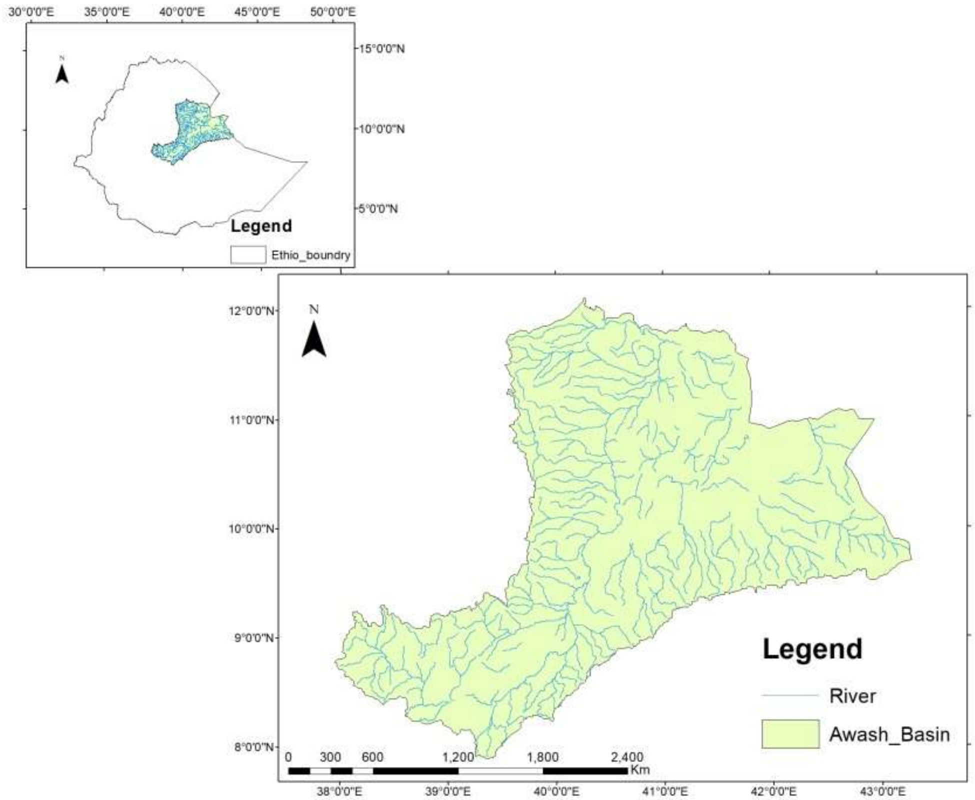

Figure: 5. 1 Study area map ARB; the figure generated with GIS software version 10.8 by the Authors. The link to the GIS software used can be found at https://www.arcgis.com/index.html

5.2.2. Data Gathering and Flood Hazard Mapping Techniques

In this study, very extensive use was made of the following scientific instruments to acquire the required information: DEM derived from the United States Geological Survey (USGS) at (http://glovis.usgs.gov) has a pixel density of 30 meters. Other helpful characteristics were the Ministry of Agriculture's land surface elevation details, the Ethiopian Metrological Agency's (EMA) yearly precipitation records, and the FAO soil map website. ERDAS IMAGINE was used to stacking, mosaic and clipped every band's layers. GCSWGS-1984 geographic coordinate system was used to geo-reference the satellite images collected. The 37N zone of the UTM projection system was used for this study area (WGS, 37N). Correspondingly, ground control points (GCP) distributed randomly, relevant field data of resource assessment, soil type, land use/land cover, and the precise positioning of areas that are vulnerable to flooding, among several other factors were collected and reviewed in the field work. Google earth pro also used to collect 90 random sample points from flooded and non-flooded areas.

5.2.3. Employing GIS models to examine data

ArcGIS 10.8 was used to analyze the satellite image data using several GIS models. Chronologically, the analysis appears as follows:

- Delineating the boundaries of the ARB to identify areas that are vulnerable for flooding. Used ArcGIS 10.8 to create a DEM with a geographic resolution of around 30 meters.
- Maps were produced based on GIS modeling. Elevation and slope were produced by DEM processing using ArcGIS 10.8. To create the elevation layer for the study, the DEM layer was divided into five classes. Slope environment, within an Arc-Map "Spatial Analyst" tool, was utilized to create a slope layer from a DEM. Drainage density is also derived from DEM. Proximity to river and soil type maps also generated using GIS.
- Using historical Annual rainfall data (1986 -2023) from meteorological Agency (EMA) within the basin and the inverse distance weight technique, the rainfall map was produced. ARB's principal meteorological sources include; A.A bole, Abomssa, Debre Sina, Debre Zeit, Dire Dawa, Gewane, Ginchi, Holeta, Kimoye, Koka Dam, Kombolcha, Kulumsa, Majete, Melkasa, Mersa, Metehara, Mille, Modjo, Shola Gebeya, Tora Showa, Adayitu, Addis Alem, Akaki, Aleltu, Aliyu Amba, and Debre Sina.
- Geographic Coordinate System WGS 1984 (GCS WGS 1984) was used to map the images used in this project, which was acquired in 2020 by Landsat 8/9, a sensor known as the Operational Land Imager (OLI), with a detail level of 30 meters. This information was used to create a LULCC map. Exemplary training samples were also created using reference sets and topography maps. The maximum likelihood method for supervised classification in ArcGIS 10.8 was used. After the imagery was categorized, the accuracy of the mapping was given more consideration, and the results were so confidently classified that they satisfied the standard criteria for classifying remote sensing images, with an overall accuracy of 96 percent and a Kappa coefficient of 0.95.
- The first flood hazard model was created using data from the Digital Elevation Model (DEM). Using equal interval categorization based on the degree of flood vulnerability, the DEM has been classed into five general categories of hazards: very high, high, moderate, low, and very low. Getahun and Gebre (2015) state that ArcGIS 10.8 was used to extract, reclassify, and weight the key factors linked to floods, such as slope,

precipitation, elevation, land use/land cover (LULC), drainage density, proximity to a river, and soil type. The Awash River Basin (ARB) flood danger zonation map was then created using a weighted overlay approach.

5.2.4. Flood hazard analysis

Elevation, slope, precipitation, drainage density, land use, soil type, and river proximity are the primary flood posing characteristics utilized in perils of flooding assessment. The research articles, expert opinions, and stakeholder conversations were used to determine the following criteria (Costache et al., 2020; Lyu et al., 2020; Das, 2019; Boulomytis et al., 2019). Previous studies classified flood-producing raster layers in accordance to their capacity to inundate the area (Abebe, 2007; Bapalu, 2013; Yalcina et al, 2011; Juan, 2006; Bishaw, 2012; Knoop, 2013). Variables related to flood threat are rated on an index of one to nine, where one denotes equal importance for both components and nine denotes more significance for one over the other. In contrast, the reciprocals 1/1 and 1/9 indicate one aspect is seen to be more significant over the other (Table 5.1) (Saaty 1980; Saaty and Vargas 1991). To perform an array of criteria evaluation of the influence on flood creation within the research area, the factors' respective weights were examined.

5.2.4.1. Elevation

Raster layers for elevation are produced using ArcGIS environment from DEM data. The elevation raster layers were categorized into five groups by the Categorization mechanism in the ArcGIS environment. According to voluminous researchers, the likelihood of flooding can be severe when elevation decreases, and the other way around Al-Rawas et al. (2001), Nyarko (2002), Bapalu (2005), Peduzzi et al. (2005), Sanyal (2003), Shrestha (2004), Todini et al. (2004), UNDP (2004), Gazi et al. (2019), Ogato et al. (2020), and Wondim (2016).

The study area was divided into five groups according to how elevation affected the risk of flooding: Very low (2287–4171 m), low (1659–2287 m), intermediate (1104–1659 m), high (680–1104), and very high (210–680 m) ***(Figure 5.2).***

5.2.4.2. Slope

The slope is an attribute property that expresses how steep is a characteristic with respect to the horizontal plane. This study is based on the fact that slope is a major predictor of areas at risk of flooding (Wondim, 2016; Alemayehu, 2007). Additionally, the value of the slope will decrease in inverse proportion to the slope of the ground. The slope coefficient decreases as the surface becomes smoother. In the environment of ArcGIS converter toolkit, DEM was converted into slopes and classed into five groups. When classifying, keep in mind that a lower slope value corresponds with increased flood vulnerability and vice versa. Accordingly, class extremely high is less than 8% and the assigned rank was 5, class high is between 8% and 21% and ranked 4, class moderate is between 21 and 40% and ranked 3, class low is between 40 and 67% and ranked 2, and class very low is greater than 67% and ranked 1(Figure 5.3).

5.2.4.3. Rainfall

When creating a map of flood threats, rainfall is essential (Ogato et al., 2020). Using historical rainfall data from meteorological stations in and around the research region, the rainfall map was created using the inverse distance weight technique (Ogato et al., 2020; Desalegn and Mulu 2020). Rainfall in the ARB averages between 940 and 1158 mm per year. Because flooding is largely caused by excessive rainfall, weight was assigned to rainfall classes. As rainfall rises, flooding discharge rises as well (Adiat et al., 2012; Blistanova et al., 2016; Gazi et al., 2019).

As a result, five classes were created using the average rainfall information. An area with higher rainfall, classified as class very high which is greater than 1100 mm/year and ranked as 5, class high (1100 - 800 mm/year) ranked as 4, moderate (800 - 600 mm/year) ranked as 3, low (600 - 400 mm/year) rated as numbered 2 and very low rated as number 1 (<400 mm/year) (Figure 5.4).

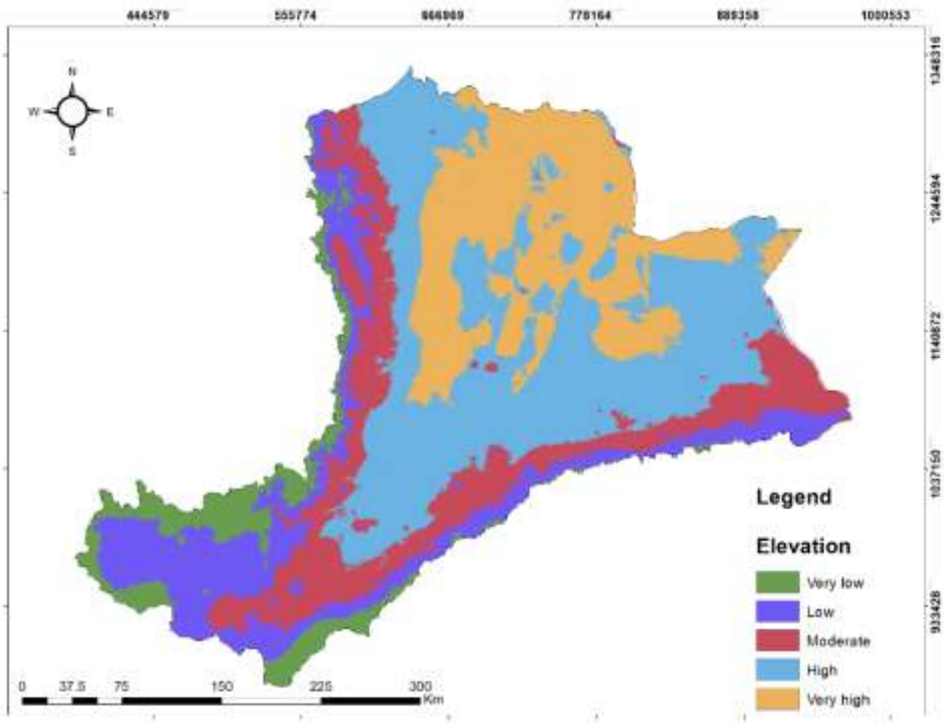

Figure: 5.2. Elevation map of Awash River basin

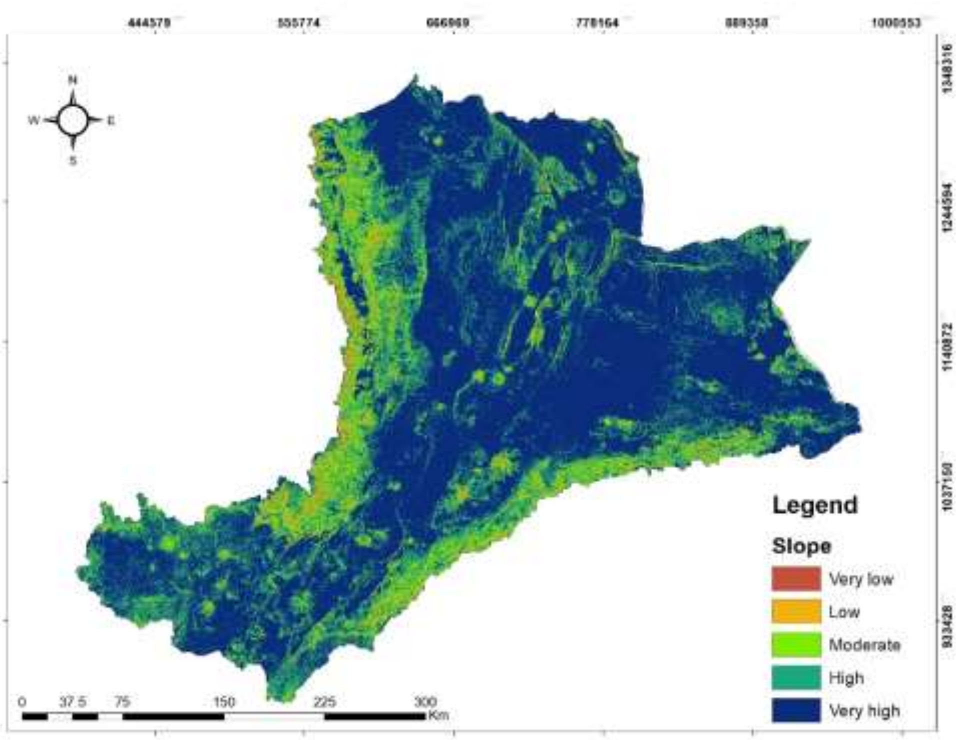

Figure: 5. 2. Slope map of Awash River basin

5.2.4.4. Drainage Density

Drainage density (Valleys) was determined using the DEM by the spatial analyst extension. But not all valleys have water in them. Drainage density is the overall length of all streams and rivers in a drainage basin as compared to the area of the drainage basin (Rahmati et al., 2016). The lower the soil permeability, the higher is the drainage density. When the effective area with low permeable is large, it will induce the drainage density to be high, and the precipitation must lead to the runoff to be high and so on. Hence the high drainage density areas tend to flood more (Chibssa, 2007; Wondim, 2016; Paul et al., 2019). A natural break represented the five-class consideration of the drainage density layer. A very high drainage Density (11 km/km^2 - 17 km/km^2) is very high and it is rated as class 5, high (6.7-11 km/km^2) is rank ed as 4, moderate (3.7 - 6.7 km/km^2) as class 3, low (2 - 3.7 km/km^2) ranked as 2 and very low ranked as 1 (<2 km/ km^2) **(**Figure 5.5).

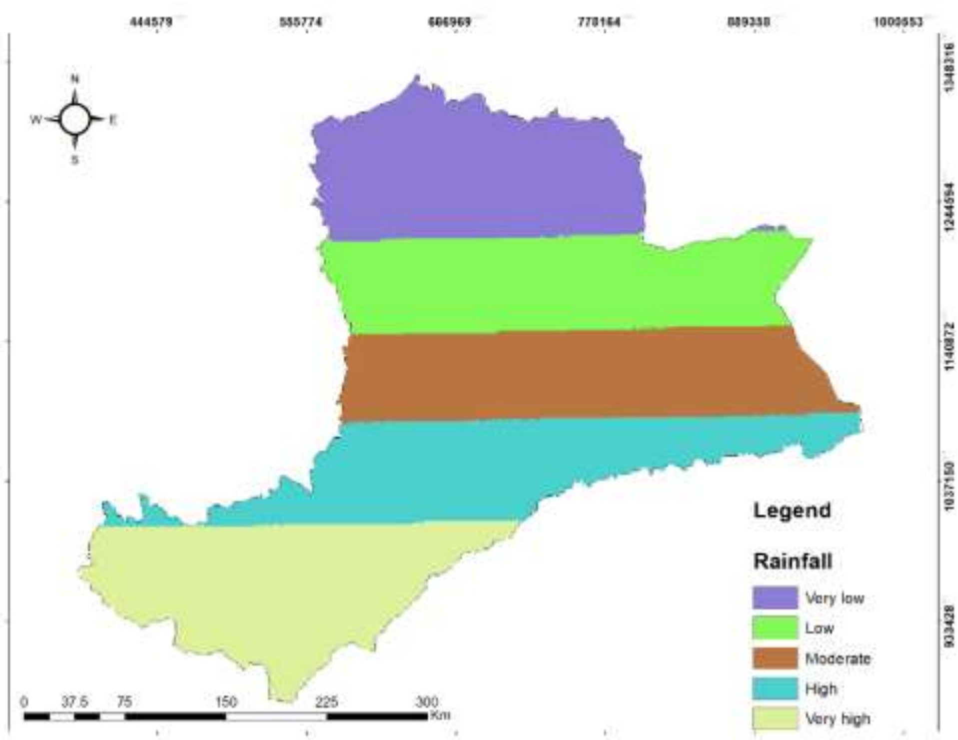

Figure: 5. 3. Rainfall map of Awash River basin

5.2.4.5. Proximity to river

River distance was one of the principal parameters applied to assess flood hazard mapping in the study basin. Overtopping and flooding in the river buffer zone are the main cases in the study region (Bapalu and Sinha, 2005; Rincón et al., 2018; Vojtek and Vojteková, 2019). In the present study, flood menace class was grouped into five classes, the basin river network is used to determine the following levels: very high (0–1,000 m), high (1,000–2,000 m), moderate (2,000–5,000 m), low (5,000–8,000 m), and very low (8,000–15,000 m) (Figure 5.6). For weighted overlay analysis, the proximity map was classed and merged into other criterion maps.

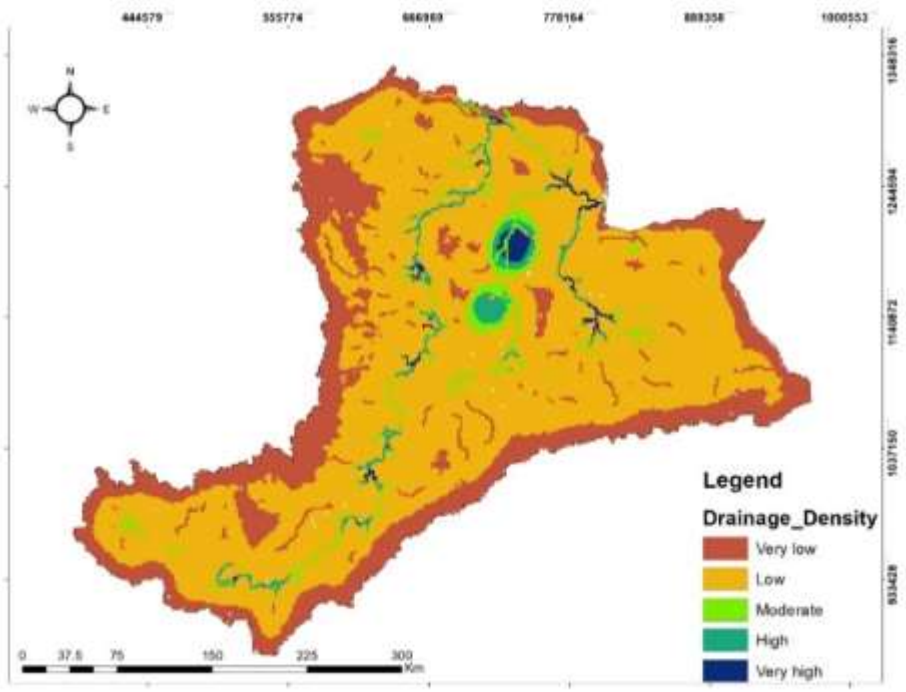

Figure: 5. 4. Drainage density map of Awash River Basin

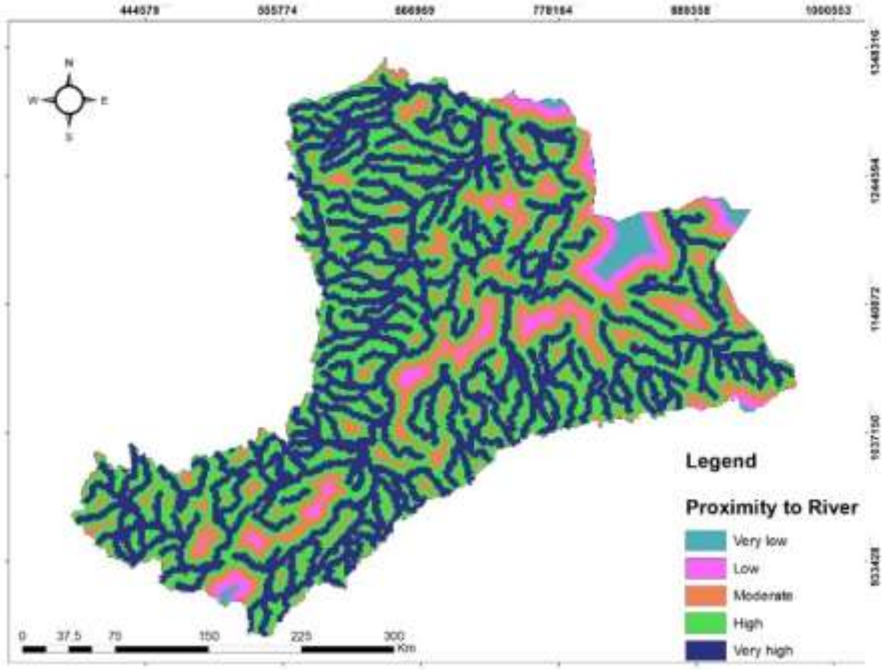

Figure: 5. 5. Proximity to river map of Awash River basin

5.2.4.6. Land-use land cover

LULC affects surface and groundwater together, debris movement, and infiltration rates within the basin. Since land cover directly influences several aspects of the hydrological cycle, including runoff behavior, concentration, infiltration, and interception, it follows that land cover also indirectly influences floods. When taken together, the previously described traits provide information about flood risk and the hydrological response (El Morjani, 2011a; El Morjani, 2011b; Sarma, 1999; Nyarko, 2002; Bapalu, 2005; Peduzzi et al., 2005; UNDP, 2004). The LULC of the ARB was reclassified into five classes and converted into a raster layer, which was dependent on its ability to amplify or to mitigate the frequent occurrence of flood. Bare land was put into very high class and ranked as 5, urban/built up land put into high class and ranked as 4, agricultural land put into moderate and ranked as 3, wetland/shrub land put into low and ranked as 2 and forest land put into very low and ranked as 1 as indicated in (Figure 5.7).

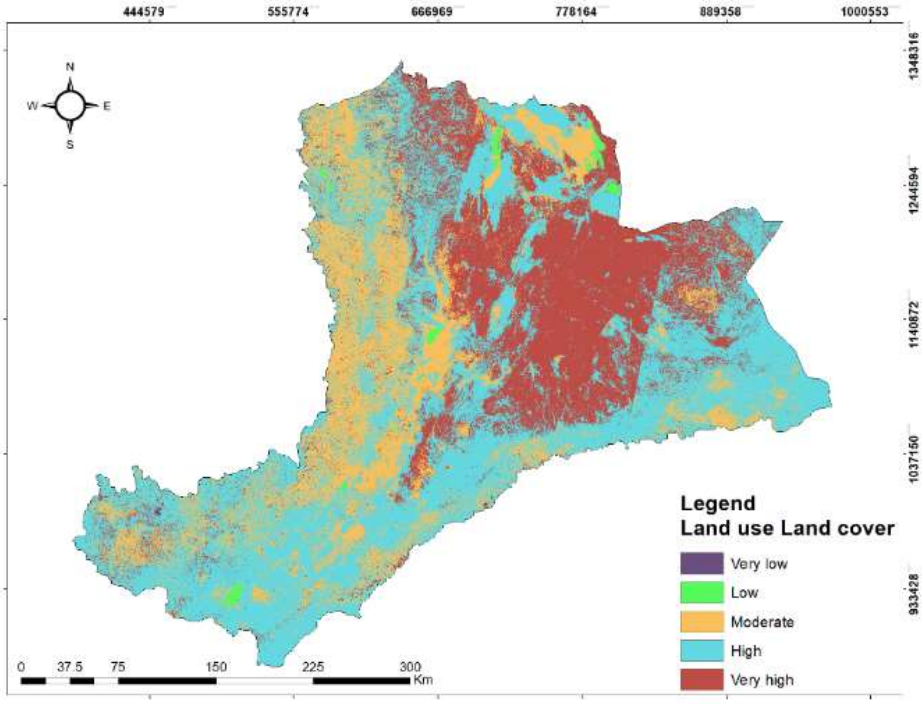

Figure: 5. 6. Land use land cover map of Awash River basin

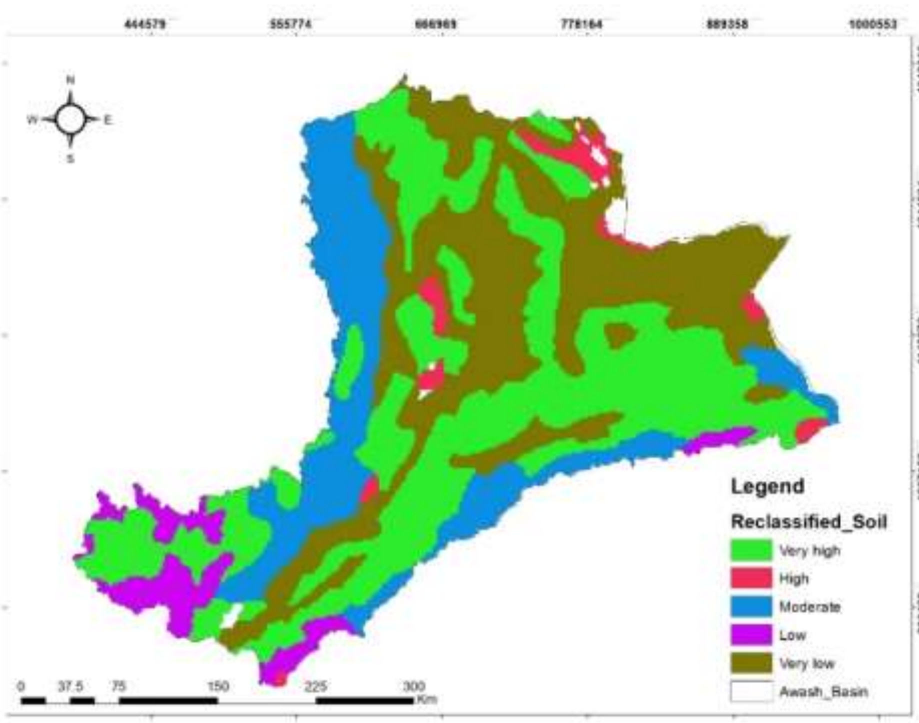

Figure: 5. 7. Reclassified soil map of Awash River basin

Table: 5. 1. The relative relevance scale by Satty (Saaty, 1980; Saaty and Vargas, 1991)

	Elevation	Slope	Drainage density	Rainfall	Proximity to river	Land use	Soil type
Elevation	1	2	3	5	7	7	9
Slope	1/2	1	2	3	5	7	9
Drainage density	1/3	1/2	1	3	5	5	7
Rainfall	1/5	1/3	1/3	1	3	5	7
Proximity to river	1/7	1/5	1/5	1/3	1	3	5
Land use	1/7	1/7	1/5	1/5	1/3	1	3
Soil type	1/9	1/9	1/7	1/7	1/5	1/3	1

5.2.4.7. Soil types

Although the range of different kinds of soil is very broad, the main approach to the hydrologic soil grouping (HSG) as used in the Ministry of Water and Energy in Ethiopia permitted the differentiation of a few main soil classes. They are: PellicVertisols, Chromic Vertisols, Chromic Luvisols, Euthric Nitosols and Lithosols (Abebe et al., 2007). The raster conversion was done on these five groups of soil types and they were reclassified respective to their ability to cause floods. Therefore very high ranked as class 5, high as class 4, moderate as class 3, low as class 2 and very low as class 1. In such a manner, it is assumed that Pellic Vertisols possess a very high flooding capacity that is reclassified as class 5, Chromic Vertisols possesses high flooding capacity as reclassified as class 4, Chromic Luvisols/cambisols possesses a moderate flooding capacity as reclassified as class 3, Euthric Nitosols possesses a low flooding capacity as reclassified as class 2 and Lithosols possesses very low flooding capacity then reclassified as class 1 (Figure 5.8). Moreover, Abebe et al. (2007), report that the ARB is dominated with vertisols soil type.

Table: 5. 2. The scale method used by Satty

Level of significance	Preference level	Justification
1	Equal significance	Two activities make equal contributions to the goal
3 (1/3)	One factor's relative importance is moderate	One activity is marginally preferred over another by judgment and expertise
5 (1/5)	Substantial or crucial significance	One service is greatly favored over another by judgment and expertise
7 (1/7)	Very important	A task is highly preferred, and its practical dominance is evident
9 (1/9)	Extreme significance	The strongest potential order of affirmation is found in the evidence supporting one activity over another
2,4,6,8	Values in the middle of two adjacent judgments	When it's necessary to compromise

Table: 5. 2. The fraction form used by Satty

	Elevation	Slope	Drainage density	Rainfall	Proximity to river	Land use	Soil type
Elevation	1	2	3	5	7	7	9
Slope	0.5	1	2	3	5	7	9
Drainage density	0.33	0.5	1	3	5	5	7
Rainfall	0.2	0.33	0.33	1	3	5	7
Proximity to river	0.14	0.2	0.2	0.33	1	3	5
Land use	0.14	0.14	0.2	0.2	0.33	1	3
Soil type	0.11	0.11	0.14	0.14	0.2	0.33	1
Sum	2.42	4.28	6.87	12.67	21.53	28.33	41

Table: 5. 3. Pairwise matrix normalization

	Elevation	Slope	Drainage density	Rainfall	Proximity to river	Land use	Soil type	Weight of the criteria
Elevation	0.4	0.47	0.44	0.4	0.32	0.25	0.23	0.36
Slope	0.2	0.23	0.3	0.24	0.23	0.25	0.23	0.24
Drainage density	0.13	0.12	0.15	0.24	0.23	0.17	0.17	0.17
Rainfall	0.08	0.1	0.05	0.1	0.14	0.17	0.17	0.11
Proximity to river	0.06	0.05	0.03	0.03	0.04	0.11	0.12	0.06
Land use	0.06	0.03	0.03	0.02	0.01	0.04	0.1	0.04
Soil type	0.045	0.026	0.02	0.01	0.01	0.01	0.02	0.02

Every weight was identified regarding their input in the realization of flood hazard to the study area depending on topographical consideration and experimental judgment that was obtained after consulting different 10 experts from ministry of water and energy, ARB office (Table 5.1; Table 5.2, Table 5.3 & Table 5.4), (Hussain et al., 2021; Vojtek and Vojtekova, 2019; Argaz et al., 2019; Gazi et al., 2019; Wondim, 2016).

