Addis Ababa University

Land degradation, Seasonal Rural Out-Migration and Sustainable Land Management in the Dry Land of upper Tekeze basin, Northern Ethiopia

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Land degradation, Seasonal Rural Out-Migration and Sustainable Land Management in the Dry Land of upper Tekeze basin, Northern Ethiopia

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Doctoral Dissertation:

In partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Geography and Environmental Studies (Environment and Natural Resource Management)

Supervisor:

Professor Assefa Abegaz (PhD),

Addis Ababa University

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DECLARATION

I declare that this dissertation, "**Land degradation, Seasonal Rural Out-Migration and Sustainable Land Management in the Dry Land of upper Tekeze basin, Northern Ethiopia**", is my own and original work. It has not previously been submitted at this or any other institution. I have fully acknowledged all of the materials and references utilized in the dissertation.

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Date: Novemb

This dissertation has been submitted for examination with my approval as the student supervisor.

Signer ID: [illegible]

Supervisor: Professor Assefa Abegaz (PhD)

Signature: ______________________________Date: November 2024

Dessertation Aproval
Addis Ababa University
College of Social Sciecnes

This is to certify that the dissertation prepared by Alemu Eshetu Fentaw, entitled: "**Land degradation, Seasonal Rural Out-Migration and Sustainable Land Management in the Dry Land of Upper Tekeze basin, Northern Ethiopia**" and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in Geography and Environemtal Studies (Environemnt and Natural Resource managment) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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External Examiner ___________________________ Signature _______________ Date ___________

Interna Examiner ___________________________ Signature _______________ Date ____________

Supervisior ________________________________Signature _______________ Date _____________

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5. Impact of Seasonal rural out- migration on SLM adoption and uses in resource poor marginal communities of Northern Ethiopian. (Ready for submission)

LIST OF ACRONYMS AND TERMS USED IN THIS THESIS

a.s.l	above sea level
CSA	Central Statistical Agency
DA	Development Agents
FAO	Food and Agriculture Organization
FDRE	Federal Democratic Republic of Ethiopia
FGD	Focus Group Discussions
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
KII	Key Informant Interviews
LDN	Land Degradation Neutrality
LULC	Land Use Land Cover
MEA	Millennium Ecosystem Assessment
MK	Mann-Kendall
UNCCD	United Nations Convention to Combat Desertification
RF	Random Forest
RUSLE	Revised Universal Soil Loss Estimation
SDG	Sustainable Development Goals
SLM	Sustainable Land Management
Wereda	The level of political administration above the Kebele

ABSTRACT

The study explores the interplay of land degradation, seasonal migration, and Sustainable Land Management (SLM) dynamics in the Upper Tekeze River Basin, Ethiopia, with a focus on land use and land cover change (LULCC), drought monitoring, soil erosion, and the impacts of migration on SLM. The study investigates the temporal and spatial dynamics of LULCC over 31 years (1990-2021) using advanced remote sensing techniques such as Google Earth Engine (GEE) and the Random Forest (RF) algorithm, using primary data from Landsat surface reflectance images. The findings reveal significant changes in LULC, including a decrease in forest, bushland, shrubland, and bareland, while water bodies, farmland, urban settlements and dry riverbeds and streams showed substantial gains. These shifts indicate ongoing land degradation and highlight the future vulnerability of the basin, emphasizing the need for SLM practices and afforestation efforts to mitigate further degradation. In parallel, the study assesse spatio-temporal drought dynamics from 1981 to 2021 using multiple indices like the Standard Precipitation Index (SPI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI). The result shows that the basin has experienced multiple episodes of moderate to extreme drought, particularly in 2002, 2004, 2009, 2015, 2016, and 2017. Soil erosion rates assessment was carried out to estimate soil erosion rates and map soil erosion in the Upper Tekeze Basin, by integrating Revised Universal Soil Loss Equation (RUSLE) with GEE. The study showed that the mean soil loss rate is 25.5 t ha^{-1} yr^{-1}. About 63% of the basin is experiencing soil erosion above the maximum tolerable rate. Specifically, 55% of the study area, which is covered by unprotected shrubland is experiencing mean annual soil loss of 34.75 t ha^{-1} yr^{-1}. Shrublands, particularly in lowland agroecologies are the most vulnerable areas. The study also revealed evidence that high mean soil loss rate of the basin can be reduced by implementing integrative watershed management and exclosures. The study further showed that that seasonal migration is triggered by factors such as drought, land scarcity, and economic pressures. The finding showed remittances and migration earnings are primarily used for basic consumption rather than investment on agricultural inputs or SLM practices, and migration is leaving behind women with the responsibility of managing less productive and degraded farmland. Labor, input, and skill limitations are also challenges faced by women in managing farmland. Finally, the study employs two-stage least squares (2-SLS) regression and Propensity Score Matching (PSM) to analayze the impact of migration on the adoption of SLM practices. The findings suggest that migration has a significant negative impact on the adoption of SLM practices. Overall, the study underscores the complex interplay between land degradation, seasonal rural outmigration, and SLM practices in the Tekeze River Basin, calling for integrated and context-specific interventions to promote SLM while considering the seasonal mobility of farm households.

***Keywords**: Land use/cover dynamics, drought dynamics, soil erosion severity and extent, determinants of seseanal out-migration, response to land degradation*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Land resources provide food and materials, regulate, and support ecosystem services. Demands on global land resources are increasing as the world's population increases. However, degradation caused by land use/cover changes is a critical environmental and developmental challenge worldwide (Arneth et al., 2019; IPBES, 2018; Mganga et al., 2016; UNCCD, 2016a). Land degradation threatens water availability, biodiversity, and the human capacity to adapt and mitigate climate change (Reed et al., 2011). Although land degradation has varied contextual definition, it is related to many processes that drive the decline or loss in biodiversity, ecosystem functions and services (Pandit et al., 2020).

Up to 25% of land worldwide is highly degraded, 36% is slightly or moderately degraded (FAO, 2011; Prăvălie et al., 2020). Globally, land productivity has declined persistently between 1981 and 2003 (Orr et al., 2017). The economic costs of land degradation are estimated at USD 490 billion per year, corresponding to three to six per cent of the agriculture gross domestic product (GDP) worldwide (UNCCD, 2016a) and up to 17% global GDP annually (ELD Initiative, 2015; IPBES, 2018). Land degradation affects more than 900 million people over 100 countries (Nyariki, 2015), however at varied rates and trends.

In light of commitments to mitigate land degradation and conserve biodiversity, international organizations are calling for vast areas of land to be restored over the next few decades (Wilson & Cagalanan, 2016). United Nations Sustainable Development Goals (SDGs) target 15.3 is aiming to mitigate desertification as stated as, "by 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world", and achieving the goal of Land Degradation Neutrality (LDN) by 2030 (UNEP, 2015; UNDP, 2015). UNCCD suggested SLM as a unifying theme for global efforts on combating desertification, climate change mitigation and land degradation reduction (Thomas, 2008). SLM has been defined as ‘‘management that combines technologies, policies and activities (Cowie et al., 2018). It offers opportunities for mitigating the effects of drought and increases the resilience of people and ecosystems to drought (Reichhuber et al., 2019).

Land degradation is a critical challenge for Sub-Saharan African countries. The major drivers are biophysical, topographic and climatic conditions, and inappropriate land management practices. The underlying factors are socioeconomic and policy-related factors such as population growth, land tenure, and other (Etsay et al., 2019). Land degradation is a serious challenge to improving rural livelihoods and food security in developing countries, particularly in East Africa. For example, recent estimates show that land degradation affected about 51%, 41%, 23%, and 22% of the terrestrial areas in Tanzania, Malawi, Ethiopia, and Kenya respectively (Kirui & Mirzabaev, 2019).

Drivers of degradation are many, complex, and interacting over time and space, among these topographic effects, land use and land cover, soil, climate, and poor land management, are the common drivers (Geist and Lambin, 2004; Turner et al., 2015). Land use and cover (LULC) change is the cause and result of global environmental change (Turner et al., 2007), and it further aggravate climate change and surface characteristics (Liu et al., 2020). Particularly, LULC changes significantly affect key aspects of earth system functioning including water, and soil (Vivekananda et al., 2021). It remains the primary source of soil degradation by affecting the ground cover, slope gradient, and the infiltration rate of water form rainfall (Lambin et al., 2001; Turner et al., 2015). Ground cover, management practices, and soil erodabilty and slope factors, which are common determinants of soil erosion are, either directly or indirectly, affected by LULC status.

Drought is among the most familiar and severe environmental problems that aggravate land degradation in eastern Africa. Because of its wider spatial extent and grave impacts, drought affects more people (Zarafshani et al., 2016). Although the impact of drought is highly felt by and always associated with the agricultural sector (Reichhuber et al., 2019; SPI, 2019), it is diverse and can be broadly classified as economic, environmental, and social (Zarafshani et al., 2016). As a major component and driver of land degradation, drought is a major shock for households who depend on agriculture in arid and semi-arid regions. In such regions, rain-fed agricultural production is highly sensitivity to drought (Gidey et al., 2018; Lei et al., 2016). Droughts intensify water scarcity and increase vulnerability (Reichhuber et al., 2019). Drought-affected households typically those who do not have the capacity to cope with damage to crops and a shortage of water. Poverty and exposure to additional non-climatic shocks in this region are the prevailing factors that aggravate drought impacts (Hermans & Garbe, 2019). Irregular rainfall pattern and increasing drought incidences in the dry land of the Horn of Africa, in general, and in Ethiopia in particular, are challenging environmental outcomes (IPCC 2007;

NAPA, 2007). In Ethiopia drought is a frequently recurring climate related natural hazard affecting the country from time to time (Gebrehiwot et al., 2011).

A decreased biodiversity and ecosystem service due to land degradation; particularly caused by frequent drought, soil erosion by water and unsustainable LULC change are leading to high rate of outmigration from rural areas (Jane & Cagalanan, 2020). Whether it is as a coping mechanism or new way of livelihood strategy, in many rural agricultural societies including in rural Ethiopia—labor out-migration is considered as important livelihood strategies to smallholder farmers (World Bank, 2008; de Haan, 1999). Although the migration is a key aspect of economic development (de Haan, 1999; Taylor and Martin, 2001), seasonal migration from agricultural areas has complex effects on agricultural production and farmland management (De Brauw, 2010). Rural out-migration affects people's decision and actions to manage resources, determine land use, and farmland management by affecting the manner of labour, and remittances interaction (Milbourne & Kitchen, 2014; Radel et al., 2019; Caulfield et al., 2019). For instance, migration could led to land degradation, land abandonment, and exposure to flooding (Jaquet et al. 2016), less farm labor (Mazambani, 1990; De Brauw, 2010) and reduced production (Williams & Paudel, 2020). Furthermore, the relationship of the migration and it remittance with agriculture and SLM depends on the sending areas' societal context, decision priorities, and cultural and demographic contexts.

Therefore, understanding the relationship between changes in rural agriculture particularly the use of farm technology such as SLM —and out-migration will provide important insights that are especially valuable for policy-makers in their effort to land degradation management and rehabilitation of the ecosystem functions and services (de Brauw, 2010; de Haan, 1999; Taylor and Martin 2001 cited in (Bhandari & Ghimire, 2016)). The view of migration as a livelihood strategy and as a coping strategy for livelihood disruption during climatic shocks; and studying livelihood in an already degraded and degrading environment should show the inseparability of land degradation, livelihood and migration in dry land areas.

This study aims to investigate land degradation as caused by LULC dynamics, and management changes; extent, and severity of soil erosion by water; drought magnetude and frequency and its linkage with seasonal rural out-migration. By understand the complex interaction and vicious circle of drought, land degradation, and migration, the study has contributed for better understanding of how frequent drought, soil erosion and LULC change contribute to land degradation and how migration is connected to land degradation/management in the context of mobile and vulnerable dry land small holders. The study brings together four interrelated research themes— LULC changes and management, drought, soil erosion, and rural households' seasonal out-migration—considering as interconnected phenomena acting and interacting connectedly creating a particular distinct scenario. Under each of these themes, the study highlighted effective management practices for scaling-up in the highlands of Ethiopia in general, and other possible strategies to land degradation that could lead to SLM practices in the Dry Land of upper Tekeze basin, Northern Ethiopia.

1.2. Statement of the Problem

Land degradation has become a serious environmental issue that threatens food security and ecosystem functioning (IPBES, 2018; Gonzalez-Roglich et al., 2019; Prăvălie et al., 2020). Climate change and extreme events, increasing global population pressure and unsustainable land management practices are causing degraded environment (IPCC, 2013; Gonzalez-Roglich et al., 2019), Land degradation negatively affects the well-being of about 3.2 billion people by affecting biodiversity and ecosystem services (Pandit et al., 2020, IPBES, 2018). Up to 25% of all land worldwide is highly degraded while 36% is moderately degraded. Land productivity has declined (Orr et al., 2017; Prăvălie et al., 2020) and has already led to five percent total global net primary productivity reduction (UNCCD, 2019).

Populations in dry lands are highly affected by land degradation due to low land productivity, extreme water shortages, and higher poverty rates (MEA, 2005). Estimates showed that out of 2.1 billion people worldwide living in rural dry lands, 444 million (21%) resided in degraded areas (UNCCD, 2019). In Africa, the expansion of land degradation affected more than half of the continent's total population, equivalent to 621 million people, and 55% of them (343 million) live in rural areas. More than half (61%) of the rural population on degraded land in Africa reside on degraded rural dry lands (UNCCD, 2019). Sub-Saharan African is facing a major challenge to achieve food security and tackle poverty through rain fed agriculture (FAO, 2015). Increased incidence of drought, and climate variability affect rain fed agriculture. (Gautam, 2006; Shiferaw et al., 2014; FAO, 2015).

Land degradation, drought and food insecurity are persistent and interconnected problems in Ethiopia and they have disrupted crop production by causing crop failure, water stress in many parts of Ethiopia (Gebrehiwot et al., 2011; Mahoo et al., 2013). Severe droughts at irregular intervals threaten the livelihoods of millions of people (Holden & Shiferaw, 2004). Drought affected the agro-socioeconomic environment in the northern, southern and eastern parts of the country (Seleshi & Camberlin 2006; Mahoo et al., 2013; Mekonen et al., 2020). In addition to drought, soil erosion is a critical problem affecting the ecosystem and agricultural productivity in Ethiopia. Although soil erosion is the oldest environmental problem in Ethiopia (Hurni, 1988; Hurni et al., 2010); many of SWC projects have been implemented following the rising global awareness on land degradation and land management, particularlyafter the severe drought of 1974 (Hurni et al., 2010; Adgo et al., 2013; Gashaw, 2018). Nevertheless, soil-erosion-induced land degradation is still a great challenge in the Ethiopian highlands (Shimels, 2012). Considering the above-mentioned complex and interwoven problems of soil erosion, drought, and rural out migration, application of SLM practice to build resilient livelihood and ecosystem is an indispensable development agenda.

Despite the crucial role of land, investments in SLM are low (Nkonya et al., 2015). There is evidence that SLM, particularly (Drought Smart Land management (D-SLM) practices optimize land use and keep in the balance ecosystem services and help building resilience of (Reichhuber et al., 2019; UNCCD, 2019). Adoption and use of SLM in Ethiopia is taken as key strategy option to tackle land degradation and increase productivity (Teklewold et al., 2013). However, studies on the level of adoption ofSLM are not conclusive. Despite potentials of sustainable agricultural practices for yield improvement (Adgo et al., 2013; Gebreselassie et al., 2015), adoption remains very low (Holden & Shiferaw, 2004; Barbier et al., 2019; Woldegebrial et al., 2018)) mostly limited to a minority of innovative land-users and practitioners (Sanz et al., 2017). For example, study by Nyanga et al., (2016) and Mahoo et al., (2013) indicated that the main reason for low level of agricultural productivity is low investment on SLM by small-scale farmers in Ethiopia. Lack of awareness about the SWC and lack of maintenance for the constructed tools (Hurni, 1993; Hurni et al., 2010; Mekuriaw et al., 2018) and tradeoff in the rate of conservation and erosion control (Holden & Shiferaw, 2004) are the main challenges.

In addition to contradicting results, most of the studies dedicated much of their analysis for human capital characteristics, economic and social aspect of SLM adoption and application (Teklewold et al., 2013a; Teklewold et al., 2013b; Abay et al., 2016; Birhan & Assefa, 2017; Wossen et al., 2015; Liu et al., 2018; Mekuriaw et al., 2018). There is scarce evidence on how SLM is implemented and affected by socioeconomic aspects of households and, who have been accustomed to frequent drought, persistent land degradation, and rural out migration (Mutyasira et al., 2018). Besides, the biophysical characteristics of drought prone areas are not well studied in relation to their land management while also struggling to cope up with drought through seasonal migration.

With growing impact of land degradation and climate change, migration as a response has received attention from researchers (Conisbee & Simms, 2003; Hummel, 2016; Morrissey, 2013; Renaud et al., 2007; Stern, 2007; Warner et al., 2009; Zetter & Morrissey, 2014) and migration as an adaptation strategy has shown rise in literature (Black et al., 2011; Icduygu & Goren, 2023). However, most the findings have treated migration as an unplanned form of adaptation and most of these researches assume that migration is a result of a failure of climate change mitigation and adaptation. On the contrary, recent findings are suggesting migration as as a valid coping mechanism for increased environmental risks, stresses and shocks that may result from climate change (Tacoli, 2009; Black et al., 2011). Climate change and environmental degradation as drivers of migration have been widely studied (Piguet, 2013; Warner et al., 2010), however there is a gap in the literature on how migration affects SLM. Moreover, the available studies on migration and the environment have been limited by both disciplinary boundaries and a lack of comprehensive framework (Smith, 2014; Giovanna et al., 2016). While migration research is often focused on those who migrate or where they migrate to (Black et al., 2011; Piguet, 2013), land management studies, on the other hand, consider all farming housholds as as stable unit (De Graaff et al., 2008; Gisladottir & Stocking, 2005; Hurni, 2000). When people migrate away from rural areas, there are fewer labor days on their farm (De Brauw, 2010), small engagement in SLM activities (Caulfield et al., 2019), and local knowledge of traditional practices gradually diminishes and disappears (Schwilch et al., 2013). In Ethiopia, there is evidence that removal of labor (including through migration) increased land degradation in the form of erosion and lower agricultural production (Holden et al., 2004; Redehegn et al., 2019). On the other hand, SLM is found to improve rural livelihoods and prevent outmigration (Schwilch et al., 2013). Internal migration is among the most significant demographic and socioeconomic phenomena in Ethiopia. Particularly, seasonal migration is a major component of land and livelihood nexus in rural areas. However, the potential importance of seasonal out-migration for land management and agricultural investment in Ethiopia remains under researched (Abebaw et al., 2019).

The study area is in land degradation hotspot areas, frequent drought history, and high level of seasonal and permanent rural out migration. Irregular rainfall pattern and increasing drought incidences in Ethiopia particularly in Waghimra are challenging environmental outcomes (IPCC, 2007; NAPA, 2007). Drought is a frequently recurring climate related natural hazard affecting Northern Ethiopia (Gebrehiwot et al., 2011), where the study area is situated. Dry lands areas of Ethiopia are particularly susceptible to land degradation because one or more of the following features are present: low-productivity ecosystems; easily degradable soils; highly variable temperature and rainfall; and dense and rapidly growing populations of economically marginalized populations (IPBES, 2018). Drought related moisture stress is the major limiting factor for crop production in Waghimra (Wale et al., 2019). The zone is dry for most of the year except during the rainy season. Recurrent droughts form the major threat to rural livelihoods and food security in the region. Waghimra represents a typical setting where multiple factors-land degradation, rainfall irregularity, drought and low socio-economic development are making the life of smallholders miserable. Thus, the need for an understanding of the complex interaction of these factors is crucial to understand their impact on livelihoods. Except studies conducted at national level or other part of the country (with their limitation and gap explained earlier in this section), it is difficult to find a single study that has been conducted in the context of the Dry Land of upper Tekeze basin, Waghimra zone. Thus, it is crucial to examine how land management is sustained under changing land use/cover managements, high soil erosion rates, and chronic drought affected and high seasonal labor migration area of the dry land of upper Tekeze basin. It is important to investigate the challenge and opportunities of land management in the context where the four interrelated themes— land use/cover changes, drought, land degradation by erosion, and rural households' seasonal out-migration— act as interconnected phenomena creating a particular distinct scenario.

In order to address these themes, the study has employed (i) Google Earth Engine (GEE) and Random Forest (FR) algorithm, and analyzed a 31 year (1990–2021) land use/land cover changes; (ii) a combined multiple drought analysis indices (such as Standard Precipitation Index (SPI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation health Index (VHI), and analyzed a 31 year (1990–2021) spatio-temporal drought dynamics; (iii) integrated Revised Universal Soil Loss Equation (RUSLE) with Google Earth Engine (GEE), and estimated soil erosion rates and mapped soil erosion hotspot areas and prioritized areas for management interventions for soil erosion reduction; (iv) household survey, semi-structured interviews, and FGD,and explored the linkage between seasonal rural-out-migration and farmland management; and (v) a two-stage least square (2-SLS) regression and propensity score matching (PSM) method, and examined the impact of migration on the adoption of SLM practice. Based on the outcomes of each of these investigations, the study highlighted possible response actions to land degradation, which could lead to SLM practices in the Dry Land of upper Tekeze basin, Northern Ethiopia.

1.3. Objective of the Study

General objective

The general objective of this study was examining the spatio-temporal land use/cover changes, soil erosion and drought dynamics and their implication, and the nexus between seasonal rural labor out-migration and SLM practice in the context of dry land smallholder farmers in upper Tekeze basin, Waghimra Zone, Northern Ethiopia.

Specific objectives

Under the general objective of the study, the specific objectives were to:

1. analyze long-term land use land cover dynamics and its implication to the management of land degradation in the study area.
2. monitor the spatio-temporal drought dynamics using multiple drought indices over the upper Tekeze basin in Waghimra zone.
3. assess soil erosion severity and prioritize erosion hotspot areas for land management planning and interventions for soil erosion reduction.
4. explore the nexus between seasonal rural out- migration and sustainable land management practice.
5. examine the impact of seasonal rural out- migration on rural households' adoption of SLM in the study area.

1.4. Research Questions

In order to address the above specific objectives, the following sets of research questions were put forward to guide the research endeavor.

- What looks like the trend and dynamics of LULC changes in the study area from 1990 to 2021? Is the area changed to more sustainable LULC or experienced degradation? In addition, what are the implications of the LULC change to the management of land degradation?
- How is the extent and severity of a 21-year (2000–2021) drought dynamics? What does it imply to SLM?
- What looks like the recent trends/ magnitude and spatial distribution of soil erosion severity in the Upper Tekeze basin? Is soil erosion reduction through area exclusure and watershed management possible in the degraded shrub lands of upper Tekeze basin?

- What is the impact of rural out migration on land management practice? Does migration lead to a loss in family labor and affect SLM adoption?

1.5. Scope of the Study

The study aims to explore the impact of land degradation, in the form of drought frequency, land use land cove change, and soil erosion by water, and migration on SLM. It explores the dynamics of LULC change, soil erosion by water and drought in the study area to assess land degradation; secondly, the study looks in to the relationship between land degradation and migration and their interaction with land management practice. Finally, the study analyzed the impact of migration on SLM adoption. The study was limited to the study of three components of land degradation, i.e., LULC change, drought, and soil erosion by water. Regarding temporal scopes, the study covered only the last 4 decades (1982-2021) for drought study and 3 decades (from 1990-2021) for LULC assessment.

1.6. Significance of the Study

First, this study will have significance to understand the status of land degradation and land management in the context of mobile farming households in the upper Tekeze basin of Waghimra Administrative zone. To date, there is no any comprehensive assessment of LULC dynamic, drought and soil erosion. More importantly, the status and relationship of SLM with seasonal migration is not studied. Furthermore, the majority of studies that have investigated land degradation and land management is in isolated and separated manner using different conceptual and theoretical framework for each concept, however, this study approaches the interrelated problems of land degradation, migration and land management in holistic approach. Therefore, this study holds significant importance in understanding the complex dynamics of land degradation, land management and seasonal rural out migration. This understanding can contribute to SLM and restoration of degraded environment in the semi-arid and arid region of Waghimra where majority of the population depend on agriculture and seasonal migration. The finding can be policy input in the understanding of the status of land degradation, soil erosion severity and hotspot areas, drought frequency and magnitude, and the relationship between migration and SLM implementation. Furthermore, the study can help policymakers and researchers gain a comprehensive understanding of land management challenges in the context of seasonal migration and inform evidence-based decision-making processes concerning enhancing SLM adoption among mobile and drought-affected households. Ultimately, the significance of this study lies in its potential to contribute to the development of more tailored and impactful interventions to support farmers who are bounded by complex problems of soil erosion, and drought while seasonal migrations is also their coping strategy that usually happen at the expense of time and labour for SLM implementation.

1.7. General Research Design

Research design is plan and procedure of research activity from the initial proposal preparation to the data collection, analysis and presentation. It involves procedures of data collection, analysis and interpretation strategies as well as the worldview of the researcher in relation to problem under investigation. The components of research design such as research philosophy, research approach and data collection tools, sampling techniques and procedures as well as method of data analysis of this study are presented in detail here under the following sub sections.

1.7.1. Research philosophy, Worldview and Research Approach

This study explores the relationship between land degradation, SLM practices, and rural out-migration. It specifically examines land use and land cover change dynamics, soil erosion magnitude and hotspot areas, drought magnitude and frequency, and the effects of rural out migration on SLM adoption with econometric models and geo-spatial data analysis. The research is based on empirical data and statistical models to answer the research questions, and draw conclusions based on statistical test significance rather than absolute certainty. The philosophical foundation of this research is grounded in pragmatism, with methodological approaches informed by post-positivism and constructivism worldview. The interdisciplinary nature of the study—integrating remote sensing, soil erosion modeling, drought assessments, and econometric modeling—provides a robust theoretical framework for analyzing the link between migration and SLM. Post-positivism acknowledges that while absolute objectivity may be unattainable, rigorous scientific methods can approximate reality more closely (Phillips & Burbules, 2000; Kuhn, 1970). This study employs remote sensing, land use and land cover classification using advanced geospatial modeling tool, and econometric modeling based on empirical observation, and statistical inference—elements best approached from a post-positivist perspective. Constructivism, in contrast, posits that knowledge is socially constructed. Therefore, qualitative methods such as interviews and surveys yield valuable insights into farmers' decision-making processes regarding land use, management practices, and migration (Guba & Lincoln, 1994; Charmaz, 2014). This study incorporates farmers' perspectives, lived experiences, and understanding to better grasp their migration decisions and land management practices.

Guided by post-positivism and constructivism, the research philosophy of this study is also rooted in pragmatism. Pragmatism is particularly relevant to this study as it allows the integration of qualitative and quantitative methods to address complex, real-world problems (Creswell & Plano Clark, 2017). Given that land degradation, rural out migration, and land management are influenced by various environmental, economic, and social factors, a pragmatic approach allows for flexibility in choosing the most suitable and reliable data collection and analytical tools (Tashakkori & Teddlie, 2010). As Morgan, (2007), stated pragmatism paradigm helps to combine quantitative and qualitative studies in synergy as followed in this study.

This study holds a mixed research approach. The main assumption of mixed approach is that the integration of qualitative and quantitative approaches for addressing a given problem. A mixed methods design is useful and brings together the strengths of both qualitative and quantitative within the same study (Creswell &Creswell, 2018). As explained in the theoretical framework, land degradation, rural out migration and land management are situated in the wider bio physical, and socioeconomics context. Strict single approach (either qualitative or quantitative only) will fail to understand and make inquiry of it. The aim of the study is both understanding the relationship between different variables for generalization and documenting specific contextual views. In these situations, applying the principles of both qualitative and quantitative approach is advantageous. Among the different types of mixed-method research design (Creswell, 2012); this study will employ the concurrent embedded with quantitative dominant design. Thus, qualitative will be embedded within the predominant quantitative data. This design enables us to utilize different methods to study different groups of study subjects (Creswell, 2009) or to address the same research question through information at different levels of analysis. The basic rationale of employing concurrent embedded mixed research design is: a). It enables the collection of two types of data simultaneously, during a single data collection phase. b). it provides a study with the advantages of both qualitative and quantitative data. In addition, by using the two different methods in this approach, a researcher can gain perspectives from the different types of data or from different levels within the study.

For the household survey, the unit of analysis are farming households, and individual members of the household. Labor availability, migration participation decision and basic demographic information as well as experiences and attitudes towards migration, land management are studied at individual household member level.

1.7.2 Data source and data collection methods

Thus, both secondary and primary data sources have been used. The primary was obtained from Satellite Images, household survey, FGD and KII. Secondary sources were also collected from government policy and strategy documents; and project documents of various organizations. The detail data collection methods are described as follow

Household survey

Sample survey methods was applied to collect primary data from households/ through structured questionnaires with closed-ended and open-ended option questions. The household survey helps to address questions; how farmers are being able to adapt the impact of drought and available livelihood options, how the communities perceive migration and what is its relationship with land degradation and land management. Structured questionnaires were used to capture information about the households' socio-economic status, historical drought impact and frequency, land degradation state, and its related impact. The questionnaire contains both open and close-ended questions translated from English to Amharic. The survey was administered through face-to-face interview and trained assistant data collectors was hired to facilitate the collection processes.

Focus group discussion (FGD)

To supplement the data collected by other methods, FGD with farmers was conducted. The objectives of the FGD are to discuss land degradation status, drivers and impacts, community livelihood strategies, constraints and opportunities; gain in-depth knowledge of the farming systems; get insight into farmer perceptions of drought magnitude, frequency and impact. Challenges and opportunities of SLM implementation; migration experience and its prospects and challenges in relation to land management. The FGD was facilitated by the DAs (Development agents) led by the researcher.

Observation and participatory rural appraisal techniques

The researcher observed different land use, homestead and plot area using a village walk or transect walk. This method helped to observe environmental, socioeconomic, livelihood conditions and information that might be overlooked during FGD, KII, and household survey. Information observed while undertaking this process was recorded and documented using photographing, note taking and was used as an input to triangulate with other data collected using other instruments.

1.8. Limitation of the Study

During the estimation of soil erosion, model validation was carried out by comparing it with previous studies conducted in the highlands of Ethiopia. However, using measured soil loss data to validate the soil erosion rate would have been more appropriate. This study estimates the soil loss on the annual time scale; however, future studies are needed on soil erosion estimation on seasonal and monthly time scales to identify the risk of soil erosion in the rainy seasons, as the rainfall is highly unevenly concentrated on the three (June, July, August) months in the basin. RUSLE-GEE depend on free and open data sources. The study mainly relied on the cross-sectional data to study impact of migration on SLM; however, it would have been preferable if longitudinal data were used to assess the impact of migrant on the adoption of SLM and to look into their change in different socioeconomic profile. Previous studies used 3-SLS method for estimating the impact of migration on conservation and agriculture (Li et al., 2013; Quinn, 2009; Williams & Paudel, 2020), however, this study only estimate the impact of migration on SLM using 2-SLS. Due to minimal investment of remittance on agricultural inputs and SLM related investments, we do not included remittance in the model to simltaneously study both migration and remittance in relation to SLM Adoption. Other reason for failing to include remittance was absence of strong instrumental variable that can explain remittance without correlating with migration. Adding remittance in the estimation may incur variation on the model result and general implication of migration to farmland management. We only interviewed the defacto[1] head of the household; sometimes we collect about the migrant from the non-migrant households. Similarly, we also collect information from the migrant him/herself, but after returning from the seasonal migration. This is the challenge of most migration studies happening due to the dilemma of collecting migration data from origins or destinations. However, we conclude that the overall data and results are somewhat more serve our purpose. Limitation also arises from the definition of seasonal migration when there is migration of the whole family. In this case, it may not fit the theory of NELM where migration is considered as family strategy and not all the family, but the family member is migrated to ease the credit and cash constraint at the household back in the sending areas.

1.9. Organization of the Dissertation

The rest of the dissertation is organized as follow: Chapter two presents a short and generalized review of related literature. Definition of core concepts, such as land, land degradation and

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[1] any of the family member acting as household head during the interview period.

migration area presented in this chapter. Conceptual framework of the research is also presented under chapter two. Chapter Three investigates into analysing land use/ land cover changes using Google earth engine and RF algorithm and implications to the management of land degradation. The fourth chapter examines spatio-temporal drought dynamics using multiple indices. Chapter Five also present soil erosion assessment and identification of erosion hotspot areas using RUSLE-GEE framework in the upper Tekeze Basin, Northern Ethiopia. Chapter Six explores the link between seasonal migration and farmland management. Finally, unlike chapter six which is more of qualitative study, chapter Seven provides statistical evidence to the impact of seasonal migration on SLM. The last chapter of the thesis, chapter eight, presents synthesis, conclusion and recommendation of the study.

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CHAPTER TWO

GENERA THEORETICAL AND EMPIRICAL LITERATURE

In this chapter of the dissertation, I begin by defining the concept of land degradation, migration and SLM. Related literatures in land degradation, migration and land management have been reviewed and presented. To show the sequences followed, firstly, the concepts of land degradation, migration and land management are defined along with major theories on the interaction of migration and development. Then, empirical studies carried out so far pertinent to the objectives of this study with respect to land degradation, migration and its effect on SLM. Finally, clear conceptual framework for the study of land degradation, migration and land degradation responses such as SLM have been presented.

2.1. Defining Land and Land Degradation

The United Nations Convention to Combat Desertification (UNCCD) defines "land" as a "terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system." It defines "degradation" as the "reduction or loss of biological productivity, resulting from land uses or a combination of processes, such as soil erosion, deterioration of soil properties, and long-term loss of natural vegetation." According to the Millennium Ecosystem Assessment (MEA 2005), "land" is defined as "a terrestrial ecosystem." Land includes not only soil resources but also vegetation, water, other biota, landscape setting, climate attributes, and ecological processes (MEA 2005) that operate within the system, ensuring its functions and services. "Land degradation" is also defined as "the reduction or loss of ecosystem services, notably primary production service" (Nkonya et al., 2015).

Both the UNCCD and MEA definitions emphasize that land degradation is a broad term that encompasses the degradation of one or more land resources, including soil, water, vegetation, and biodiversity, resulting in a decline in their quality (Utuk & Daniel, 2015). Almost all definitions of land degradation involve the degradation of resources in terms of agricultural suitability, primary productivity levels, and natural ecosystem functions. From another perspective, land degradation is a consequence of land mismanagement, unsustainable land use, land cover changes, and a mismatch between land qualities and land use (Beinroth et al., 1994; Abdelrahman, 2023). This study focuses on three major forms of land degradation: land use and land cover change, soil erosion by water, and the impact of frequent climate extremes, particularly drought.

2.2. Land Degradation, Its Drivers and Implications

Land degradation could arise from soil erosion caused by wind, or water; deterioration of the physical, chemical and biological properties of soil; long-term loss of natural vegetation (UNCCD, 1994; Adeel et al., 2005; UNCCD, 2016a; Orr et al., 2017). According to Nkonya et al. (2015) healthy land ecosystems is "land" that function well and ensure their services—is essential to sustainable development, including food security and improved livelihoods.

Understanding the drivers, and pressure of land degradation is one of the major knowledge gaps identified, and is a crucial component of addressing land degradation as a whole (ELD-Initiative, 2013; Turner et al., 2015). Drivers of land degradation include all external factors that can act either directly or indirectly to result in declines in biodiversity, anthropogenic assets, ecosystem service (IPBES, 2018). These drivers are complex, and subjected to various interactions over time and space (Turner et al., 2015; IPBES, 2018)) due to varying interactions and causal factors that could lead to diverging consequences in different contexts (Baumgartner & Cherlet, 2015). Drivers of land degradation can be categorized as direct or proximate and underlying drivers (Lambin & Geist, 2004; Baumgartner & Cherlet, 2015). The proximate causes of LD include biophysical factors (land cover and vegetation, soil resilience, climate,) and unsustainable land management techniques. The underlying causes of LD include poverty, decentralization, access to agricultural extension service, the policies and institutional or other socioeconomic factors that determine land management practices. Proximate and underlying causes may be related to each other, for instance through feedback loops or synergistic processes, making it difficult to assess the influence of a single factor (Kirui & Mirzabaev, 2015; Nkonya et al., 2015; Lambin et al., 2001; Geist &Lambin, 2004; Andersson et al., 2011; Von Braun et al., 2013).