5.2.5. Analysis of flood hazard maps using multiple metrics (AHP)

The flood drivers were ranked and given weights using the AHP, a multi-criteria decision-making technique according to their potential effects on the emergent outcome. An objective, organized method for evaluating and integrating the effects of several aspects is provided by an approach to decision-making that uses multiple criteria is the Analytic Hierarchy Process (AHP). Multiple tiers of independent and dependent, both qualitative as well as quantitative information are placed on top of one other. This approach ranks groups of tasks otherwise used as standards to determine their level of significance (Saaty, 1980, Yalcina et al., 2011). Rasterized and classed elements is weighted potential flood causing factors that were matched and compared (Table 5.5). After an evaluation of these multiple strata using weighted overlay, after the ultimate map had been generated, it was divided into classes according to how each layer affected the likelihood of flooding.

Table: 5. 4. Eigen vector Parameter weights derived via contrast of a pairwise matrix

	Criterion weight (Normalized weight)	Influence (%)
Elevation	0.36	36
Slope	0.24	24
Drainage density	0.17	17
Rainfall	0.11	11
Proximity to river	0.06	6
Land use	0.04	4
Soil type	0.02	2
Total	1.00	100

A component's relative importance in relation to another is determined using the weighting technique. Something's weight in a weighted overlay gives it greater significance in relation to other elements. A comparison was made between one of the seven raster layers. Elevation, slope, drainage density, rainfall, proximity to a river, land use, and soil type are considered in accordance with the Analytical Hierarchical Process (AHP) to draw up the map of flood hazards using a GIS (Yalcina et al., 2011; Juan, 2006; Bishaw, 2012; Babalu, 2013).

The values of Numerical Consistency ratio (CR) are obtained as follows (Equation 5.1, Equation 5.2 and Equation 5.3) and must be within the scientific standard which is less than (< 0.1). Thus, the obtained Consistency ratio to compare pair-wise weights was 0.07 which indicates that pair-wise weights are at acceptable level (Table 5.6). Besides that, the CR result confirmed that the reliability of judgment is consistent.

$$CR = \frac{CI}{RI} \qquad \text{(Equation 5.1)}$$

The value of the consistency index (CI) can be acquired by:

$$CI = \frac{\lambda_{max} - n_i}{n_i - 1} \qquad \text{(Equation 5.2)}$$

λ_{max} derived from the equation that follows:

$$\lambda_{max} = \sum_{n=1}^{ni} \frac{(PW)_n}{n_i \, w_n} \qquad \text{(Equation 5.3)}$$

Where, *W* is the weight vector

Table: 5. 5. Derived Consistency ratio (CR)

	Elevation	Slope	Drainage density	Rainfall	Proximity to river	Land use	Soil type
Elevation	1	2	3	5	7	7	9
Slope	0.5	1	2	3	5	7	9
Drainage density	0.33	0.5	1	3	5	5	7
Rainfall	0.2	0.33	0.33	1	3	5	7
Proximity to river	0.14	0.2	0.2	0.33	1	3	5
Land use	0.14	0.14	0.2	0.2	0.33	1	3
Soil type	0.11	0.11	0.14	0.14	0.2	0.33	1
Criterion weight	0.36	0.24	0.17	0.11	0.06	0.04	0.02

	Elevation	Slope	Drainage density	Rainfall	Proximity to river	Land use	Soil type	Weighted sum value	Criterion weight	Ratio
Elevation	0.36	0.48	0.51	0.55	0.42	0.28	0.18	2.78	0.36	7.7
Slope	0.18	0.24	0.34	0.33	0.03	0.28	0.18	1.58	0.24	6.6
Drainage density	0.12	0.12	0.17	0.33	0.3	0.2	0.14	1.38	0.17	8.1
Rainfall	0.07	0.07	0.05	0.11	0.48	0.2	0.14	1.12	0.11	10.2
Proximity to river	0.05	0.048	0.034	0.036	0.06	0.12	0.1	0.45	0.06	7.5
Land use	0.05	0.03	0.034	0.02	0.02	0.04	0.06	0.25	0.04	6.25
Soil type	0.03	0.02	0.023	0.015	0.012	0.013	0.02	0.13	0.02	6.5

$$\lambda_{max} = \frac{7.7 + 6.6 + 8.1 + 10.2 + 7.5 + 6.25 + 6.5}{7} = 52.85/7 = \underline{\underline{7.55}}$$

$$CI = \frac{\lambda_{max} - n_i}{n_i - 1} \qquad \frac{7.55 - 7}{7 - 1} = 0.09166$$

$$CR = \frac{CI}{RI} \qquad \frac{0.09166}{1.32} = 0.069 = \underline{\underline{0.07}}$$

Random index (RI) can be acquired from standard tables (Table 5.7) (Saaty, 1980). RI value determined by the number of the parameters, hence, random inconsistency value for seven parameters is *1.32* as per clearly stated in the table.

Table: 5. 6. Value of Random Inconsistency (RI)

n	1	2	3	4	5	6	7	8	9	10
RI value	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

Weighted value received in the pair-wise comparison indicates that Elevation, slope factor, drainage density, rainfall, proximity to river, land use and soil type are to be merged in ArcGIS, the highest weight is assigned to elevation and the least weight given to the soil type factor. Flood hazard map of ARB was prepared on the basis of the formula/equation (Equation 5.4).

$$\text{Flood hazard} = \sum W_i X_i \qquad \text{(Equation 5.4)}$$

Where

W_i = weight of factor i;

X_i = criterion score of factors i

Hence, based on the calculated and finding results of weighted factor the flood hazard map for study area can be generated as follows.

Flood hazard = 0.36 × [Elevation] + 0.24 × [Slope] + 0.17 × [Drainage density] + 0.11 × [Rainfall] + 0.06 × [Proximity to river] + 0.04 × [Land use] + 0.02 × [Soil type]

5.2.6. Model validation

Checking of flood hazard mapping is critical to the understanding of whether the output map is correct or not. One of the most common methods of validation used globally are the area under the curve (AUC) of the Receiver Operating Characteristic (ROC) techniques is used to quantitatively authenticate the results of the categorization of flood hazard map produced in this paper. Unlike the area under the curve (AUC) which describes the extent to which particular classes can be separated, the possibility curve is known as the receiver operating characteristic (ROC) curve. The true positive rate (TPR), also known as sensitivity, is plotted on the ordinate (y-axis) of a ROC curve, while the false positive rate (FPR), also known as 1-specificity, is plotted on the x-axis (Wang et al., 2020a, b; Hu et al., 2020). In addition to this Wang et al. (2020a, b), clearly described as, a true positive (TP) indicates how many flood samples were successfully categorized, whereas a false negative (FN) indicates how many non-flood samples were incorrectly classified. True negatives (TN) show how many non-flood samples were appropriately categorized, whereas false positives (FP) show how many flood samples were misidentified. The values are calculated as:

$$TPR = \frac{True\ Positive}{True\ Positive + False\ Negative}$$

$$Specificity = \frac{True\ Negative}{True\ Negative + False\ Positive}$$

$$FPR = 1 - Specificity$$

Then AUC is also calculated for this ROC curve. The capacity to discriminate or separate will improve as the AUC value gets closer to 1 (Saha 2020; Mind’je et al., 2023; Mind’je et al., 2019; Rana et al., 2024). Ninety (90) sample point features are randomly selected and generated using Google Earth images based on the flood history of the basin and then compared using the ArcGIS overlay environment (Figure 5.9). These sample sites yield findings regarding false positives, false negatives, true positives, and true negatives. After that, TPR and FPR values are calculated. Finally, the AUC is calculated and the ROC curve is displayed with the help of SPSS and the Excel spreadsheet, AU- ROC values were calculated (Nam et al., 2002; Lin et al., 2019; Mandal, 2018; Vakhshoori, 2018). AUC-ROC validated model efficiency is often categorized as low from 0.5 to 0.6, average from 0.6 to 0.7, good from 0.7 to 0.8, very good from 0.8 to 0.9, and excellent if it is from 0.9 to 1 (Nefeslioglu et al.; 2010 Yesilnacar, 2005). AU-ROC is computed numerically in the manner described below: (Equqtion 5.5)

$$\mathrm{AU-ROC} = \sum_{i=1}^{n} (Xi + 1 - Xi) \times [\mathrm{yi} + \frac{yi+1-yi}{2}] \qquad \text{(Equation 5.5)}$$

Where

n is the threshold value; i is the threshold value; xi is the ratio of pixels with false positive values that indicate the presence of floods in flood regions; and yi is the percentage of flood areas with genuine positive values that indicate the presence of floods.

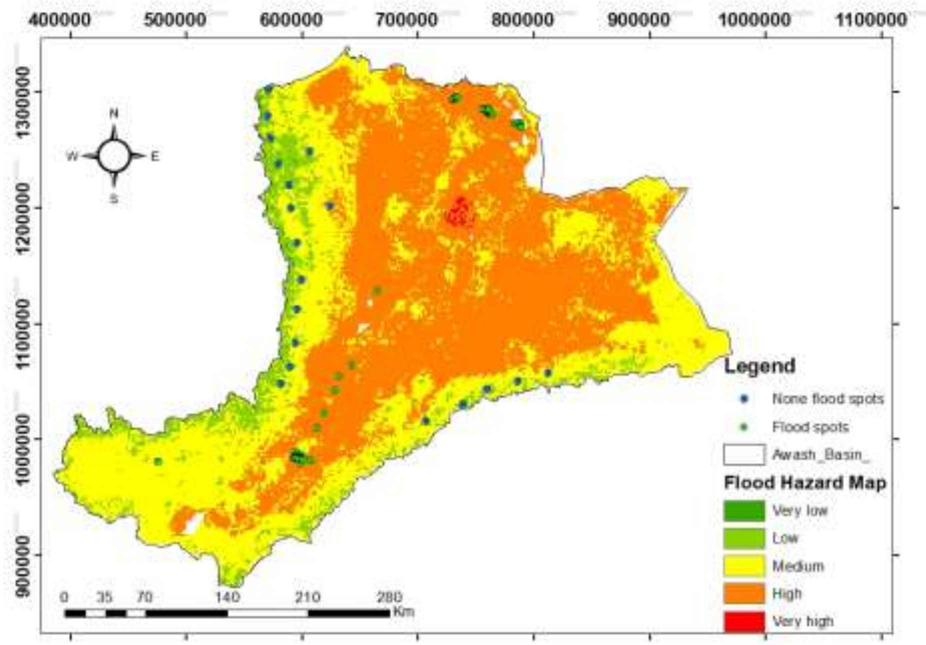

Figure: 5. 8. Sample points for validation

5.3. Result and Discussion

The majority of the awash river basin area coverage, 5,855,130.12ha (51.4%), is under high flood hazard, according to the results of the flood hazard analysis (Table 5.8 and Figure 5.10). The next largest area covered is the moderate vulnerability area under flood hazard, which makes up 4,625,378.51ha (40.6%) of the entire awash river basin area coverage. An exposed area of 866,358.09 hectares (7.6%) of the basin's total area is faced low level threat of flooding. The drainage density, elevation, and slope level are more indicative of flood hazard exposure than the other factors, and this is also supported by numerous other researches. Floods are directly related to drainage density; the likelihood of flooding increases with drainage density while a reduction of the drainage density results in a lesser flood risk. Moreover, surface runoff in places of high drainage density increases the flood risk as the valley courses are the main location where drainage can rapidly be emptied into (Das, 2018; Paul et al., 2019).

Flooding is far more likely in low-lying places than it is in higher elevations (Das, 2019; Khosravi et al., 2019). Furthermore, it has been shown that floods and incidents of flooding are more likely to occur on gentler slopes (Radmehr, and Araghinejad, 2015; Khosravi et al., 2018).

Numerous studies have shown that rainfall patterns and flood dangers in the Awash River basin, particularly in large towns like Dire Dawa, are closely related; the length, amount, and severity of rainfall all affect how floods become apparent (Hong et al., 2018; Sahana, 2019; Das, 2019; Sitotaw and Hailu, 2018). The amount of rainfall that has been recorded in the region with a greater risk of being flooded is so small that the greater rainfall experienced in the upper basins has been causing major effects in the region of the lower basin.

According to reports from the Ministry of Water and Energy, there has been recurrent flooding after the main rainy season in some areas of the ARB, including the area near Dubti down to Lake Abe, the area between Debele and Gewane around Lake Yardi, and the area 30 km north of the Awash town (Girma, 2010). Lower stream from the ARB, most of the regions are vulnerable to serious flood hazard as a result of growing agricultural fields and urbanism. According to researchers, metropolitan areas surrounding a river are especially vulnerable to floods because their high population density, vital infrastructure and important economic assets (Das, 2018; Khosravi et al., 2016b; Khosravi et al., 2016a). Bishaw (2012) claims that a change in land use, including increased agricultural production, heightened the quantity of overflow produced a zone of elevated risk of flooding in lower stream regions of the basin. As a result, it is evident that floods occur frequently in the Awash River Basin each year, causing both material losses and related social repercussions. One of the main causes of this is the climate and other related aspects.

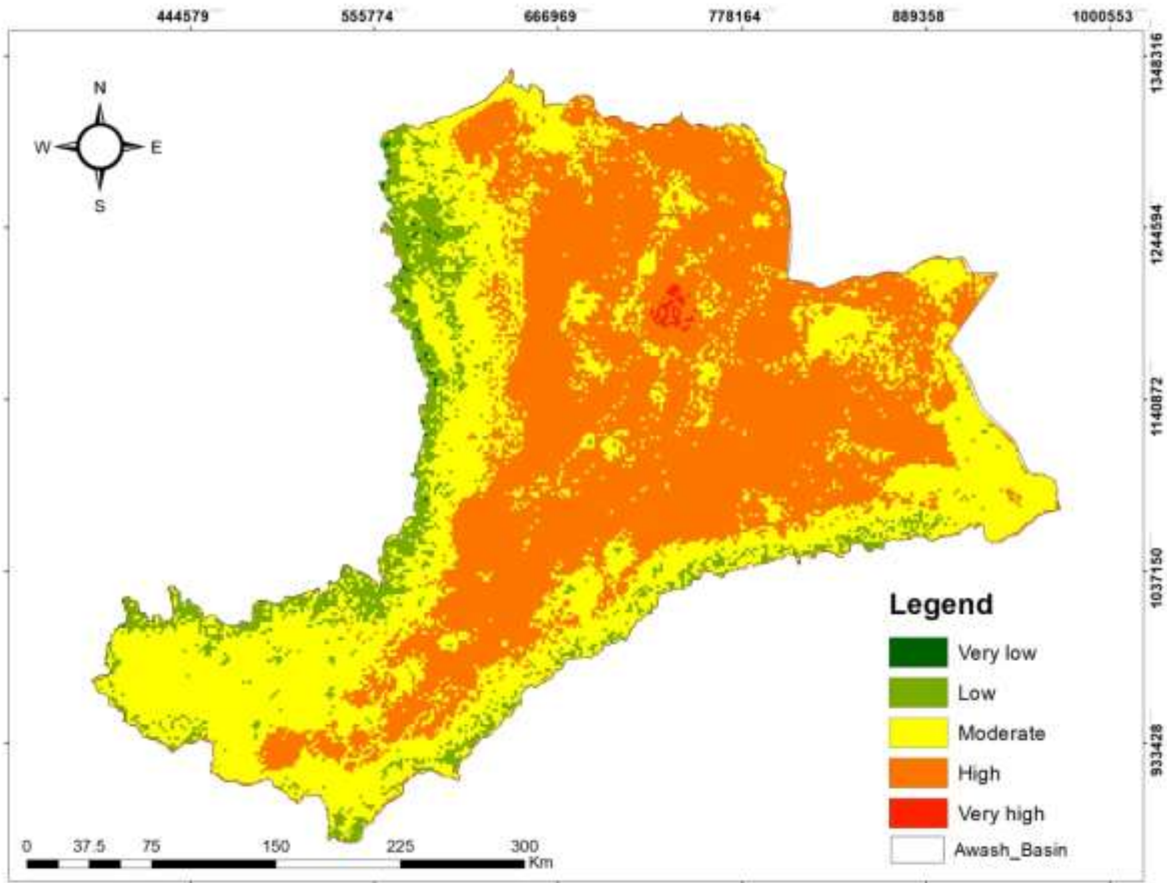

Figure: 5. 9. ARB flood hazard map

Increases in grazing, agriculture, and urbanization have all significantly reduced the ground's porosity and enhanced overland flow in the basin. Consequently, floods occurred annually in the basin. The major implications of flood hazard maps towards SDGs are various, such as identifying flood-vulnerable spots affected by climate change-induced flooding. In aligning with the SDGs goal to combat climate change impacts (SDG 13), flood hazard maps provide better understandings of flood hazards to implement mitigation actions. In addition, flood hazard maps provide significant support to urban planners in the design of flood-resilient infrastructure to ensure sustainable urban development, enabling them to meet SDG 11—sustainable cities and communities. Moreover, flood hazard assessments contribute to ecosystem and biodiversity conservation, as flooding affects natural habitats on land; hence, it meets SDG 15—life on land. By conjugating both SDG 11 and SDG 13, flood hazard maps substantially contribute to early warning systems and disaster preparedness to lower communities' vulnerability (UN, 2017; UN-Water, 2017).

Table: 5. 7. Coverage of flood-hazard areas

Class of hazards	Coverage of the area in Ha	Percentage (%)
Very low	10,428.67	0.1
Low	866,358.09	7.6
Moderate	4,625,378.51	40.6
High	5,855,130.12	51.4
Very high	23,481.11	0.2
Total		100

5.3.1. Validation

In the figures and tables of this analysis of flood hazard, areas identified as flood prone by the Awash River basin authority have been systematically cross-referenced with the results. Academics strongly advise data calibration and validation to ensure the degree of accuracy for the used flood hazard model (Keval H. Jodhani, 2023). We have used AUC-ROC methods to validate the generated flood hazard map through AHP method. Hence, the obtained AUC is 0.92, which falls into the excellent range per the criteria. This demonstrates how well the flood hazard map matches the actual situation on the ground. The AHP model developed has large prediction accuracy due to the result created. It suggests that the model's overall performance is excellent and that it can forecast the particular catastrophic occurrence. The ROC curve and the study's AUC value are shown in (Figure 5.11). Furthermore, the findings were compared to historically defined flood hazard regions of the basin as well as reviewed in light of the relevant literature to validate the results. This, therefore, installs a comprehensive approach to substantiate the accuracy and reliability of the flood theme map.

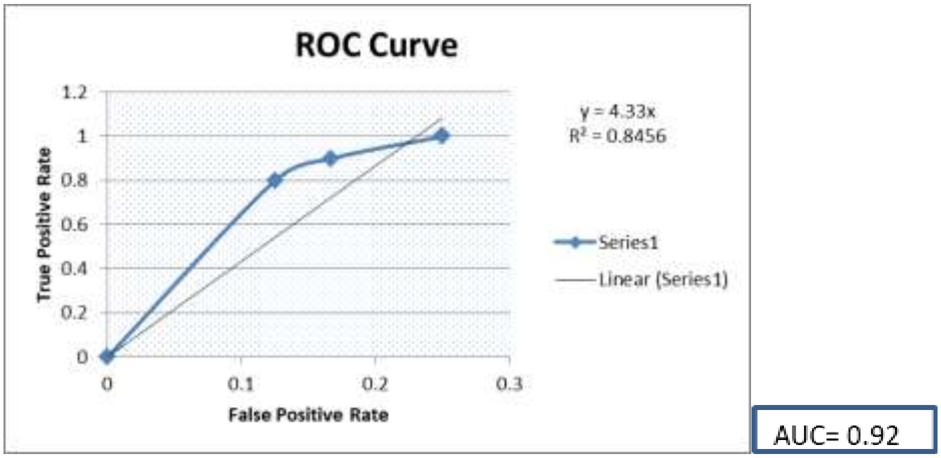

Figure: 5. 10. The AU-ROC curve for flood hazard map of Awash River Basin

5.3.2. Methodological limitations

Remote sensing has provided us with enough details about the flood hazard mapping analysis; however, it is important to appreciate the presence of numerous limitations. There were several reasons and conditions, such as the air conditions, the calibrations of the sensors, and the various natures of land covers, that really impacted the precision of the data from remote sensing. There is also some overlapping of spectral signatures on various types of land cover, and this can cause biases in the classification, hence distorting the classification of land use. Based on that, high-resolution imagery laced with ground truth validation, like field surveys and assistance with the help of Google Earth, can be of immense help in ameliorating the high level and precision of the information supplied by the conclusive studies.

5.4. Conclusion and Recommendation

In conclusion, this paper established the main goal of creating flood-hazard zone maps through GIS analysis combined with weighted sum overlay or AHP techniques in the ARB. Flood risk depends on various factors including elevation, drainage density, slope, yearly rainfall, river proximity, land use, land cover, and soil types which this research utilized for its evaluation. Slope together with drainage density and elevation act as critical flood risk factors which generate the highest vulnerability in the basin's downstream sections. Heavy rainfall plus climate change impact serve as the primary agents that cause flooding within these areas since upper-basin precipitation generates heavy flooding across lower regions. The research demonstrates broad areas in the basin face high flooding hazards extending ratings ranging from extremely high to extremely low flood hazards. The results of this paper offer essential information combined with recommendations which help researchers alongside researchers and city planners involved in the assessment and control of flood hazards. The study demands evaluation of operating methodologies for better comprehension of flood processes throughout the Awash Basin area. The authors ensured the verification of the map of flood hazards through thorough data comparison with the information provided by the Awash River basin authority in order to establish its reliability and accuracy. Moreover, the verification expending AU-ROC curve shows the strength of the model, with excellent AUC value of 0.92. The result of such work assists in making effective strategies for the control of flood risk and planning the environment in the ARB. Because of the high risk of flooding, it is important to use nature-based solutions (NBS) as long-term and economical ways to reduce flood risks in the ARB. In particular, the following NBS suggestions are present: restoring and protecting wetlands and riparian zones, planting trees and afforesting, promoting sustainable land use and cover management, including NBS in flood mitigation policy, getting the community involved, and educating them. In the Awash River Basin, we can use these nature-based solutions to make the landscape more resilient, which will help reduce flooding and improve the environment and the daily activities of the residents. Additionally, outcomes of this paper provide insights for policymakers, environmental planners, and basin authorities to design targeted mitigation strategies in Awash River basin. Moreover, it highlights how geospatial techniques could potentially be applied to assist sustainable, nature-based flood mitigation initiatives, advancing scientific understanding and practical solutions for environmental resilience in flood-prone areas.

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CHAPTER SIX: ASSESSMENT OF SOIL EROSION AND SEDIMENT TRANSPORT INDEX IN THE AWASH RIVER BASIN, ETHIOPIA: AN APPLICATION OF THE USLE MODEL AND GIS TECHNIQUES

6.1. Introduction

Numerous studies conducted throughout the world have shown that soil erosion is responsible for 85% of the decline in land quality. This erosion reduces crop productivity by 17% and affects soil fertility, which in turn causes land degradation (Singh and Panda, 2017). Soil entities are necessary for life, either directly or indirectly. However, land degradation, which is caused primarily by soil erosion, has the potential to have an environmental impact on a variety of human activities, most notably crop productivity (Tully et al., 2015; Pimentel et al., 1995). Food security and sustainable agricultural production are impacted by land degradation in sub-Saharan Africa as a result of soil erosion and nutrient decreases (Kassie et al., 2007). In addition, high rainfall and soil erosivity caused by shallow soil depth and weak soil structure can be mentioned as reasons for severe land degradation (Usman et al., 2017; Eaton, 1996). The main causes of land degradation are inefficient soil conservation planning, exhaustive farming, farming on steep slopes, and the removal of various types of vegetation due to overgrazing, deforestation, rapid population growth, and urbanization (Bekele, 2019; Bayramin et al., 2003; Pimentel, 2013; Reusing et al., 2000; Schiettecatte et al., 2008; Nkonya et al., 2016).

Soil erosion is a well-known issue in the highlands of East Africa, leading to soil degradation across broader regions of the area (Gachene CK, 1995; Tiffen, 1994). Ethiopia has the greatest rate of erosion, particularly (Gessesse et al., 2014; Lanckriet S. et al., 2014). In Ethiopia, the yearly loss of soil due to high runoff varies from 16 to 300 t ha -1 year-1. The primary factors contributing to this loss include slope gradient, type and depth of land cover, and high precipitation intensity (Hawando T, 1995; Tesfaye A et al., 2014).

Ethiopia's highlands have very significant land degradation; yearly soil loss from agricultural land alone is estimated to be between 100 and 300 t ha-1 year-1 (Birhanu A, 2014; Tiruneh G, 2015). Out of 60 million hectares of agriculturally productive land, 27 million hectares have the potential to erode, and approximately 2 million hectares of land are permanently lost from use for production (Birhanu A, 2014; Tiruneh G, 2015).

Moreover, soil from croplands vanishes at a rate of 42 tons ha-1 year-1 on average, and up to two billion tons ha-1 year-1, or one billion USD, are gone (Ma et al, 2014; Sonneveld et al, 1999). In highland regions, soil erosion affects agriculturally productive land, which makes up 45% of the nation's total land area (Tiruneh G, 2015). According to Ma et al. (2014), Ethiopia is now the country with the lowest crop production per plot of land compared with other countries. This is the result of erosion removing topsoil, which lowers the rooting depth and depletes nutrients. It also causes water loss and nutrient storage capacity, which reduces agricultural productivity (Bekele T., 2019; Haileslassie et al, 2008; Sertu S. 2000).

Researchers such as Desta L. (2000) reported that overgrazing, deforestation, farming on steep slopes, and rapid population increases are the main causes of soil erosion in Ethiopia. The ARB is known by its varying topography, climate and land use features that intensify soil erosion, consequently threatening crop production and environmental feature. The unique challenges nowadays Awash River basin facing include high rates of deforestation, rapid expansion of agriculture on steep slopes, and inconsistent rainfall patterns affected by climate change.

Determining the yearly soil loss, the amount of soil lost as a result of water-induced erosion, the geographic distribution of soil erosion, and the extent of soil erosion spurred on by catchment runoff is therefore crucial. The estimates offer a comprehensive understanding of the factors and processes affecting soil erosion as well as potential soil losses brought on by alterations to land use and landscape composition. To calculate the global quantity of runoff-related soil erosion, many people use soil erosion models. These include the Water Erosion Prediction Project (WEPP), Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Loss Equation (MUSLE), Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS), and Agricultural Nonpoint Source model (AGNPS). Wischmeier and Smith's (1978) USLE and Renard et al. (1997), RUSLE are two of these models that have been used in numerous researches to estimate soil loss (Zerihun et al., 2018). The Universal Soil Loss Equation (USLE) and its enhanced variant, the Revised Universal Soil Loss Equation (RUSLE), are the soil erosion models that are most frequently used. This is partly because of their ease of use, minimal data requirements, capability to be applied to various topographical reliefs and locations (Dutta et al., 2015), and successful implementation of conservation and mitigation methods based on anticipated outcomes

(Terranova et al., 2009; Vijith et al., 2017). Due to its relative simplicity of use and capacity to forecast solely soil losses from sheet and rill erosion under particular cropping and management system conditions, the USLE (Wischmeier and Smith, 1978) is the most widely used erosion prediction model globally (Smit, 1999). Most of the RUSLE model's improvements and modifications are difficult to apply to new locations since it depends on continuous, accurate data for computation (Kim et al., 2005), such as maximum 30-minute rainfall intensity, rainfall kinetic energy, and soil erodibility (Renard et al., 1997). Such vital data are usually unavailable at various study sites due to a number of different technological issues. Numerous studies conducted throughout Ethiopia have used and verified the USLE model's suitability for Ethiopian agro-ecology (Ali & Hagos, 2016; Bekele et al., 2019; Brhane & Mekonen, 2009; Hailu et al., 2015; K. Tsegaye et al., 2019; Tesfaye et al., 2018). Hence, we have employed the USLE model for this study.

Additionally, after upstream soil erosion brought on by heavy rainfall, sediment yields are carried downstream by surface runoff (Freebairn et al., 1996). Furthermore, higher yearly precipitation brought on by climate change and enhanced complex rains are contributing to an increase in soil erosion and sediment transportation (Mullan, 2018). It goes without saying that a variety of agent elements, including wind, heavy rainfall, and water flow, can exacerbate soil erosion. However, it is important to note that intense water flow or runoff can carry sediments at relatively high levels (Alhamid, 2002; Horton, 1945; Vanoni, 2006). Calculating the yearly soil loss and sediment transport driven on by water-induced erosion thus becomes crucial. The sediment transport index (STI) can also be calculated, as suggested by Moore and Burch (1986), using the raster calculation environment in ArcGIS. Hence, owing to the many factors mentioned above, soil loss and sedimentation due to severe erosion have become threats in the Awash River basin.

The study not only calculates soil loss estimation but also try to locate spatially soil erosion hotspots, supporting conservation efforts in the study area. Analysis of the sediment transport index (STI) along with soil erosion provides a substantial understanding of sediment dynamics within Awash River basin systems, which is various erosion studies overlooked regularly, hence this study try to fill the gap. For significant sustainable land management and community engagement strategies the findings provide an authority for policy-making.

The findings are directly links to local livelihoods, encouraging stakeholder participation in mitigation efforts, highlighting the importance of socio-economic engagement in soil conservation practices. Furthermore, the paper findings have significant implications regarding soil and water conservation strategies, and agricultural planning in the study area. The study firmly emphasized the importance of addressing the complex nexus between land use, climate, and soil quality in the Awash River basin in order to achieve integrated soil and water conservation.