Human activities represent the most important force shaping the degradation of ecosystems in all of the world's major biomes. Agricultural activities continue to increase across much of the world driven by increasing demands for food. Also, more recent global change drivers, such as climate change exacerbating impacts (IPBES, 2018). Because of their role in shaping the severity and frequency of occurrence of other degradation driver's, change in climatic variables such as temperature, rainfall, and extreme events e.t.c. are major concern as driver of land degradation.

There are local and global assessments to study the extent and severity of land degradation and its associated risks. However, there is a great disparity in the methods and datasets used among these studies. Despite such variation in methods and datasets used, there is strong agreement that land degradation is severing environmental problem affecting livelihood of billions of people and natural ecosystem. Populations in dry lands are specifically affected by land degradation due to low land productivity, high levels of water shortages, high population and high poverty rates (MEA, 2005). Estimates showed that out of 2.1 billion people worldwide living in rural dry lands, of these 21% of them resided in degraded areas (UNCCD, 2019). In Africa, the expansion of land degradation affected more than half of the continent's total population, equivalent to 621 million people, 55% of them (343 million) live in rural areas. While estimating dry land degradation, Africa not only hosts the world's largest population on degraded rural dry lands, but also more than half (61%) of the rural population on degraded land in Africa reside on degraded rural dry lands — particularly on rural hyper-arid dry lands (46%) and semi-arid dry lands (26%) (UNCCD, 2019).

2.3. Theoretical Considerations in Migration and Development

Concept of migration has moved across various conceptual and operational definitions. The focus of this study is internal migration, particularly seasonal rural out migration with its impact on SLM. Although internal migration has many forms, this study focuses only on the sending area. The study also did not separate weather the migration was rural to urban or rural to rural. However, both rural out migration to urban areas and rural agriculturally high potential districts characterize the migration pattern from the study area.

There are several theoretical explanations through which the nature, characteristics and drivers of migration are explained and their linkage with the sending areas development are hypothesized. The dominant migration theories in this regard are neo-classical approach, the world system theory and the New Economics of Labour Migration (NELM). In most migration models, migration decisions made by individuals and shaped by wage differences between migrant origins and destinations (Tylor, 1999). However, the NELM represents a fundamental change in the way the connection between migration and development is conceptualized. Previous research separated the determinants of migration from the impacts of migration on sending areas. NELM viewed as household livelihood diversification strategy to minimize risk during market failure; where in developing countries financial markets for the poor are inaccessible (Taylor, 1999). NELM has also argued that migration decision is household level decision rather than individual (Stark & Bloom, 1985; Stark, 1991; Portes, 2010; Kurekova, 2011; and Kings, 2012). Maintaining decision at household or family level, the NELM argued that migration decision is a product of multi- faceted characteristics of the household and households' response against the prevailing failures of financial, credit and labour market (Massey, *et al*., 1993). This study is guided by NELM, where migration is taken as family strategy and its effect on the sending area production is taken as center of discussion.

The role of migration on development is complex and much debated (de Haan, 1999; Taylor & Martin, 2001; Williamson, 1988). Much of previous, the literature has focused on whether migration has positive effects on the welfare of migrants or the economies destination areas. NELM argues that migration play role in easing production and investment constraints. It argues that :(1) migration decisions are part of family strategies to raise income, obtain funds to invest in new activities, and insure against income and production risks; and remittances, or in some cases simply the potential for remittances, consequently set in motion a development dynamic by loosening production and investment constraints faced by households in poor developing country environments.

Nevertheless, the effects of migration on rural livelihoods are context-dependent and heterogeneous across space, socio-ethnic, and gender groups and tend to change over time; hence, no easy generalizations could be made (Nguyen et al., 2019; de Haas, 1999; de Haas, 2007). NELM is only supported in the case of available remittances.

The impacts of migration and remittances should be assessed relative to what migrant sending economies would have looked like without migration. Moreover, factors influencing migration decisions subsequently shape the impacts of migration and remittances upon households. The economic, institutional and environmental background that initiate migration decision have also impact on the impact of remittance on the sending areas. For example, poor market infrastructure, particularly in rural areas from which many migrants come, discourages the production of goods for markets. Incomplete or missing credit markets in migrant sending areas make it difficult to harness remittances for local investment. In underdeveloped rural regions like the context of the Waghimra Zone, infrastructural developments are limited, alternative livelihoods area scares, and poverty rate is almost high. This context is a challenge that obstructs the flow of remittance towards productive investment such as farm inputs and SLM. Creating a fertile ground for migration and remittances to contribute to broad-based income growth in migrant sending areas is the key to promoting development from migration.

Rural-urban migration is strongly associated with agriculture (de Haas & Solé-benet, 2001; de Haas, 2006; Jaquet et al., 2016). It affects farmer’s action in resource management, land use, and impact ecological processes and biodiversity by how labour, remittances, and institutions interact each other (Milbourne & Kitchen; Radel et al., 2019; Caulfield et al., 2019). Households' migration decisions are made based on multidimensional factors. Adverse climate conditions have been considered as the underlying causes of migration in developing rural areas. However, the interaction of climate and contextual drivers of migration, including economic, social, demographic, and political factors (Black et al., 2011), shape migration decisions. Among extreme climate events, droughts have significant adverse effects on smallholder farmer agricultural production and can potentially lead to livelihood losses and subsequent migration out of rural areas (Falco et al., 2019; Hermans & Mcleman, 2021).

2.4. Concepts and Principles of Sustainable Land Management Practices

In response to land degradation, the concepts of SLM have introduced and have been implemented all over the world. SLM is a system of technologies that aims to integrate ecological and socioeconomic principles in the management of land for agriculture and other uses in a sustainable manner (UNEP 1991; Abdelrahman, 2023). The term and the concept of SLM have been acknowledged in scientific and policy makers. SLM is widely promoted as a response to land degradation and desertification (Schwilch et al., 2013). The origin of the term SLM goes back in 1992 when it was defined by the UN Rio Earth Summit as “the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions.” IWG on FESLM, (FAO, 1993) define SLM as “combination of technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously: maintain or enhance production/services (Productivity) - reduce the level of production risk (Security); protect the potential of natural resources and prevent degradation of soil and water quality (Protection); be economically viable (Viability) - and socially acceptable (Acceptability). Sustainability is a major issue in the principle and definition of SLM. It is a measure of the likelihood that a particular land use will remain physically, economically and socially suited or appropriate to a particular location for a significant period. Production must be sustained, increased, but so too must the qualities of the land resources. World Bank (2006) also defines SLM as a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental to meet rising food and fiber demands while sustaining ecosystem services and livelihoods. WOCAT defines SLM as the use of land resources—including soils, water, animals, and plants—to produce goods that meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions (WOCAT 2007). The definition of SLM has continuously improved and made to represent a holistic approach to achieving long-term productive ecosystems by integrating biophysical, socio-cultural and economic needs and values (Holing, 2001; Schwilch et al., 2009; Sanz et al., 2017). FAO, (2006) indicates some of SLM indicators including ecological sustainability, technological sustainability, social and cultural sustainability, economic sustainability, institutional sustainability.

SLM seeks to integrate the management of land, water, biodiversity, and other environmental resources to meet current and future human needs while sustaining ecosystem services (World Bank, 2006). This definition outlines a broad set of SLM practices. This includes D-SLM that belongs to the group of nature-based solutions (NbS). An NBS can involve conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems. DSLMS are a group of specific land management clusters that are specifically recommended for drought-affected areas. D-SLM improves the resilience to drought for the land-users and society. There is evidence that D- SLM interventions improve the soils' capacity to accept, retain, release and transmit water, and increase plant water use efficiency. They increase the water supply where it is needed by living organisms or by reducing water demand using drought-resistant crop varieties (Reichhuber, et, al, 2019).

2.5. The Nexus between Land Degradation, Land Management and Ruralout Migration

Land degradation and migration are closely interconnected processes, which are mediated by other intervening social, economic, political, demographic, and environmental processes, operating at scales from the local to the global. Households that are heavily dependent on basic ecosystem goods and services often turn to migration as a means of diversifying their livelihood strategies or as a response for impacts of immediate on setting environmental extreme events such as drought as well as slow onset land degradation in the form of unsustainable LULC change, and soil erosion caused reduction of soil fertility. In developing dryland areas, migration tends to flow from areas of more degradation to those of less, with drought often elevating migration flows. The connections between land degradation and migration are complex, and are mediated by intervening social, economic, political, demographic, and environmental processes that operate at scales from the local to the global (Mcleman, 2017). Because the poor in developing countries reside primarily in rural areas and are dependent on agriculture, rural poverty and environmental degradation are obviously closely related (Todaro, 1989; Ezra, 2001).

Migration literature has considered environmental constraints as one of the prime causes of population mobility, especially from dry regions, where water rather than land is the primary limiting factor (Shah, 2010). The growing numbers of researchers are investigating the complex link between land degradation, climate change and migration. The potential link between migration and climate change as well as environmental stress by climate variability is expressed in two main categories of push factors: first sudden-onset climate-related disasters such as floods and hurricanes are push factors with identifiable fear-and-consequence-driven push factors. These threaten human life and are already resulting in forced migration from disaster areas. Many scholars argue that individuals who are temporarily or permanently forced off their land "because of a marked environmental disruption" should be considered "climate refugees" (Warner, 2010). The second push factor is a slow onset of climate which is related with gradual decline of soil fertility, soil erosion and desertification. These factors are the result of deteriorating climate and environmental stress that aggravate population mobility (DePaul, 2012). Generally, migration can occur in two scenarios, first it will be resulted as an immediate environmental disaster caused by climate variability or change, second migration can appear as a perceived adaptation or coping mechanism for perceived slow environmental degradation or climate change impacts. In the first, case migration is common in short radius and internal migration which is always not well planned by the migrant; while in the second case, the nature of migration can be international or long distance and usually ranges from well planned to less informed migration.

For the last two decades, there has been an increasing interest in linkages between the environment, particularly land degradation and migration, both within the scientific community and among policy makers. Numerous studies and reports assume that land degradation and environmental change will be a major cause for increasing population movements in the future. IPCC has indicated that "the gravest effects of climate change, by causing immediate environmental catastrophes and slow on-setting chronic land degradation, may be those on human migration as millions will be displaced" (IPCC, 2007; Hummel, 2012). There exists a question of whether migration is" migration for adaptation" or "migration as livelihood." The discourse on migration lays between two different narratives; the one, environmental migration narrative, often focuses on the migrant's constrained agency around timing and destination (Renaud et al., 2011). Furthermore, it has been suggested that environmental migration involves the abandonment of weakening livelihoods systems and places becoming uninhabitable (Black & Schmidt-Verkerk, 2011; McLeman, 2011) and the economic migration literature conceptualizes migrants as wage maximizing agents responding to income differentials between sending and receiving regions (Todaro, 1969).

The other unsettled argument is whether migration and land management practice are interrelated with each other and if they do in what condition and the nature of the relationship. Environmental constraints such as land degradation have long been seen as one of the prime movers of populations. Populations have had to move to new areas after sedentary agriculture exhausted natural soil fertility in the former location. In dry regions, population growth has resulted in overuse of water and land and, in turn, eventual out-migration (Bilsborrow, 1992). Existing migration theories treat environmental-stress-induced migration as a distress phenomenon influenced by ‘push’ factors. Such migration can in turn lead to suboptimal land use and further degradation of land owing mainly to shortage of labor of able-bodied persons of the households. Environmental factors, in general, form part of the set of structural factors that motivate households to make a variety of decisions, including migration.

Seasonal migration often happens in winter after the harvest time during which land management should have been practiced. The absence of the male household member during this period will certainly affect the labor provision for land management practice and adoption level. This will lead to the hypothesis those households who have participation in seasonal migration will have less likely adopted land management. Moreover, when they adopt, they will have a low level of adoption intensity.

However, despite the above argument, because migrants have earned additional income from migration, there is a possibility that migrant households might invest on land management practice and might adopt multiple land management practices on their farm. However, the evidence on impact of remittances on agriculture, in terms of investment for SLM is mixed. Those from the relatively better economic strata are likely to invest in agriculture as compared to those who are not (Shah, 2010). On the extreme side of the above argument is the view that seasonal migrant farmers might spent less time on the farm, given their pessimistic view about the productivity of their land and the uncertainty of the summer rainfall. Farmers will less engage on the farm and sometimes will be idle for that it will be good for rehabilitation of the land. Finally, it is very important to question whether the farmer who works the whole year on the farm is significantly different from the mobile/ migrant farmer on the adoption of land management practice.

The conceptual framework of this study encompasses the general interaction of nature, ecosystem and human. Human action and behavior, whether directly or indirectly is inseparable from its natural as well as built environment and vice versa. For the sake of focus, the framework has narrowed to a level where it is possible to see a complete process of land, environment and human decision.

Land cover/land use serves as an 'umbrella indicator' that allows stratification/disaggregation of the land productivity and soil organic carbon indicators. Changes in land cover/land use give a first indication of the loss or degradation and restoration of land and soil quality. Soil is an important indicator of overall land quality (UNCCD, 2015). SLM is defined as ‘the stewardship and use of land resources, including soils, water, animals and plants, to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions’ (WOCAT, 2007; Olsson et al., 2017). Therefore, the condition of land degradationand migration can be in a causal relationship and create—alone or combined—more vulnerability and stress on livelihood strategies. These strategies then lead to a change in land management or increased outmigration. Adapted coping mechanism and responses, specifically migration and land management strategies can in turn have either positive or negative change on the natural resource access or biophysical components of the environmental. The complete link between the major concepts is presented on Fig. 2.1.

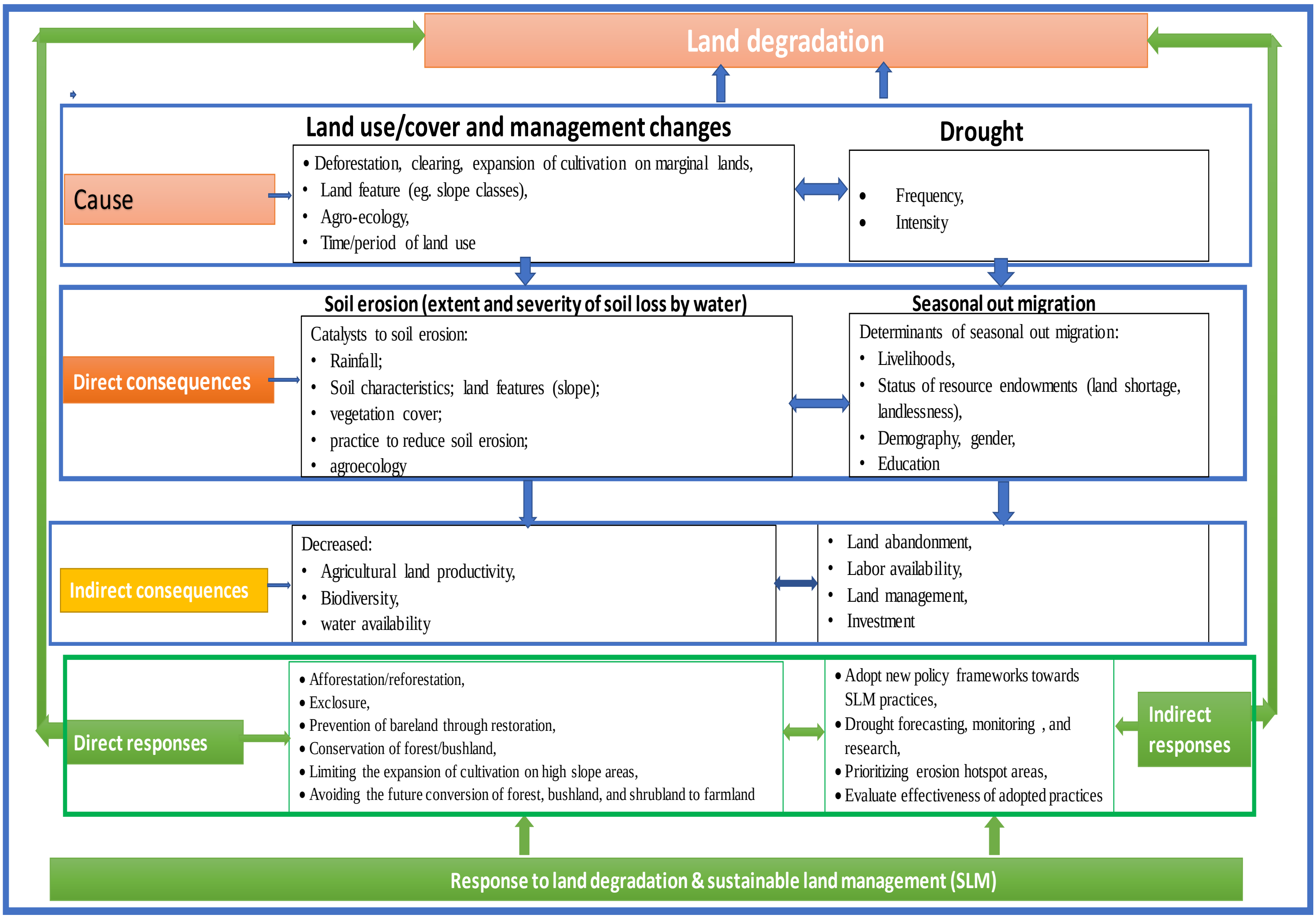

Fig.2.1. Sketch of conceptual framework linking land degradation, causes, consequences (direct and indirect consequences), and responses to land degradation (direct and indirect responses) leading to SLM in the Dry Land of upper Tekeze basin, Northern Ethiopia (conceptualized and reproduced from available literatures).

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CHAPTER THREE

ASSESSING LAND USE AND LAND COVER CHANGES WITH GOOGLE EARTH ENGINE AND RANDOM FOREST FOR LAND DEGRADATION MANAGEMENT IN THE UPPER TEKEZE BASIN, ETHIOPIA [2]

Abstract

Land use and land cover (LULC) change without appropriate management practices has been identified as a major factor contributing to land degradation, with significant impacts on ecosystem services, climate change and hence on human livelihoods. Therefore, up-to-date and accurate LULC change data and maps at different spatial scales are significant for regular monitoring of existing ecosystem, proper planning of natural resource management and promotion of sustainable regional development. This study investigates the temporal and spatial dynamics of land use land cover (LULC) changes over 31 years (1990–2021) in the upper Tekeze River basin, Ethiopia, utilizing advanced remote sensing techniques such as Google Earth Engine (GEE) and the Random Forest (RF) algorithm. Landsat surface reflectance images from Landsat Thematic Mapper (TM) (1990, 2000, and 2010), and Landsat 8 Operational land imager (OLI) sensors (2021) were used. Besides, auxiliary data were utilized to improve the classification of LULC classes. LULC was classified using the Random Forest (RF) classification algorithm in the Google Earth Engine (GEE). OpenLand R package was used to map LULC transition and intensity of changes across study period. Despite the complexity of the topographic and climatic features of the study area, RF algorithm achieved high accuracy, 0.83 and 0.75 overall accuracy and Kappa values, respectively. The LULC change results from 1990 to 2021 showed that forest, bushland, shrubland, and bareland decreased by 12.2, 24.8, 1.2, and 15.4%, respectively. Bareland has changed to farmland, settlement, and dry riverbed and stream channels. Expansion of dry stream channels and sandy land surfaces has been observed from 1990 to 2021. Bushland has shown an increment by 17.2% from 1900–2010 but decreased by 19.5% from 2010 to 2021. Throughout the study period, water, farmland, dry stream channels and riverbed, and urban settlements showed positive net gains of 484, 8.7, 82 and 26778.5%, respectively. However, forest, bush, shrub, and bareland experienced 12.17, 24.8, 1.2, and 15.37% losses. The observed changes showed the existing land degradation and the future vulnerability of the basin which would serve as evidence to mitigate land degradation by avoiding the future conversion of forest, bushland, shrubland to farmland, on the one hand, and by scaling up sustainable farmland management, and afforestation practices on degraded and vulnerable areas, on the other hand.

Keywords: Land use and land cover change, LULC transition dynamics, LULC changes along slope gradients, LULC dynamics implication to land management, land degradation

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3.1. Introduction

Land use and land cover change (LULCC) without appropriate management practices has identified as a major factor contributing to global land degradations, with significant impacts on ecosystem services and climate change, which in turn affect human vulnerability (Patz et al., 2005; Verburg et al., 2009). The term LULCC expresses modification of the earth's terrestrial surface, mainly the results of interaction between natural and anthropogenic processes (Dinka & Chaka, 2019; Mekonnen et al., 2018). It affects earth's system functioning (Lambin et al., 2001, 2003; Verburg et al., 2009) and its capacity to support human needs and increases the vulnerability of places and people to climatic and economic shocks (Lambin et al., 2003; Roy & Inamdar, 2021). At the local scale, changes in the use of land and its cover affect watershed runoff, micro-climatic resources, groundwater, land degradation processes, and landscape-level biodiversity (Arévalo et al., 2020; Bewket & Abebe, 2013; Lambin et al., 2003). Climate-driven land-cover modifications and human activities mediated by institutional factors, markets, policies, and global forces drive land-cover changes (Lambin & Meyfroidt, 2010; Meyer & Turner, 1996). In general, LULCC is a critical driver of global environmental change, significantly impacting ecosystems, climate dynamics, and human vulnerability. Understanding these changes is essential for developing effective land management and conservation strategies.

Therefore, up-to-date and accurate LULC maps at different spatial scales are significant for regular monitoring of existing ecosystems, proper planning of natural resource management and promotion of sustainable regional development (Feng et al., 2022; Midekisa et al., 2017; Vivekananda et al., 2021). LULCC has been observed across the world (Geist & Lambin, 2002; Lambin et al., 2003; Han Liu et al., 2020; Winkler et al., 2021). Many studies also have been made at continental (Midekisa et al., 2017), and regional (Brink & Eva, 2009; Bullock et al., 2021), and local levels (Ayele et al., 2018; Belete et al., 2021; Bewket & Abebe, 2013; Birhan & Assefa, 2017; Birhanu et al., 2019; Dessu et al., 2020; Dinka & Chaka, 2019; Etefa et al., 2018; Gashaw et al., 2018; Engida et al., 2021; Minta et al., 2018; Tadesse et al., 2017; Taye et al., 2023; Tewabe & Fentahun, 2020) level. Many researchers have studied LULC change in different parts of Ethiopia using GIS and remote-sensing techniques (Ayele et al., 2018; Belete et al., 2021; Bewket & Abebe, 2013; Birhan & Assefa , 2017; Birhanu et al., 2019; Dessu et al., 2020; Dinka & Chaka, 2019; Etefa et al., 2018; Gashaw et al., 2018; Getu Engida et al., 2021; Minta et al., 2018; L. Tadesse et al., 2017; Taye et al., 2023; Tewabe & Fentahun, 2020). These local studies have yielded mixed results. An earlier study by Zeleke and Hurni,

(2001) reported expanding cultivated land at the expense of forest and grass lands from 1957 to 1995 in Dembecha areas. Bewket and Abebe, (2013) found a reduction of natural vegetation cover and expansion of open grassland, cultivated areas, and settlements from 1957 to 2001 in the upper Blue Nile basin. In the same basin, Gashaw et al. (2018) found an increase in cultivated land and built-up area at the expense of forests, shrubland, and grassland from 1985 to 2015. Mekonnen et al. (2020) reported an increment in agriculture and settlement areas along with shrinks in forests and woodland cover in the Central Rift Valley of Ethiopia. In Awash and Afar-Danakil basins, Ayele et al. (2018) found the conversion of grazing land into plantation trees and area closure. In Gelan watershed, Birhan and Assefa (2017) found a decrease in forest and wetland and increase in shrubland, cultivated land, grassland, bareland, and settlement area. Most of these studies concluded that, like the trends on the global scale, the most remarkable change in Ethiopia is toward agricultural land, built-up/settlement areas (Gashaw et al., 2017; Mekonnen et al., 2018; Regasa et al., 2021). Nevertheless, few other studies showed forest recovery under protected areas. For example, Alemayehu et al. (2009) found a considerable increase in dense forest in semi-arid Eastern Tigray from 1965 to 2005. Similarly, Nyssen et al. (2009) reported increase in forest cover in Bella-Welleh watershed in Waghimra zone of Ethiopia.

Geographically, most of the studies in Ethiopia are concentrated in Rift valley (Kindu et al., 2013; Mekonnen et al., 2018), Blue Nile basin (Bewket & Abebe, 2013; Ewunetu et al., 2021; Gashaw et al., 2017; Teferi et al., 2013; Wakjira et al., 2020; Zeleke & Hurni, 2001), central Ethiopia and Awash basin (Dinka & Chaka, 2019; Gebrie et al., 2021; Minta et al., 2018). However, such type of studies are lacking in the northwestern and eastern part of the country (Regasa et al., 2021) generally, and in the arid and semi-arid catchments of upper Tekeze basin in Waghimra administrative zone, in particular, except a few studies made on Tekeza catchments in Tigray (Alemayehu et al., 2009; Jan Nyssen et al., 2009; Teka et al., 2013). The upper Tekeze basin is the most degraded and drought-prone area with erratic rainfall. Due to their nature of rigid topography, most of the land is either degraded or highly vulnerable to feature degradation. Due to the severity of land degradation, government intervention in SWC has been introduced decades ago. The ecological restoration programs under SLM practices, such as terraces and bunds, and establishing exclosures on communal grazing lands are among others. Following this program from 2010 to 2015, about 15 million people have contributed unpaid labour each year and more than 12 million hectares of land have been rehabilitated through implementing physical and biological conservation measures (Seyoum, 2016).

However, as the level and cause of the previous degradation, drivers of degradation and LULCC, and the effectiveness of conservation practices are contextual; the current understanding of LULCC and its implication to current and future degradation is not well studied. Therefore, this study is conducted in data scares region of Northern Ethiopia and fills the data/information gap by providing up-to-date LULC information and its implication to land degradation management.

Methodologically, several studies have improved land-cover change measurements in recent decades, and scientists' ability to monitor changes in LULC has improved due to the application of GIS and remote sensing technology (Lambin et al., 2003; Verburg et al., 2009). However, accurate LULCC assessment is still vital study for evidence based policy advising and strategies to achieve future conservation measures (Abdullah et al., 2019; Arévalo et al., 2020; Ayele et al., 2018; Mekonnen et al., 2018). In contrast to traditional remote sensing methods, GEE offers cutting-edge technologies and unrestricted access to a broader range of remote sensing data, fostering the formation of transformative land-change research issues (Wang et al., 2020). GEE has been used for a variety of applications and at various scales of analysis (Traganos et al., 2018), including drought assessment (Fentaw et al., 2023; Sazib et al., 2018), Normalize difference vegetation index (NDVI) mapping (Robinson et al., 2017; Sazib et al., 2018; Wu et al., 2020), and land cover classification (Piao et al., 2021; Tsai et al., 2018). Researchers have used this platform for land cover classification (Luo et al., 2021; Phan et al., 2020; Piao et al., 2021; Qu et al., 2021; Tsai et al., 2018; D. Zhang & Zhang, 2020), and it has been suggested that GEE is very useful in spatial data management for its fast and easy computation.

GEE also provides various pixel-based machine learning classification algorithms. RF, support vector machines, K-nearest neighbor, artificial neural network, and classification and regression tree can improve classification accuracy by reducing collinearity and over-fitting (Piao et al., 2021). Among theses, Support Vector Machine (SVM) and RF are two widely used algorithms (Amini et al., 2022; D. Zhang & Zhang, 2020) for a variety of earth science applications, including modelling forest cover, LULC and object-oriented mapping (Abdi, 2020; Araki et al., 2018; Oo et al., 2022). However, RF has gained great popularity and become one of the best classification algorithms in LULC mapping due to its better efficiency and higher accuracy, and the need for a few parameters (Amini et al., 2022). While several studies of developed region used RF on GEE platform for LULC change mapping, fewer studies have used it for less developed regions (Kumar & Mutanga, 2018). Although several studies have been conducted on LULCC in Ethiopia, none of them used GEE and RF for data access and classification. Unlike previous LULCC studies that use ArcGIS and maximum likelihood classification, this study use GEE for data accesses, preparation, and computation. Moreover, RF algorithm has been used for classification of LULC.

Therefore, the overall objective of the study is to analyse the temporal and spatial dynamics of LULC in the last 31 years (1990–2021] and its implication for SLM practices in the upper basin of Tekeze River in Waghimra Administrative Zone of Ethiopia.

3.2. Data and Methods

3.2.1. Study Area Description

The study was conducted in upper Tekeze basin in Waghimra administrative zone of Amhara Regional State, Northern Ethiopia. It covers an area of 4593 Km^2 and geographically extends from 12.11^0 to 13.13^0 N latitude and 38.40^0 to 39.30^0 E longitude (Fig. 3.1). The area's elevation ranges from 1060 to 3880 m above sea level (Fig. 3.1). The slope of the area ranges from flat plains to steep escarpments. The mean slope of the zone is 19.17%. Undulated topography with poor vegetation cover characterizes most par of Waghimra administrative zone, particularly the southwest and the northern part of the study area.

The zone in one of the most drought-affected areas in the past. Land degradation; frequent drought; and the high population densities characterize it (Hermans-Neumann et al., 2017; Hermans & Garbe, 2019). Migration for short-term employment has been a feature of the livelihoods of the poorest in Waghimra. Most young people consider migration for work to be a temporary response to an inadequate cash flow (Wubet et al., 2019). Waghimra is part of Ethiopia's northern highlands, which are highly vulnerable to climate change, including extreme climate events such as droughts. High vulnerability to drought and famine, growing population pressure and land degradation have resulted in reduced yield. People residing in Waghimra are frequently in immediate need of food aid. Although NGOs and governmental organizations could encounter basic needs, the root cause of food insecurity is related with the region’s degraded ecosystem and not yet tackled.

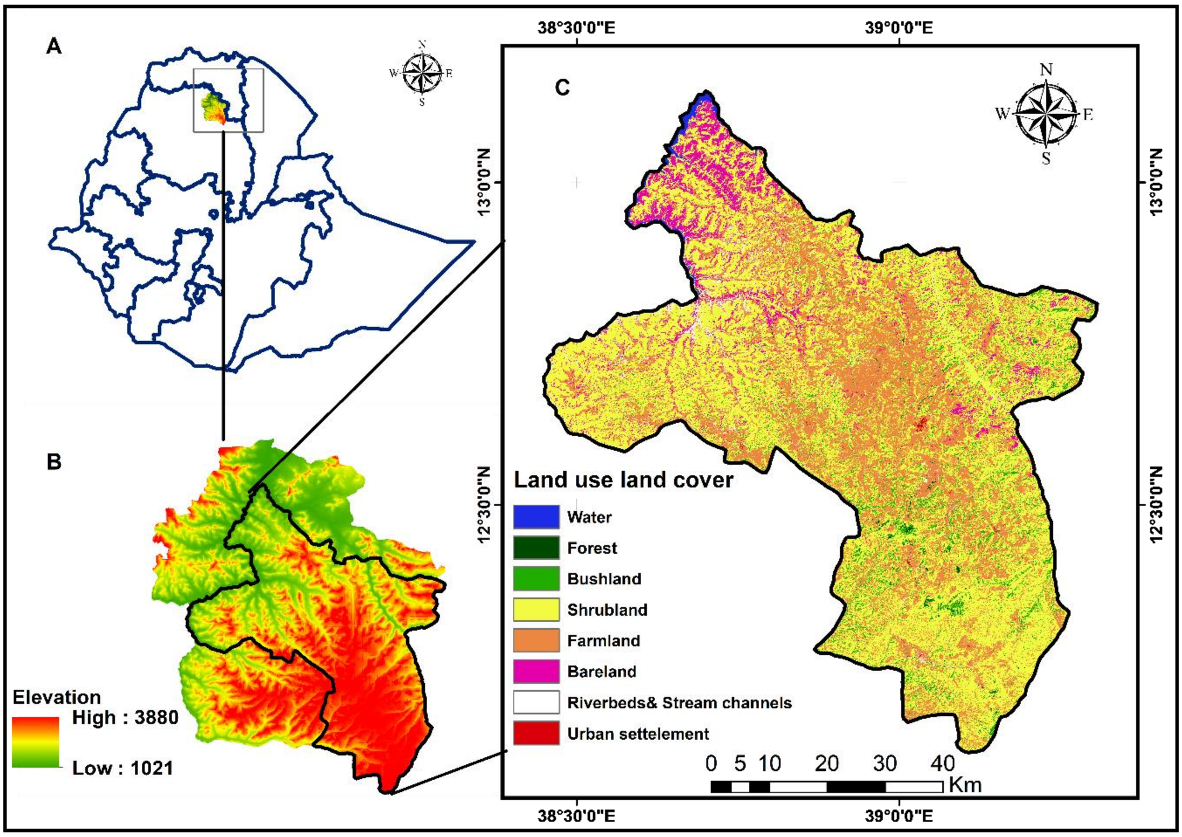


Fig. 3.1. Location of the study area: a) in Ethiopia, b) in Waghimra Adminstrative Zone c) studied sub-basin showing LULC. (Reproduced from Eshetu & Abegaz, 2024).

In almost all parts of the Tekeze basin, the summer (*Kiremt)* rain starts in June and ceases around the end of August (Bisrat & Berhanu, 2019). Specifically, the mid and high-altitude areas receive rainfall from late June to early September, while in the lowland parts of the basin, it extends from early July to mid of August. The primary crop production system is rain fed of the summer season. About 63% of the annual rainfall is in July and August. The area's annual minimum and maximum temperatures are 12.02^{o}C and 30.4^{o}C, respectively (Fig. 3.2).

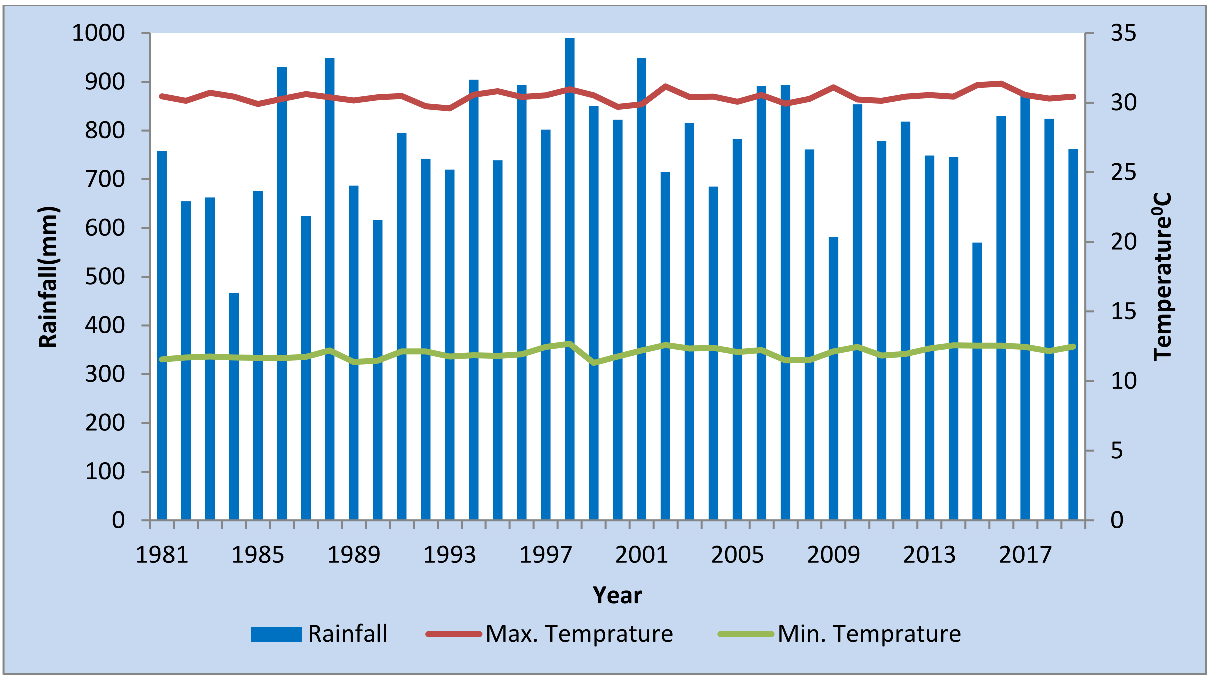


Fig. 3.2. Annual rainfall, mean annual minimum and maximum temperature of the study area from 1981 to 2021 (derived from monthly CHIRPS-v.2). (Reproduced from Fentaw et al., 2023)

3.2.2. Data

This study used level 2 surface reflectance (SR) products from Landsat 5 -TM and landsat 8 OLI sensors available in the GEE. The U.S. Geological Survey (USGS) provides the level 2 SR data from Landsat 8 generated using the Land Surface Reflectance Code (LaSRC) algorithm. For Landsat 4 to 7, SRs are derived with the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) algorithm (Ermida et al., 2020). Landsat collection 2 level 2 data have undergone a series of atmospheric and geometric corrections and are science products with values added and highly processed Landsat products (Pinto et al., 2020; Roy et al., 2014). These SR collections ensure that multi-date images are comparable and allow more stable and reliable land change analyses (Tsai et al., 2018). SR is generally more appropriate for measuring and monitoring vegetation and other land cover types at the land surface (Robinson et al., 2017; Roy et al., 2014; Vermote et al., 2016).