Therefore, using the Universal Soil Loss Equation Model (USLE) with the integration of GIS and remote sensing technology, the main goals of this study was to estimate the severity level of soil erosion, estimate the average annual soil loss rate, compute the sediment transport index and identify and prioritize critical erosion prone areas for conservation planning.

6.2. Methodology

6.2.1. Description of the Study Area

The Awash Basin is traced amid latitudes $7^0$53' - 12^0 and longitudes $37^0$57' - $43^0$25' (Figure 6.1), spans 112,000 square kilometers, is home to 10.5 million people, and has an annual surface area of more than 4.9 billion metric tons (MEFCC, 2018). The height above sea level varies from 210 to 4195 meters. The Awash River spans portions of Oromia, Somalia, Amhara, and the Afar region, totaling 1250 km in length (Tiruneh et al., 2013). The river drains into the saline Lake Abbe on the Djiboutian border after mounting the highland close to Ginchi town on the west side of Ethiopia's capital, Addis Ababa and travels into the famous Afar Triangle across the rift valley (Sonder and Peden, 2008).

In upper and middle Awash, the rainfall pattern is bimodal, with the major rainy season lasting from July to September and a brief wet season from March to May. The upper and lower part of the Awash River basin experiences various climates, vacillating from humid to desert. The Awash River Basin's soil is classified as high clay soils that are conducive for producing cotton, clay loam and sandy loam for growing cereals and sugarcane, and sandy soil for range grass pasture (MEFCC, 2018; Edossa et al., 2010; Hailemariam, 1999).

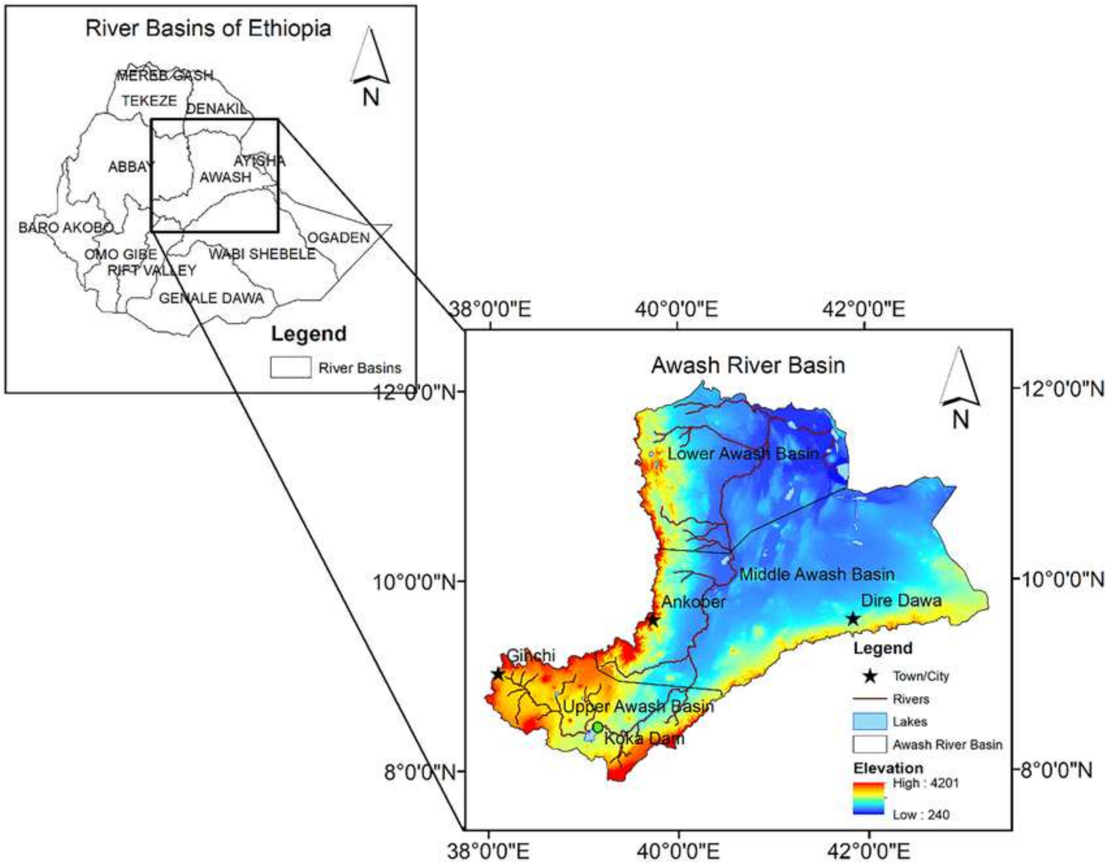

Figure: 6.1. Study area map

(Image sources: Tola, Sintayehu Yadete & Shetty, Amba, 2021; DEM & shape file source, United States Geological Survey USGS)

6.2.2. Data Sources

The techniques for predicting soil loss have evolved over time. The most often used equation for estimating soil loss over an entire river basin is the Universal Soil Loss Equation (USLE), which consists of five elements whose values are determined using their formulas. The following empirical equation, which is the sum of five important erosion-governing characteristics, was used to quantify soil erosion in the study area using the USLE model (Wischmeyer W., 1978):

$$\mathbf{A} = R \times K \times LS \times C \times P$$

Numerous sources are used to obtain the USLE model variables. The tropical rainfall measurement mission (TRMM) website and Ethiopian Metrological Agency (EMA) provides annual rainfall data, which are used to calculate the rainfall erosivity factor (R-value). The FAO soil portal database is also used to calculate the soil erodibility factor (K value), which is composed of the organic matter content, texture, and structure of the soil in the research area.

A 30 m digital elevation model (DEM) sourced from USGS were used to create a seamless elevation surface after using hydrological correction process which is used to fill and remove any sinkholes before calculating flow accumulation, slope gradient factor (LS value) and slope length. Following proper normalization and reclassification procedures all raster datasets were generated for each USLE factor (R, K, LS, C, and P). The land use also classified from Landsat 7 Images, using a supervised classification and the classification accuracy was validated using confusion matrix. The produced overall accuracy was 95% and a kappa coefficient was 0.95, confirming the precision of this classification. Classified land-use was used to estimate the crop factor (C) and conservation practice factor (P) (Figure 6.2).

6.2.3. Rainfall Erosivity Factor (R)

Rainfall erosivity, or the R factor, is an index of rainfall erosion that is the average annual total storm value in a particular locality. It was computed using daily and annual rainfall data that was collected from 28 meteorological stations located within the Awash River Basin (Table 6.1). The R factor for Ethiopia can be calculated via an equation that applies IDW (inverse distance weighted) techniques (Hurni, 1988; Kaltenrieder et al., 2007).

$$\mathbf{R} = 0.55 * MAP - 24.7$$

Where: R is the rainfall erosivity factor in MJ mm ha-1 yr-1 and MAP is the mean annual precipitation (mm)

6.2.4. Soil Erodibility Factor (K)

The soil erodibility factor (K), one of the key components of soil erosion, is often understood as the rate of soil loss per unit of erosion index (Wischmeyer W., 1978). The primary soil factors that affect the K-factor, according to Bahrami (2005), are the soil texture (composition of sand, silt, and clay), organic matter concentration, soil structure index, and soil permeability index. Accordingly, the FAO-UNDP (1984) soil database, which was modified for Ethiopia by Hurni (1988) and Helldén (1987), was used to estimate the soil erodibility (K) factor for the Awash

River basin on the basis of the percentage of soil texture. On the basis of the percent composition of sand, silt, and clay (soil texture) in relation to the percent organic matter equation, the K values for the various soil types in the research region were computed, as formulated by Moore & Burch (1986).

$$\mathbf{K_{USLE}} = f_{csand} * f_{cl\text{-}si} * f_{orgc} * f_{hisand}$$

Where:

f_{csand} is the coarse-sand content,

$f_{cl\text{-}si}$ represents the clay-to-silt ratio,

f_{orgc} indicates the organic carbon content,

Whereas f_{hisand} signifies a high sand content

$$fcsand = \left[0.2 + 0.3 * Exp^{\left[-0.256*ms*\left(1-\frac{msilt}{100}\right)\right]}\right]$$

$$fcl - si = \left(\frac{msilt}{mc + msilt}\right)^{0.3}$$

$$forgc = \left(1 - \frac{0.25*orgC}{orgC + Exp^{(3.72-2.95*orgC)}}\right)$$

$$fhisand = \left(1 - \frac{0.7 * \left(1 - \frac{ms}{100}\right)}{\left(1 - \frac{ms}{100}\right) + e^{\left[-5.51+22.9*\left(1-\frac{ms}{100}\right)\right]}}\right)$$

Where: m_s – is the sand fraction content (0.05-2.00 mm diameter) [%]; m_{silt} –is the silt fraction content (0.002-0.05 mm diameter) [%]; m_c –is the clay fraction content (<0.002 mm diameter) [%]; orgC –is the organic carbon content [%].

Table: 6.1. Mean annual Rainfall of Awash River Basin

No.	Gauge Station	Mean annual RF (mm)
1	A.A bole	1037.91
2	Abomssa	870.42
3	Adayitu	308.08
4	Addis Alem	1092.63
5	Akaki	982.43
6	Aleltu	1045.91
7	Aliyu Amba	1109.32
8	Debre Sina	1389.30
9	Debre Zeit	844.68
10	Dire Dawa	584.97
11	Gewane	489.69
12	Ginchi	1041.47
13	Holeta	1039.52
14	Kimoye	948.21
15	Koka Dam	636.75
16	Kombolcha	994.51
17	Kulumsa	810.85
18	Majete	1079.94
19	Melkasa	796.67
20	Mersa	953.06
21	Metehara	478.05
22	Mille	281.78
23	Modjo	903.54
24	Shola Gebeya	913.21
25	Tora Showa	827.62
26	Tulubolo	1063.52
27	Wuchale	1167.50
28	Ziway	720.61

Data source: Ethiopian Meteorological Agency (2023)

6.2.5. Topographic Factor (LS)

The topographic factor is obtained by multiplying the slope factor's length (L) by its gradient (S) (Schiettecatte et al., 2008). If all other variables remain the same, the slope length factor (L) is the ratio of soil loss from the slope of the given length to that from the slope of the land with a length of 22.13 meters. Furthermore, under the same conditions, the slope gradient factor (S) calculates the ratio of soil loss from a certain slope gradient to that from land with a 9% slope

(Wischmeyer W., 1978). To calculate the LS for three-dimensional terrain with a unit contributing area, Moore and Wilson (1992) presented the following simplified equation:

$$\textbf{LS} = (As/22.13)^m * (\sin B/0.0896)^n$$

ArcGIS 10.8 was used to evaluate the gradient factors and slope length. The USGS Earth Explorer DEM, which has a resolution (grid cell) of 30 m * 30 m was employed in this study. In the ArcGIS 10.8 environment, the flow accumulation, slope gradient, and slope steepness were produced via the DEM. The following academics proposed LS factor analysis, including Freeman (1991), Griffin et al. (1988), and Pham (2018): However, the following equation, which was proposed and simplified by Mitasova et al. (1999), was used to derive the LS factor for this study:

$$\textbf{LS} = (m+1)* (\text{Flow accumulation*cell size}/22.13)^m \ X \ (\sin(\text{slope angle } *0.01745)/0.0896]^n$$

Where: the cell size represents the resolution of the grid (30 m), 22.13 is the length of the research field plot, and the flow accumulation is the number of cells contributing flow to a given cell.

Where FA is the flow accumulation, the cell size is the size of the DEM data (30 × 30 m), the slope angle is in radians, and m = 0.5 (it ranges 0.4 – 0.7) and n = 1.3 (it ranges 1.0 – 1.4) are the exponent values proposed by (Liu, 2000; Mitasova, 1996).

6.2.6. Estimation of Crop/Cover Management Factor (C)

The ratio of soil loss from a particular agricultural management system to that from permanently fallow land is known as the crop management factor (C), and all other factors are assumed to remain constant (Girmay et al., 2020). The C-factor is a measure of the total effect of all the interrelated cover, crop, and crop management variables on the rate of soil erosion. According to Wolka et al., (2015) and Degife et al. (2021), when the C- factor ranges from 0 to 1, a value close to 0 indicates substantial conservation efforts in the area, whereas a value close to 1 infers that poor conservation practices can lead to severe soil erosion.

The land use and land cover map of the study river basin was created using a Landsat 7 ETM+ image of 2020 data from USGS for free. The image had a spatial resolution of 30 m x 30 m. Using ArcGIS 10.8 software; supervised digital image classification methods were used. Land use classification was conducted by the maximum likelihood classification method. Google Earth was used to create a number of reference points that were subsequently validated on the ground. We assessed the accuracy of LULC classification in the research area via a systematic sampling technique. The kappa coefficient, overall accuracy, user accuracy, producer accuracy, and agreement between the picture categorization findings and the ground truth were measured.

Finally, the research basin yielded the following six land use land cover types, as indicated in (Table 6.2) urban area, barren land, deep water body and forest cover. In the ArcGIS 10.8 environment, reclassification tools were used to assign the corresponding (C) values to each land use and land cover class. Finally, the study area's (C) factor raster layer was constructed by assigning an adapted (C) value to each land use and land cover class.

Table: 6.2. Land use and land cover of the Awash River Basin with area coverage and given C values

Land use Type	Area coverage in Ha	C Value	Source of References
Agricultural land	3,193,068	0.15	Hurni (1985), Bewket and Teferi (2009)
Barren land	8,262,189	1	Eweg et al. (1998); Hurni (1985)
Forest cover	94,435	0.01	Hurni (1985); Zerihun et al. (2018)
Wetland	63,221	0001	Wischmier and Smith (1978); Hurni (1985) and Kaltenrieder (2007)
Urban area	66,907	0.5	Moges and Bhat (2017)
Deep Water	14,117	0	Girma and Gebre (2020)
Grand Total	11,693,936		

6.2.7. Estimation of the Conservation/Support Practice Factor (P)

Pham (2018) stated that the impact of a farming system or land use on soil erosion is the support practice factor (P). It stands for methods such as contouring, strip-cropping, and terracing that stop runoff from eroding soil. This identified three key conservation methods are widely practiced in the Awash River basin, the majority of farmers predominantly adopting and practicing in their farmlands and neighborhood. P values vary from 0 to 1, where 0 represents an excellent man-made facility for mitigating erosion and 1 signifies the absence of such a structure (Pham, 2018). Slope range maps and ArcGIS's spatial analyst tools were used to obtain the P-factor values. P values for each slope range were determined by choosing representative values that were recommended by Shin (1999) (Table 6. 3).

Table: 6.3. P value for the respective slope (%)

Derived and used by Shin (1999); Wischmeier and Smith (1978); Bewket and Teferi (2009); Gelagay and Minale (2016); Esa et al (2018); Gashaw et al (2018); Yesuph and Dagnew (2019).

Slope (%)	Terracing	Contouring	Strip cropping
0 -7	0.1	0.55	0.27
7-11.3	0.12	0.6	0.3
11.3-17.6	0.16	0.8	0.4
17.6-26.8	0.18	0.9	0.45
>26.8	0.2	1	0.5

6.2.8. Soil loss Analysis

The average annual soil loss was calculated on a grid cell basis by multiplying the respective USLE factor values (R, K, LS, C, and P) interactively using the Spatial Analyst Tool Map Algebra Raster Calculator in the ArcGIS environment (Figure 6.2).

Where A is the annual soil loss (t ha−1 year−1); R is the rainfall erosivity factor (MJ mm h−1 ha−1 year−1); K is the soil erodibility factor (Mg ha−1 MJ−1 mm−1); LS is the slope length factor (dimensionless); C is the management factor (dimensionless); and P is the dimensionless conservation practice factor.

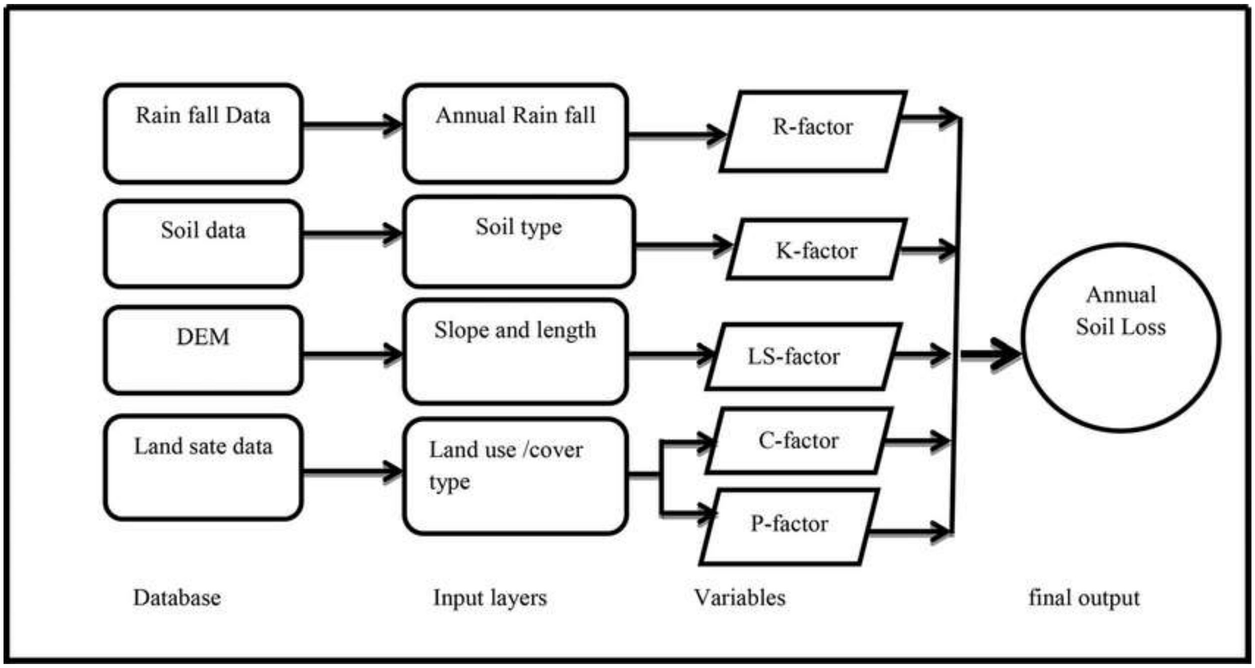

Figure: 6.2. Methodological workflow for estimating soil loss *Image source (Endalamaw* et al. *2021*)

6.2.9. Sediment Transport Index (STI)

The sediment transport index (STI) can be calculated as suggested by Moore and Burch (1986); Burrough and McDonnell (1998) using the raster calculation environment in ArcGIS; the equation is as follows:

$$\mathbf{STI} = (m+1) * (As/22.13)^{m} * \sin (B/0.0896)^{n}$$

Where: As is the specific catchment area (the region contributing to the upslope per unit contour length) estimated using one of the available flow accumulation algorithms in hydrology toolboxes; B is the local slope gradient in degrees; the contributing area exponent, m, regularly ranges from 0.4 to 0.6; and slope exponent, n, usually ranges from 1.3 to 1.6.

As per Wischmeyer W. (1978), the STI is a basic element of the USLE because it can estimate spatial sediment transport volume and analyze soil erosion features, and it is dimensionless. According to Voulgarist et al. (1998) it is regarded as one of the best theoretical models for time-dependent, cross-shore sediment transport and is most frequently utilized in morphological model techniques. Its components are caused by wave asymmetry and mean flow. In the Raster Calculator, the STI can be calculated based on the following formula:

=Power (‘’flow_accumulation_Raster”/22.13, 0.6) * Power (sin (Slope_Raster”/0.0896), 1.3

6.4. Results and Discussion

6.4.1. Rainfall Erosivity (R) Factor

The annual average precipitation of the study area is approximately 1372 mm per year and ranges from 1 mm to 5,996mm (Figure 6.3). The value of the rainfall erosivity factor (R) in the Awash River basin, which was estimated to range from 0 to 3145.93 MJ mm ha-1 h-1 year-1 (Figure 6.4) is greater than many other findings because of the higher rainfall intensity in the study area, especially in the upper catchment and winter seasons. When the R- value is lower, the research area experiences less intense rainfall and rainfall that are less likely to erode the soil (Asmamaw, 2019).

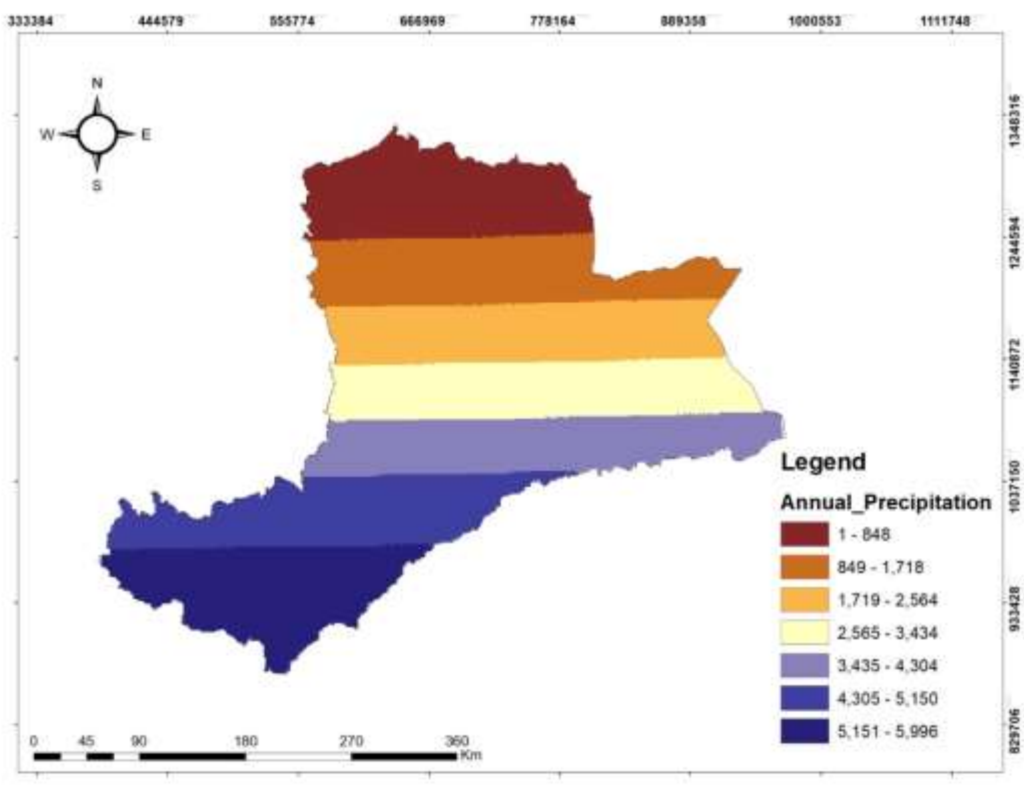

Figure: 6.3. Annual precipitation map of the Awash River Basin

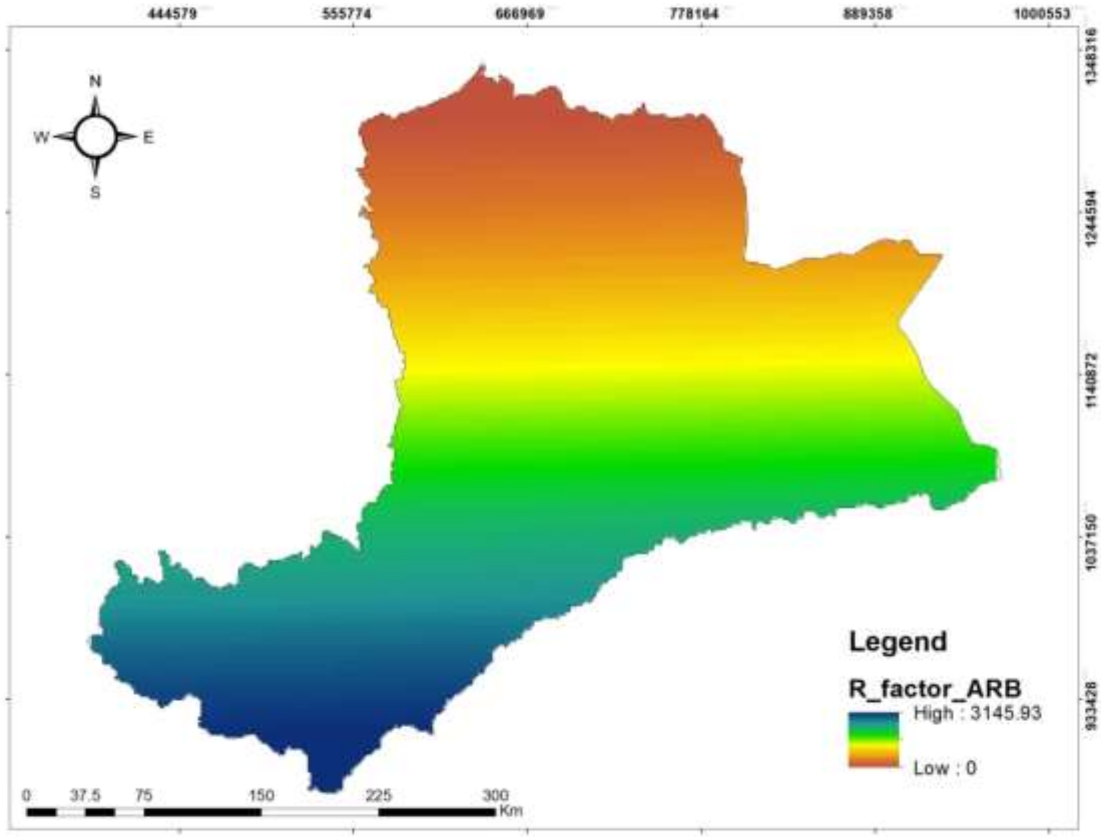

Figure: 6.4. Rainfall Erosivity (R) factor map of the Awash River Basin

6.4.2. Soil Erodibility (K) Factor

The soil categories of the study area consisted of various soil types, including eutric nitosols, lithosols and vertisols (Figure 6.5). The K-value of the study area ranged from 0.104261 to 0.172815 (Figure 6.6), which is similar to findings of the K value in tropical soils, which ranges from 0.06 - 0.48 EI-Swaify S. A. (1982), and According to the FAO–UNDP (1984), the majority of Ethiopian soils have K values between 0.05 and 0.6. In the study area, the organic matter content ranged from 0.99 to 0.75% (Table 6.4). The low clay and organic matter levels in the designated watershed region are amplified by the high K value, which implies high soil erodibility and exposure to severe soil erosion (Bartoli et al., 1992).