Four sets of digital satellite imageries from TM and OLI sensors for the years 1990, 2000, 2010 and 2021 were used to examine LULC dynamics (Table 3.1). Years of analysis (1990, 2000, 2010, and 2021) were selected purposely to align with significant socio-political events in Ethiopia and Northern Ethiopia. Accordingly, the 1990 image indicates the land and environmental condition during the Derg regime. The year 2000 represents the aftermath of the fall of the Derge regime and the early period of Ethiopian People Revolutionary Democratic

Front (EPRDF) regime. During these periods, environmental management and protection were not the government's top priorities. The year 2010 represents the efforts of soil and SWC and SLM programs in different parts of Ethiopia, including the study area. In 2010 the government of Ethiopia launched nationwide ecological restoration and area exclosure programs (Mekuria et al., 2018; MoFED, 2010). Finally, the 2021 image represents the current biophysical status and observed changes after 2010 area exclosure and degraded land restoration policy. In order to minimize the seasonality effects, images were mainly selected from January to February.

Table 3.1. Details of satellite images and other datasets used in the study

Satellite	Sensor	Date of accusation	Spatial Resolution
Landsat 5 SR	TM	1990-01-07	30m
Landsat 5 SR	TM	2000-01-01 to 2000-02-28	30m
Landsat 5 SR	TM	2010-01-01 to 2010-02-28	30m
Landsat 8 SR	OLI	2021-01-28	30m
ASTER GDEM			30m

Auxiliary data

Previous studies have shown that different remote sensing indices are sensitive to different types of LULC and enhance classification accuracy (Aljenaid et al., 2022; Lin et al., 2020; Luo et al., 2021; Phan et al., 2020; Qu et al., 2021). To improve classification accuracy, spectral indices retrieved from the original bands, such as NDVI, Normalized Difference Water Index (NDWI), Normalized Difference Moisture Index (NDMI), Normalized Difference Built-Up Index (NDBI), were used as additional bands in this study. Furthermore, the tasselled cap ratio was derived and incorporated in the classification bands. The Tasselled Cap component is widely applied to characterize vegetation conditions. These indices measure the presence and density of green vegetation, total reflectance, and soil moisture content (Qu et al., 2021). After visually inspecting the pattern and accurateness of the index, by overlaying on known sample points, the derived indices were evaluated and added to the classification bands. In addition, topographic variables, such as elevation and slope were used as auxiliary variables for the classification.

3.2.3. Data Processing and Classification Overview

An overview of methodological framework applied in this study is shown on Fig. 3.3. The majority of the image processing and analysis for the study was implemented through GEE. All data sets used in this study are freely available on GEE. We have filtered cloud-free, dry season (January to February) SR images clipped to the study area. Indices were also derived from these cloud-free images and added as an independent band to the original Landsat images. Indices and other axillary data were generated using the GEE API. After we had obtained all the required bands, we overlaid the training and validation points of each LULC on the final image. The sample points were selected using field data, Google earth imageries, and NDVI threshold. Then, tuning machine learning classifier hyper parameters, generating classification maps, and assessing the accuracies of classified maps was performed. Finally, the total area, and the change of each LULC class, the temporal pixel transition matrix from one LULC category to the other was calculated to assess and analyse LULCC patterns.

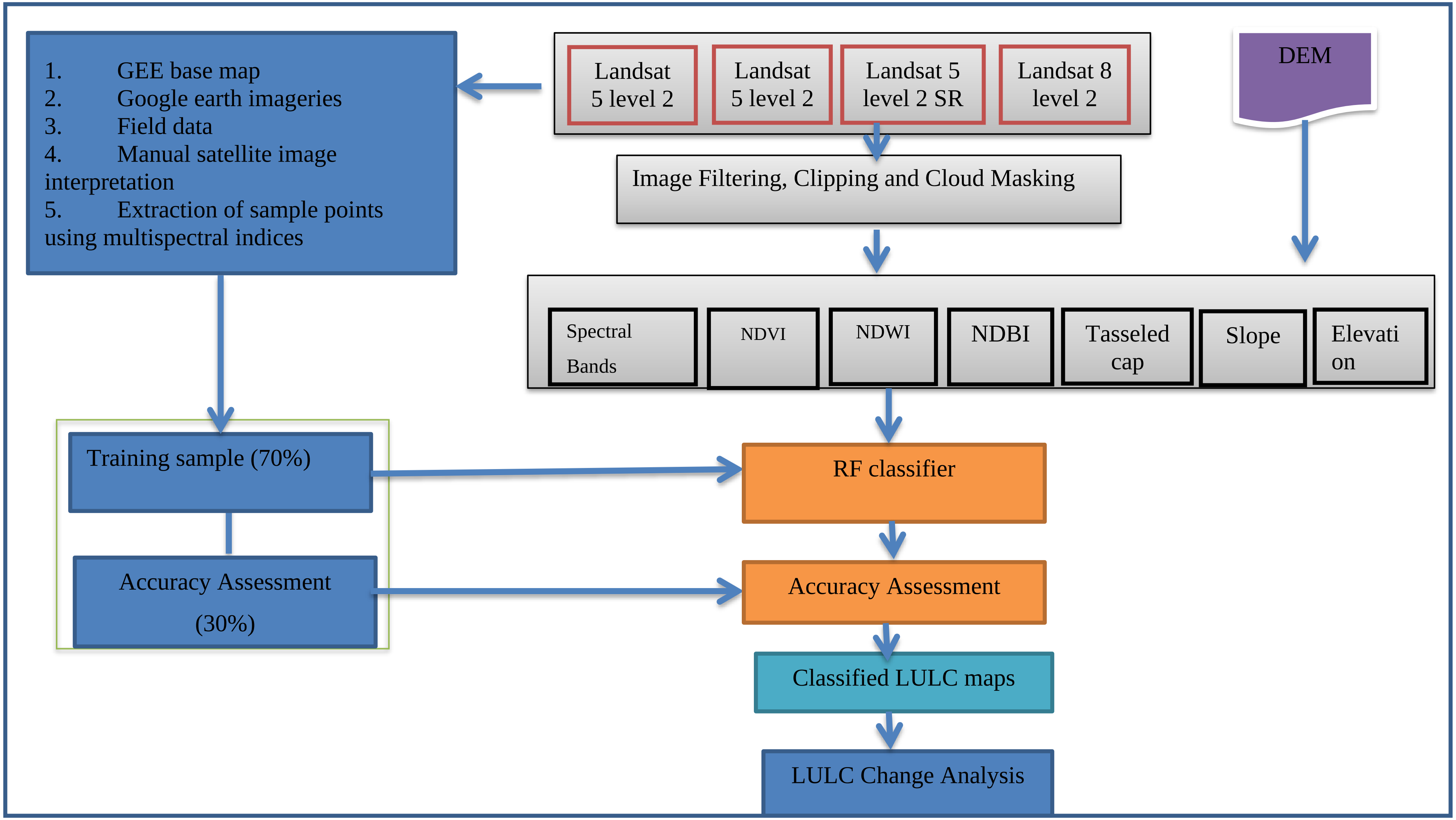


Fig. 3.3. Schematic overview of the methodological framework of the study.

3.2.4. LULC Classification Schemes

As described in Table 3.2, eight LULC types were identified in the study area. All training and validation samples were collected based on field survey data and manual visual interpretation of high-resolution images from Google Earth and the GEE base map. This method is widely applied in literature (Phan et al., 2020; Piao et al., 2021; H. Zhang et al., 2020). Multi-temporal Google Earth aerial imageries were used to select suitable training sites for the eight LULC types from the acquired Landsat images. For the earlier study periods (1990 and 2000), the available Google Earth imageries corresponding to the study area are less precise than those from 2010 to 2021. However, the false colour interpretation of the acquired satellite images was employed to identify sample points from all land covers. This photo interpretation technique was also enhanced by incorporating axillary data in the classification algorithm. For example, the NDVI threshold was used to identify vegetation. Dry and high-reflecting bareland was also easily identified with the help of the Tasseled caped dryness index. In addition, the temporal stability principle was considered to select sample points. For example, church forests are among the convenient sample points in the study area due to their stability for extended periods. Riverbeds and urban settlements were also easily identifiable features and have been stable since their existence. 1721 ground control points (GCP) were collected and used for the LULC classification.

Table 3.2. Description of LULC classes used in the study area

No	LULC classes	Description
1	W	An area of land covered with surface water such as lakes, rivers, and ponds.
2	F	Areas covered by dense natural trees forming closed or nearly closed canopies, mainly growing naturally in the reserved land, church compounds and riverbanks, and plantation.
3	BL	Areas covered with small trees, woody bushes, sparse canopy trees, dense vegetation grown in protected areas and hillsides.
4	ShL	Areas covered with short shrubs and bushes with little useful wood, usually stony with a very rugged micro relief. It may include a mix of small clusters of plants or single plants dispersed on open grassland.
5	FrL	Cultivated land, crop fields, fallow lands, rural settlements fenced with trees that are commonly found around homesteads.
6	BrL	Areas of sand, rock or soil with very sparse to no vegetation.
7	RbSc	Dry riverbeds, stream channels, gullies, and sandy flooded area.
8	UrS	Urban settlement and residential areas.

Note: W = water body, F = forest, BL= bushland, ShL= shrubland, FrL= farmland, BrL= bareland, RbSc= dry river beds and stream channels, and UrS = urban settlements and residential areas

3.2.5. Classification Method and Process in GEE Using RF Algorithm

Machine learning-based classifiers help identify complex patterns while at the same time minimizing the problem of data dimensionality (Piao et al., 2021). The RF consist many individual decision trees. Each decision tree has several nodes, and the majority vote determines the result. The algorithm not only randomly selects sub-samples from the input variables but also randomly selects the best feature through a voting process to establish the splits in the nodes of trees. According to a systematic review from 2010 to 2019, the RF algorithm is one of the most frequently used classification algorithms. Hence, this study applied the RF classification algorithm for LULC classification. Among the 1721 sample points, 70% were used for training the RF classifier, and the remaining 30% were used for validation. The number of decision trees was set to 50, which was found to be the optimum number producing a good accuracy level. The accuracy evaluation was performed using indices including the user's accuracy (UA), producer's accuracy (PA), overall accuracy (OA), and kappa coefficient (Fonte et al., 2020; Sharma et al., 2018; Story & Congalton, 1986). These accuracy indices are calculated by constructing confusion matrix using GEE syntax. The GEE inbuilt code for construction of error matrix and calculation of LULC accuracy is based on Stehman (Stehman, 1997).

3.3. Result and Discussion

3.3.1. Accuracy Assessment of The LULC Maps

Table 3.3 shows the details of the accuracy evaluation of the RF classification (user's accuracy (UA), producer's accuracy (PA), and overall accuracy (OA)) and Kappa classification. The accuracy evaluation for each classified image was calculated by constructing a confusion matrix. The RF classifier produced overall accuracy assessments of 0.83, 0.86, 0.88, and 0.88 for 1990, 2000, 2010, and 202, respectively, and the Kappa accuracies were 0.75 (1990), 0.79 (2000), 0.83 (2010), and 0.82 (2021). As compared with the other LULC classes water had high classification accuracies each year because its reflectance is easier to distinguish from other categories, whereas bareland and urban settlements had lower accuracies. There was also a challenge to differentiate the spectral characteristics of bushland and forest areas due to the narrow spectral signature difference among these land cover types. Although the area coverage of forest was low in the study area, it was essential not to merge with bushlands. We think it is crucial to quantify and identify the church forests, riverine trees, and plantations that are sparsely located across the study area. Compared with surface water and vegetation, the built-up and barren areas showed a relatively low accuracy. The aridity of the northern part of the study area challenged the identification of barren land from urban settlements, dry stream channels, sandy floode plains and sparse shrubs. However, the incorporation of the axillary data; elevation, slope, and tasseled cap indices, helped improve the identification of these resembling spectral characteristics. Note that urban settlement in 1900 was almost absent because it was very small during this period, and most of the settlement was a rural settlement with similar reflectance value with farmland and bareland. Fig. 3.4 shows the land cover classification maps for 1990, 2000, 2010, and 2021.

Table 3.3. Accuracy of the RF classification algorithm

Year	Accuracy	LULC classes								OA	Kappa
		W	F	BL	ShL	FrL	BrL	RbSc	UrS		
1990	UA	0.82	0.88	0.63	0.81	0.83	0.80	0.93	1	0.83	0.75
	PA	0.95	0.82	0.71	0.8	0.91	0.9	0.45	0.005		
2000	UA	0.83	0.64	0.82	0.85	0.88	0.80	0.94	1	0.86	0.79
	PA	0.93	0.84	0.81	0.82	0.89	0.86	0.89	0.70		
2010	UA	1	0.88	0.78	0.88	0.90	0.81	0.90	1	0.88	0.83
	PA	0.97	0.77	0.82	0.82	0.93	0.92	0.76	0.75		
2021	UA	1	0.74	0.82	0.84	0.91	0.86	0.91	1	0.88	0.82
	PA	0.93	0.81	0.85	0.86	0.90	0.91	0.89	0.82		

Note: UA= user's accuracy, PA = producer's accuracy, OA = overall accuracy, W = water body, F = forest, BL= bush land, ShL= shrubland, FrL= farmland, BrL= bareland, RbSc= dry river beds and stream channels, and UrS = urban settlements and residential areas

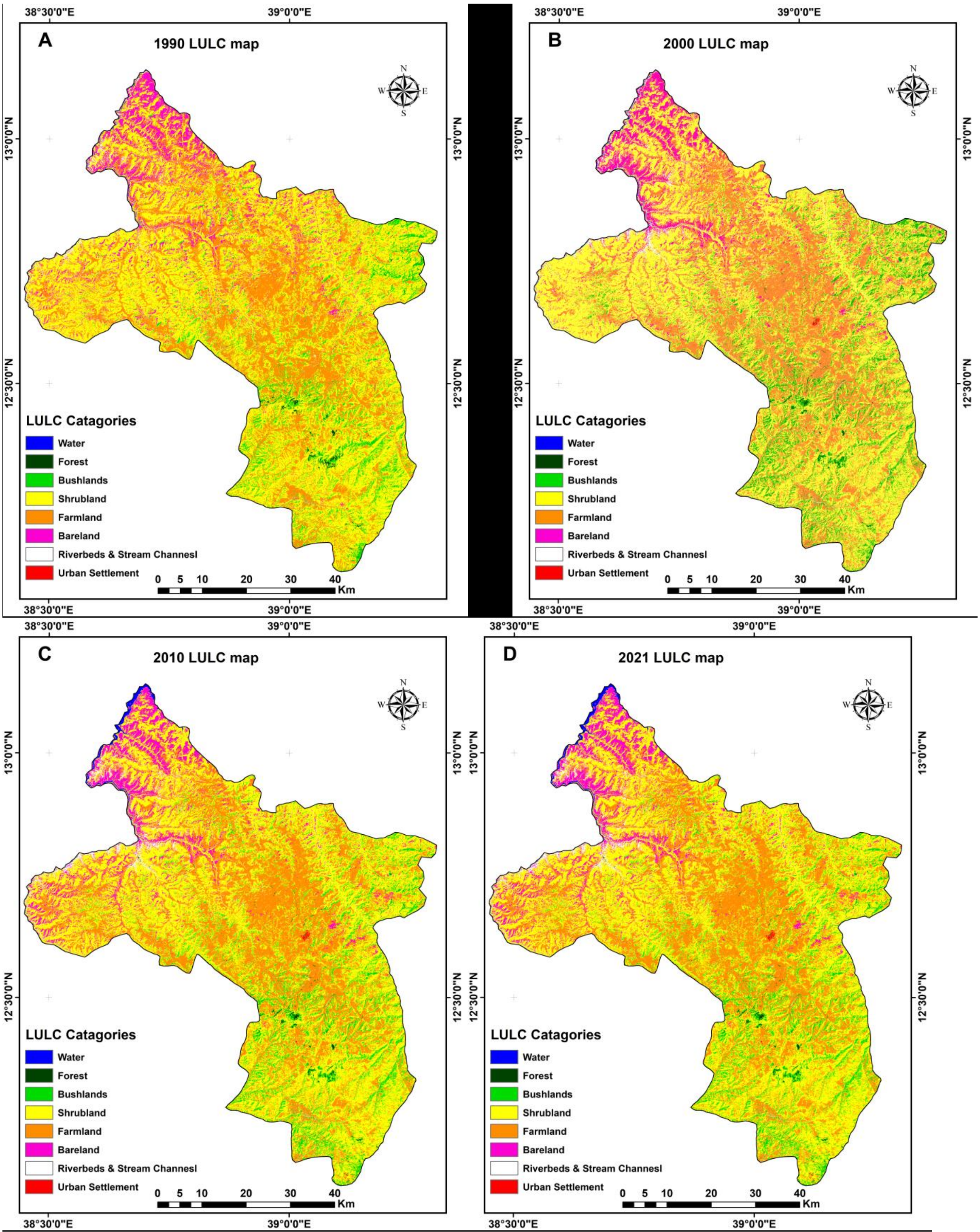


Fig. 3.4. LULC of the arid and semi-arid land of upper Tekeze basin in 1990 (C), 2000 (B), 2010 (C), and 2021 (D).