Table 6.4: FAO soil database information with the f value and K factor

Soil unit symbol	sand % topsoil	silt % topsoil	clay % topsoil	OC % topsoil	fcsand	fcl-si	forgc	fhisand	K_Factor
BE	36.4	37.2	26.4	1.07	0.200862	0.851385	0.90537	0.999948	0.15482
I	58.9	16.2	24.9	0.97	0.200001	0.756314	0.927169	0.994235	0.139438
XK	48.7	29.9	21.6	0.64	0.200048	0.849492	0.976766	0.999299	0.165874
ZO	43.2	24.6	32.4	0.4	0.200072	0.777174	0.992355	0.99978	0.154268
JC	39.6	39.9	20.6	0.65	0.200678	0.882603	0.9758	0.999897	0.172815
RE	68.3	15.1	16.6	0.5	0.2	0.800526	0.987425	0.963429	0.15231
VC	22.4	24.5	53	0.69	0.203952	0.707879	0.971627	0.999997	0.140277
XK	48.7	29.9	21.6	0.64	0.200048	0.849492	0.976766	0.999299	0.165874
I	58.9	16.2	24.9	0.97	0.200001	0.756314	0.927169	0.994235	0.139438
RC	63.5	19.2	17.3	0.76	0.200001	0.824712	0.963065	0.985505	0.156548
I	58.9	16.2	24.9	0.97	0.200001	0.756314	0.927169	0.994235	0.139438
VP	25.1	12.2	62.7	0.68	0.201064	0.580181	0.972718	0.999995	0.11347
I	58.9	16.2	24.9	0.97	0.200001	0.756314	0.927169	0.994235	0.139438
BK	81.6	6.8	11.7	0.44	0.2	0.74063	0.990605	0.718479	0.105426
YH	50.4	29	20.6	0.3	0.200032	0.851285	0.995672	0.999	0.169377
YH	50.4	29	20.6	0.3	0.200032	0.851285	0.995672	0.999	0.169377
VC	22.4	24.5	53	0.69	0.203952	0.707879	0.971627	0.999997	0.140277
RC	63.5	19.2	17.3	0.76	0.200001	0.824712	0.963065	0.985505	0.156548
VC	22.4	24.5	53	0.69	0.203952	0.707879	0.971627	0.999997	0.140277
NE	68.4	10.5	21.2	0.6	0.2	0.717859	0.980337	0.962738	0.135504
BD	32.7	30.3	37.1	3.28	0.200877	0.786747	0.750197	0.999976	0.118558
VC	22.4	24.5	53	0.69	0.203952	0.707879	0.971627	0.999997	0.140277
NE	68.4	10.5	21.2	0.6	0.2	0.717859	0.980337	0.962738	0.135504
NE	68.4	10.5	21.2	0.6	0.2	0.717859	0.980337	0.962738	0.135504
XH	54.8	20.6	24.9	0.53	0.200004	0.788418	0.985552	0.997509	0.155022
RD	82.1	6.7	11.3	0.27	0.2	0.743431	0.996424	0.703729	0.104261

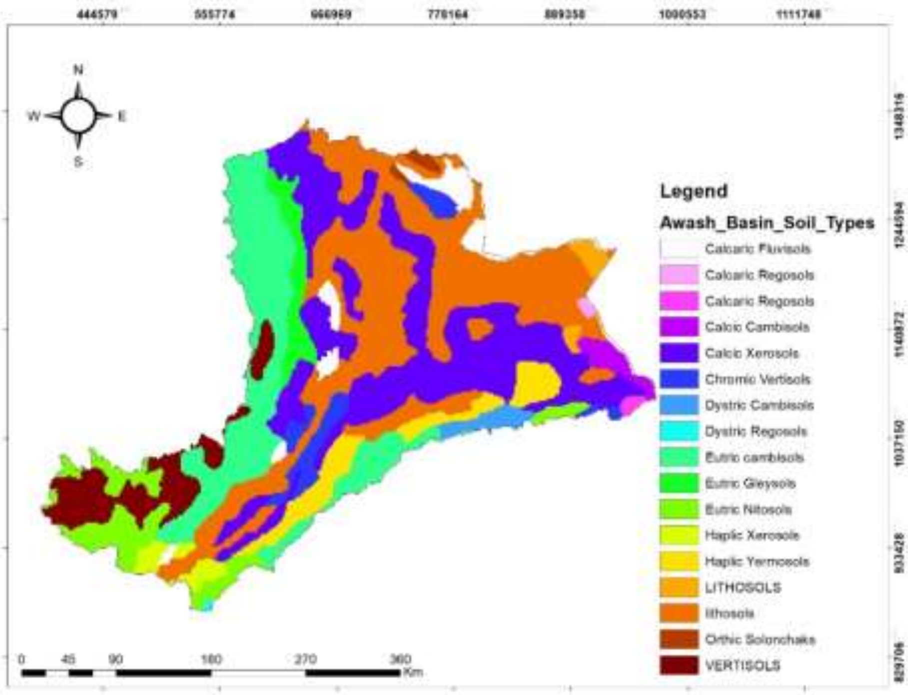

Figure 6.5: Soil map of the Awash River Basin

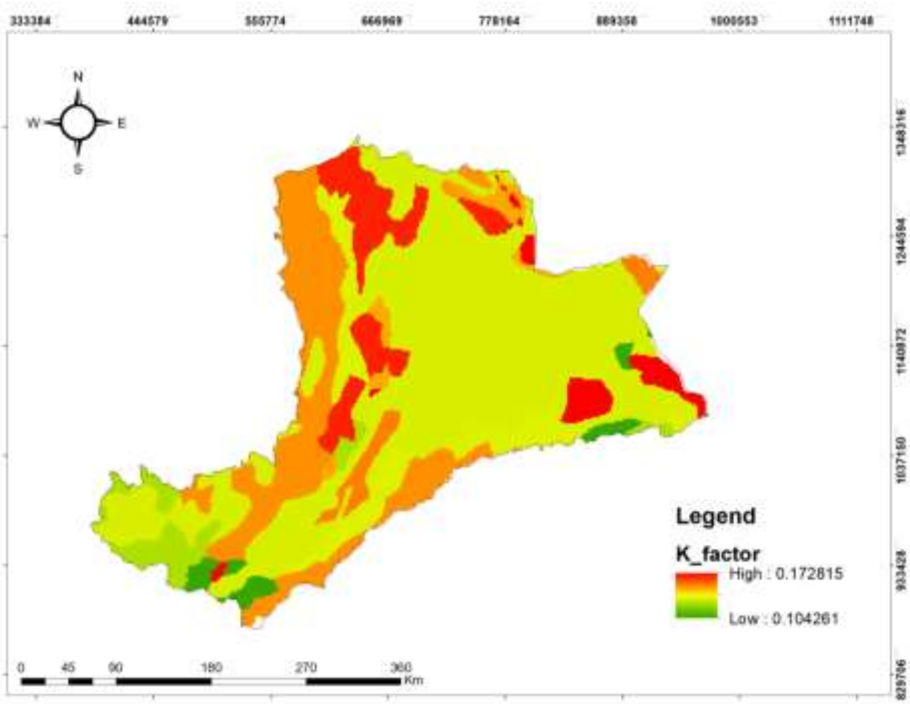

Figure 6.6: K factor map of the Awash River Basin

6.4.3. Topography factor (LS factor)

The majority of the basin is covered with flat areas or gentle slopes, and the slope lengths are shorter (Figure 6.7). The LS factors of the study area range from 0 to 50773.1 (Figure 6.8), and scholars have reported that higher LS values indicate greater erosion vulnerability due to high velocity and runoff accumulation. Moreover, the quantity of erosion is determined by the interaction of the slope angle and length. As a result of this interaction, the effects of slope length and degree of slope should always be considered together (Mitasova et al., 1999).

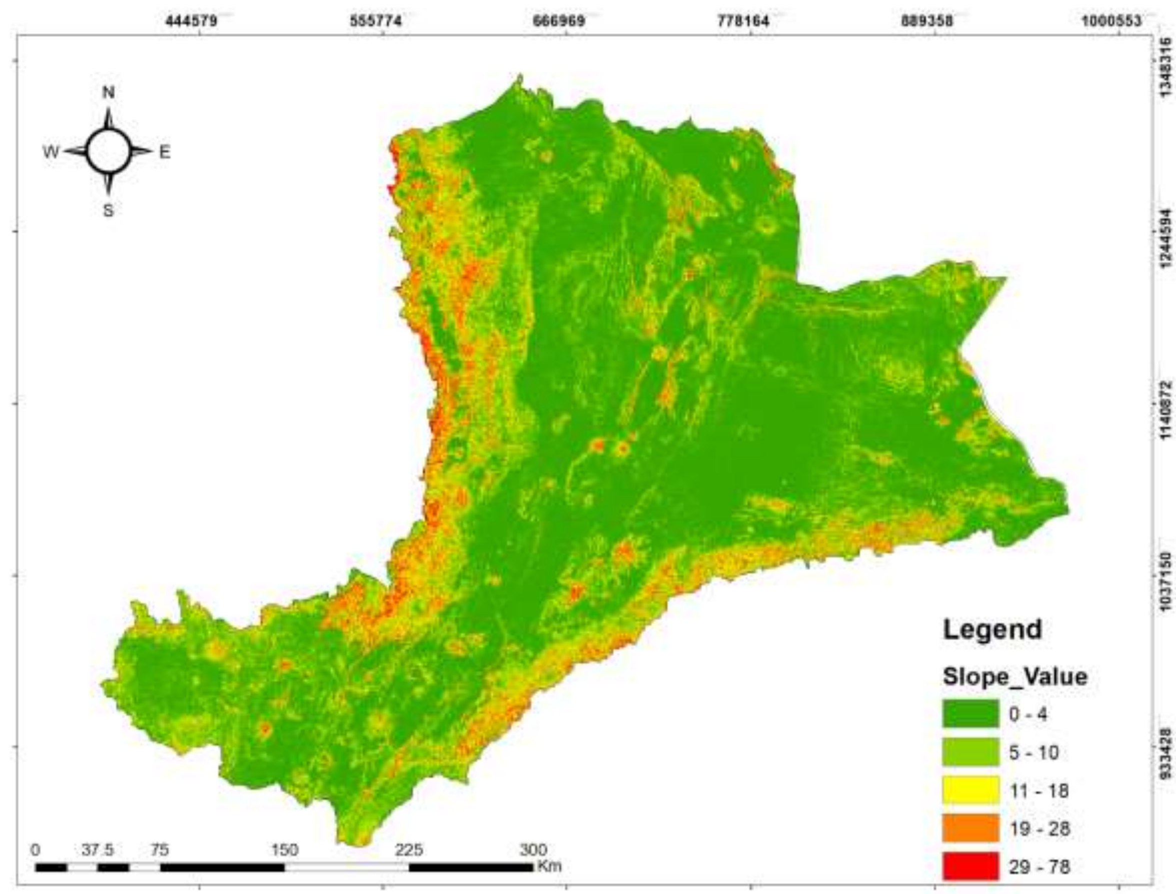

Figure 6.7: Slope map of the Awash River Basin in Radians

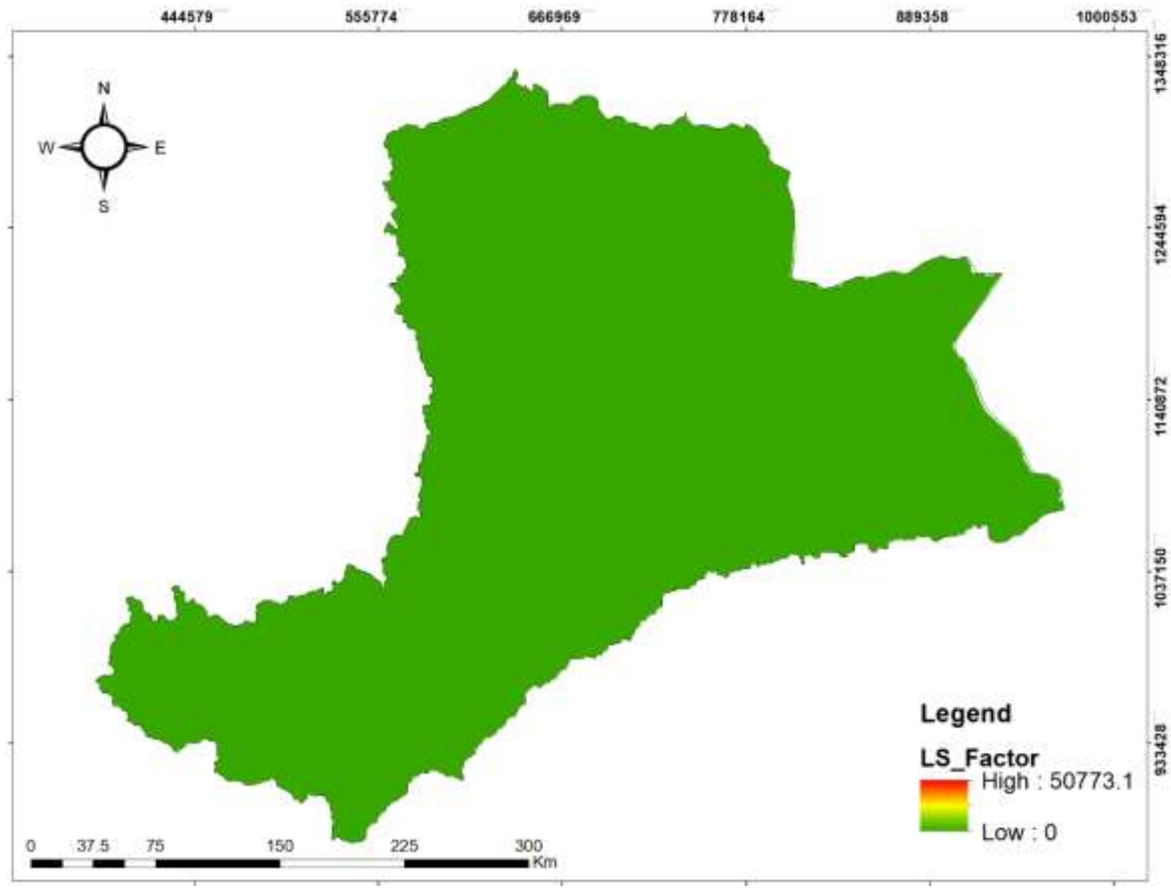

Figure 6.8: Topography length and slope (LS) factor map of the Awash River Basin

6.4.4. Cover and Management (C _Factor)

On the basis of satellite image classification, the Awash River basin LULC was classified into six classes: agricultural land, forestland, barren land, urban area, wetland, and deep water bodies (Figure 6.9). Urban land is the dominant land use type in the study area, which covers more than 49% of the total study area, whereas other land uses cover between 0.5 and 26% of the study area. The C-factor of the Awash River Basin ranges from 0 to 1 (Figure 6.10); a relatively high C value indicates increased exposure to soil loss. The area coverage of each land use class is clearly identified. Deep water bodies cover 14,117 ha of land; the highest area is covered by urban areas, which account for 5,690,778 ha of land; barren land, agricultural land, forest areas and wetland areas also cover 3,098,318, 2,733,068, 94,435, and 63,221 ha of land, respectively. The overall accuracy of image classification and the kappa coefficient value are 96 and 0.95, respectively, which indicates that it is an acceptable result per scholars and scientific standards (Anderson et al., 1976; Landis, 1977).

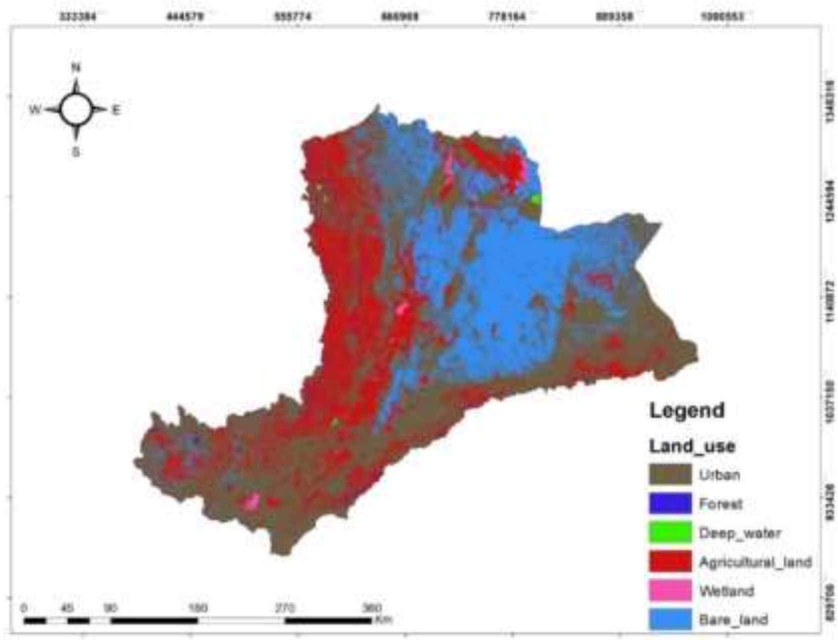

Figure 6.9: Land use and land cover map of the Awash River Basin

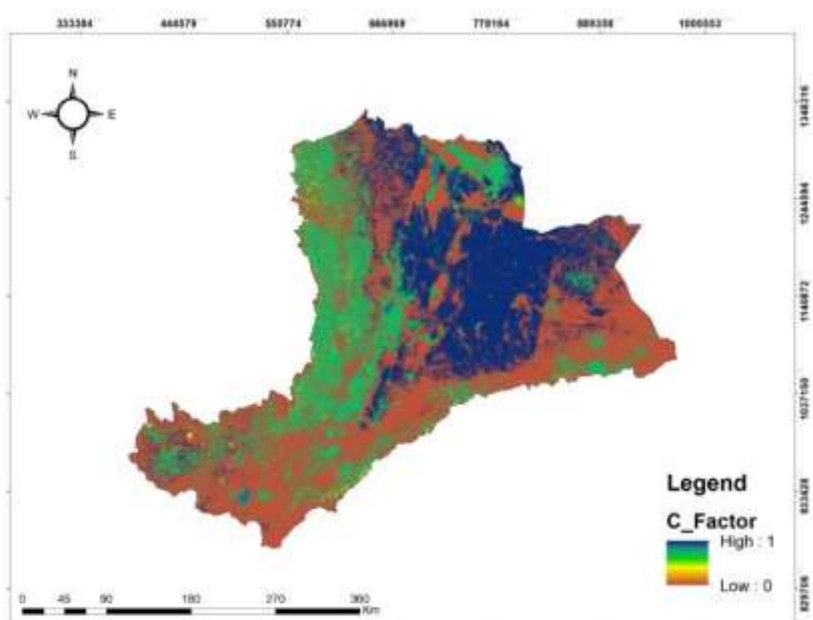

Figure 6.10: C factor map of the Awash River Basin

6.4.5. Conservation Practice Factor (P)

The conservation practice (P) factor, often referred to as the erosion control practice factor, is a measure of how much soil is lost when a particular conservation practice, such as contouring, strip cropping, or terracing measures, is used in comparison to the loss experienced when upslope and downslope cultivation is used (Wischmeyer W, 1978). The p factor for the study area ranged from 0.55 to 1 (Figure 6.11). A higher P value indicates greater erosion vulnerability in the specified watershed.

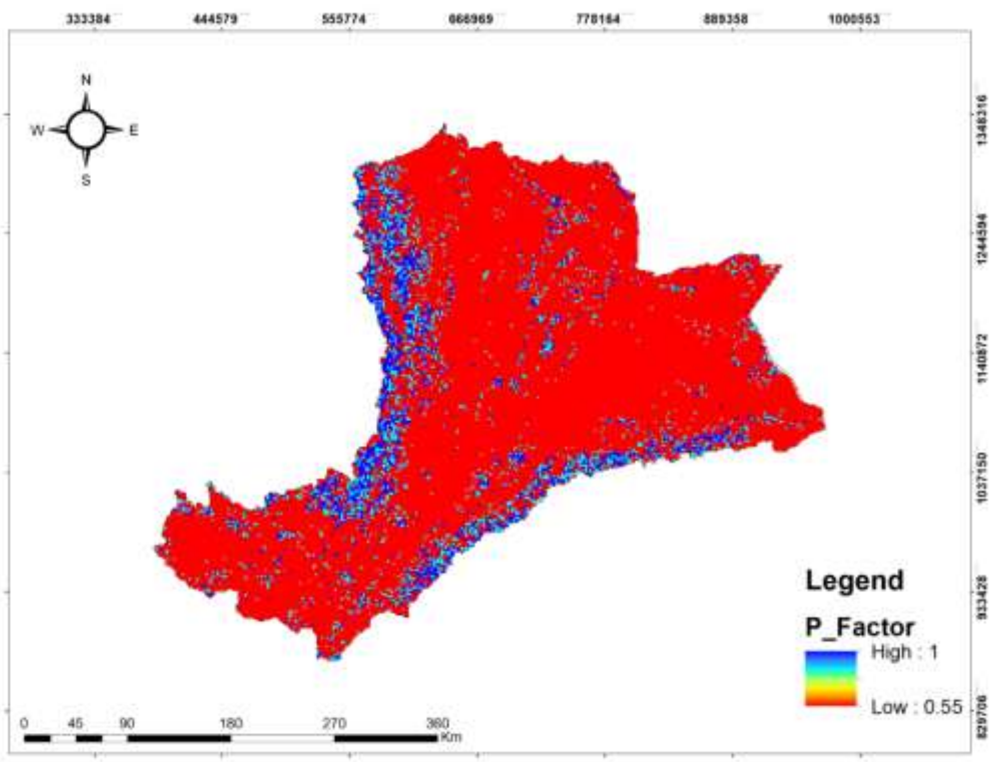

Figure 6.11: P factor map of the Awash River basin

6.4.6. Soil Loss Potential

The average annual soil loss was estimated via analysis of the rainfall Erosivity factor (R), soil erodibility factor (K), slope degree factor (LS), cover management (C), and support factor (P) using the ArcGIS 10.8. The USLE map shows that the annual average soil loss potential (A) in the Awash River Basin is displayed in (Figure 6.12).

The result reclassified in to five classes based on natural break techniques in ArcGIS. The results illustrate that the annual average soil loss in the basin ranges from 0 to 31,049,739 ton ha -1 year -1. The highest coverage region of the research area has the lowest result, which ranges from 0 to 121,502 ton ha -1 year -1, indicating that soil erosion in this part of the basin is minimal.

The second-highest area coverage registered from 121,502 ton ha -1 year -1 to 852,091.1036 ton ha-1 year-1 soil losses, which indicate that soil erosion is largely present and is thought to be of moderate severity. The remaining areas range from 852,091.1036 ton ha-1 year-1 to 3,165,620.626 ton ha-1 year-1, which is considered a high-severity area for soil erosion; the remaining areas range from 3,165,620.626 ton ha-1 year-1 to 8,766,797.363 ton ha -1 year -1, which is considered very high severe; and the remaining 8,766,797.363 ton ha -1 year -1 to 31,049,739 ton ha -1 year -1, which is considered an extremely severe potential area for erosion. The large share of the Awash River basin falls under the slope percentage of 0 to 10%; hence the erosion mainly witnessed in this area is significantly low. Moreover, the presence of forest and grass, which play a vital role in protecting soil from erosion, is also important. According to Kumar et al. (2012), recurrent changes in vegetation cover result in erosion rates, particularly in semiarid regions. Hence, vegetation plays a major role in preventing severe soil erosion.

Agriculture is predominantly supported by contouring and terracing in the study area, which improve the protection of the soil against losses. The remaining research area, which has slope percentage coverage between 0% and 10%, is severely affected and has a considerable rate of soil loss. Owing to heavy rainfall and runoff in the higher catchments, the lowest areas of the basin, Metehara, and the lower awash area have the highest rate of soil loss. Bizuwerk et al (2003), revealed that the spatial locations of the high spot area for soil erosion in this study shown that the potential soil loss is often greater along the steeper slope banks of streams. There are other locations of severe soil erosion across the basin, and they are usually connected to land uses that have a high propensity for erosion. The basin's plain region has the lowest susceptibility to soil erosion. Wolka et al. (2015), reported that the acceptable soil loss limit in the central rift valley is less than 10 t ha-1 year-1 on average; similarly, Hurni (1993) reported that, for Ethiopian highlands, the limit ranges from 6 t ha-1 year-1 to 10 t ha-1 year-1, and the estimated soil loss also ranges from 1248 to 23,400 million t ha-1 year-1 from 78 million hectares of pasture, ranges and cultivated fields all over Ethiopia.

Moreover, the maximum average tolerable erosion limit is approximately 11 t ha−1 year−1 (Renard et al., 1996). The total annual estimated soil loss of the Awash River Basin is 31,049,739 ton ha-1 year-1, and the mean annual soil loss is estimated to be approximately 28.6 ton ha-1 year-1. According to Wolka, Renard and Hurni analysis, this number is above the tolerable limit of soil loss, but, owing to rapid urbanization and the intensive scale of forest degradation, this number is also expected to increase inevitably unless the necessary precautions and measurements take place. The finding of the study specifies profound implications regarding ecological sustainability and agricultural productivity. Soil erosion rates are not only determine soil quality, level of organic carbon content and fertility but also affect the productivity of local agriculture, which highly relies on nutrient rich of top soil layer.

Moreover, sedimentation in water bodies has substantial impacts on fisheries and irrigation sustainability at downstream of the basin. Correlating with socio-economic consequences, poor productivity can lead to food insecurity, famine and poverty in the basin. Hence, interventions and effective soil management are significant, centering on promoting agroforestry, enhancing practices of contour farming on steep slope areas, and participatory soil and water conservation practices that strengthen environmental and economic resilience.

Other studies in different parts of Ethiopia have reported average soil loss estimates as follows: Negese et al. (2021); for the Chereti watershed, Northeastern Ethiopia (38.7 t ha−1 year−1); Elnashar et al. (2021); for the Blue Nile Basin (39.7 t ha−1 year−1); Bekele (2021), for the Anka-Shashara watershed (15.22 t ha−1 year−1); Tsegaye and Bharti (2021), for the Anjeb watershed, Northwest Ethiopia (17.3 t ha−1 year−1); Hurni (1985a), for the highlands of Ethiopia (20 t ha−1 year−1); M. Jothimani et al. (2022), for the kulfo River catchment, Rift Valley (68.47 t ha−1year−1); and And Mequanent (2022), for the Tashat watershed, northwestern Ethiopia, reports 64.2 t ha−1 year−1. In addition, Bizuwerk A. et al., (2003) reported that the estimated amount of soil loss in the Awash River Basin is approximately 37,684,000 t ha−1 year−1 from 11.2 million hectares, with an average soil loss estimation of 28.84 t ha−1 year−1.

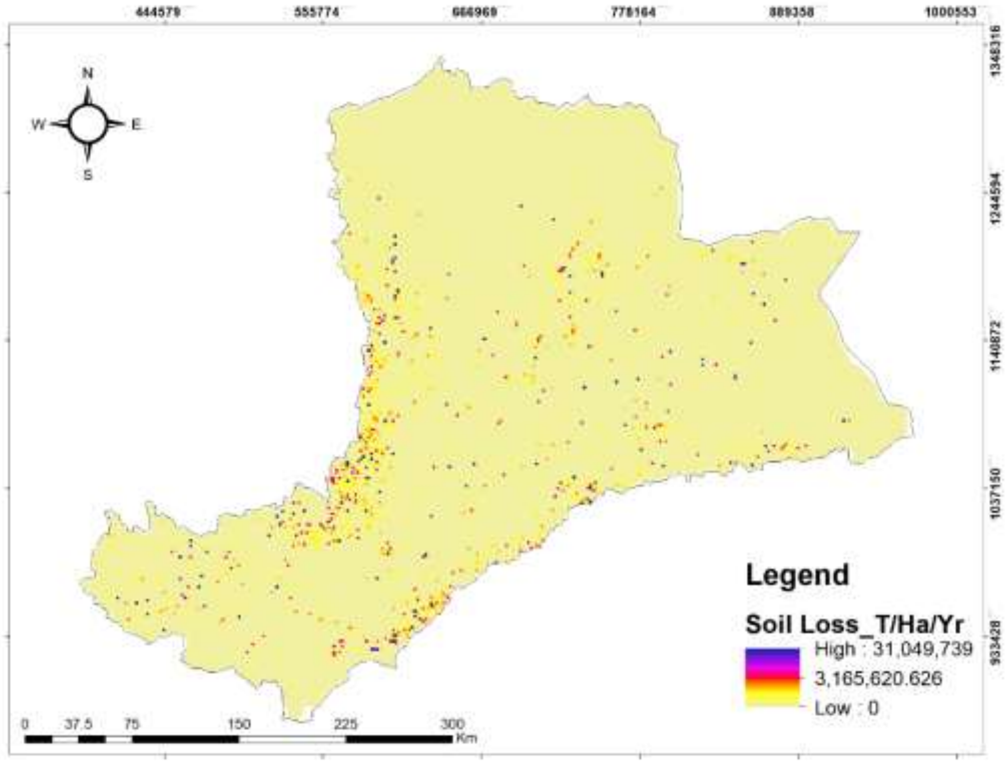

Figure 6.12: Average soil loss estimation map of the Awash River Basin

6.4.7. Sediment Transport Index (STI)

In the Awash River Basin, the STI ranges from 0 to 247,097 (Figure 6.13), meaning that the stream flow in the Basin has a very large ability to transport the given size ranges, but with full consideration of other factors such as channel morphology, land use land cover of the area, and sediment supply of the Basin, the STI can be interpreted and analyzed for better conservation management. Moreover, Ahmad and Dar (2019) indicate that the highest values of the Sediment Transport Index (STI) are associated with steep slopes and the lower regions of the catchment, which are prone to significant soil erosion and degradation. Conversely, the lowest STI values, indicative of reduced sediment mobility and accumulation, are found in areas characterized by dense vegetation in the upper catchment of the basin. The findings of this study reveal that agricultural lands are the predominant contributors to overall sediment export within the Basin. This phenomenon is likely attributable to several interconnected factors, including the cultivation of steep terrain at upstream of the Basin, intensive cultivating practices, and suboptimal land management strategies. Consequently, these results underscore the imperative need to promote sustainable land management practices, particularly in areas characterized by steep slopes. Implementing such techniques is essential to mitigate sediment loss and enhance the ecological integrity of the Basin.

6.4.8. Validation of Model Results

While some researchers (Adornado and Yoshida 2010; Nonta nanandh and Changno 2012) support the use of ground trothing as a crucial tool for improved validation procedures, other researchers (Panagos et al. 2015; Nakil and Khire 2016) advocate comparing the results with other soil erosion results from the same watershed, basin, or results at the national or regional scale. Therefore, the validity of this study is checked by contrasting its findings with those of previous studies done in the Awash River Basin. To ensure that the results are accurate, observable, and relevant, field observation was also done. Degife et al. (2021); Yesuph and Dagnew (2019) also employed comparable strategies. Additionally, the finding from this result were compared quantitatively from the results estimated by revised universal soil loss equation (RUSLE) which is different model used from this study, ensuring a contextual understanding of the study area.

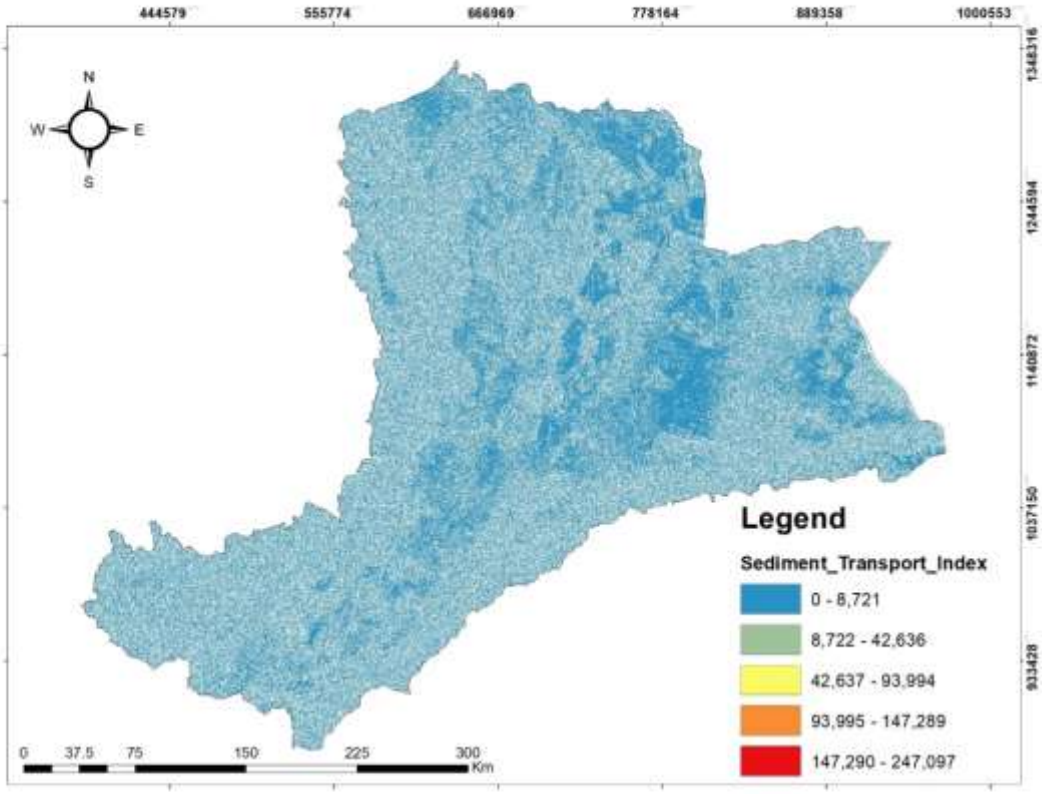

Figure 6.13: Sediment Transport Index map of Awash River Basin

6.4.9. The Hyperlink between Soil Erosion and Sediment Transport

The two are processes that are interconnected whereby erosion is the detachment of soil by water and sediment is the transportation of eroded materials. While both soil erosion and sediment transportation affect the earth's environment significantly, it is evident that they significantly affect the water environment. Viewed in this light, the issues of soil erosion, or the detachment of the topsoil layer through water and sediment transportation, or the movement of the eroded material are critical facets of the earth environment. Erosion is the loss of the uppermost layer of soil through water or wind, according to Pimentel et al., (1995). This results in sediment transportation; this is the moving of the particles of the soil from one spot to another through Aeolian or hydraulic means. These include factors such as sediment size and flow velocity during the transport phase when the soil particles detach during erosion (Mason & Hage, 1976).