3.3.2. LULC Change in the Study Area

In 1990, shrubs covered 55.93% (256866 ha) followed by agriculture, which covered 26.84% (123250 ha), and bareland, which covered 9.11% (39408 ha) of the study area (Fig.3.4a and Table 3.4). Water bodies, forest and bushland each accounted for 0.1, 0.5, and 7.05% of the study area, respectively. Urban settlement and residential areas covered only 1.66 ha of the study area. In 2000, shrubland and farmland remained the most predominant land cover types, accounting for 242284 ha (52.76%) and (132724.28 ha) (28.90%) of the study area, respectively (Fig. 3.4b and Table 3.4). Forest cover increased by 160 ha, accounting for 0.51% of the entire study area. In 2000, bushland was 42334 ha, increased by 30.7% (9953 ha) from the 1990s coverage. Bareland and stream channels combined covered 8.45% of the study area in the 2000 LULC map.

On 2010 LULC map, the study area was covered by: 51.30% shrubland, 30.04% farmland, and 8.33% bushland (Fig. 3.4 C and Table 3.4). Other land use types covered the remaining 10.28% of the area. Shrubland, bush land, and forest cover decreased by 6691, 4083, and 406 ha, respectively, from 2000 to 2010. These reductions were due to expansion of 5212 ha farmland, 14 ha bareland, and 2364 ha riverbed and stream channels. Compared to the preceding study period, water body has increased dramatically by 1529 ha. This was due to the accumulation of water in the Tekeze River's channels due to the Tekeze Hydroelectric Dam's construction. Forest cover has decreased by 4066 ha compared to the previous study period. Except for what has been observed in bushland decline and shrubland increase, LULC distribution in 2021 is comparable with that in 2010. The study area was still dominated by shrubland, followed by farmland, as they have been for the last two decades. Only water bodies, shrubland, and urban settlements expanded. Unlike the past 20 years study period; bush lands have experienced the most significant decline in this period. Conversion to shrubland and encroachment of riverbeds and flooded sandy stream channels are the prime cause of bushland decline.

The general trend in the last three decades (1990-2021) showed that water, farmland, stream and riverbed, and urban settlements and residential areas were increasing. The remaining land covers classes, forest, bush land, shrubland, and bareland, decreased by 12.17, 24.79, 1.18, and 15.37%, respectively. Settlement, and water bodies, riverbed, and stream channels have also expanded, indicating the expansion of dry stream channels and sandy land surfaces in the study area. Generally, the water body has increased by 81.17 ha every year from 1900 to 2021. In contrast, forest land increased by 12.17% from 1990 to 2021, with a rate of 8.84 ha yearly. Bushland has shown a continuous increment in the first two consecutive decades (1900–2010) by about 17.24%. However, it experienced a decline of 19.56% in the next decade from 2010 to 2021. Throughout the study period, water, farmland, stream channels, riverbed, and urban settlements showed positive net gains of 483.97, 8.70, 82.14, and 26778.47%, respectively. At the same time, forest, bush, shrub, and bare LULC classes experienced losses of 12.17, 24.79, 1.18, and 15.37%, respectively.

Table 3.4. Magnitude and pattern of LULC change in the upper Tekeze basin (1990-2021)

LULC classes	1990		2000		2010		2021		1990 2021 change	Annual rate of change
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	%	(ha)
W	503.14	0.11	594.1	0.13	2123.13	0.46	2944	0.64	483.97	81.17
F	2178.8	0.47	2339	0.51	1932.7	0.42	1914	0.42	-12.17	-8.84
BL	32380.7	7.05	42333.6	9.22	38251.10	8.33	24352	5.30	-24.79	-267.62
ShL	256865.8	55.93	242284.30	52.76	235593.5	51.30	253823	55.27	-1.18	-101.44
FrL	123249.7	26.84	132724.3	28.90	137936.4	30.04	133897.2	29.16	8.64	354.91
BrL	39407.8	8.58	32421.7	7.06	34436.2	7.50	33353	7.26	-15.37	-201.87
RbSc	4657.4	1.01	6362.8	1.39	8727.13	1.90	8483	1.85	82.14	127.52
UrS	1.7	0.00	185.2	0.04	245.15	0.05	446	0.10	26778.47	14.81
Total	459245		459245		459245		459212*			

*No data on 33 ha

Fig. 3.5 shows that the rate of LULC change during the studied time intervals. The length of bars on the right indicates that annual change in the 3 period was not identical. Left of Fig. 3.5 shows that the size of the change during the first-time interval (1990–2000) was the largest. The next two periods experienced decreasing change. On the right side of Fig. 3.5, the first interval (1990 to 2000) was with the fastest change intensity in terms of the annual rate of LULC change, and it decreased in the period between 2000 and 2010, and then in latest period.

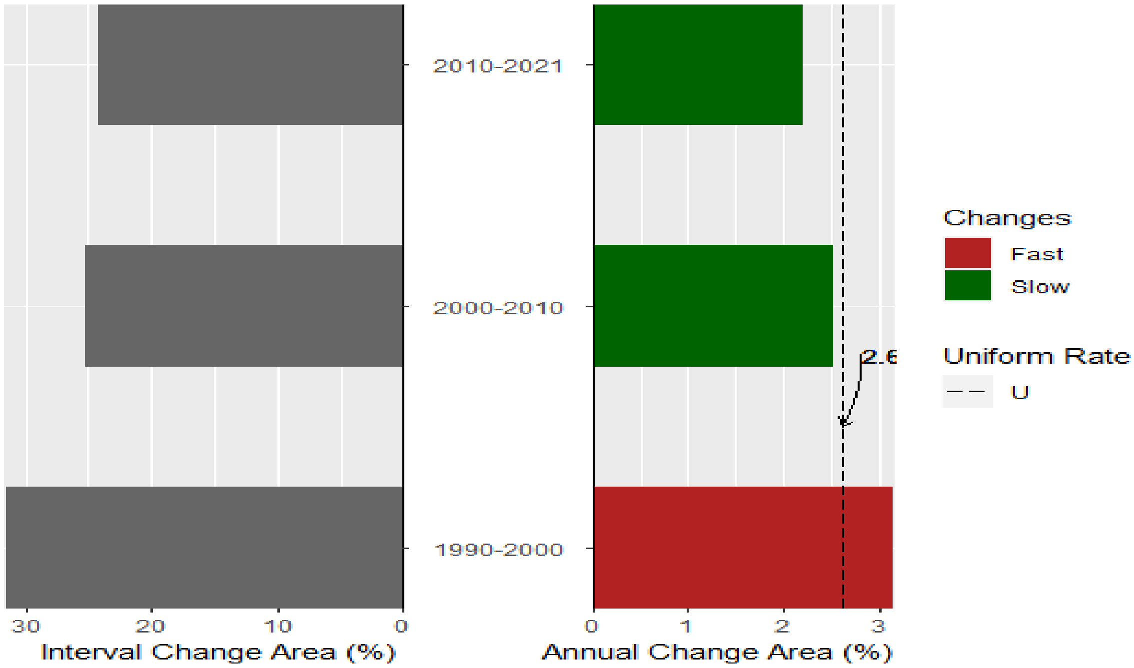


Fig. 3.5. LULC change intensity across the three studied time intervals (1990-2000, 2000-2010, 2010-2021). Bars that extend to the left of zero show the percentage of change, and bars that extend to the right of zero show the percentage of change per year within each time interval. Uniform rate (U) assumes if the annual changes were spread evenly over the study period.

3.3.3. LULC Transition Dynamics

The land-use transition matrix between 1990–2000, 2000–2010, and 2010-2021 were derived using java script code in the GEE environment. Multistep (Fig. 3.6) and one-step (Fig. 3.7) transition graphs were produced in OpenLand package in R software (Exavier & Zeilhofer, 2020). The purpose of generating a transition matrix was to identify the magnitude of the transition of pixels under a specific land cover class to another land cover category. This matrix showed the magnitude and direction of LULC changes within the study area. All LULC types experienced changes, and the intensity of change differed among the seven LULC classes.

LULC transition from 1990 to 2000

Multi-step LULCC transitions from 1990 to 2000, 2000 to 2010 and 2010 to 2021 presented in Fig. 3.6. About 60.5% of land covered by water in 1990 transformed to 2000 without change. The remaining portion of land covered by water in 1990 (147.37 ha or 29.2%) was changed to dry riverbeds and stream channels. Despite the conversion of water bodies to dry riverbeds and stream channels in 2000, 67.3 ha of land covered by a dry riverbed in 1990 also changed to a water body in 2000. Nevertheless, from 1990 to 2000, other land use types also changed to a water body. The remarkable conversion was from a shrub in which 199 ha of its cover changed to a water body. Despite the net areal extent increment of frost from 1990 to 2000, 809 and 502.42 ha of forest were changed to shrubland and bushland respectively. However, another

613.55 and 552.61 ha of land covered by bushland and shrub in 1990 have changed to forestland. The appearance of trees and agroforestry in irrigated areas might be reasons for addition of 345.34 ha to forests. During 1990-2000, 56.47% of bushlands remained unchanged while 38, 3.33, and 1.9% were converted to shrubland, farmland, and forest. The remaining small portion has changed to water, bareland, stream channel, and riverbed. From 256610 ha of land covered with shrubland in 1990, 73.78% of it remains unchanged. The other 3588, 20411, and 7885 ha of shrubland changed to farmland, bush land, and bareland, respectively. The reaming 1.5% of shrub bland changed to water, forest, riverbed, and stream channel. Bareland experienced the greatest instability; only 46% of its coverage in 1990 remained unchanged from 1990 to 2000. The primary conversion was towards shrubland, farmland, and dry riverbed. In this transition period, increase in areal coverage of dry riverbed and stream channels have been observed. This increment was due to conversion from shrubland farmland and water bodies. This conversion of shrubs and farmland into dry riverbeds indicates severe drought that leads to dry, flooded farmlands and sandy and highly dispersed shrubs.

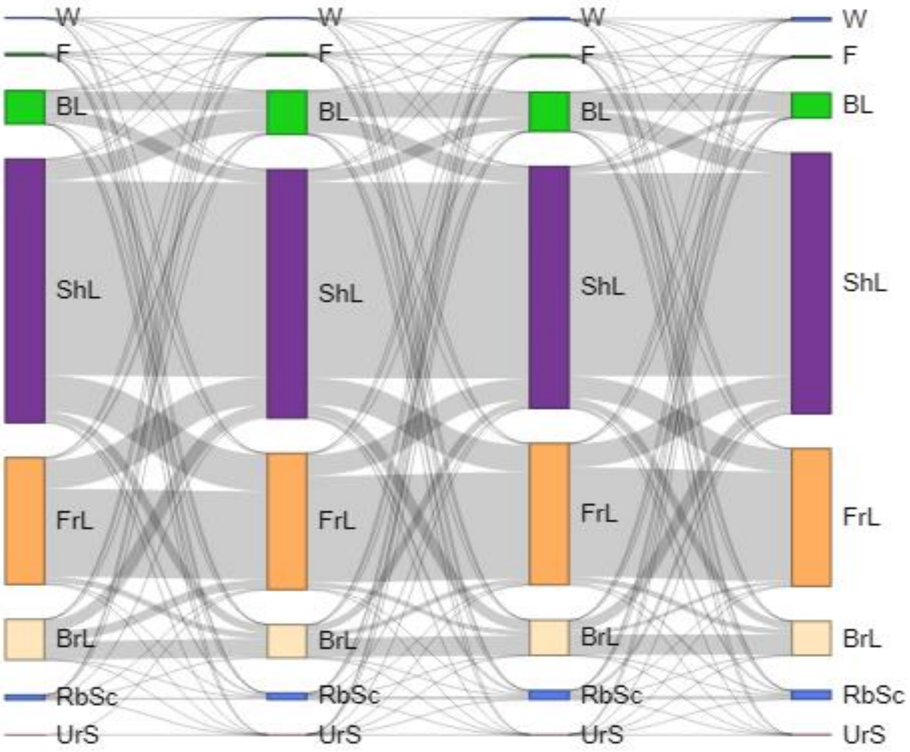


Fig. 3.6 Multi-step LULC transition between 1990 and 2021 in the upper basin of Tekezi River; size of colored bars and transition links are displayed proportionately to area in Km^2. (Note: W = water body, F = forest, BL= bush land, Shl= shrubland, FrL= farmland, BrL= bareland, RbSc= dry river beds and stream channels, and UrS = urban settlements)

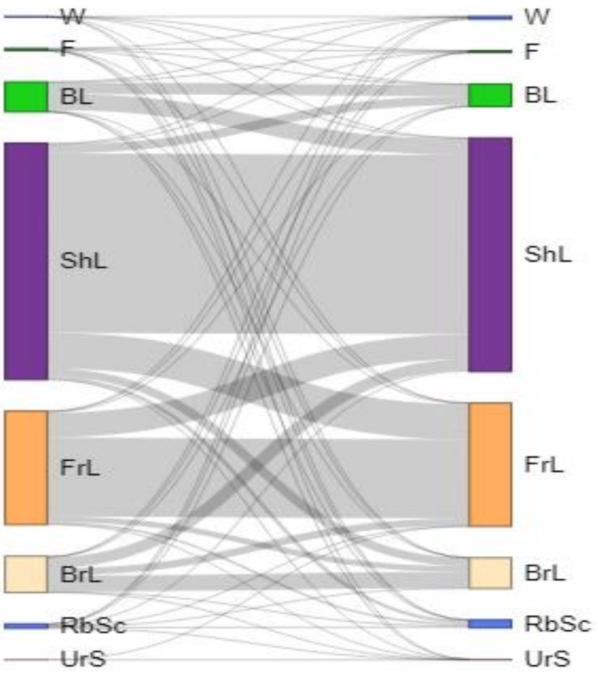


Fig. 3.7 One-step LULC transition from 1990 to 2021 in the upper Tekezi Basin. The left bars represent LULC classes and their proportion in 1990; the right-side bars represent the LULC classes and their proportional size in 2021. Links are displayed proportionately to area in Km^2. (Note: W = water body, F = forest, BL= bushland, Shl= shrubland, FrL= farmland, BrL= bareland, RbSc = dry river beds and stream channels, and UrS = urban settlements)

LULC transition from 2000 to 2010

Water has experienced the most tremendous increase in this period, gaining 1579.11 ha of land. While 19.23% of its cover comes from 2000, 18.41%, 27.63%, and 27.67% were transformed from shrubland, bareland, riverbeds, and stream channels. Forest cover has decreased from 2807 ha to 1935 ha due to the encroachment of shrubs and bushlands. Bush and woodland have gained a net of 3754 ha of land from 2000 to 2010. Almost 2000 ha of the increment come from shrubland. About 400 ha of land was also converted from farmland and forest. During 2000-2010, shrubland and farmland showed the highest stability, in which 79% and 78.45% of the pixels were unchanged. On the other hand, forest, bush, and bare and dry riverbeds have experienced the greatest transition in which only 40, 58.57, 59.22, and 53% of their coverage, respectively, were unchanged from 2000 to 2010. Although there was a bidirectional transition, the transition of pixels of farmland and shrubland to bareland was marked. Similarly, land that was covered by bareland and shrubland have also changed to farmland in this period. The areal coverage of forest has shown a reduction because of the conversion to bush and shrublands. Both conversions to and from stream channels and riverbed were observed during this period. The net increase in the area coverage of this land cover type was primarily due to the conversion of shrub and barelands to stream channels and riverbeds. Unlike the previous study period, urban settlement has considerably increased in this period.

LULC transition from 2010 to 2021

During the final period, water bodies, shrubland, and farmland have shown greatest stability having 88.32, 83.93, and 77.19% unchanged land cover from 2010 to 2021. However, forest cover, bush Land, and bareland have shown the lowest transition possibility having only 46.46 45.68, 57.9% of their 2010's coverage transformed to 2021 coverage. 19034 and 1028.07 ha of bushland have converted to shrubland and farmland in 2021, respectively. On the other hand, much of the forest cover in 2010 has changed to bushland. Shrubland, which has the highest gain in this period, has gained majority of its area coverage from the conversion of bushland, bareland, dry riverbeds, and stream channels. The water accumulation on the Tekeze river channel from the end of 2009 continues to expand up to 2021.The LULC of the upper Tekeze basin has experienced irregular gain and loss, however high intensity of change between the study periods. Fig. 3.8 shows the frequency of change of each pixel in the study time interval and the areal percentage of these frequencies of changes. Almost half of the land in the overall basin experienced LULC change from 1990 to 2021. 51.01% of the basin was unchanged throughout the study period. However, 23.2, 19.7, and 6.1% of the land experienced 1, 2 and 3 times change respectively during the study period.