Additionally, there is a significant relationship as well as linkages between soil loss and sediment transport. Using Pearson correlation coefficient, soil loss and sediment transport index (STI) are correlated statistically; the result for this correlation is ($r = 0.86$), which indicates a positive significant relation between the two factors , signifying that higher STI values are linked with increased soil erosion rates (Figure 6.14). According to Ahlgren et al. (2003), the coefficient (r) values vary from +1 to -1, with +1 indicating a perfect positive correlation, 0 indicating no connection, and -1 indicating a perfect negative correlation.

Future physical environmental effects include a degradation of water quality and quality of aquatic habitat due to higher levels of sediment in rivers and streams resulting from soil erosion (Tullos et al., 2009). Sediment transport also produces alterations in channel morphology and size and sediment distribution that in turn influence the riverine morph dynamics. In addition, regions experiencing threatening soil erosion would record higher runoff, which degrades the transport of silt into nearby water bodies. This may lead to siltation in which silt accumulates, reducing the volume and quality of water (Lal, 2003). In the Awash River basin, risks for irrigation and hydropower dam siltation hazards arise from soil erosion and sedimentation.

Soil loss reduces agricultural production and jeopardizes the ability of ecosystems to support people, leading to soil structural decline as well as the loss of soil organic carbon, which is important in soil productivity as well as the sequestration of carbon from the atmosphere (Cameron et al., 2013). Zhang et al., (2014) also attributed sedimentation that is caused by silt to water lead to eutrophication, which reduced oxygen levels that lead to hypoxia, changes in the cycling of nutrients, and an overall decline in the quality of water bodies that threatens the biota and related biodiversity. Many more adverse economic impacts of soil erosion and sediment transport arise out of reduced crop productivity, the necessity to confine sediment in streams, and the need to rehabilitate eroded landscapes (Pimentel, 2006).

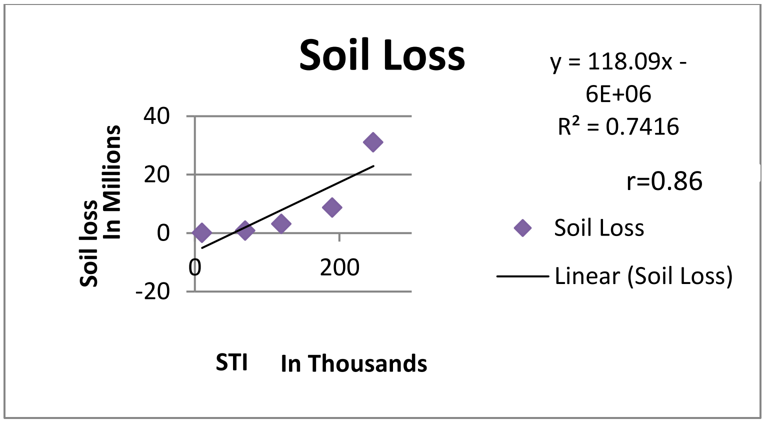

Figure 6.14: Statistical correlation of STI and Soil loss

6.4.10. Environmental Planning and Policy Implications

The modeling and assessment of the sediment transport of soils in the Awash River Basin support the critical importance of effective environmental planning and sustainable management of erosion. Systemic approach should be used including concepts such as integrated land management, community involvement, and effective government policy frameworks. These are concluding studies for land use planning to observe the areas that are most susceptible to erosion, drawing of erosion hazards to guide the region, ecological restoration regions meant for planting trees and shrubs. Measures to be taken by policy include supporting programs of likely agro-forestry and likely land use while limiting hazardous activities in weak areas and encouraging the financial support for the conservational work (Bewket, 2003). Involving local people through education and imputing agro ecological measures will improve the levels of conserving the environment and its management (Sharma 1999; Bewket and Sterk, 2002). By working with collaboration of local communities, we can easily extract innovative and indigenous solutions to soil erosion and enhance effective soil conservation efforts that address their specific needs and challenges. Active and participatory involvements of stakeholders can empower farmers to implement best management practices such as cover cropping, agroforestry, and contour farming. Community based conservation projects that incorporate traditional knowledge will enhance resilience against erosion and combat severe soil degradation in the Awash River basin. Moreover, procurement of structures for erosion control and promoting Integrated Water Resources Management guarantees coherent soil and water management aiming at reducing erosion and promoting eco-visualization in the basin.

6.5. Conclusion and Recommendation

This study estimated the annual soil losses in the research area, using the USLE modeling. From the ArcGIS analysis, it was deduced that the majority of the catchment region has low to moderate erosion levels, while the remaining catchment coverage has extremely high to extremely severe erosion levels. The remainder is slightly prone to soil erosion since the majority of the basin slope percentage is plain. Also, catchment soil erosion is well controlled by the forest, grass, and well-farmed agricultural ventures. This is due to the concentration of high runoff and increased rain, especially in the upper catchment of the Basin, and hence the high rate of soil losses in the downstream part of the Basin. Rates of soil loss vary from 0 - 31,049,739 ton/ha/yr. with STIs varying between 0 - 247,097. Specifically, the study underscores the need to promote suitable and sound land management practices for combating dangers related to soil erosion and promoting soil health under conditions of climate change volatility, including the widespread application of contour farming and establishing agroforestry corridors in the basin is highly commended. Moreover, integrate with local organizations and stakeholders to support the adoption of soil conservation practices and enhance a monitoring and evaluation framework to assess the progress.

Furthermore, stating awareness among the parties and enhance scientific approach incorporation into framework policies remain central as critical principles that would protect the basin’s ecological system, food stability, and sustainable agriculture. This paper evaluates the connection between transporting agents of sediment and soil erosion and reveals that there is a complex interaction system between water and sediment elements on water bodies and also on landforms. Failure to understand this interaction limits effective practices aimed at checking soil erosion and checking on the health of affected ecosystems. Subsequent studies should focus on the implementation of context-appropriate and site-specific management that supports ecological restoration alongside sustainably producing food and allied crops from at risk environments. For that reason, methods that pinpoint how all these systems are related to land use, climate change and other human activities should be enhanced. Therefore, scholars and decision-makers can implement the study according to the disclosed results. For the vicinity of the Awash River Basin where erosion and sediment deposition hazards are high, sustainable measures against erosion in relation to topography and the current land use type are highly desirable.

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CHAPTER SEVEN: MAPPING SUITABLE SITES FOR NATURE BASED SOLUTIONS TO MITIGATE FLOOD HAZARDS IN THE AWASH RIVER BASIN ETHIOPIA USING A HYBRID ANALYTIC HIERARCHY PROCESS AND FUZZY APPROACH

7.1. Introduction

Floods are among the most devastating natural disasters, claiming millions of lives and causing billions of dollars in damage globally. Worldwide, the likelihood of detrimental impacts from rising temperatures and the ensuing repercussions of the risks associated with hydro-meteorology are growing (Lehner et al., 2006; Führel et al., 2012, and European Environmental Agency, 2017). Many forms of flooding, including sudden floods in hilly areas, in floodplains, river flooding, Coastal storms in coastal zones and pluvial floods in metropolitan, can happen following prolonged rainfall or other severe weather conditions (WMO, 2011). Overflows killed about 24 million people worldwide and generated US$765 billion in damage between 1951 and 2017 (EM-DAT, 2017).

In addition to being one of Ethiopia's most frequently flooded regions; Awash River Basin (ARB) is among the principal basins in the Rift Valley of the country (Jothimani et al., 2021; Wondim, 2016; Kefyalew, 2003). Additionally, possible risks from flooding in the basin area's downstream sector were among the other hazardous events that are crucial to the region. Heavy rains in the highlands of the ARB and significant releases from the dams in Koka throughout the rainy season, particularly in August (Ashenafi, 2016; Jothimani et al., 2021), cause devastation to communities near any part of the river and floods downstream (Abebe, 2007). Major cities in the ARB were also frequently under risk for flooding. For instance, Adama had catastrophic floods in 2008, 2009, and 2016, which resulted in large costs for numerous municipal areas (Yonas et al., 2022; Dejene et al., 2017). Due to a variety of circumstances, including terrain, changes in land cover and use, steep slopes, extreme weather, population growth, rapid urbanization, and higher watercourse operations, the majority of metropolitan areas in the ARB are very vulnerable to floods. Therefore, it is imperative to create efficient flood control and mitigation strategies to minimize the effects.

In the last decades, globally, grey solutions (dams, embankments, levees, etc.) are desired to mitigate flood risks (Muller et al, 2015). But, recently European Environmental Agency (2017) depicts that using grey infrastructure only cannot solve flood problems. In addition to that grey infrastructures are more costly investment and provide limited services with damaging the surrounding ecosystems that are vital to people welfare (Palmer et al., 2013; Zischg et al., 2018). Furthermore, it is challenging to adapt conventional mitigation techniques or "grey" infrastructure such as concrete structures, pumping stations, and underground drain pipes to future uncertainties like climate change. Therefore, Nature Based Solutions (NBS) are utilized to improve ecosystems in cities, minimize flooding, and reduce vulnerability to climate change (Cohen-Schacham, 2016; Denjean, 2017). NBS, or interventions that exploit natural processes, are frequently able to evolve (Kuller et al., 2019; Faivre et al., 2018; Voskamp and Van de Ven et al., 2015).

NBS was first introduced as a novel concept in Europe during the late decade of 2000 by the European Commission (2015) and the International Union for Conservation of Nature (IUCN) (Cohen-Shacham, 2016; Lafortezza et al., 2018). NBS (such as forest regeneration, watershed/river re-naturation, and wetlands restoration) has the ability to address a number of environmental issues, such as natural disasters brought on by urbanization and extreme climates (Liu et al., 2015; Dong et al., 2017; European Commission, 2016)

Numerous studies portray NBS as a broad phrase that is used to address a variety of natural and societal issues based on ecosystems and natural processes, whereas it is thought of as an overarching idea that includes numerous eco associated methods (Cohen-Shacham, 2016). NBS shares various equivalent notions related to its functioning. There are several NBS sister thoughts that includes ecosystem-centered adaptive management, green infrastructures, and blue-green infrastructure (Laddaporn R. et al., 2020). For instance, a system of natural places, features, and green spaces in freshwater, terrestrial, and rural and urban settings could be linked to by the term "green infrastructure" (Naumann et al., 2011; WWAP, 2018 & Selman, 2008). These days, there is growing interest in using NBS to deal with a variety of Water-associated problems both internationally and in Africa (2017; Frantzeskaki et al., 2019; Kalantari et al., 2018; Seddon et al., 2020).

Additionally, NBS would successfully lower significant dangers to people and their possessions just as well as grey infrastructures. The main distinction is that NBS may offer numerous other advantages, such as bettering sociocultural conditions and the quality of the air and water (Dong

X et al, 2017). Alongside to the benefits of carbon sequestration and air pollution reduction, NBS are an effective storm-water control strategy for reducing sedimentation , upland flows, and load of nutrients following severe rainfall occurrences (Rowe, 2011; Ellis, 2013; Lin, 2015; Adhikari and Hartemink, 2016; Chapman and Hall, 2022; Keesstra, 2018). Furthermore, in terms of ecological restoration, these NBS applications specifically assist the UN sustainable development goals for sustainable cities and communities (SDG 11), life below water (SDG 14), and life on land (SDG 15).

Nature-based solutions may be applied on varying levels such as small-scale urban practices like green roofs and bio-retention cells as well as large-scale practices that occur on a regional scale like floodplain restoration and reforestation work on river basins (Ruangpan et al., 2020). However, most of the literature is focused on small urban NBS, but little is done to study NBS at large scale in watershed or basin scale. The primary reason behind this gap could be explained by the increased complexity and expense of large-scale projects, as well as the relative scarcity of interventions implemented on the catchment / basin level (Acreman et al., 2021). A deeper insight into the operation of the NBS and its time development is impossible without the further development of researches on the catchment or river-basin level. However, there is still a significant gap in the body of knowledge of evidence-based NBS performance as only about 8% percent of the existing literature deals with water regulation, and much of it focuses on the microclimatic impacts and recreation. The use of NBS as a flood mitigation tool in the Ethiopian setting is constrained and not adequately studied, and few studies examined hybrid methods, which combine NBS with other traditional engineering constructions (Acreman et al., 2021). Moreover, multi-stakeholder involvement is crucial to filling in the knowledge gaps in large-scale NBS implementations and integrated approaches of NBS with traditional engineering methodologies. In Ethiopia, Nature based solutions especially at large or at catchment level significantly practiced by various NGOs, but recognizing the indeginous knowledge (IK) of the community and government bureau's role in NBS activities at all scales are important. We can mention and described in detail here some of effective NBS projects at large scale level implemented in Ethiopia by aid of NGOs, the first one is the Bale Eco-region (BER) by Farm Africa and Humbo tebela NBS project by world vision. Such projects can be seen as a role model for better understanding of NBS concepts in Ethiopia, and enable to assess the NBS contribution to flood mitigation efforts in detail.

Recent research demonstrates that NBS can consistently solve a variety of issues. These include flood hazard lessening (Song et al., 2018), increasing groundwater recharge, reducing surface-level contamination of water (Donnell et al., 2018), reducing erosion and particulate transport (Loperfido et al., 2014), enhancing retained nutrients and loss (Loperfido et al., 2014), sustaining water in the soil, and enables growth of vegetation, controlling floods and sediment retention (Acreman et al., 2013), supporting biodiversity (Kalantari, 2019), and controlling erosion (Karlsson, 2015; Ali, 2007). Henceforth, to mitigate flood hazards caused by recurrent impacts of worldwide warming, consideration of NBS is significantly important. Moreover, Geospatial Information Systems (GIS) based identification of suitable location for the implementation of NBS is a preliminary step to attain the target of mitigating the severe impacts of warming temperatures.

According to Demesouka et al., (2013); Malczewski and Rinner (2015) Suitability mapping is rapidly leading the way in this field and is a powerful tool for supporting spatial decisions. Studies have employed GIS in combination of Multi-Criteria Decision Analysis (MCDA), including the Analytical Hierarchy Process (AHP), to identify several target locations for NBS implementation (e.g., Higuera Roa et al., 2023; Pittman et al., 2022; Bousquet, 2024; Bousquet et al., 2023; Wójcik-Made et al., 2025; Brillinger et al., 2022; Ruangpan et al., 2021; Ozkiper, 2022; Pittman et al.,2022).

Hence, this paper aimed to produce suitable locations for integrated/hybrid NBS implementation to overcome the impacts and devastating damages of flooding. Further, this study report plays a significant role by providing detailed suitable sites and types of nature-based mitigation measures to curb the risk and susceptibility of floods in the ARB. Moreover, this research paper undertakes to explain the relative sustainability of integrated NBS and the conventional engineering methods, or grey infrastructure, and how they appeal to ecological services and biodiversity in the study area.

7.2. Methodology

7.2.1. Study Area Description

7.2.1.1. Locations

The Awash River Basin is located between latitudes $7^0$53’ and 12^0 and longitudes $37^0$57’ and $43^0$25’ (Figure 7.1). It has an area of 112,000 km2, is home to 10.5 million people, and produces about 4.9 BM^3 of surface water annually (MEFCC, 2018). The elevation varies from 210 to 4195 meters above sea level. The Awash River spans portions of the Oromia, Somali, Amhara, and Afar regions along its 1250 km overall length (Tiruneh et al., 2013). The river originates on the high plateau close to Ginchi town on the west side of Ethiopia's capital, Addis Ababa. It runs into the Afar Triangle via the Rift Valley until ending in the salty Lake Abbe on the Djibouti border (Sonder and Peden, 2008). Regarding to elevation, the Awash River Basin is separated into three sections: the Lower Awash, which includes the Eastern catchment and areas between 500 and 1000 meters; the Middle Awash, which includes areas between Koka Dam and Awash station (areas between 1000 and 1500 meters); and the Upper Awash, which covers the upstream portions from Koka Dam (areas above 1500 meters) (MEFCC, 2018; Edossa et al., 2010; Hailemariam, 1999). In Upper and Middle Awash, the rainfall pattern is bimodal, with the major rainy season lasting from July to September and a brief wet season lasting from March to May. The Awash River Basin's climate varies from humid to arid in its higher and lower regions. ARB's soil is classified as sandy soil for pasture with range grasses, clay loam and sandy loam for producing cereals and sugarcane, and high clay soils for growing cotton (MEFCC, 2018).

7.2.2. Data and Sources

7.2.2.1. Land use/land cover

When choosing appropriate locations to apply NBS for flood hazard mitigation measures, land use and land cover are crucial considerations. Cloud-free Landsat ETM scenes, were acquired for paths 166–168 and rows 52–54 from Landsat 8/9 Operational Land Imager (OLI), and were examined properly. A cloud cover range of Landsat images were 0–10%, where the vast majority of the image is clear or covered with insignificant clouds, that can allows better observation and analysis of the earth surface features. Moreover, the satellite images obtained in September

2024. Rigorously assessed and tracked changes in the study area's land cover and land use. An image has a 30 m depth resolution and 11 band width. The images were geo-referenced to the Universal Transverse Mercator (UTM) map projection (Zone 37), WGS 84 datum, and were acquired from the United States Geological Survey (USGS) via https://earthexplorer.usgs.gov/ open source. The same recent boundary shape file of the research region was used to clip or extract satellite images in order to clearly show changes in land use and land cover. Supervised digital image classification methods were applied using ArcGIS 10.8 software. Land use was categorized using the maximum likelihood classification approach, and more than 100 reference points created from Google Earth were utilized to validate the correctness of the classified image. A systematic sampling strategy was used to evaluate the research area's LULC categorization accuracy.

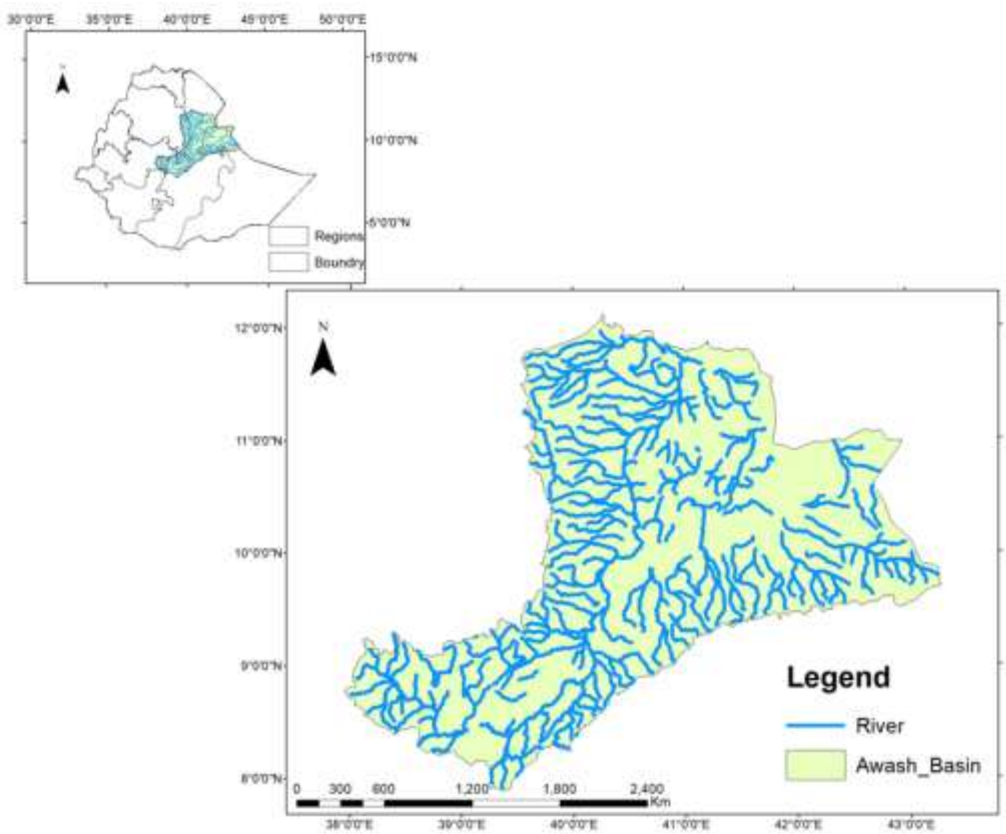

Figure: 7.1 Location map Awash River Basin; the figure created by the authors using GIS software version 10.8 (Tilahun et al., 2025). The GIS program utilized is available at https://www.arcgis.com/index.html.

7.2.2.2. Digital Elevation Model (DEM)

ArcGIS 10.8 was used for DEM processing to generate elevation and slope. The DEM layer had been divided into five classes in order to construct the elevation layer for the investigation. A slope layer was created from a DEM using the Slope environment in an Arc-Map "Spatial Analyst" tool. Slope is a significant component that affects how suitable the areas for flood hazard mitigation measures are. An area's steepness is indicated by its slope. The 30m DEM resolution slope map was produced using Earth Explorer (https://earthexplorer.usgs.gov). The slope map from DEM was created using the slope function from the Surface Analysis of the Spatial Analyst tool of ArcGIS 10.8.

7.2.2.3. Soil type map

The International Soil Reference Information Center (ISRIC) and FAO was used as a reference map to create the soil map of the study area, and the FAO/ISRIC global soil map was clipped to fit the study area's shape and reclassified into five soil type classes. The FAO soil database website provided the soil map free of any cost. According to Abebe et al. (2007), the soil types were Pellic Vertisols, Chromic Vertisols, Chromic Luvisols, Euthric Nitosols, and Lithosols.

7.2.3. Suitability Analysis

A multi-criteria decision-making method called the Analytic Hierarchy Process (AHP) uses a hierarchical structure to depict the problem (Dos et al., 2021). This approach makes it feasible to derive a standard hierarchy of priorities by defining a criterion value, comparing it with the selected target-related site locations, and combining all the preferences into the optimal scenario (Friess, 2017). Table 7.1 establishes a framework to balance the multi-criteria by assigning a weight to each characteristic according to its predefined level of importance. Setting a goal is the first stage of a multi-criteria decision-making process. The goal of this study is to create a map that indicates appropriate locations for the installation of structures that reduce the risk of flooding. Determining elements or criteria based on each parameter's description and justification is the second phase (Table 7.2). Following a review of the literature and expert knowledge, these criteria were selected (Pareta, 2013). The following actions were made in accordance with the study's goal.

Table 7.1: Relative importance Saaty, 1986

Level of significance (AHP) way	Triangular fuzzy numbers (l, m, u)	Definition	Rationalization
1	(1, 1, 1)	Least/Equal significance	Contributes the lowest level to the goals.
3 (1/3)	(2, 3, 4)	The relative relevance of one component is moderate	Experience and judgment favor one criterion somewhat over another.
5 (1/5)	(4, 5, 6)	Substantial or crucial significance	Experience and judgment strongly favor one criterion over another.
7 (1/7)	(6, 7, 8)	Very important	A criterion has a significant impact on the aims' success.
9 (1/9)	(8, 9, 9)	Extreme significance	The evidence that favors one criterion over another has the strongest degree of affirmation.
2,4,6,8	-	Values between two assessments that are adjacent	Can be put to use as needed.

7.2.3.1. Rasterization

Rasterization, often known as vectorization, is the process of converting an image described in vector graphics format (shapes) into a raster representation (pixels or dots) for keeping in a bitmap data format or for presentation on a video display or printer. Additionally, rasterization is the process of converting vector data to raster.

7.2.3.2. Euclidean Distance Calculation

Each cell's relationship to a collection of sources is described by the Euclidean distance operation. The function provides the distance between each cell center and the closest set in the raster formatted information set. The Euclidean distance output is a raster file format with several layers or rings that are concentric from the point of reference. Meters, kilometers, miles, and other linear units are used to express the distance. In this study instance, a map of the distance from river lines was calculated using Euclidean distance.

7.2.3.3. Reclassification

This is the procedure for giving a raster information set's various classes weight. The goal of this procedure is to demonstrate the various circumferential layers and their placement and suitability. In this study the datasets reclassified were slope in raster, Elevation in raster, land use in raster, Euclidean distance of river, and Soil type data in raster format. Moreover, each reclassified parameter ranked based on their significance to mitigate flood hazards. Ranking conducted based on the literature review and personal or expert judgments. Every criterion is rated according to the decision maker's preferences in the ranking method. Each element was weighted based on the assessed significance for choosing flood hazard mitigation sites in order to provide criterion values for each evaluation unit.

Each data set was standardized to a common scale of 1, 2, 3, 4, and 5 (value 1 = Very low suitable, value 2 = low suitable, value 3 = moderately suitable, value 4 = High suitable, and value 5 = Very High suitability) in order to merge all the layers to process overlay analysis. The biggest influence/suitable factor were ranked 5 on a scale of 1 to 5, while the lowest influence/suitable element were ranked 1.

Table 7.2: Used measures and justification

Criteria	Definition	Justification
Land-use types	Combination of various land uses including urban area, forest land, agricultural land, bare land, shrub land, and water body	The LULC of the ARB was transformed into a graphic layer and classed into five classes, which was dependent on its suitability to NBS measures, specifically floodplain restoration, wetland and river widening. Bare land and Wetland put into very high suitable class and ranked as 5 (Very high), agricultural land and Forest put into high suitable for specific NBS measures and ranked as 4 (High), Because urban and built-up areas are often impermeable, there is little chance of water seeping in (Lee et al., 2018a, 2018b). Therefore, in order to

		reduce urban floods, particular NBS actions are required. Hence, Urban area was put into moderate suitable class and ranked as 3 (Moderate), Shrub land/Grass land put into low and ranked as 2 (Low) and Aquatic bodies put into very low and ranked as 1.
Slope	The inclined nature of a region's surfaces	The water carrying capacity of a slope is determined by its steepness. Water usually gathers or remains stagnant in locations that are generally mild and level, while it flows swiftly in steeper terrain (Zhang et al., 2019). Hence, Gentle slopes (≤ 5%) allow for easier penetration of precipitation into the earth, decreasing surface runoff and consequent floods (Morbidelli et al., 2018). When it comes to developing and sustaining NBS features, gentle slopes are typically easier and less expensive than steeper terrain. Additionally, lower slopes were deemed acceptable for NBS, such as dam construction by FAO since they would establish a new aquatic body in the area., where slopes are defined as <5◦ ranked as 5 (Very high suitable for Retention and wetlands), 5 – 10◦ ranked as 4 (High), 10 – 20◦ ranked as 3 (Moderate), 20 – 30◦ ranked as 2 (Low), and >30◦ considered as unsuitable and ranked as 1 (Very low). For dam construction and NBS measures at lower stream sections, a lower slope is more appropriate (Rezaei et al., 2013).

River proximity	Locations that are close to rivers or that are inside river buffers	Distance from river < 1 km: NBS can directly intercept and filter runoff before it enters the waterway by placing them close to rivers. This may lessen the water quality peak flow that enters the river. By establishing a buffer zone and maybe offering habitat for riparian plants and animals, being near rivers can also improve the ecological value of NBS (Fletcher et al., 2014). According to Staes et al., (2009) areas that are extremely close to rivers and waterways are more vulnerable to flooding after a strong storm. This is due to the fact that river overflows and shallow water tables are common in these regions. It therefore requires particular NBS measures. Hence, the classes are reclassified: 0 -1000m ranked as 5 (very high), 1000 – 2000m ranked as 4 (high), 2000 – 3000m ranked as 3 (Moderate influence), distance from river ranges from 3000 to 4000m considered as class 2 (Low) and >4000m ranked as 1 which is Very Low suitable for NBS implementation.
Soil types	Combination of various soil types within ARB including PellicVertisols and Lithosols	ARB soil types classified as PellicVertisols, Chromic Vertisols, Chromic Luvisols, Eutric Nitisols and Lithosols (Abebe et al., 2007). Thus, it is hypothesized that Eutric Nitisols have a Very High appropriateness class (5) to NBS measurements; it is deep, well drained and stable structure. Ideal for reforestation, infiltration trenches and bio-retention

		techniques. Chromic Luvisols relatively fertile and stable, with high appropriateness class (4) to NBS measures; such as buffer strips, agroforestry and other vegetation based NBS. Chromic Vertisols is includes highly clay content causes for poor drainage; suited for wetland construction and retention ponds, having moderate suitability class (3). Pellic Vertisols is comprises of very high clay concentration and prone to waterlogging and cracking. Has low appropriateness class (2). Lithosols suitability class is very low (1); this soil type often known as very shallow and poor water holding capacity, and inappropriate for NBS measurements except slope stabilization. Additionally, Vertisols are the most common soil type in the Awash River Basin, according to Abebe et al. (2007).
Elevation	Highland and lowland area	Numerous studies indicate that lowland areas are primarily affected by floods. Lowland locations are therefore more vulnerable to flooding and runoff. Given that water usually flows from highland regions to lowland places, (Manfreda et al., 2011), to help reduce flooding, several NBS measures should be implemented in various elevation zones. Additionally, lower altitudes are thought to be appropriate for dam site building since they facilitate water pooling Al-Ruzouq et al., (2019) and NBS measures. The classes are reclassified: <1000m ranked as 5 (very high),

	1000 – 1500m ranked as 4 (high), 1500 – 2000m ranked as 3 (moderate), 2000 – 2500 considered as class 2 (Low) and >2500m ranked as 1 (very low suitable for NBS)

Standardizing each factor/criterion score was the third stage. To enable comparisons, it is crucial to assign each factor's appropriateness values to a comparable scale (Table 7.3). P. Asare et al., (2022) also ranked the relative importance of particular NBS measures to flood mitigation by expert knowledge and the hierarchy of higher to lower significance was as follows: slope (4.6), elevation (4.2), Proximity to rivers (3), land use types (3), and soil types (1.4). We have also included a related literature and expert opinion in order to define our own relevance scale of each parameter in order to provide a relevant assessment in a certain context. Following a pairwise comparison of each component with every other factor, all five factors underwent a normalized process (Table 7.4) and passed the consistency test to complete the final weighting (Kiker et al., 2005; Malczewski, 1999; Islam et al., 2019).

Table 7.3: The relative relevance scale developed by Satty (Saaty, 1980; Saaty and Vargas, 1991)

Parameters	Slope	Elevation	Proximity to river	Land use types	Soil types
Slope	1	3	5	7	9
Elevation	1/3	1	3	5	7
Proximity to river	1/5	1/3	1	3	5
Land use types	1/7	1/5	1/3	1	3
Soil types	1/9	1/7	1/5	1/3	1
Column sum	1.788	4.676	9.533	16.333	25

In the fourth phase, weights were established for each criterion according to how important they were for the Arc map (Table 7.5). The final stage was combining the chosen criteria and confirming the outcomes after the AHP approach had calculated the percentage of weights. Using the ArcGIS weighted overlay tool, a layer of appropriate flood hazard mitigating sites in the research region was created depending on the weight of the specified criteria. The following are illustrative descriptions of the methodology.

Table 7.4: Normalized matrix

Parameters	Slope	Elevation	Proximity to river	Land use types	Soil types
Slope	0.559	0.641	0.525	0.429	0.36
Elevation	0.187	0.214	0.315	0.306	0.28
Proximity to river	0.112	0.071	0.105	0.183	0.2
Land use types	0.08	0.043	0.035	0.061	0.013
Soil types	0.062	0.030	0.021	0.020	0.04

Table 7.5: Final parameter weights

Parameters	Slope	Elevation	Proximity to river	Land use types	Soil types	Final weight (Average)	Normalize final weight	Final weight (%)
Slope	0.559	0.641	0.525	0.429	0.36	0.503	0.515	51.5
Elevation	0.187	0.214	0.315	0.306	0.28	0.260	0.266	26.6
Proximity to river	0.112	0.071	0.105	0.183	0.2	0.134	0.137	13.7
Land use types	0.08	0.043	0.035	0.061	0.013	0.046	0.047	4.7
Soil types	0.062	0.030	0.021	0.020	0.04	0.035	0.036	3.6
Average sum						0.977	1.00	100

Equations 7.1, 7.2, and 7.3 yield the values of the Numerical Consistency ratio (CR), which must fall within the scientific criterion of less than (< 0.1). As a result, the resulting consistency ratio for comparing pairwise weights was 0.07, indicating that pairwise weights are within an acceptable range. In addition, the CR result verified the consistency of judgment dependability.

$$CR = \frac{CI}{RI} \quad \text{Equation 7.1}$$

The value of the consistency index (CI) can be acquired by:

$$CI = \frac{\lambda_{max} - n_i}{n_i - 1} \quad \text{Equation 7.2}$$

λ_{max} derived from the equation that follows:

$$\lambda_{max} = \sum_{n=1}^{ni} \frac{(PW)_n}{n_i w_n} \quad \text{Equation 7.3}$$

Where the weight vector is denoted by W

Standard tables (Table 7.6) can be used to obtain the random index (RI) (Saaty, 1980). As the table makes obvious, the random inconsistency value for five parameters is 1.12 because the RI value is based on the number of parameters.

Table 7.6: RI value

n	1	2	3	4	5	6	7	8	9	10
RI value	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

Based on the provided data the result for λ_{max} is 5.34, and CI calculated value is 0.085, hence CR is computed using RI = 1.12 for n = 5: CR = 0.085/0.12 = 0.076. Since CR value is less than 0.01, the comparison matrix is reliable. Therefore, Suitability map can be generated using weight sum overlay function in ArcGIS environment (Equation 7.4).

$$\text{Suitability} = \sum W_i \, X_i \qquad \text{Equation 7.4}$$

Where

Wi = weight of factor *i*;

Xi = criterion score of parameters *i*

Hence, based on the calculated and finding results of weighted factor the suitability map for study area can be generated as follows either using raster calculator or weighted overlay function.

Suitability map (AHP) = 0.515 × [Slope] + 0.266 × [Elevation] + 0.137 × [Proximity to river] + 0.047 × [Land use types] + 0.036 × [Soil types]

7.2.4. Fuzzy AHP model (FAHP)

The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is a fuzzy logic-based Analytic Hierarchy Process (AHP). AHP practice and the fuzzy AHP technique are comparable. According to Putra et al., (2018), the fuzzy triangle scale is where the AHP scale is initially accessed in the fuzzy AHP technique. Compared to standard AHP, fuzzy AHP is a somewhat complex methodology that requires more numerical calculations to evaluate compound priorities, which increases the effort. Fuzzy AHP is far better than standard AHP because decision-makers are more certain in performing interval judgments than static valuations, according to Rabia Arikan (2016).

Fuzzy AHP will perform better when we use results from surveys or personal human perceptions. Figure 7.2 illustrates the five steps of the fuzzy-AHP technique employed in this study.

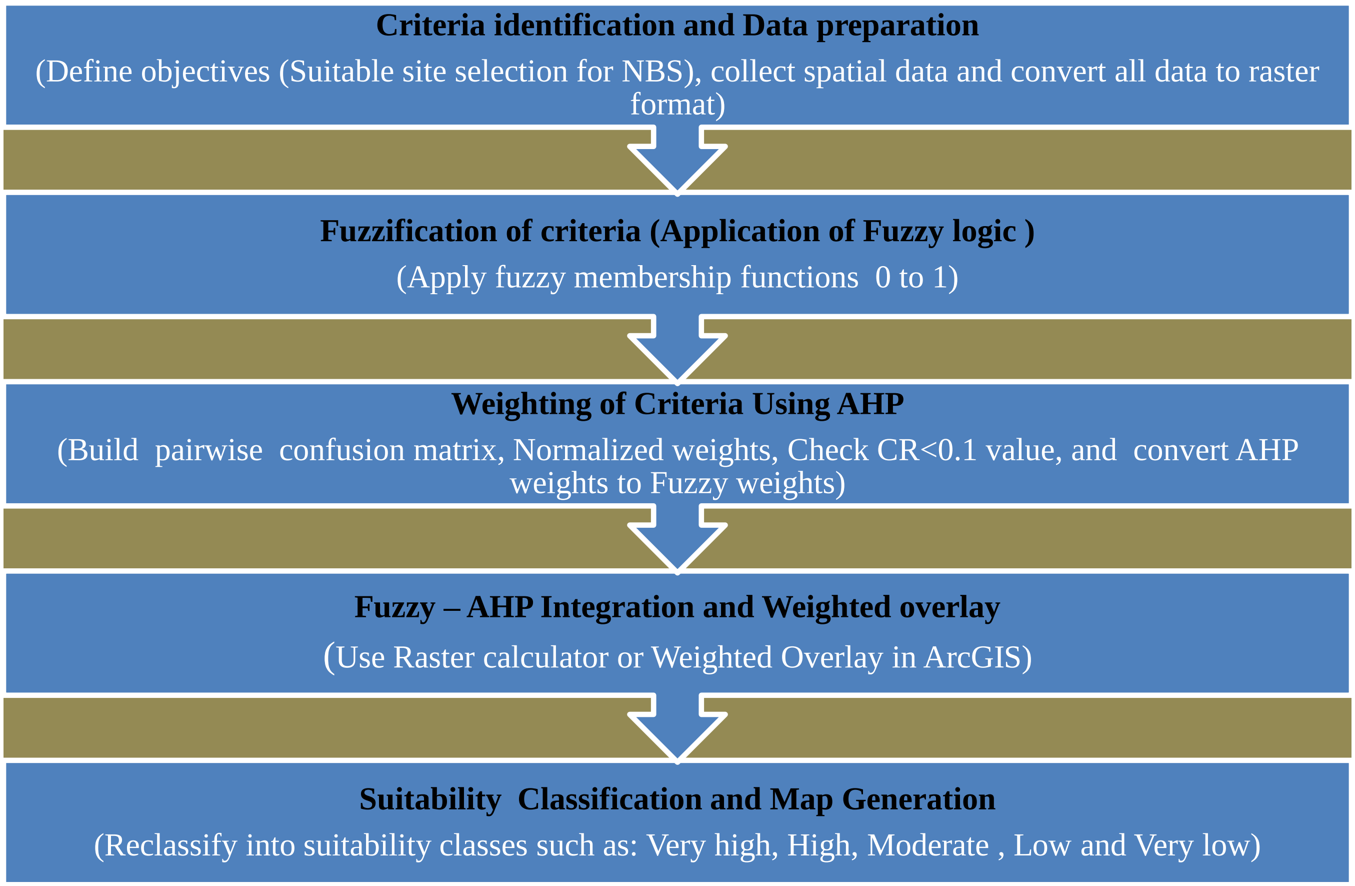

Figure 7.2: Workflow to Generate Suitability map using the Fuzzy-AHP Approach

Table 7.7: Fuzzy Decision Matrix of Criteria

Criteria	Slope	Elevation	Proximity to river	Land use types	Soil types
Slope	(1,1,1)	(2,3,4)	(4,5,6)	(6,7,8)	(8,9,9)
Elevation	(¼,⅓,½)	(1,1,1)	(2,3,4)	(4,5,6)	(6,7,8)
Proximity to river	(⅙,⅕,¼)	(¼,⅓,½)	(1,1,1)	(2,3,4)	(4,5,6)
Land use types	(⅛,⅐,⅙)	(⅙,⅕,¼)	(¼,⅓,½)	(1,1,1)	(2,3,4)
Soil types	(⅑,⅑,⅛)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(¼,⅓,½)	(1,1,1)

In fuzzy method generating fuzzy decision matrix criteria (Table 7.7) is significant step to proceed to the next part of fuzzy methods. The geometric mean was then used to determine the criterion's relative importance. Buckley's (1985) formula was used to determine the geometric mean (Equation 7.5 plus Equation 7.6) (Table 7.8).

$A1\ x\ A2\ x\ An = (l1, m1, u1)\ x\ (l2, m2, u2) \ldots x\ (ln, mn, un) = (l1l2ln, m1m2mn, u1u2un)$
Equation 7.5

Geometric Mean = $(l1l2ln, m1m2mn, u1u2un)^{-n}$ Equation 7.6

Where the least, median, and largest member values for each criterion are l, m, and u, respectively. And the conditioning factors are A1, A2, and An.

Table 7.8: fuzzy geometric mean (ri = l, m, u)

Criteria	l	m	u
Slope	3.2875	3.9363	4.4413
Elevation	1.6438	2.0362	2.4915
Proximity to river	0.8027	1.0	1.2457
Land use types	0.4014	0.4911	0.6084
Soil types	0.2252	0.254	0.3042

$$wi = ri\ x\ (r1 + r2 + r3) = (lwi, mwi, uwi)$$ Equation 7.7

Here, ri is the geometric mean and Wi is the relative fuzzy weight based on Equation (7.7). Equation (7.8) was used for de-fuzzification in order to generate the average weight (Aw) (Tella et al., 2020) (Table 7.9).

$$Aw = \frac{lwi + mwi + uwi}{3}$$ Equation 7.8

Table 7.9: Fuzzy weight of Criteria (Wi)

Criteria	l	m	u
Slope	0.3616	0.51	0.6983
Elevation	0.1808	0.2638	0.3917
Proximity to river	0.0883	0.1296	0.1959
Land use types	0.0442	0.0636	0.0956
Soil types	0.0248	0.0329	0.0478

Equation (7.9) was used to determine the normalized average weight (Ni) from the defuzzified data (average weight) (Table 7.10),

$$\text{Ni} = Aw/\sum n\ i = 1\ Aw \quad \text{Equation 7.9}$$

Table 7.10: Defuzzified and Normalized results

Criteria	Average Weight (A_n)	Normalized Weight (N_i)	Final Weight (%)	Rank
Slope	0.5233	0.5017	50.17	1st
Elevation	0.2788	0.2673	26.73	2nd
Proximity to river	0.1379	0.1322	13.22	3rd
Land use types	0.0678	0.065	6.5	4th
Soil types	0.0352	0.0337	3.37	5th

Fuzzy logic theory can improve the way factors are categorized to prevent ambiguity. These elements' contents may have started off as distinct limits. Fuzzy membership functions, however, can effectively manage factor uncertainty (Chang et al., 2008). Determined through the probability of becoming a member of a set, the Fuzzy Membership often reclassifies the factor value as a number scale from 0 to 1. "0" denotes a factor value that is completely outside of the set. "1" denotes that this factor value is fully included in the set. The likelihood of membership increases with the number, according to the factor scale value of possibilities (Raines et al., 2010). Following that, we have created the suitable location map for NBS measures within the Awash River basin using a raster calculator. The fuzzy-AHP or fuzzy hybrid technique was used to create the end suitable map (Equation 7.5):

$$\text{Suitability AHP-Fuzzy} = \sum W_i X_i \qquad \text{Equation 7.5}$$

Where

Wi = Weight of factor of AHP *i*;

Xi = Criterion score of parameters of Fuzzy membership *i*

Suitability map (Fuzzy - AHP) = 0.515 × [Slope Membership] + 0.266 × [Elevation Membership] + 0.137 × [Proximity to river Membership] + 0.047 × [Land use types Membership] + 0.036 × [Soil types Membership]

7.3. Result and Discussion

The most important step before proceeding to map suitable areas is identification of types of NBS, which are proposed to be practically implemented in the ground. Hence, types of NBS to be implemented in the downstream part of the ARB are identified by the knowledge of experts. The study engaged ten (10) experts within the Ministry of Water and Energy (MoWE), who have extensive experience in flood hazard management. This group included experts with extensive experience in implementing NbS. The preferred NBS are listed by their ranks within (Table 7.11) as favorable to be implemented at lower slope and elevation levels, close to the main river line with suitable soil types alongside land use classes.

Hence, based on the experts' selection, widening of water bodies/rivers and floodplain enlargement/restoration are ranked first for positive impacts regarding flood hazard mitigation. Natural Bank Stabilization and Retention/Detention Ponds were preferred second by the experts for positive impacts, and the Integrated Approach (NBS combined with gray infrastructure, e.g., dams) ranked third, and Lake/Wetland Restoration and Riparian Buffer Strips ranked fourth for high positive impacts. Afforestation/Reforestation ranked fifth and upper watershed restoration ranked sixth by the experts for positive impacts within Awash River Basin.

Table 7.11: Shows the preferred NBS techniques selected by experts with their consequent ranks. Rank 5 stands for very positive impact of NBS, 4 for high positive, 3 for medium, 2 for low, and 1 for very low positive impacts of NBS. The final rank and scoring are applied using the Likert Scale method.

No.	NBS Option	Final Ranking
1	Afforestation/Reforestation	1
2	Retention/Detention Ponds	4
3	Natural Bank Stabilization	4
4	Lake/Wetland Restoration	2
5	Floodplain Enlargement/Restoration	5
6	Widening of Water Bodies/Rivers	5
7	Riparian Buffer Strips	2
8	Integrated Approach (NBS combined with gray infrastructure, e.g., dams)	3
9	Upper watershed restoration	1

Based on the Likert-scale ranking (Table 7.11) approach Floodplain enlargement/restoration, Widening of Water Bodies/Rivers, Natural Bank Stabilization, Retention/Detention Ponds, integrated approach, Lake/Wetland Restoration and Riparian Buffer Strips has received the greatest ratings in the case studies since it can offer several advantages, such expanding the river's space, lowering the speed of runoff, trap sediments, regulate temperature, promoting ecosystem and biological diversity, safeguarding people and property, increasing recreational space, and enhancing the quality of water (Hamed, 2019).

Lujan et al., (2025); Waylen et al., (2025); Ruangpan et al., (2021); Alves et al., (2018a) and Kuller et al., (2019) also reported similar results preferences based on expert judgments. In addition to the highly preferred NBS, Green roofing is more practicable in urban area with highland characteristics area, and rain water harvesting is more suitable to be implementing within gentle to moderate slope area in highland area. Moreover, upper basin restoration activities and reforestation alongside overall soil and water conservation activities are highly recommended in upper stream part of Awash River basin to halt potential flood, soil erosion and sedimentation in downstream areas of the basin.

After careful analysis the selected types of NBS by experts and suitability parameters to select suitable areas for implementation of selected NBS in Awash River basin have been done properly and the suitable area is mapped in ArcGIS environment (Figure 7.3 and Figure 7.4). The selected location for NBS implementation, are more suitable for NBS such as, Retention/Detention Ponds, Natural Bank Stabilization, Lake/Wetland Restoration, Floodplain Enlargement/Restoration, Widening of Water Bodies/Rivers, Riparian Buffer Strips, and Integrated Approach (NBS combined with gray infrastructure, e.g., dams). Moreover, Table 7.12 clearly illustrates the suitable area and percent coverage: 37.92% of the Awash River basin is very highly suitable for implementing NBS, covering an area of 4,346,794.64 ha; 31.46% is highly suitable, covering 3,606,363.24 ha; 12.35% is moderately suitable, accounting for 1,416,433.23 ha; 11.90% is low suitability with an area of 1,364,663.74 ha; and 6.37% is very low suitability with a coverage of 730,241.95 ha.

This NBS are more effective and sustainable to be implemented within gentle slope, lowland elevations, close to river line, with permeable types of soil (eg. Eutric Nitosols) and land use types such as wetland, forest, agricultural and bare lands. Expert knowledge from the ministry of water and energy provides preference for different NBS measures within Awash River basin, lead to select suitable sites for proposed NBSs. Area specific NBS implementation is highly supported also by (Stagakis et al., 2019).

According to the experts' assessments, floodplain enlargement and restoration was one of the specific NBS that received the highest score. In order for modified channels of rivers and flooding areas to self-regulate and exist in a less volatile state, it is necessary to return them to a more natural condition (Brierley et al., 2022). It was discovered to be especially successful in more level and lower elevations, which not merely lowers the risk of flooding but also improves water quality, increases ecosystem connectivity throughout the region, and provides habitat for native species. By establishing green buffer zones alongside streams, integrating floodplain restoration can have significant ecological advantages that increase ecosystem resilience and biodiversity (Nilsson et al., 2018). Floodplain rehabilitation in these areas can absorb large volumes of runoff during periods of high rainfall, delay the flow rate, and reduce the highest possible discharge in downstream locales (Mubeen et al., 2021).

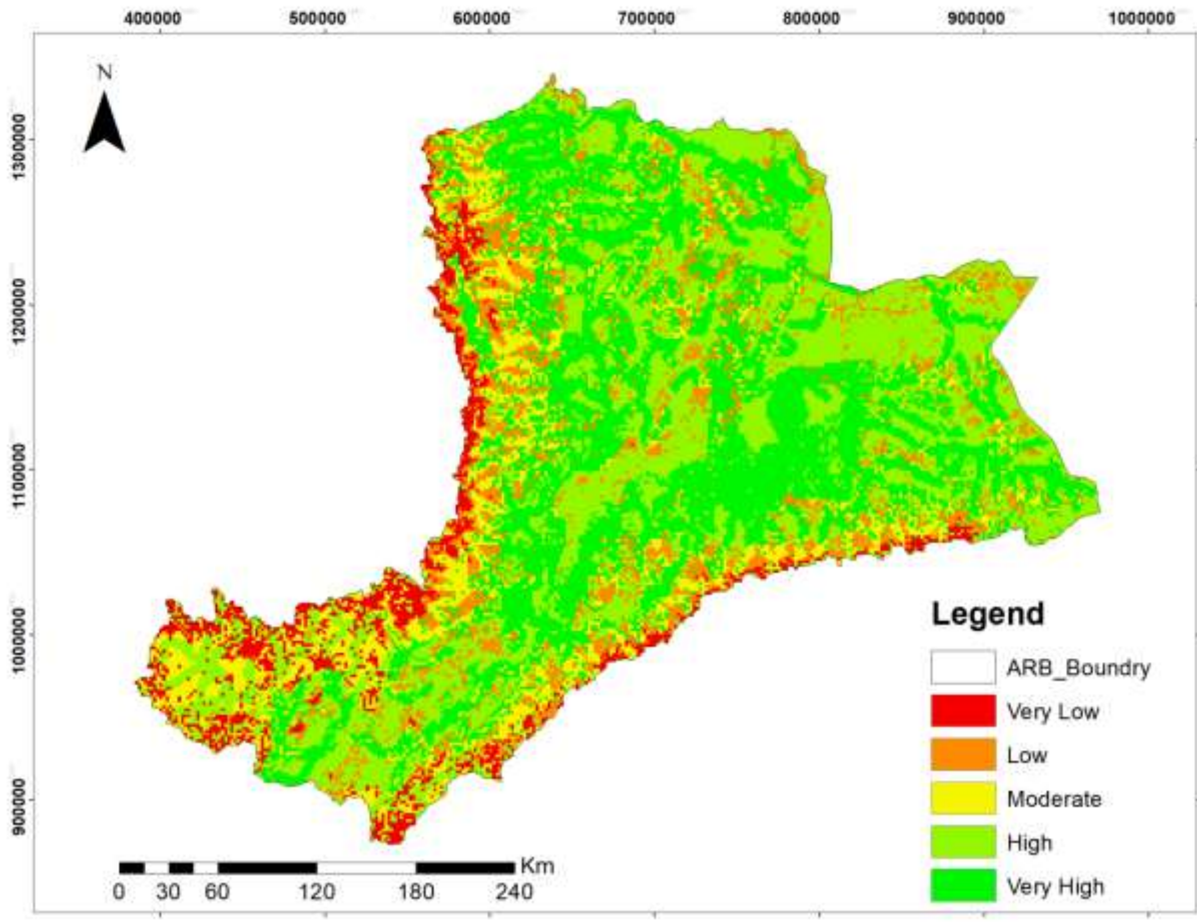

Figure 7.3: AHP-Fuzzy Hybrid model suitability map.

The AHP-generated weight and fuzzy membership findings were multiplied in this graphic. For suitability analysis, the hybrid technique is a highly important, well-known, and often used method. Moreover, Fuzzy-AHP hybrid model is commonly used for complex environmental modeling by researchers.

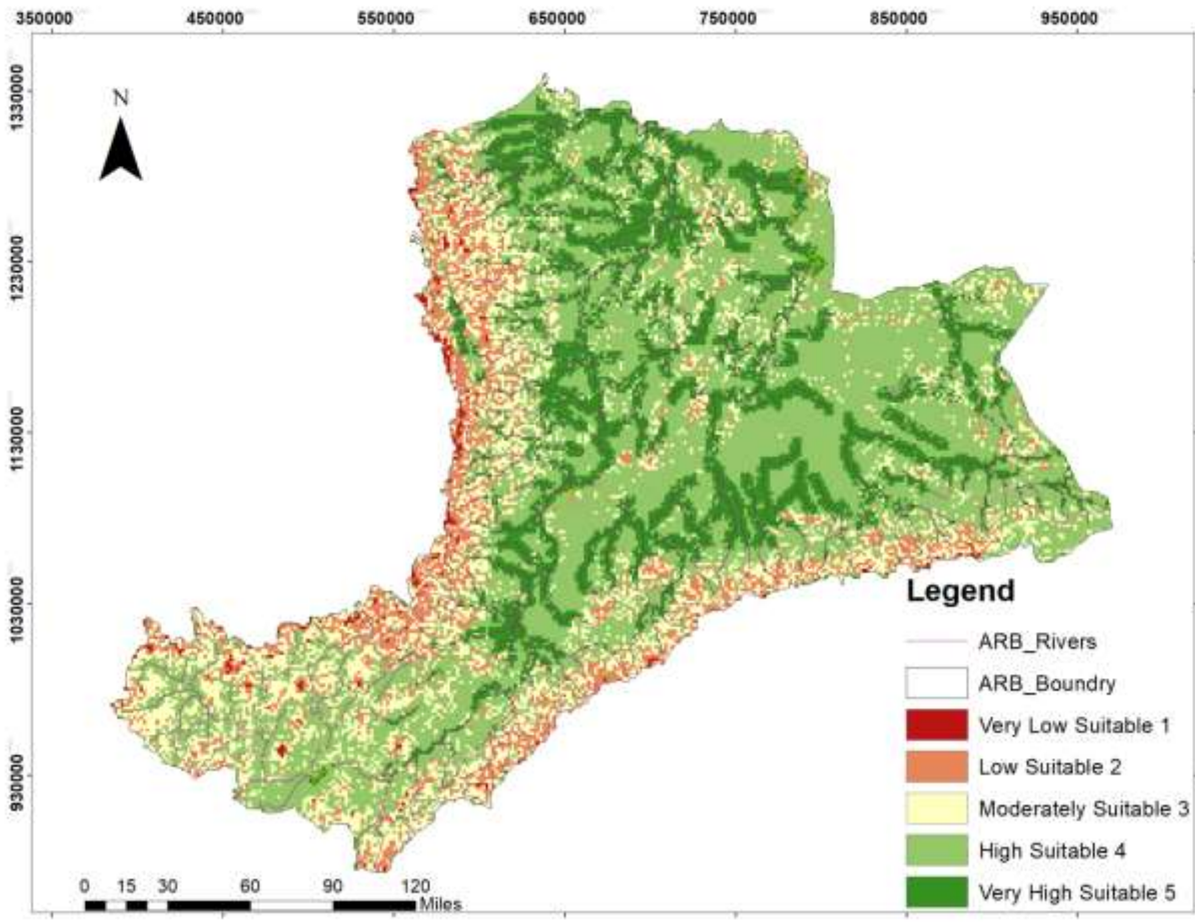

Figure 7.4: AHP model suitability map, the weight obtained from AHP analysis used also to AHP-Fuzzy hybrid approach. But, this suitability image used only AHP approach, which used also as a confirmation for the significant reliability of the hybrid approach. The image highlights similar suitable sites identification both in hybrid and AHP approach images. AHP used an interpretation of relative importance, considered structured weighting determined by expert knowledge which is subjective.

By establishing habitats that can improve regional biodiversity, this natural storage capacity promotes ecological health in addition to helping to mitigate floods. It is favorable for the channel to flood the floodplain more frequently so that the river can use more storage space there. Additional actions could include excavating or extending the floodplain, lowering the river channel bed, rerouting river channel flows, turning meadows into wetlands, and establishing more water storage spaces.

The goal of these modifications is to improve flood plain area and storage while decreasing river velocity. It's been discovered that floodplains are more effective at reducing flood flows than upland wetlands (Acreman et al., 2013; Acreman et al., 2021).

Other particular NBS strategies for ARB downstream areas include river naturalization, which involves restoring riverside passageways, removing engineering embankments, and re-vegetating riverbeds and banks. River and stream re-naturalization aims to reduce downstream floods by enhancing preservation of water and absorption (Browder et al., 2019; Soar et al., 2021). In addition, introducing of geotextile matting can be used to stabilize embankments, and bioengineering techniques are crucial for stabilizing riverbanks (Jany et al., 2013). Additionally, it can produce a structurally sound and biologically rich environment (Eisenberg et al., 2019). Aside from stock exclusion, riparian planting and forest protection can provide shade for waterway ecosystems, lowering temperatures (McKergow et al., 2022; Ellawala et al., 2019), as well as reinforce riverbanks and accumulate fines, lowering erosion rates over time (Boothroyd et al., 2004; Micheli et al., 2002; Quinn, 2005; Quinn et al., 2004; Zaimes et al., 2019; Hughes, 2016; Zhang et al., 2010; Sweeney et al., 2014).

Along with riparian buffer strips, bio-retention efforts also offer significant environmental benefits. Bio-retention systems, which composed rain gardens, bio-swales, and vegetated infiltration strips, are storm water management systems made consisting of plants planted on top of a specific media or substrate that allows for infiltration, retention, and treatment of stormwater runoff (Auckland Council,2024; USEPA,2021; Vijayaraghavan et al.,2021). They have been shown to effectively eliminate metals, nitrogen, organic and microbiological contaminants, and suspended particles (Biswa et al., 2022). Even in low-permeability soils, they also reduce volume and peak flow. Runoff decrease of up to 59% was measured by Winston et al., (2016). The installation of bio-retention systems covering 12% of the catchment area in Sydney's metropolitan catchments was shown to minimize the average annual flood damage of a storm event with a 20-year return duration by about AUD$1.2 million (Wu et al., 2023). Furthermore, bio-retention systems provide benefits such as heat control, improved air quality, retention of carbon, enhanced regional economies and employment development, entertainment and learning possibilities, and increased biodiversity (World Bank, 2021). According to Kavehei et al., (2018) bio-retention sites can also store 2.4 kg/m2 of carbon. Bio-retention swales have also been reported to have greater species diversity and richness (Kazemi et al., 2011). Additionally, retention ponds, the other NBS, are essential for upstream storage because they collect runoff and permit a progressive release of water. Particularly in urban and agricultural regions vulnerable to heavy runoff, the planned installation of these ponds can capture and preserve excess runoff from upland regions; managing downstream flood hazards (Griffiths et al., 2024). In order to lessen the burden on areas downstream, the retention ponds serve as a buffer by collecting storm water and releasing it gradually (Griffiths et al., 2024).

Other highly preferred NBS techniques were wetland restoration. Wetland can be distinct in two dimensions, natural and constructed wetlands. The landscape's natural wetlands can maintain downstream base flows as well as retain and buffer flows (Baker et al., 2009; Mitsch et al., 2007). Vegetative resistance slows flows across wetlands while also offering storage capacity and space to build up flood flows. Natural wetland restoration can improve ecosystem services and restore natural hydrological dynamics (Tomscha et al., 2021). Reforestation has a lower influence on peak flow reduction and flood management. Furthermore, they have a major effect on water and nutrient balances (Hansen et al., 2018; Hattermann et al., 2006; Knox et al., 2008). According to research, wetlands can reduce maximum flows by up to 15%, flood regions by up to 55%, and peak flows by up to 42%. Prospective climate change projections are anticipated to reduce peak flows by 15-20% (Walters et al., 2016). Additionally, the most often used NBS for surface waters are constructed wetlands (CWs). Pollutants include nutrients, organic materials, and suspended particles are eliminated by CWs (Kadlec et al., 2009). CWs can be used at a variety of locations within a catchment, such as headwaters, the middle or bottom of the catchment. In addition to that, there are major ecological benefits to improving the basin's land cover both upstream and downstream. Furthermore, it has been demonstrated that forests lower urban air pollution (Abhijith et al., 2017). Tree-cover can lessen localized floods when combined with ponds or wetlands (Green et al., 2021). In metropolitan settings, Green pathways, nature preserves, and spots for recreation function as well as designated flooding pathways, easing previously flooded areas (Marapara et al., 2021).