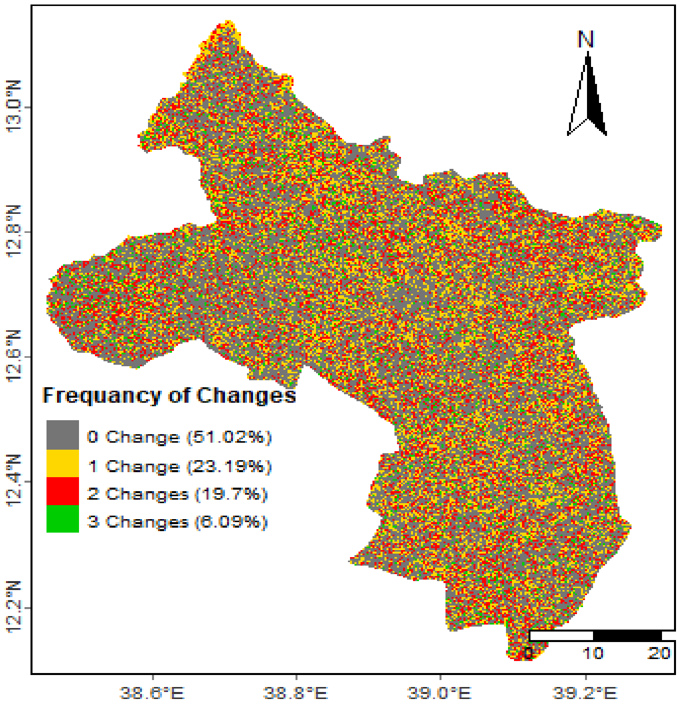


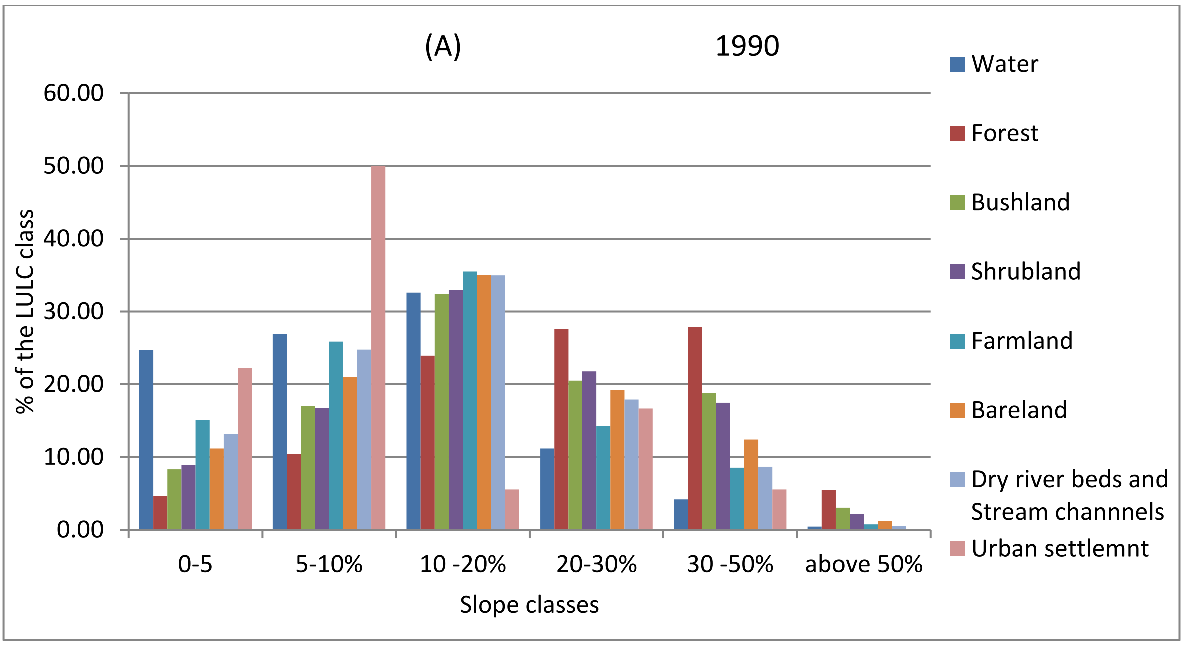
Fig. 3.8. Frequency of changes of pixels from one LULC category to other categories between 1990 to 2021 at three-time intervals (1990-2000, 2000-2010, and 2010-2021) in upper Tekeze basin from

3.3.4. LULC Distributions and Changes along Different Slope Classes and Agro-Ecological Zones

In the study area in 1990, 65.54% of the land cover lay below 20% slope. In addition, 32.66% were between 20% and 50% slope gradients (Fig. 3.9A). Only 1.76 % of the land cover was found above the 50% slope. . In all study periods, more than 26% of the lands cover lies between 20 to 50% slope gradient. A very small proportion of the total land cover, less than (1.76%) was found above the 50% slope. 35% of the farmland lies between the slope classes 10-15.

Regarding the distribution of the different LULC categories across the different slope gradients, Fig. 3.9 shows the percentage of the total land cover of each class that lies on each slope class. Looking at the recent LULC distribution among different slope classes, the forest was distributed throughout all slope gradients. Almost the gentle and higher slope gradients were nearly equal in forest coverage (Fig. 3.9B).

Farmland was distributed across all the slope classes. Only 15% of the farmland was found below 5% slope. While 60% of the total farmland is found between 5 and 20% slope, there is still a significant proportion of farmland (14.47%) between 20 and 30% slope gradient. The study area has long history of crop cultivation where most of the cultivable land is already occupied by croplands. Recent expansion of farmlands is on high slope areas where critical care is needed in order to protect SWC. Similar trend, increased cultivation of steep slopes has been observed in other part of Ethiopia (Etefa et al., 2018). In this agro ecology, the farmland lies in high slope classes. This aggravates land degradation through water erosion processes and washed away of soil nutrients. The highland agroecology which most of its part is distributed across high slope gradient and elevation constitute Dega agroecology. This agroecology is good at agricultural production. Particularly legumes plants, wheat, and barley are produced on fragmented plots. This high slope area cultivation in this zone requires continuous efforts to conserve soil and water so that the productivity will sustain to the future. Although we have found forests, bushes, and shrubs fairly distributed from the lower to the higher slope, their proportion is considerably high on the higher slope gradient. Forest, bush, and shrub percentage on the extremely high slop area (i.e., above 50%) is 4.4%, 2.57 %, and 2.36 %, respectively. This may be due to the growth of vegetation in areas with less human intervention.



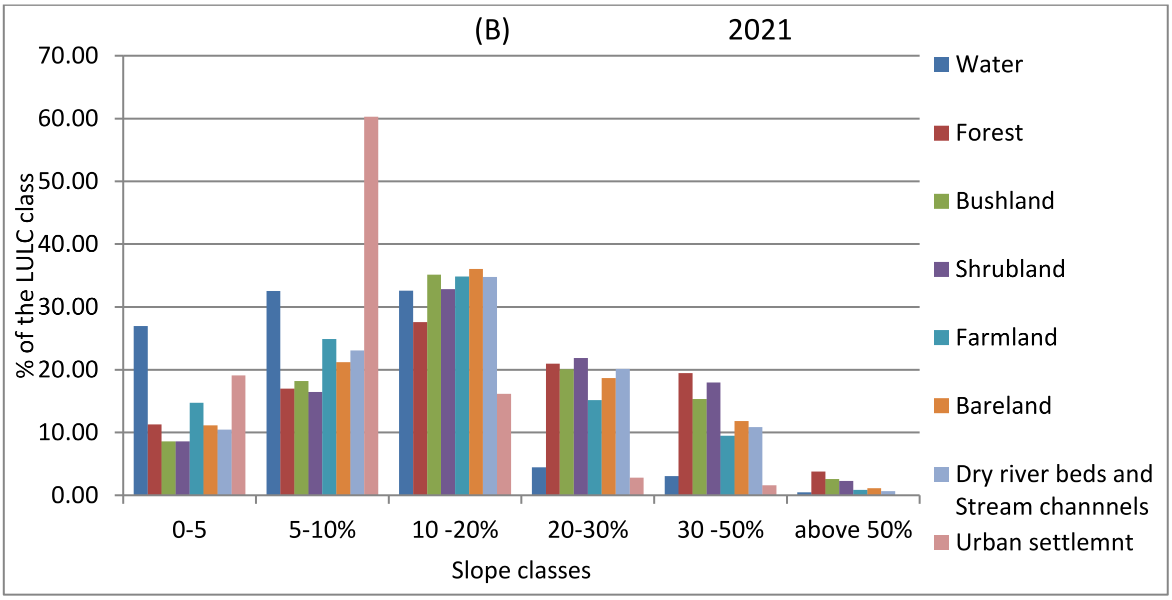


Fig. 3.9. Distribution LULC types across different slope gradients in upper Tekeze basin in 1990 (A) and 2021 (B)

Land use is the primary driver of land degradation, when compared with soil type, terrain, or climatic factors. The general pattern of LULC change shows that the study area is either degraded or vulnerable to degradation. In addition to this, the trend of LULC change indicates no sign of improvement in vegetation cover. The observed increase in farmland, stream channels and riverbeds; conversion of bushland to shrubs and bareland; and decrease in forest cover are an indication of land degradation in the study area. For instance, as farmland land was expanded at the expense of other land use and land cover units, bush and forestland declined, increasing the vulnerable area to soil erosion. The increase in dry riverbeds and stream channels is also at the expense of shrubland. The increase in dry riverbeds and stream channels alone is an indication of degraded land. The combined effect of erratic rainfall, poor vegetation cover, and high human and livestock population pressure on land resources may have contributed to an increase in dry riverbeds, stream channels, and further expansion of bareland.

From the agro-ecological perspective, the high and mid-altitude are better in terms of forest and bushland distribution. Bareland and dry riverbeds are less available in this agro-ecological zone. For example, Gazigibla District, whose major part lies on mid and high latitudes, holds 65.2, 44.87, 54.42, and 49.8% of the total forest coverage in 1990, 2000, 2010, and 2021. The lowland part of the study area, which is also semi-arid and arid climate, was found to be more vulnerable to land degradation due to its LULC status. The finding showed that this part of the agro-ecological zone has greater area coverage of bareland, riverbeds and stream channels. Due to this and a steep slope and ridged topography, the majority of the land is vulnerable to soil erosion. For instance, the lowland part of the study area, Zquala district, has shown significant degradation as expressed in vegetation cover and expanded bareland. Riverbeds and stream channels are also abundant, which are indications of gully formation.

3.3.5. Implication of the LULC Dynamics to the Management of Land Degradation in the Study Area

Land cover is one of the factors that determine the rate and status of land degradation (Birhan Asmame & Assefa Abegaz, 2017). Reduction in vegetation cover is the major cause of soil erosion particularly in mountainous ecosystem. After vegetation cover is removed, factors such as the steepness, length, and shape of a slope become important accelerator of erosion (Hurni et al., 2010). This process increased sheet, rill, and gully erosions by reducing the protection of soil cover. This study identifies land use transition from and to vegetation cover to assess the degradation level and trend. The vegetation cover at the base year (1990) was minimal; particularly forest was only 0.47% of the total basin and bushland also was 7.5% of the basin in 1990. This indicates that the LULC of the study area was already degraded and was potentially exposed to soil erosion. Shrubland that covers 56% of the study area is characterised by very spare small tress and bush, the ground consist of exposed rock and soil. The land covered by this LULC category is also prone to soil erosion. Considering the topographic and LULC diversity of the basin, dense bushes and forest are helpful for erosion management and reduction of land degradation. The study assessed the level of afforestation or reforestation, and forest conservation: by studying persistence of or change to vegetation from 1990 to 2021. Conversion of forest, bush land, and shrubland to other LULC types (urban settlements, bareland, riverbed and stream channel, farmland) was identified as vegetation degradation while the reverse change is gain of vegetation. Fig. 3.10 shows the distribution of vegetation gain and loss, persistence of farmland and shrub from 1990 to 2021.

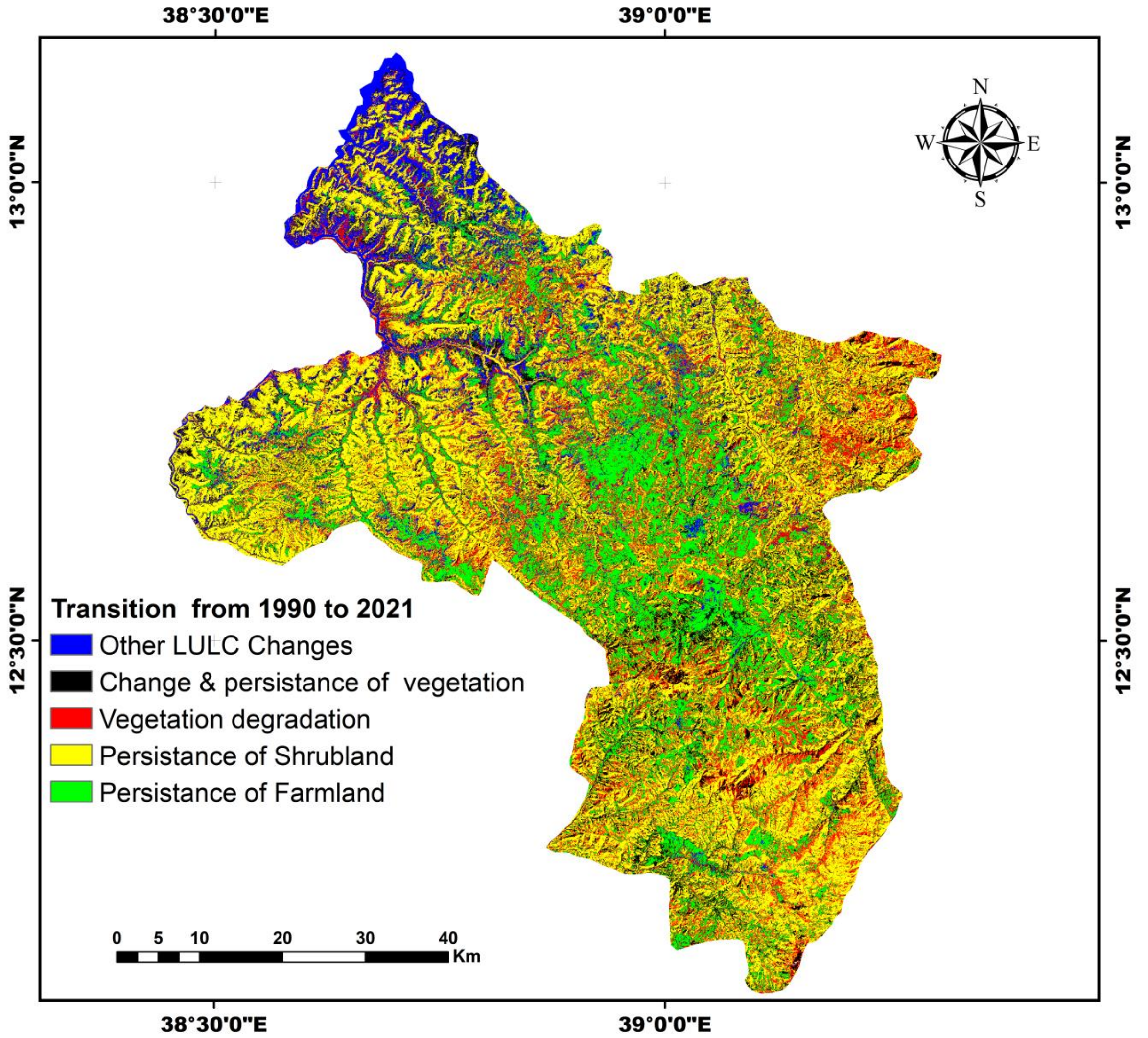


Fig. 3.10. Changes/conversion to and persistence of LULC in the upper Tekeze basin from 1990 to 2021

The overall trend observed in the study area is the decline of forest cover, bushland, and shrub and an increase in farmland (including rural settlement), dry riverbeds and stream channels, and urban settlement. Even forestland was and is very small in area coverage; no afforestation or reforestation through plantation is observed over the study period (Fig. 3.10). Bushland has decreased, but was increasing from 2000 to 2010 due to area closure introduction; however, it has decreased from 2010 to 2021. Bareland has changed to farmland, shrub; and washed away by flooding, continuously changed to dry riverbeds and stream channels. This LULC types are highly susceptible for erosion. Moreover, slope, elevation, and high surface temperature aggravate the rate of soil degradation. Previous studies showed that in Ethiopian mountains, soil degradation due to water erosion is a major threat to agricultural production (Hurni et al., 2010). The observed expansion of dry stream channels is an indication and aggravating factor of soil erosion.

A Land cover change interacts with hydrological cycle. Infiltration, runoff production and soil erosion are determined by the nature of ground cover. Low level of vegetation cover and expansion of barelands area responsible for high surface runoff and hence soil erosion. The observed LULC dynamic of the basin showed that there is poor vegetation cover, extensive land of barelands. Furthermore, there is increased areal extent of dry riverbeds and stream channels that are the results of high surface erosion during intense rainfall. Particularly in the ridged topography of the northern part of the basin, there is expansion of increased dry river stream channels. Along the course of these valleys there are many springs that emanate along the contacts of the different rock (Hagos et al., 2015) as they drawn down ward to the lower part of the basin, they have developed wide flood plain and eroded bare grounds, and expanding dry river beds. Due to low retention capacity of the soil, low vegetation cover, and steep slope, the erratic rainfall has produced wide and many irregular dry streams. These many stream channels bring flow to the farmlands on the hillside and lowland areas, destroying vegetation, and crops during rainy season.

In addition, the constructed hydroelectric dam has changed the hydrological regime of the basin by increasing water at the back of the dam as well as by widening the Tekeze river channel. The sideways of the river has been washed away, shrubs have been reduced and bare, and dry riverbeds have expanded. In the same basin, Welde and Gebremariam (2017), reported that the mean annual stream flow and annual sediment yield of the Tekeze dam watershed shows an increase in average annual stream flow. Similarly, sediment yield change shows an increment. Implementation of SWC measures, construction of hydropower dam and micro-dams for irrigation are predominantly found in the Upper catchments. The land use dynamics observed in the study area would have clear effect on the erosion rate, sediment yield, and expansion of many irregular dry riverbeds and stream channels. This has an implication to the managements of land degradation in the basin, requiring integrative effort to manage the land change system in the way it benefits the soil and hydrological regimes.

3.4. Discussion

The LULC change studies provide useful information for a better understanding of previous practices, current LULC patterns, and future LULC trajectory (Hussain & Karuppannan, 2023). A change in LULC is one of the major causes of changes in the Earth's system functioning (Seifu et al., 2023). The expansion of agricultural land, for example, happen at the expense of shrub and other vegetated lands, which finally causes soil erosion, sedimentation, and loss of biodiversity. Land cover changes are usually caused by human activity such as urbanization, agricultural expansion, and deforestation. This study shows the LULC changes dynamics in the Upper basin of Tekeze in Waghimra Zone of Northern Ethiopia for the last three decades. Advanced techniques of LULC classification aided by GEE cloud computing platform and RF algorithm was used to study the LULC dynamics of the study area. The methods applied produced an excellent overall accuracy and kappa coefficient. The overall accuracies are 0.83, 0.86, 0.88, 0.88 with Kappa coefficients of 0.75, 0.79, 0.83 0.82 for 1990, 2000, 2010, and 2021 classified images respectively. The overall accuracy and kappa coefficient of this study is comparable with (Abebe et al., 2022; Feng et al., 2022).