Integrating of gray structure and chosen NBS approaches are also widely implemented and beneficial to decrease flood hazard and sediment reduction. Various modeling techniques are utilized to contrast the efficiency of numerous NBS alternatives or NBSs to more conventional or robust engineering solutions. The study indicated a rapid decrease in the likelihood of flooding associated with the completion of conventionally engineered flood remedies. On the other hand, the introduction of an NBS strategy may result in a more gradual reduction in flood risk (Jacob et al., 2014).

In general, Successful implementation of the proposed NBS has offered different environmental and social benefits which are generally acknowledged by numerous scholars. Water and air purity, noise suppression, erosion and landslide diminution, temperature modulation, habitat interconnection, soil health, biodiversity, and carbon storage Groundwater recharge, flood management, and water supply are widely recognized environmental benefits. NBS provides additional societal benefits such as food and raw resources, recreation, tourism, health and well-being, job prospects, energy efficiency, asset appreciation, and cohesiveness in society (Wishart et al., 2021; Ommer et al., 2022; van Zanten et al., 2023).

Table 7.12: Suitability class in terms of Area (ha) and percent coverage

Suitability Class	Sum of Area (ha)	Percent coverage (%)
Very Low Suitable	730,241.95	6.37
Low Suitable	1,364,663.74	11.90
Moderately Suitable	1,416,433.23	12.35
High Suitable	3,606,363.24	31.46
Very High Suitable	4,346,794.64	37.92
Grand Total	11,464,496.80	100

7.3.1. Validation

The ArcGIS environment was used for this study's validation, utilizing the following functions: Segmentation and classification by generated accuracy random points (Figure 7.5) and compute confusion matrix. The AUC-ROC curve was then created using ArcGIS 10.8's ArcSDM-5.03.01 extension tools, and comparing the generated random points with the suitability map.

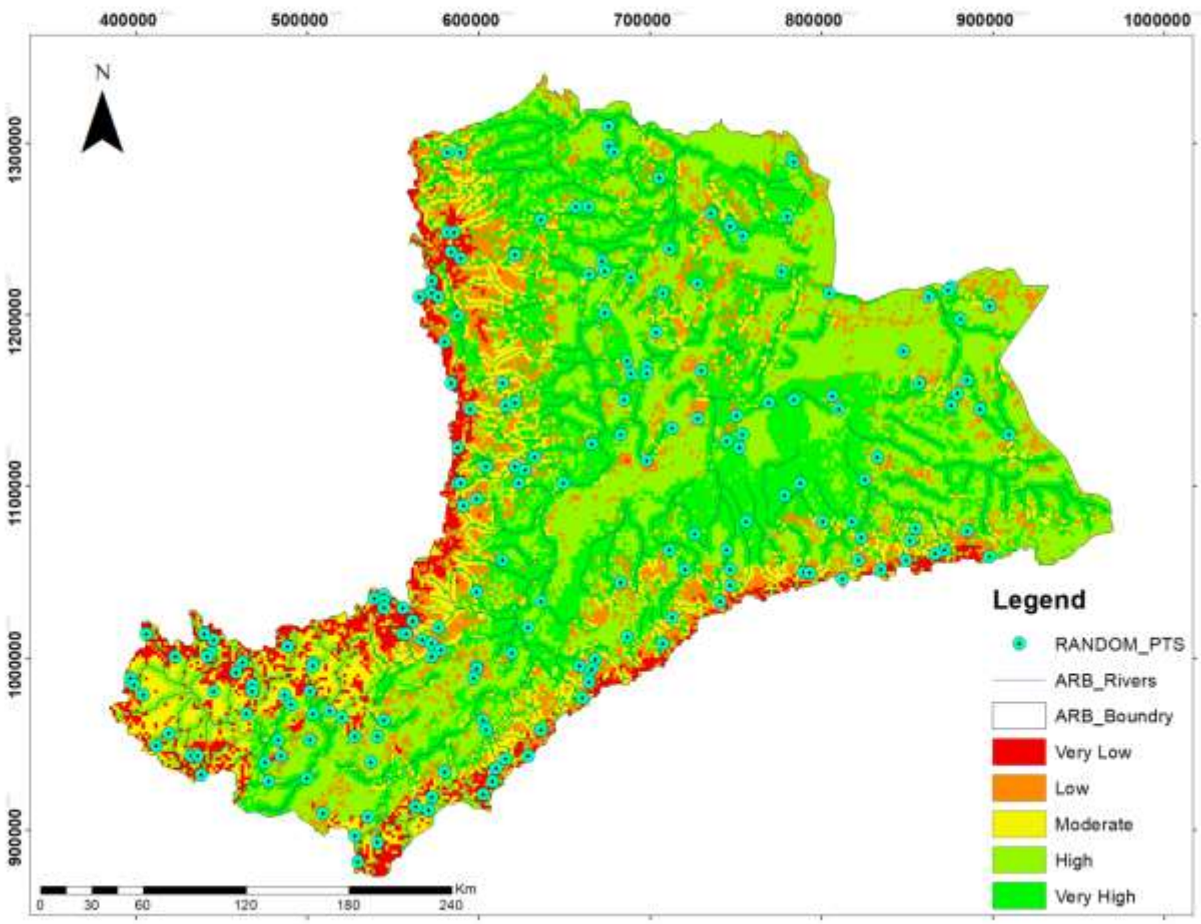

Figure 7.5: Randomly generated points to validate the produced suitability map.

In the first place the suitability map validation was conducted based on randomly generated sampling points that are assigned both the predicted suitability class and a reference class. A reference class was generated based on expert interpretation of high resolution satellite image and existing land features. Then confusion matrix was generated in ArcGIS environment using compute confusion matrix tools of spatial analyst function. The output shows that there is substantial agreement between suitability map and reference data. The kappa coefficient is approximately 0.9 and the overall accuracy result meet the standard acceptance level (Table 7.13). The result demonstrated that, the strong suitability assessment and also it confirms that the map is highly favorable for decision making, and planning applications.

Table 7.13: Accuracy assessment

Class Value	C_1	C_2	C_3	C_4	C_5	Total	U Accuracy	Kappa
C_1	39.0	0.0	0.0	1.0	0.0	40.0	1.0	0.0
C_2	1.0	38.0	0.0	0.0	1.0	40.0	1.0	0.0
C_3	2.0	2.0	35.0	0.0	1.0	40.0	0.9	0.0
C_4	0.0	2.0	0.0	37.0	1.0	40.0	0.9	0.0
C_5	1.0	1.0	1.0	1.0	35.0	39.0	0.9	0.0
Total	43.0	43.0	36.0	39.0	38.0	199.0	0.0	0.0
P Accuracy	0.9	0.9	1.0	0.9	0.9	0.0	0.9	0.0
Kappa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9

Second, the created suitability map using the AHP-Fuzzy approach has been validated using AUC-ROC methodologies. According to the criteria, the obtained AUC is 0.86, which is in the excellent range. This illustrates how closely the suitability map reflects the real-world circumstances. Because of the outcome, the constructed AHP-Fuzzy model has high prediction accuracy. It implies that the model can predict the specific appropriate sites and performs exceptionally well overall. Figure 7.6, displays the ROC curve and the study's AUC value. To thoroughly authenticate the findings, the data were examined alongside superior-resolution satellite images of the region and evaluated in light of relevant expert opinions and literature. Scholars highly recommend data validation and calibration to guarantee the model's level of accuracy (Keval H. Jodhani, 2023).

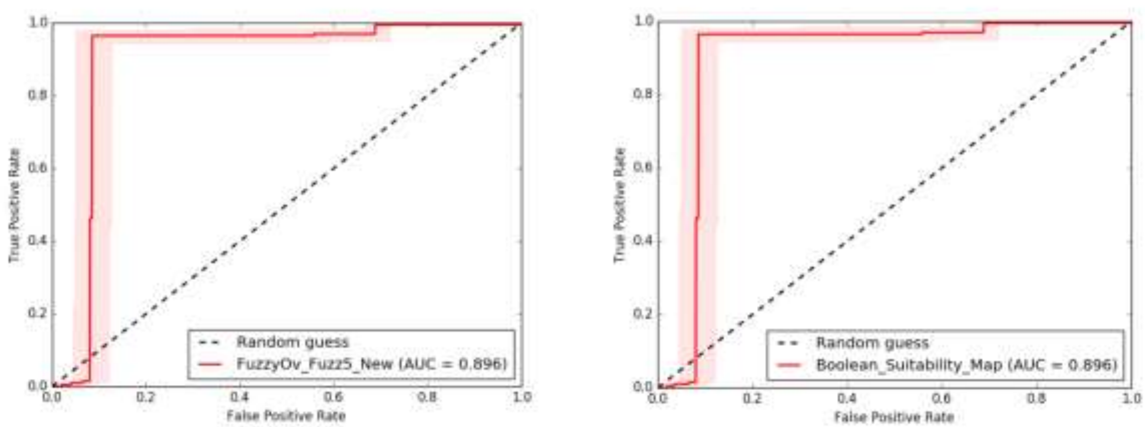

Figure 7.6: ROC – AUC Validation curve

Furthermore, in the tables and figures of this analysis of suitability, areas identified as suitable areas are also cross-referenced by other images using a Boolean logic approach (Figure 7.7). Boolean logic is known as simple, transparent, and more objective. It ignores the degree of suitability and uses a strictly suitable or not suitable interpretation. Frequently used as a preliminary or validation method for fuzzy or AHP-based suitability models. Hence, the high suitability area for NBS practices produced by AHP-fuzzy models is also validated by the produced image of the Boolean logic model. Moreover, the ROC-AUC value of the Boolean logic image was approximately about 0.896, which is at the standard threshold level.

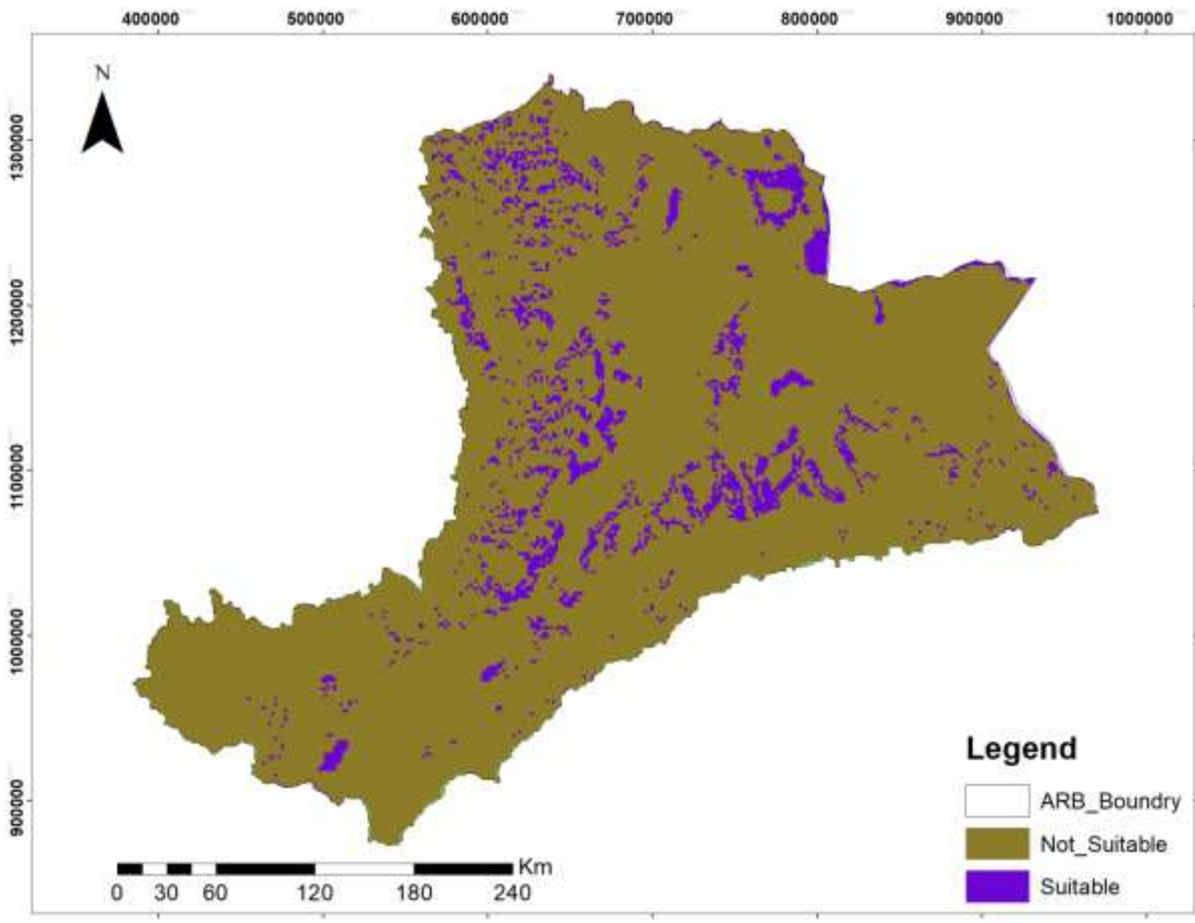

Figure 7.7: Boolean logic model suitability map. Frequently used as preliminary or validation method for Fuzzy or AHP based suitability models. The image depicts suitability only in two dimensions, either suitable or not. Hence, the image validates the other two images, which are generated by the AHP and AHP-fuzzy approaches. Identified suitable areas are clearly similar to the previously generated images (Figure 7.3 and Figure 7.4).

7.4. Conclusion and Recommendation

In accordance with the purpose of this investigation final ideal place to carry out NBS to mitigate flood hazards in study area was successfully completed. The NBS selection was determined by combining efforts of expert judgment and literature reviews. The selected NBS are ranked; widening of water bodies/rivers and floodplain enlargement/restoration is ranked first for positive impacts regarding flood hazard mitigation. Natural Bank Stabilization and Retention/Detention Ponds were preferred second by the experts for positive impacts, and the Integrated Approach (NBS combined with gray infrastructure, e.g., dams) ranked third, and Lake/Wetland Restoration and Riparian Buffer Strips ranked fourth for high positive impacts. Afforestation/Reforestation ranked fifth and upper watershed restoration ranked sixth by the experts for positive impacts within Awash River Basin.

The spatial finding revealed that 37.92% of the study area with 4.3 million ha area coverage, is highly suitable for proposed NBS, and emphasizing significant potential to mitigate flood hazards within the study area. This NBS are more effective and sustainable to be implemented within gentle slope, lowland elevations, close to river line, with permeable types of soil (eg. Eutric Nitosols) and land use types such as wetland, forest, agricultural and bare lands. The validation process conducted based on ArcGIS and ROC-AUC approaches, both are confirmed that the suitability map was accurate and reliable. The kappa coefficient is 0.9 and AUC is equal to 0.86. moreover, the suitability map was also validated by cross image referencing using Boolean logic methods, which is also validate the reliability of the suitability map significantly.

Hence, the finding result magnifies the promise of NBS as a significant flood reduction mechanism and to enhance ecological benefits, such as, ecosystem balance, biodiversity and community resilience. The combination of expert opinions, literature reviews, spatial analysis, and validation process proves that the concept of NBS strategies is well fitted to targeted implementation purpose. Moreover, it provides scientifically grounded foundation for decision makers and for strategic plan development in the locations that are subjected to flooding. Ultimately, the present investigation emphasizes the feasibility and effectiveness of NBS as sustainable, environmentally friendly and biodiversity promoting measures to manage floods within the Awash River basin. Such strategies can play a great role in resilient landscape management, and decrease flood risks in Ethiopia and other flood prone nations.

Finally, this study recommend, prioritizing very high suitable areas for implementation of selected NBS within Awash River basin (Figure 7.8), particularly floodplain restoration, river widening, retention/detention ponds, integrated approach, wetland restoration and natural bank stabilization. Furthermore, promoting the integrate use of NBS and gray infrastructure to enhance flood resilience for sustainable and multifunctional flood management. In addition, incorporating local stakeholders and experts opinions are ensured ecological compatibility and acceptance by the community. Utilizing high resolution suitability map is very essential for land use planning, zoning and efficient NBS implementation.

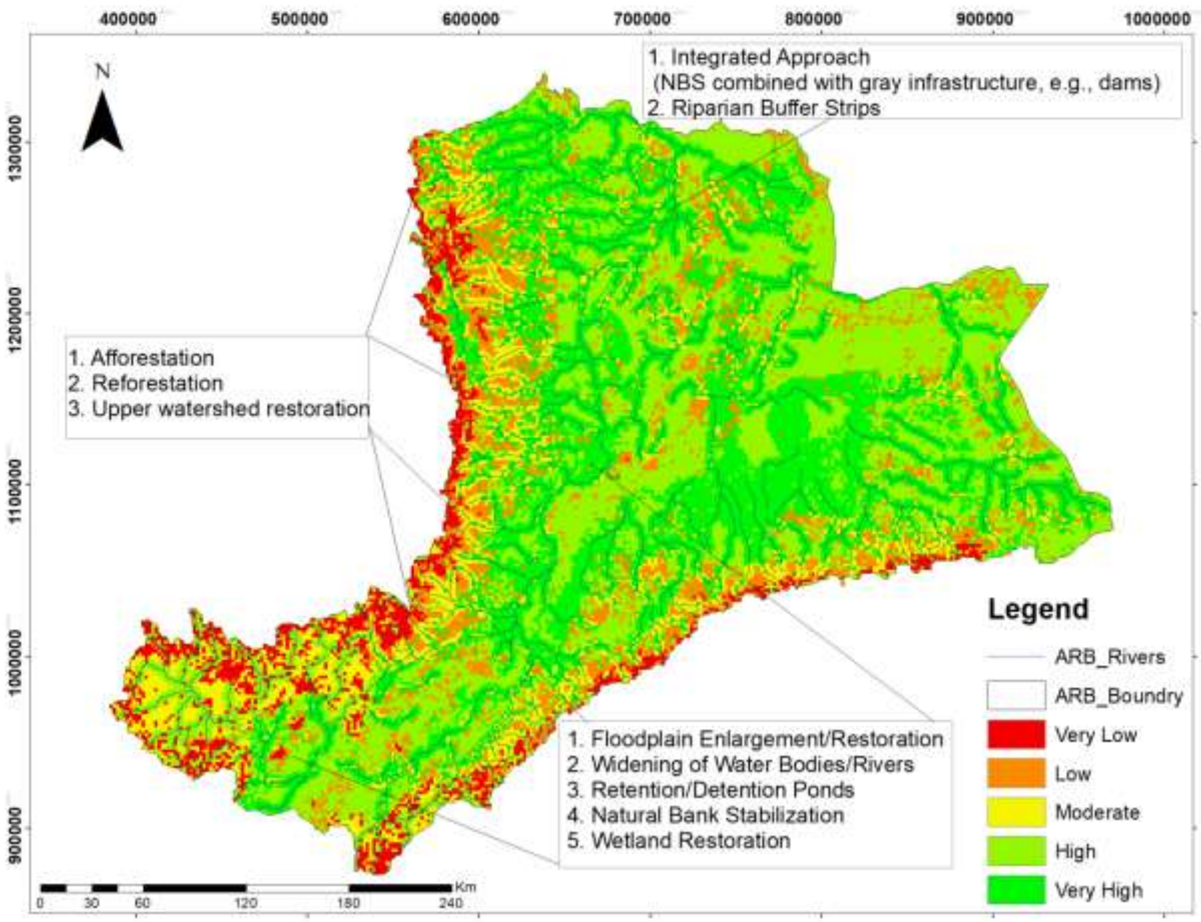

Figure 7.8: Recommended NBS over identified suitable locations within Awash River Basin.

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CHAPTER EIGHT: SYNTHESIS OF KEY FINDINGS, CONCLUSION AND RECOMMENDATION

8.1. Synthesis of Key Findings

The combined findings of the research demonstrate that the flood risks in the Awash River Basin do not have a single cause; however, these risks are the products of the interaction of high rate of climatic fluctuations, land-use transformation, and population growth. Long term, statistically-grounded analyses of climate trends indicate that there is a steady increase in temperature and a statistically significant reduction in the amount of precipitation which is characterized with growing variability in rainfall. High temperatures increase the rate of evapotranspiration and soil dryness, and precipitations are becoming more unpredictable and extreme. These climate changes have led to increased and extreme rainfall patterns that will interact with modified land surfaces, and hence increase flood risk. Spatial segregated examination of land surface temperature (LST) and vegetation revitalization (NDVI) also indicates that vegetation loss and growth of impermeable areas enhance surface temperatures and reduce of the functioning natural component of the basin hydrological regulation. Findings suggest that the rise in land surface temperature (LST) between 2000 and 2020 was strong with the dramatic enhancement being higher in downstream and urbanized areas of the basin. Areas where vegetation is smaller recorded constantly high values in LST. Moreover, the information also shows that the Normalized Difference Vegetation Index (NDVI) and LST have a significant negative relationship, which supports the assumption that vegetation loss has a direct positive impact on surface warming. Reduction in vegetation cover weakens surface shading, soil retention of moisture and soil capacity to absorb precipitation thus increasing runoff. On the other hand, sites having an elevated level of vegetation and wetlands among others recorded lower LST with a stable environment. These findings are indicative of the central role of vegetation and natural land cover in climatic moderation of microclimatic and hydrological variability. To that end, this paper establishes that climate change acts as a multiplier of stresses, which are increased by land-use change and population pressure become more perilous to flood risks in combination.

At the same time, the analysis of land-use and land-cover processes reveals how the accelerated human population growth and urban sprawls have significantly altered natural terrain landscape, reduced infiltration rates, altered the pool of floodplains, and increased the surface runoff, which collectively increase the susceptibility to floods. During the past thirty years, cities have grown tremendously and barren areas, shallow waters and agricultural lands have reduced. The wetlands had an interesting upsurge which was mainly due to landscape change brought about by floods and not a planned restoration. In addition, statistical testing establishes a good positive relationship between population growth and urban expansion, and the type of natural land cover showed negative association with population growth. Therefore, the research paper shows that uncontrolled land use and quick urbanization have exacerbated the risk of floods, and there is a necessity to implement land-use planning strategies, which consider ecosystem operations and flood protection.

The flood hazard mapping study identifies zones of differing hazard intensity and offers a comprehensive geographical depiction of flood threat throughout the Awash River Basin. The findings indicate that low-lying areas, gentle slopes, floodplains, and areas near river channels particularly in the middle and lower portions of the basin are the key locations where flood hazards are concentrated. About 5,855,130.12ha (51.4%) of the Awash River Basin's total area is under high risk of flooding. Because of their physical location and hydrological interconnectedness, these regions are frequently impacted by seasonal flooding. The analysis verifies that the primary parameters influencing the distribution of flood hazards are rainfall, elevation, slope, land use, drainage density, and proximity to rivers. The study area's drainage density, elevation, and slope level are more predictive of vulnerability to flood hazards than the other variables. The robustness of the Hazard map for planning purposes is confirmed by the validation results, which show strong model dependability. The study highlights the significance of spatial planning and risk-informed land management by showing that flood hazards in the Awash River Basin are spatially predictable and heavily influenced by both natural topography features and human-induced land use changes.

Using ArcGIS 10.8, the rainfall erosivity factor (R), soil erodibility factor (K), slope degree factor (LS), cover management (C), and support factor (P) were analyzed to determine the average yearly soil loss. The Awash River Basin's annual average soil loss potential (A) is shown in (Figure 6.12) of the USLE map. Using ArcGIS's natural break algorithms, the results were categorized into five classes. The findings show that the basin's average annual soil loss varies between 0 and 31,049,739 tons ha-1 year-1.

Hotspots for erosion are seen in the upper and middle basin regions, suggesting that upstream deterioration is a major factor in soil loss and sediment production. Since a sizable portion of the Awash River basin has a slope percentage between 0 and 10%, there is very little erosion in this region. Additionally, the existence of grass and forests is crucial for preventing soil erosion. Hence, the Awash River Basin is predicted to lose 31,049,739 tons of soil annually, with a mean of roughly 28.6 tons of soil annually.

The STI in the Awash River Basin runs from 0 to 247,097 (Figure 6.13), indicating that the stream flow in the Basin has a very large capacity to transport the specified size ranges. Steep slopes and higher areas of the river basin, those are vulnerable to severe soil erosion and degradation, are linked to the highest values of the Sediment Transport Index (STI). On the other hand, regions with extensive vegetation in the basin's upper watershed have the lowest STI values, which are a sign of decreased sediment movement and accumulation. Consequently, this study's validity is verified by comparing its results with those of earlier research conducted in the Awash River Basin. Therefore, in order to reduce soil erosion and sedimentation and guarantee long-term basin sustainability, land management and nature-based interventions are crucial.

Together, the two studies exhibit a high level of interdependence between flood risks and soil erosion in the Awash River Basin. Loss of the soils in the uplands enhances sediment movement and causes instability in the channels; on the other hand, the downstream floodplains experience more exposure to floods due to the reduced channel capacity and disturbed flow regimes. All these observations highlight the need to ensure that there are basin-scale planning frameworks which incorporate erosion prevention, land-use control, and flood risk zoning in order to reduce flood risks and enhance environmental resilience.

Therefore, that a study of the key determinants shows that the flood risk factors in the Awash River Basin are the result of interaction of climatic fluctuations and land-use changes caused by human induced land use land cover change. This observation highlights the need to adopt comprehensive environmental planning mechanisms that pay more consideration to landscape fortification and the restoration of ecosystem as a sustainable solution measure to mitigate flooding.

Hence, the last purpose of the current research was to establish a viable mitigation approach to address another frequent problem of floods along the Awash River Basin. As such, the research question was which of the environmental planning and mitigation strategy was best suited to question the intensity and geographical coverage of the floods in the basin. The results related to this purpose thus provide a direct response to the research question, showing that Nature-Based Solutions (NBS) represent a very plausible and spatially acceptable method to reduce the risks of floods in the Awash River Basin, provided that the methods of geospatial and decision-making are strong.

The following summaries are the main findings for the last specific objective of the study. To begin with, the integration of Geographic Information System (GIS) analysis with an Analytic hierarchy Process (AHP)-Fuzzy hybrid Multi-criteria decision-making model was demonstrated to be useful in identifying the best location points where large scale NBS can be implemented at the river basin level. The methodology successfully met sophisticated environmental parameters and expert-data on uncertainty resulting in a spatially explicit suitability map that informs the strategic flood-reduction strategies.

Second, the basin was found to have a large area that was favorable with regard to NBS implementation. About 69.38 per cent of the Awash River Basin is classified under the high to very high suitability class and therefore, a lot of potential to scale up NBS is evident beyond only isolated urban or pilot interventions. This observation supports the idea that Nature-based flood mitigation activities at the basin level can be practiced in the most heavily flood-prone basin in Ethiopia and, therefore, demonstrates the fact that flood mitigation is possible through the involvement of the natural landscape processes and not just the use of engineered flood-control structures solely.

Third, the analysis reinstated that bio-physical determinants have decisive influence on the suitability of NBS. The topography of the region, elevations, closeness to rivers, highly permeable soils: Eutric Nitisols, and the type of land use areas, such as wetlands, forests, agricultural lands, and bare lands, were invariably found to be the most favorable geographical areas, which could support the successful and sustainable deployment of NBS. These notes support the need to match NBS design with the inherent features of the landscape instead of using standardized designs on non-uniform landscapes.

Fourth, prioritization in terms of experts revealed that the most effective NBS practices in reducing flood hazards in Awash River Basin include expansion and naturalization of floodplains, river widening, natural banks stabilization, and retention/detention ponds. Combined measures involving NBS and traditional grey infrastructure were also observed as having a strategic value, especially in the downstream and high-risk flood regions which could be under served by single solutions. The above listed measures directly address the underlying causes of flooding through increased natural water holding, decreased runoff velocity, increased infiltration and restoration of the linkage between rivers and floodplains.

They in turn will give long-term benefits of reducing flood risks and at the same time enhance ecosystem functions and landscape resilience. Lastly, the suitability evaluation was thoroughly proven. The confusion matrix provided a Kappa coefficient of 0.9 and the receiver operating characteristic area-under-curve analysis gave an AUC of 0.86, all of which holds the predictive accuracy to be high. Further validation using the Boolean logic also proved the strength of the identified suitable areas. The findings show that the created suitability maps have been reliable decision-supporting maps in land-use planning, flood-risk management, and long term climate-adaptation approaches.

Altogether, the results provide a clear answer to the research question: the best environmental planning approach in case of severe flooding risks in the Awash River Basin is the spatially optimal application of the Nature-Based Solutions, supplemented with the expertise and combined with the traditional infrastructure in cases of need. It is also the most effective way of reducing the impact of floods as well as ensuring sustainability through making the basin sustainable in terms of biodiversity, ecosystem service delivery, and community resilience, thus ensuring that the main objective of managing the basin in a sustainable manner is achieved.

8.2. Conclusion

The dissertation that is being presented offers a thorough assessment of the flood risks in the Awash River basin. It does this by carefully examining the dynamics of land-use-land-cover, climate variability, land-surface processes, soil erosion, the distribution of flood hazards, and the applications of Nature-Based Solutions (NBSs) in managing flood mitigation. The integration of the findings indicates that flood hazards in the basin are not caused by isolated hydrological occurrences, but rather by the combination of anthropogenic and climate-driven processes.

The flood hazard mapping confirms the finding that riverine networks are at continuous risk of high floods in low-lying terrains, having gently inclined slopes, and being located near riverine networks. In the ARB, flood-hazard zone maps were generated using GIS analysis in conjunction with weighted sum overlay or AHP approaches. This study used a variety of parameters to assess flood risk, including elevation, drainage density, slope, annual rainfall, river proximity, land use - land cover, and soil types. The downstream portions of the basin are more vulnerable to flooding due to slope, elevation, and drainage density. Since precipitation from the upper basin causes major floods in lower regions, high rainfall combined with the effects of climate change are the main causes of flooding in these places. According to this research, there is a considerable risk of flooding in several parts of the basin, with scores ranging from extremely high to extremely low.

The results also suggest that acute soil erosion in upland areas leads to sedimentation of river channels and flood plains therefore reducing the capacity of conveying power and increasing the risk of floods in the downstream areas. The high rate of soil erosion in the downstream portion of the Basin is caused by the concentration of high runoff and increased rainfall, particularly in the upper catchment. Soil loss rates based on USLE range from 0 to 31,049,739 tons/ ha/yr. while STIs range from 0 to 247,097. Additionally, grass, forests, and well-managed agricultural operations all effectively reduce watershed soil erosion. The relationship between sediment carrying agents and soil erosion is also assessed in this paper, which demonstrates the intricate system of interactions between water and sediment components on both landforms and water bodies.

This paper has investigated the changes in land-use/land-cover in connections with growth in population at the Awash River Basin in terms of flood hazards by the use of remote sensing and geographic information system technology. Highly attained imagery classified using supervised method in 1990, 2000, 2010, and 2020 data, were analyzed and interpreted to explain temporal patterns. The results show that urban areas have grown significantly and steadily since 1990 to 2020 that corresponds very well with the high rate of urbanization and demographical growth in the basin. The further confirmation of the existence of a positive correlation between the increase of population and the development of urban areas is obtained by Pearson correlation analysis, as it indicates that there is a strong interdependence between two variables. The requirement of increased rates of population, urbanization and land consumption were observed in the study area in 2020. This associated demographic and spatial expansion could change the land-use and land-cover patterns, and in the process increase flood risks.

As a result, this has led to an increased rate in population growth and unplanned urban sprawl where land-use patterns have significantly changed the surface porosity of the soil and the land to the extent that it reduces natural infiltration as well as dysfunction in the floodplain. At the same time, even long-term climatic studies can show the progressive rise in temperatures and increased variability in rainfall contributing to the aggravation of hydrological extremities due to the decrease in mean annual rainfall. Using a geospatial method and non-parametric statistical trend analysis, the effects of climate change in the Awash River basin were verified. These methods enable precise identification of regions in the research area with notable climate changes by statistically and geospatially, verifying the results for several time periods. Loss of vegetation and increase in the land surface temperature increases these pressures as they affect the intrinsic ability of the basin to manage runoff.

The dissertation shows that spatially optimized Nature-Based Solutions provide a viable and efficient flood mitigation solution for the Awash River Basin in response to these challenges. A significant portion of the basin is very suitable for NBS implementation, according to the GIS-based AHP–Fuzzy suitability framework, especially in areas which have favorable topography, soil characteristics, land use, and hydrological conditions.

Implementing NBS in areas with gentle slopes, lowland elevations, near riverbanks, permeable soil types (such as Eutric Nitosols), and land use types like wetland, forest, agricultural, and bare lands is more sustainable and successful. The opinions of experts and literature reviews were combined to decide the NBS selection. The chosen NBS are ranked, with expanding the size of rivers and water bodies and the restoration of floodplains coming up first for their beneficial effects on reducing the risk of flooding. The experts ranked Natural Bank Stabilization and Retention/Detention Ponds second for constructive impacts, the Integrated Approach (NBS combined with gray infrastructure, such as dams) third for high positive impacts, Lake/Wetland Restoration and Riparian Buffer Strips fourth for their actual impacts.

For beneficial consequences in the Awash River Basin, experts placed afforestation/reforestation fifth and upper watershed restoration sixth. Therefore, the findings highlight NBS's potential as a major flood mitigation method and to improve ecological advantages like biodiversity, ecosystem balance, and community resilience. The idea of NBS methods is well suited to the intended implementation goal, as demonstrated by the integration of expert opinions, literature studies, spatial analysis, and validation procedures. All things considered, the study concludes that integrated basin-scale environmental planning, which is focused on nature-based solutions, is the rigorous path toward achieving sustainable mitigation of flood risk and hazard within the Awash River Basin.

8.2.1. Future Research Directions

Future studies ought to focus on the need to include hydrodynamic flood modeling to the currently used suitability and hazard mapping frameworks to better represent the depth, speed and duration of floods in different climate and land-use conditions. This inclusion would make the assessment of flood risks more operational. Future research should concentrate on the application of site-specific and context-appropriate management that promotes ecological restoration in addition to the sustainable production of food and related crops from at-risk areas. Therefore, methods that identify the connections between all these systems land use, climate change, and other human activities must to be improved. As a result, the study's reported results can be used by academics and decision-makers.

Further research is also needed to assess the performance and maintenance issues of adopted Nature-Based Solutions in the long-term, as well as their socio-economic gains, economical aspects, and ecosystem service co-benefits. Awash River Basin Scaling Pilot NBS sites would be important to be empirically monitored. The effects of the proposed climate-change conditions in terms of flood risks and adaptability of NBS should also be studied in the future because downscaled climate models will be used to evaluate new risk trends. Furthermore, the inclination of integrating community-based knowledge and viewpoints among stakeholders into the spatial decision-making systems may improve the level of local acceptance and success in implementation.

8.2.2. Implications for Policy and Practice / Decision Makers

Given the importance of land-use planning and flood risk management in Ethiopia, the implications of the findings of this dissertation are profound in relation to the environmental policy. The strong links between the land-use change, climate variability, flood hazards, and soil erosion highlight the need to have integrated, multi-sector planning strategies at the river basin scale. The protection and restoration of floodplains, wetlands, and vegetated landscapes should be the priority of the policy makers as the main elements of the flood mitigation policy. The flood hazard and NBS suitability maps produced in this project provide real-life decision-supporting aids with the potential of informing zoning ordinance, any infrastructure location, and investment prioritization. Regulatory regimes should also shift out of reactive strategies of flood control to proactive and ecosystem-driven reduction strategies of risks. By introducing Nature-Based Solutions into national climate adaptation, Basin/watershed management, and urban development plans, the resiliency would be strengthened, as well as by providing multiple environmental and social advantages multiplied.

8.2.3. Environmental Planning and Policy Implications towards Soil Erosion

The modeling and evaluation of the sediment transport in the Awash River Basin help to realize an additional significance of the environmental planning and the proper management of the erosion processes. This should be a systemic approach and include such concepts as integrated land management, community participation, and good governmental policy frameworks.

The research is a decisive structure of land-use plan which is to locate regions prone to soil erosion, and mark zones of erosion hazards to inform decision-making of the region, mark the ecological restoration steps to be afforested with trees and shrubs, and direct allocation of resources. The policy measures ought to consequently endorse agro- forestry, wise land-use, and limiting dangerous operations in their susceptible areas with financial means to maintain conservation programs (Bewket, 2009).

The degree of environmental conservation and management will increase if communities are involved through education and the implementation of agro-ecological techniques (Sharma, 1999; Bewket and Sterk, 2002). Through partnership with such communities, it will be possible to harvest new and local solutions to soil erosion and this would improve the efficacious soil conservation efforts that will meet their unique demands and issues. Stakeholder involvement can empower the farmers through the active and participatory approach of adopting the best management practices like cover cropping, agro forestry and contour farming. The resilience to erosion and the harsh soil degradation among Awash River basin will be enhanced with the implementation of community-based conservation efforts that will cultivate the application of traditional knowledge. Further, the erosion-control facilities will be acquired and the Integrated Water Resources Management will ensure the coherent soil-water management, in order to decrease the current erosion and in wait of encourage eco- visualization of the basin.

8.3. Recommendations

Provided with the combined findings of the dissertation, the following are the recommendations being made:

• It is suggested that the highest priority should be placed on areas that are highly suitable to implement the selected solutions based on nature and apply them on a large-scale or a basin-scale level in the Awash River Basin. Particularly, it is proposed to focus on floodplain restoration and river widening, creation of retention/detention ponds, integrated measures, wetland restoration, and natural bank stabilization in the areas with the high risks.

• Wetland restoration is an important component in the motive of improving the natural habitat modification, because it will also improve natural water retention, reduce the effects of flooding, and increase the biodiversity, concurrently.

• In addition to this, reforestation also is of considerable use when it comes to soil stabilization and water management; the increased forested terrain along carefully planned areas of land will be able to bring down surface water run-off, which will ultimately restrain the risks of floods.

• Active encouragement of agro-forestry activities including triangular farming that is a conglomeration of agricultural productivity and ecological benefits is a sustainable approach to develop resistant landscapes that benefit the local population and natural well-being.

• The land-use planning rules are to be tightened to restrict spontaneous urban growth in flood prone areas and ecologically sensitive areas.

• Upland areas should be promoted to practice soil and water conservation to reduce erosion and transportation of sediment to downstream floodplains.

• In the areas surrounding the Awash River basin where erosion and sediment deposition threat are highly evident, sustainable topography-sensitive erosion control practices are in urgent need to be taken.

• National and regional planning frameworks should have integrated flood hazard maps and NBS suitability assessments as obligatory decision support solutions.

• Where feasible, hybrid flood management approaches involving the combination of nature-based solutions and the current grey infrastructures are to be taken into account.

• These nature-based solutions will help solve the immediate issues related to land-use changes and flood hazards and follow the overall sustainability goals across the region and enhance the resiliencies in the long term.

• Institutional coordination and capacity building of the water, land, urban planning and environmental agencies should be promoted.

• Pragmatic nature-based approaches to stakeholder needs which fulfill the needs of the social and economic aspects and protect the ecological integrity should be mathematically practiced by the stakeholders.

8.3.1. Knowledge Contribution

The dissertation has a value addition to the scientific knowledge and practice. First, it provides one of the most exhaustive basin scale evaluations of flood hazards within the Awash River Basin serving to combine land use dynamics, climatic trends, land surface processes, soil erosion measures together with flood hazard mapping and Nature Based solutions to mitigate flood hazards at larger scale level into a single analytical platform.

Second, the study proposes a productive contribution to the methodology by showing the effectiveness of integrating GIS-based multi-criteria analysis (AHP) with Fuzzy methods of decision-making to find good locations and types of Nature-Based Solutions. The soundness and effectiveness of this integrative method in application to the environmental planning issues has been supported by validation results.

Third, the study provides empirical data on a data-deficient area, thus adding to the knowledge on the interaction between anthropogenic activities and climatic variability to affect the risk of flood in semi-arid river basins. Lastly, the dissertation offers actionable spatial application, and planning knowledge, that fills the gap between theoretical studies and practical flood risk management so as to present a repeatable model to be used in other flood prone basins of Ethiopia and other similar by other places.

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APPENDEIX

List of Published Manuscripts:

Appendeix 1: Mapping Flood Hazard Area in the Awash River Basin (ARB), Ethiopia Using GIS and AHP Approach

Appendeix 2: Assessment of Soil Erosion and Sediment Transport Index in the Awash River Basin, Ethiopia: An Application of the USLE Model and GIS Techniques

Appendeix 3: Analysis of Land Use Land Cover Changes and Population Dynamics in Awash River Basin (ARB), Ethiopia Using GIS and Remote Sensing

Appendeix 4: Trend Analysis of Climatic Variables Using Statistical Approach in Awash River Basin (ARB), Ethiopia

Appendeix 5: Mapping Suitable Sites for Nature Based Solutions to Mitigate Flood Hazards in the Awash River Basin Ethiopia Using a Hybrid Analytic Hierarchy Process and Fuzzy Approach

Appendeix 6: Soil erosion modeling and Sediment transport index analysis using USLE and GIS techniques in Ada'a Watershed, Awash River Basin, Ethiopia

APPENDEIX 1

Gebremichael *et al. Geoscience Letters* (2025) 12:12
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Geoscience Letters

RESEARCH LETTER

Open Access

GIS-based mapping of flood hazard areas and soil erosion using analytic hierarchy process (AHP) and the universal soil loss equation (USLE) in the Awash River Basin, Ethiopia

Abayneh Gebremichael[1*], Ephrem Gebremariam[2] and Hayal Desta[3]

Abstract

Floods are the second most significant hazard in Ethiopia, primarily due to the country's diverse topography, including highland mountains and lowland plains. The Awash River Basin faces numerous environmental challenges, such as land degradation, topsoil erosion, high population density, water deterioration, wetland destruction, desertification, and salinity issues. Floods exacerbate these challenges, making effective flood hazard mapping vital for land use planning and mitigation strategies. This study aimed to create a GIS-based flood hazard map and estimate annual soil loss using the Universal Soil Loss Equation (USLE) while identifying the primary causes and impacts of flooding and soil erosion in the basin. Key parameters for the flood mapping included elevation, slope, drainage density, mean annual rainfall, proximity to rivers, land use, land cover change, and soil type. The results indicated that ~ 51.4% (5,855,130.12 ha) of the basin is highly susceptible to flooding, while 40.6% (4,625,378.51 ha) is moderately prone, and 7.6% (866,358.09 ha) is at low risk. The study identified drainage density, elevation, and slope as crucial factors influencing flood vulnerability. Additionally, the total estimated soil loss in the Awash River Basin was found to be 31,049,739 tons per year, with a mean annual loss of 28.6 tons per hectare. This research pioneers the combined study of flood hazards and soil erosion in the study area, where such an integrated analysis has not been previously conducted. It contributes to enhanced flood management and environmental planning while aligning with the Sustainable Development Goals (SDG 13) regarding climate change mitigation and adaptation.

Keywords Flood hazard, GIS, AHP, USLE, Drainage density, Elevation, Soil loss

Background Information

Flooding is among the most common and spatially scattered natural hazards in the world, and causes substantial destruction in different parts of the world. This has led to significant annual losses in terms of human and financial aspects (Shu and Finlayson 1993). A flood is described as a body of water that is not submerged or as occurring when silt and/or water are present in regions that are not commonly known as water bodies (Martini and Loat 2007; Ward 1978).

Flood is the second major hazard in Ethiopia next to drought (ERCS 2012). The reason behind this is the topography of highland mountains and lowland plains

*Correspondence:
Abayneh Gebremichael
abaynehtilahun@yahoo.com
[1] Environmental Planning Ph.D Program, EiABC, Addis Ababa University, P.O.Box 518, Addis Ababa, Ethiopia
[2] Senior Researcher at Emerging City Lab, Chair of Environmental Planning, EiABC, Addis Ababa University, Addis Ababa, Ethiopia
[3] Environmental Planning Competence Center, Chair of Ecosystem Planning and Management, EiABC, Addis Ababa University, Addis Ababa, Ethiopia

APPENDEIX 2

Discover Sustainability

Research

Assessment of soil erosion and sediment transport index in the Awash River Basin, Ethiopia: an application of the USLE model and GIS techniques

Abayneh Gebremichael[1] · Ephrem Gebremariam[2] · Hayal Desta[3]

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Abstract
In the fight against soil erosion, Ethiopia has a formidable obstacle. The Awash River Basin issue is addressed in this paper. Soil loss and the sediment transport index (STI) in the Awash River Basin were predicted using GIS and the Universal Soil Loss Equation (USLE) Model. Using the Universal Soil Loss Equation (USLE) in conjunction with Geographic Information System (GIS) and remote sensing technologies, this study evaluates the spatial distribution and intensity of soil erosion in the basin. The result of annual average soil loss shows a significant range from 0–31,049,739 t/h/y after analyzing of various soil, DEM, topographical and meteorological data, obtained from USGS and EMA. The broader implications of this finding are highlights the significant capacity of land management potential in study area. The result of sediment transport index which computed based on flow accumulation and slope gradients, ranges from 0–247,097. The finding stipulates that considerable increment of soil loss and sedimentation in the study area, and promote for implementing reforestation and contour farming, to mitigate potential erosion's impact. Hence, sustainable erosion mitigation strategies in the upper part of the basin should to be considered. Furthermore, this study emphasizes how important land use patterns, erodibility of soil, and erosivity of rainfall are associate in exacerbating of erosion. This information is significant for conservation and the development of sustainable agricultural frameworks. In portions of the study Basin that are prone to soil loss and sediment deposition, sustainable erosion management measures according to topography and current land use types are strongly recommended.

Keywords USLE · Sediment transport index · Land degradation · Soil erosion · Soil loss · GIS

1 Introduction

Numerous studies conducted throughout the world have shown that soil erosion is responsible for 85% of the decline in land quality. This erosion reduces crop productivity by 17% and affects soil fertility, which in turn causes land degradation [92]. Soil entities are necessary for life, either directly or indirectly. However, land degradation, which is caused primarily by soil erosion, has the potential to have an environmental impact on a variety of human activities, most notably crop productivity [82, 107]. Food security and sustainable agricultural production are impacted by land

✉ Abayneh Gebremichael, abaynehtilahun@yahoo.com; Ephrem Gebremariam, ephrem.gebremariam@eiabc.edu.et; Hayal Desta, hayal.desta@eiabc.edu.et | [1]Environmental Planning Ph.D. Program, EiABC, Addis Ababa University, P.O.Box 518, Addis Ababa, Ethiopia. [2]Senior Researcher at Emerging City Lab, Chair of Environmental Planning, EiABC, Addis Ababa University, Addis Ababa, Ethiopia. [3]Environmental Planning Competence Center, Chair of Ecosystem Planning and Management, EiABC, Addis Ababa University, Addis Ababa, Ethiopia.

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Discover

APPENDEIX 3

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scientific reports

OPEN

Analysis of land use land cover changes and population dynamics in Awash River Basin (ARB), Ethiopia using GIS and remote sensing

Gebremichael Abayneh Tilahun[1]✉, Ephrem Gebremariam[2] & Hayal Desta[3]

Alongside population expansion and global warming, land use land cover change (LULCC) is a vital component of environmental change on a worldwide scale. In many developing countries, the dynamics of land use and land cover are becoming increasingly noticeable, and the main causes of these dynamics are globalization, rapid economic development, and population augmentation. The primary cause of human-induced land use and land cover change, which primarily occurs in nations like Ethiopia, is rapid population increment. The study area, the Awash River Basin (ARB), has several serious problems, including growing population, urbanization, water resource scarcity, and land degradation. The dynamics and relationship between population growth, land-use, and land-cover change in the study area with respect to flood threats were to be examined in this study. LULCC imbalances were examined and comprehensive supervised land use classification maps were created using the geospatial techniques used in GIS and RS. In the same year, the 1990, 2000, 2010 and 2020 classifications had estimated overall accuracies of 94, 97.6, 99, and 96, with kappa coefficients of 0.92, 0.97, 0.99, and 0.95. In general, there was a 1.3% decrease in agricultural land over the three decades (1990–2020); however, there was a 50% decrease in bare land, a 43% decrease in deep water bodies, a 13.7% increase in forest cover, a 191% increase in the wetland category, and a 121% increase in urban area. The population is expected to expand by 8.638 million to 16.8 million between 1990 and 2020. The results of the Pearson correlation analysis showed that the bare land, deep water bodies, agricultural land, and forest coverage all had negative Pearson r figures (− 0.75, − 0.49, − 0.28, and − 0.25, respectively). On the other hand, both urban and wetland areas have favorable correlations with population growth (0.94 and 0.89, respectively). Furthermore, for 1990, 2000, 2010, and 2020, the corresponding annual estimated land consumption rate (LCR) was 0.29, 0.28, 0.26, and 0.34. Flooding may have resulted from changes in land use and land cover since then due to population growth and growing amounts of built-up land. In order to mitigate the effects of flooding and unanticipated rapid land use change, it is crucial to take into account nature-based solutions that are characterized as sustainable. Furthermore, this research helps to achieve the Sustainable Development Goals for 2030: Goal 15 involves investigating land use changes and conservation efforts to protect ecosystems and biodiversity.

Keywords Land use land cover change, Population growth, Pearson correlation, Land consumption rate, GIS, RS

Alongside population expansion and global warming, land use land cover change (LULCC) is a crucial component of environmental change on a worldwide scale. LULCC has recently gained international attention. Therefore, taking into account land use and land cover dynamics is a crucial component in achieving sustainable

[1]Environmental Planning Ph.D. Program, EiABC, Addis Ababa University, P.O.Box 518, Addis Ababa, Ethiopia. [2] Emerging City Lab, Chair of Environmental Planning, EiABC, Addis Ababa University, Addis Ababa, Ethiopia. [3]Environmental Planning Competence Center, Chair of Ecosystem Planning and Management, EiABC, Addis Ababa University, Addis Ababa, Ethiopia. ✉email: abaynehtilahun@yahoo.com

APPENDEIX 4

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Regular Article

Trend analysis of climatic variables using statistical approach in Awash River basin (ARB), Ethiopia

Abayneh Tilahun Gebremichael [a,*], Ephrem Gebremariam [b], Hayal Desta [c]

[a] Environmental Planning Ph.D. Program, SBE, Addis Ababa University, Ethiopia
[b] Emerging City Lab, Environmental Planning, SBE, Addis Ababa University, Ethiopia
[c] Environmental Planning Competence Center, Ecosystem Planning and Management, SBE, Addis Ababa University, Ethiopia

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Mann Kendall
Sen's slope
Temperature
Precipitation
Climate variability
Trend analysis
Climate change

ABSTRACT

In the Awash basin, population and economic output are already severely impacted by climate unpredictability. Reducing natural hazards, droughts, and food insecurity requires an assessment and comprehension of previous climate changes. Temperature and precipitation trend analysis is essential for researching the effects of climate change and developing mitigation strategies. Supplementary precipitation and earth skin temperature is also obtained from NASA website in CSV format. Non-parametric statistical trend analysis is significant to mitigate climate change impacts. Hence, the main objective of this study is to analyze trends of temperature and precipitation to stipulate the trends of climate change of the entire Awash River basin. The results show that during the past forty years, annual rainfall has significantly decreased while temperature has slightly increased. Concisely, the finding indicates the rising impacts of climate change within study area. While temperatures continue to rise throughout the year, particularly in autumn and spring, precipitation is declining, mostly in the spring. Such approach enhanced our understanding of climate change temporal patterns as well provide significant mitigation measures, such as afforestation, sustainable land management and early warning climate systems to combat impacts of climate variability in the basin.

1. Introduction

Global warming is frequently linked to climate change, which has been witnessed all across the world. Long-term variations in the average values of climatic parameters are known as climate change. It has a direct or indirect impact on global warming and is linked to both natural and man-made activities (IPCC, 2007). Since 1850, the average global temperature has increased, increasing in the second half of the 20th century by 0.6 °C. Substantial global warming is currently occurring (Kennedy, 2019). Temperature is not the only change. The close connection between the hydrological process and climate dynamics and its components has led to changes in precipitation characteristics, elevated air humidity, enhanced evaporation, and modifications in soil moisture content and overflow (Bates & Kundzewicz, 2008). Hence, Regional and local variations in yearly precipitation have been noted, though (IPCC, 2007; Basistha et al., 2009; Wang & Qin, 2017).

Similar to this, changes in temperature, precipitations, and other climatic variables significantly affect changes in flooding and hydrodynamic extremes (Wang et al., 2005). According to Asfaw et al. (2018), the hydrological regime of the majority of the world's regions will undergo substantial changes by 2050. Intensive deforestation, farming, volcanic activity, and industrialization are some of the primary reasons for changing the climate that have been lately linked to it. Green House Gases (GHG) emissions into the atmosphere are increased by activities like burning fossil fuels, which are fueled by fast economic and population expansion (Yang & Lu, 2015).

The human and livestock populations of the Awash River basin, one of Ethiopia's 12 river basins, have been severely impacted by the region's food insecurity due to its persistent droughts, periodic floods, and a very volatile climate (Edossa et al., 2010, pp. 1441–1460; Yang & Lu, 2015; Onyutha et al., 2015; Adeba et al., 2015). Poverty, fast population growth, drought, and flooding made many people susceptible to innumerable disasters. Ethiopia is among the sub-Saharan nation most vulnerable to natural disasters such as floods and droughts (Society, Ethiopian Red Cross, 2012; Authority, Awash Basin, 2017). In the Awash basin, population and economic output are already severely impacted by climate unpredictability. Significant crop yield reductions and livestock deaths have resulted from the basin's severe droughts led to increasing

* Corresponding author.
E-mail addresses: abaynehtilahun@yahoo.com (A.T. Gebremichael), ephremgebremariam@eiabc.edu.et (E. Gebremariam), hayaldesta@eiabc.edu.et (H. Desta).

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APPENDEIX 5

Contents lists available at ScienceDirect

Nature-Based Solutions

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Mapping suitable sites for nature based solutions to mitigate flood hazards in the awash river basin Ethiopia using a hybrid analytic hierarchy process and fuzzy approach

Abayneh Tilahun *, Ephrem Gebremariam , Hayal Desta

Department of Urban and Regional Planning, School of Bult Environment, Addis Ababa University, P.O.Box 518, Addis Ababa, Ethiopia

ARTICLE INFO

Keywords:
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Suitability
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AHP, and Fuzzy

ABSTRACT

Flood hazards in the Awash River Basin, Ethiopia, are exacerbated by climate change, posing significant risks to communities and ecosystems. Practicing of effective Nature Based Solution (NBS) is widely common mechanism to mitigate flood hazards. In Ethiopia, the use of NBS for flood hazard mitigation is not yet extensively acknowledged and applied throughout the nation's basins and watersheds, and it is only used in urban and large-scale settings with limited effectiveness. After careful analysis the selected types of Nature Based Solution by experts and suitability parameters to select suitable areas for implementation of selected NBS in Awash River basin have been done properly and the suitable area is mapped in ArcGIS environment. The method used AHP-Fuzzy hybrid is a combination of Analytic Hierarchy Process and fuzzy logic that is used to improve site suitability evaluation by incorporating expert opinions and uncertainty to define the strength of decisions that can be implemented in NBS. The study clearly illustrates the suitable area and percent coverage: 37.92% of the Awash River basin is extremely well-suited for implementing NBS, spanning a space of 4346,794.64 ha; 31.46% is highly suitable, covering 3606,363.24 ha. The selected NBS is more effective and sustainable to be implemented within gentle slope, lowland elevations, close to river line, with permeable types of soil (eg. Eutric Nitosols) and land use types such as wetland, forest, agricultural and bare lands. The suitability map is validated using confusion matrix with kappa coefficient of approximately 0.9 and Receiver Operating Characteristic Area under the Curve methods with result Area under the Curve is 0.86. The results demonstrated a strong suitability assessment and confirmed that the map is highly favorable for decision making and planning applications. The study provides scientifically grounded foundation for decision makers and for strategic plan development in the flood prone regions.

1. Introduction

Floods are among the most devastating natural disasters, claiming millions of lives and causing billions of dollars in damage globally. Worldwide, the likelihood of detrimental impacts from rising temperatures and the ensuing repercussions of the risks associated with hydrometeorology are growing [1,2], and [3]. Many forms of flooding, including sudden floods in hilly areas, in floodplains, river flooding, Coastal storms in coastal zones and pluvial floods in metropolitan, can happen following prolonged rainfall or other severe weather conditions [4]. Overflows killed about 24 million people worldwide and generated US$765 billion in damage between 1951 and 2017 [5].

In addition to being one of Ethiopia's most frequently flooded regions; Awash River Basin (ARB) is among the principal basins in the Rift Valley of the country [6-8]. Additionally, possible risks from flooding in the basin area's downstream sector were among the other hazardous events that are crucial to the region. Heavy rains in the highlands of the ARB and significant releases from the dams in Koka throughout the rainy season, particularly in August [9,6], cause devastation to communities near any part of the river and floods downstream [10]. Major cities in the ARB were also frequently under risk for flooding. For instance, Adama had catastrophic floods in 2008, 2009, and 2016, which resulted in large costs for numerous municipal areas [11]. Due to a variety of circumstances, including terrain, changes in land cover and use, steep slopes, extreme weather, population growth, rapid urbanization, and higher watercourse operations, the majority of

* Corresponding author.
E-mail address: abaynehtilahun@yahoo.com (A. Tilahun).

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APPENDEIX 6

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Geoscience Letters

RESEARCH LETTER **Open Access**

Soil erosion modeling and sediment transport index analysis using USLE and GIS techniques in Ada'a watershed, Awash River Basin, Ethiopia

Abayneh Tilahun[1*] and Hayal Desta[2]

Abstract

Ethiopia faces a significant challenge in combating soil erosion. This study addresses the concern within Ada'a watershed of the Awash River basin. GIS and the Universal Soil Loss Equation (USLE) Model were used to predict soil loss and the sediment transport index (STI) in the Ada'a watershed of the Awash River basin. RUSLE model required intensive rainfall data registered continuously for 30 min, due to unavailability of this Rainfall data USLE model were preferred. Moreover, USLE model was chosen because of its straightforward methodology and accessibility to data. The study's objectives were to determine the mean annual soil loss rate, STI, and to identify and rank the most important erosion-prone spots for soil conservation planning. Using the interactive Spatial Analyst Tool Map Algebra Raster Calculator in the ArcGIS environment, the mean annual soil loss was estimated based on grid cells by multiplying the corresponding USLE factor values (R, K, LS, C, and P). The STI was also calculated on the Raster Calculator in ArcGIS using flow accumulation and slope gradients. The result shows that R, K, LS, C, and P factor values were estimated in the watershed as 344.9 to 879.65 MJ mm h^{-1} $year^{-1}$, 0.11 to 0.38, 0% to 22.23%, 0 to 1, and 0.55 to 1, respectively. The overall annual soil loss in the watershed ranged from 0 to 457.4 tons ha^{-1} $year^{-1}$. The Sediment Transport Index ranges from 0 to 856.193. The result implies there is increasing rate of soil losses and sediments observed at alarming rate. The highest rate of soil loss was found in the watershed's lowest parts. Accordingly, sustainable erosion control mechanisms based on topography and land use types are highly recommended, especially in the upper part of the watershed.

Keywords USLE, Sediment transport index, Land degradation, Soil erosion, Soil losses, GIS

Introduction

Globally, soil erosion accounts for 85% of land quality deterioration (Singh 2017). This in turn causes a 17% decline in agricultural output and a permanent degradation of the land (Gessesse 2014). Life on earth is either directly or indirectly reliant on soil, and land degradation caused by soil erosion has advanced impacts of human activities and the environment (Bishop, 2014; Dotterweich Markus 2013; Hansen 2001), primarily on crop productivity (Pimentel 1995; Tully et al. 2015). According to Kassie (2007), soil erosion in sub-Saharan Africa results in nutrient loss, land

*Correspondence:
Abayneh Tilahun
abaynehtilahun@yahoo.com
[1] Environmental Planning Ph.D. Program, EiABC, Addis Ababa University, 518, Addis Ababa, Ethiopia
[2] Environmental Planning Competence Center, Chair of Ecosystem Planning and Management, EiABC, Addis Ababa University, Addis Ababa, Ethiopia

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