The finding of this study shows that there is a decline in vegetation cover and no marked improvement in forest cover and other vegetation as expected following the continuous land management programs. This finding is in line with (Mekonnen et al., 2018; Moisa et al., 2022; Shiferaw et al., 2019; Tesfaye et al., 2014; Wakjira et al., 2020) who reported a substantial decrease of forest cover, grasslands, and bush-shrub-woodland. However, the finding is against reports by (Seifu et al., 2023) who reported increase in woody savannas, deciduous broadleaf, grasslands, permanent wetlands, and mixed forest areas and reductions in croplands, water bodies in Baro-Akobo River Basin of Western Ethiopia. Similarly, in recent LULC dynamics of Blue Nile River, increment in plantation has observed in North Gojam sub basin (Ewunetu et al., 2021). However, in this study, no significant increment was observed in plantation such as eucalyptus tree.

In the same basin, Nyssen et al. (2009) reported an increase in vegetation cover in the Bella-Woleh watershed in Waghimra zone. Because our study covers a large areal extent and was not limited to a single watershed, the finding is not comparable with this study. However, Welde and Gebremariam, (2017) reported a reduction of shrubland and grassland due to the expansion of the agricultural practice in the area in the same basin. In another part of Ethiopia, but with the similar environmental conditions, (Shiferaw et al., 2019) reported a decrease in bush-shrub-woodland and natural forests in Afar Region. In the Blue Nile basin, Gashaw et al. (2017) reported decreased coverage of shrub andbush LULC for 30 years (1985-2015). Similar decreasing trends were reported by Dinka and Chaka, (2019) and Minta et al. (2018). The continuous decline of forest, shrub, woodland cover was primarily due to the expansion of the urban built-up area and cultivated and rural settlement areas. The decrease in shrub/bushland use and land cover implies that the land is vulnerable to soil erosion and flooding, affecting farmland productivity in the areas. Despite the loss of vegetation cover in the study area, the areal extent of conversion to bareland was not found to be a marked finding. Nevertheless, there was a decline in bareland cover due to conversion to farmland, riverbeds, and stream channels. Unlike other studies such as Ewunetu et al., (2021) and Birhan & Assefa , (2017) water body has expanded in the study area during the recent decades of the study period. Surface water accumulation has increased along the river channel of the Tekeze River, particularly at the back of the Tekeze hydroelectric power dam. This increment has positive implication for the surrounding ecosystem and livelihood of communities residing in the study area.

The pattern of temporal LULC changes was highly complex, with a multidirectional transition from one LULC to the other. It does not have a clear trend except the overall transition towards the LULC categories that have gained from decade to decade and throughout the study period. Due to climatological effects, LULC has undergone a series of transitions, for example, from farmland to eroded/flooded bareland, from bareland to dry stream channels and riverbeds, and to flooded, sandy shrubland. The probability of transitions to forestland and bushland was very low from decade to decade. Instead, a higher probability of transitions was recorded from all land use types to farmland, shrubland, bareland, and dry riverbeds and stream channels.

All the changes observed in the study area showed that there is unhindered land degradation as manifested by the decline of the existing forest cover and no sign of afforestation. Furthermore, the degradation of bushes and shrubs, expansion of dry stream channels, and barelands are causes and an indication of degradation. Many studies have shown that surface erosion is minimal in areas where the soil is covered by vegetation (Dinka & Chaka, 2019).

What is specific to this study is that the expansion of farmland is less pronounced than other studies such as Mekonnen et al. (2018) and Moisa et al. (2022). Farmland has increased only by 8.70 from 1990 to 2021; there was a slow transition of other land cover types to farmland every decade. The possible reason is that almost no land was left for further expansion. Topographic, hydro-climatic and soil degradation are challenges to farmland expansion as well as crop production. However, the recorded increase in cultivated land was at the expense bush and shrubland. This aggravates the vulnerability of soil to erosion.

LULC driving factors in Ethiopia includes demographic, socio-economic and institutional factors (Etefa et al., 2018). Like the rest of Ethiopian basins, these factors apply to upper Tekeze basin. Nevertheless, physical and climatic elements that trigger significant LULC (Lambin et al., 2001) are among the driving forces in the arid and semi arid land of upper Tekeze Basin. As observed in the LULC change across agro ecologies, the drier and rigid topography of the lower basin was hotspots of vegetation degradation and hence is susceptible for soil erosion by water. This study demonstrated that although there is not significant farmland expansion, urban and infrastructural induced LULC change in this marginal arid and semi arid basin, topographic; agro ecological and climatic factors such as aridity and frequent drought could cause land cover change and challenge land degradation management.

Although many implications to land degradation can be associated and discussed based on the observed LULC change magnitude and direction, future research should focus on understanding of the impact of LULC change on the water resources, ecosystem productivity and then livelihood security in the study area.

3.5. Conclusion

This study focused on the status and trends of LULC changes in the semi-arid and arid land catchment of Tekeze River in Waghemra Administrative zone of Amhara region, Ethiopia. LULC classification was performed using RF algorithm on GEE computing platform based on sample datasets with sufficient auxiliary data. The methodology combined seven axillary data and took the fast processing and variable controlling ability of both GEE and RF classification algorithm. Although the landscape of the study area is so complex and hence hinders accurate identification of pixels of different land cover, the classification accuracies and visual inspection of classified images ensured that the RF classifier yielded consistent and accurate maps for the study area.

The study demonstrates that the arid and semi arid land of upper Tekeze basin in Waghimar Adminstrative zone has experienced land use/land cover change over the last thirty-one years. The finding revealed that the water body has expanded 4.8 times from its 1990 coverage by increasing on average 81.17 ha every year 1900 to 2021. The expansion of water body was primarily due to the accumulation of water behind Tekeze hydroelectric dam. Forest increased by 7.36% in the first 10-year interval and decreased by 17.37 and 0.98% in the next two decades from 2000 to 2021. Bushland has shown continuous increment during the first decade (from 1990 to 2000) by about 30.74% and decreased by 9.64 and 36.34% from 2000 to 2010 and 2010 to 2021 respectively. The study revealed that most of vegetation degradation was happened during from 2000 to 2021 despite the installation of conservation and restoration government policies. Positive vegetation changes were limited in small pocket area exclosure and managed watersheds. Overall, throughout the whole study period, 2435.04, 10647.44, 3825.67 44, and 444.27 ha net gain was recorded on water bodies, shrubland, dry riverbeds and stream channels, respectively. Water body has per year from 1990 to 2021. Dry riverbeds and stream channels, and farmland have increased by 82.14 and 8.64% respectively during the same period. On the other hand, 8028.69, 6056.25, 3043.15, and 265.12 ha loss was recorded on bushland and, bareland, shrubland, and forest cover, respectively.

The study area's Woynadega and Dega agro-ecological districts are better regarding vegetation cover. Furthermore, bareland and dry riverbed are less available in these agro-ecological zones. The finding showed that this part of the agroecological zone has greater area coverage of bareland, riverbeds, and stream channels. However, the semi-arid and arid low land part of the study area was found to be more vulnerable to land degradation because of its LULC status. Combined with a steep slope and ridged topography, the majority of the land is vulnerable to land degradation particularly to soil erosion. For instance, the lowland (*Kolla* agroeoclogy) part of the study area has shown remarkable degradation expressed by the increment of bareland, riverbeds and stream channels. Furthermore, the areal coverage of forest and bushland is minimal compared with the Dega and Weyna-dega agroeology and upper part of the basin.

The general trend observed in the study area is the decline of forest cover, bushland, and shrub and an increase in farmland and rural settlement, dry riverbeds and stream channels, and urban settlement. Forestland was and is very small in area coverage; no afforestation or reforestation through plantation is observed over the study period. Shrubland in the basin is characterised as sparse, short shrubs, over sandy, rocky landscape. Coupled with to the steep slope, rigid topography, and high surface aridity, observed LULC change aggravates soil erosion, biodiversity loss and disturbance of hydro climatological balance in particular and land degradation in general in the study area.

Results from this study provide an important input to decision makers in their effort towards sustainable land use planning and management. The study highlights the need for implementation of sustainable LULC practices such as large-scale reforestation, area exclosure, and prevention of bareland through restoration of degraded areas, conservation of forest and bushland, and limiting the expansion of cultivation areas in high slope regions. Despite being one of the most severe hotspots of land degradation due to its history of significant degradation and drought, the land restoration programs initiated decades ago have not significantly influenced the LULC dynamics. Therefore, it is crucial to evaluate the past restoration approaches and adopt new policy frameworks towards SLM. In general, the study suggests that urgent measures must be taken to mitigate the observed land degradation by avoiding the future conversion of forest, bushland, and shrubland to farmland while scaling up SLM, reforestation, and afforestation practices on degraded and vulnerable areas.

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CHAPTER FOUR

MONITORING SPATIO-TEMPORAL DROUGHT DYNAMICS USING MULTIPLE INDICES IN THE DRY LAND OF THE UPPER TEKEZE BASIN, ETHIOPIA[3]

Abstract

Due to Ethiopia's broad variations in biophysical and climatic variables, an accurate understanding of local-level drought is critical for sustainable drought risk management. This study aims to monitor spatio-temporal drought dynamics over Tekeze basin from 1981–2021 using Standard Precipitation Index (SPI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation health Index (VHI). The analysis relied on data from Moderate Resolution Imaging Spectroradiometer (MODIS) datasets and CHIRPS-v2. Google Earth Engine (GEE) was used to obtain data, process NDVI trends, and calculate drought indices (DI). Man-Kendall trend analysis and Pearson correlation were also employed to examine the trend and association of DI and climate variables. The SPI showed that the basin was affected by moderate, severe, and extreme drought in 1984, 1985, 1987, 1993, 1997, and 2015. TCI and, VCI, analysis indicated that 2002, 2004, 2009, 2015, 2016, and 2017 were severe and extreme droughts. The NDVI showed a decreasing trend throughout most of the basin, except for pocket areas of the managed watershed, area closures, and irrigation sites. Rainfall in July emerged as a critical factor in determining NDVI, LST, TCI, and VCI in July and August. While VCI strongly correlates with precipitation and LST is less correlated. Although all DIs are robust in assessing agricultural droughts, VCI detected more land areas under severe and extreme drought than TCI. The study underscores the importance of larger weights to VCI in correctly classifying drought, particularly in drylands where precipitation is crucial in determining vegetation health

Keywords: Drought monitoring, MODIS drought indices, VHI, Temperature Condition Index; Tekeze basin; Waghimra; Ethiopia

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4.1. Introduction

Drought is a recurring natural phenomenon caused by a decrease in rainfall below its long-term average (Mishra & Singh, 2010; Patel & Yadav, 2015; Schneider, 1996). It affects agricultural output and results in a drinking water shortage for people and livestock, leading to food shortages, migration, and loss of life (Hermans & Garbe, 2019; Kogan & Guo, 2016). Some of the most severe droughts of the twenty-first century occurred in the US, Australia, and the Horn of Africa led to substantial damage to agricultural production and food insecurity (Kogan & Guo, 2016). Drought can be broadly divided into four categories, according to Mishra and Singh (2010) and Wilhite and Glantz (1985): meteorological, agricultural, hydrological, and socio-economic. The length of the dry period (1-2 months) and degree of dryness relative to the average value are used to define meteorological drought. A meteorological drought with crops and soil characteristics over one to six months is referred to as an agricultural drought. Hydrological drought is a situation where there is insufficient water in streams, reservoirs, and groundwater over six to forty-eight months or longer.

According to studies, up to 6 and 16% of the world's land was affected by extreme to severe droughts, respectively (Kogan & Guo, 2016; Kogan, 1995). Between 1960 and 2006, 25% of natural disasters in Africa were caused by drought (Gautam, 2006). Between 1960 and 2016 in Africa, there were 289 recorded droughts, over 414 million people affected, and nearly 700,000 deaths (Centre for Research on the Epidemiology of Disasters/CRED 2016; Mekonen et al., 2020). Droughts are common in Sub-Saharan Africa (Hermans & Garbe, 2019; Kotir, 2011) and have become more common in East Africa due to global warming (Nooni et al., 2021). Drought threatens food security in this region (Shiferaw et al., 2014). Drought effects have a greater impact in this region due to extreme rural poverty and political as well as economic instabilities (Dercon et al., 2005; Gray & Mueller, 2011; Hermans & Garbe, 2019; Butterfield, 2011; Richman et al., 2016).

Ethiopia frequently experiences droughts (Mekonen et al., 2020; Negasa et al., 2022). The magnitude, frequency, and severity of drought greatly vary with respect to the biophysical variations. However, the national drought frequency has increased from decade to decade. One of the worst droughts that hit the nation in more than 50 years was the one that occurred in 2015 (Roop et al., 2016). One in ten people was food insecure due to severe crop failures from rainfall deficits up to 50% below average (FAO, 2016). Previous research has shown that most Ethiopian rural households experience food insecurity during drought periods due to their rainfall-dependent agricultural production (Hermans & Garbe, 2019).

Many drought studies have been conducted in Ethiopia (Bayissa et al., 2018; Bayissa et al., 2019; Bisrat & Berhanu, 2019; Gebrehiwot et al., 2011; Temam et al., 2019; Teshome & Zhang, 2019; Viste et al., 2013; Wolde-Georgis, 1997; Zeleke et al., 2017). Most of these previous studies on monitoring agricultural droughts in Ethiopia focus on the national level (Measho et al., 2019). Due to greater altitudinal range, extreme topographic variations, diverse agro-ecology, and climatic conditions, local-scale analysis of spatial and temporal drought magnitude and frequency are critical for drought monitoring and early warning. It is worth noting that the droughts that have taken place in Ethiopia in the past have not been uniformly severe, frequent, or widespread across the country. Instead, most were more localized or regional (Viste et al., 2013). In which season the drought occurred also poses a question of which part of the country is most affected. The southern and southeastern lowlands experience the rainy season during spring, while the northern and northwest regions experience it during summer (June-September). The spring rains are crucial for spring crops, which contribute up to 15% of the national food crop, as well as for planting long-season crops that are harvested between September and December (Degefu, 1987; Funketal. 2003; McCann, 1990; Zeleke et al., 2017). However, in the northern highlands, most of the annual precipitation falls in July and August (Viste et al., 2013). In addition to the climatic variations, the existing high variation of surface and groundwater availability, infrastructural development, and level of vulnerability of communities, require more emphasis on local-level and context-specific assessment of drought. This study is conducted in the less favored, marginal Wag-himra administrative zone, where all the lands lie in the Tekeze basin. Almost all drought years that Ethiopia experienced affected the study area (Bayissa et al., 2018; Mera, 2018; Wolde-Georgis, 1997). However, this is the only local-level drought study that integrating VCI and TCI conducted in this part of Tekeze basin to model the spatial and temporal variation of agricultural and meteorological drought.

Over the past decades, numerous remote sensing vegetation and thermal-based DI have been widely applied for detecting and monitoring regional and global meteorological droughts (Bai et al., 2012; Gu et al., 2007; Kogan, 1995; Sheng et al., 2017; Son et al., 2012; Wang et al., 2018). Among these MODIS-derived DI, the VCI, TCI, and VHI are recommended by World Meteorological Organization (WMO) as global to local DI (Xie & Fan, 2021). The VHI, which combines VCI and TCI, is one of the most popular satellite-based indices used for drought assessment (Li et al., 2020; Bento et al., 2020).

Methodologically, most drought studies in Ethiopia have applied SPI for drought analysis (Bisrat & Berhanu, 2019; Lelamo et al., 2022; Temam et al., 2019; Tefera et al., 2019 Zeleke et al., 2017). Due to the challenges of relying solely on SPI in detecting drought, RS is a popular drought assessment for its capability of identifying droughts (Liang et al., 2017; Wuet al., 2019; Zeng et al., 2022). Only a few studies (Chere et al., 2022; Gebrehiwot et al., 2011 and Wassie et al., 2022), have used a combination of SPI and RS-based DI in Northern Ethiopia. Despite the contribution of these studies to the literature and understanding of drought conditions in Ethiopia, there are still gaps to be filled by further studies. Studies incorporating TCI and VCI in their methodology assume that temperature and rainfall determine vegetation health equally. The contributions of the VCI and the TCI to the VHI are similar due to the absence of empirical data on the contributions of vegetation and temperature to vegetation health (Bento et al., 2020; Kogan, 1997 and Zeng et al., 2022). However, some evidence indicates that the contribution of VCI and TCI is not equal in all climate and vegetation types (Bento et al., 2020). For instance, dry land crops and vegetation are more sensitive to rainfall stress than temperature increments leading to VHI persistently dominated by VCI (Bento et al., 2020). In contrast, temperature factors dominate when detecting vegetation drought in polar regions (Zeng et al., 2022). This study examines the role of TCI and VCI in detecting different drought conditions and finally applies the α value suggested by Bento et al. (2020) to estimate VHI. This study aims to assess drought's spatial and temporal variations over the upper Tekeze basin in Waghemra zone by applying the SPI, VCI, TCI, and VHI. Specifically, the study aims to; 1) Analyse the magnitude and frequency of agricultural drought using VCI, TCI, and VHI. 2) Analyse historical time series trends of vegetation cover. 3) Examine the spatial and temporal pattern of meteorological drought using SPI. 4) Examine the role of TCI and VCI in detecting different drought grades and suggest the possible share of TCI and VCI in estimating VHI.

4.2. Material and Methods

4.2.1. Study Area Description

The study is conducted on the upper Tekeze basin in Wag-himra administrative zone of Amhara Region, Ethiopia. It is located between 38° 15’ 0”E to 39° 15 0 E and 12° 25 0”N to 13° 250 N. Based on the 2007 Ethiopian census, this zone had a total population of 426,213, with an area of 9,039.04Km^2.

The district's elevation ranges from 989 to 4043m above sea level. The area is characterized by undulated topography with severe land degradation. The slope of the area ranges from flat plains (<2%) to very steep escarpment (>50%). The average slope of the zone is 19.17%. Based on the elevation, the zone has three different climatic divisions (zones). These climatic zones are the *Kolla* (Tropical zone, elevation < 1830 m), Woina Dega (subtropical zone, elevation ranges between 1830-2440 m), and Dega (cool zone, elevation >2440).

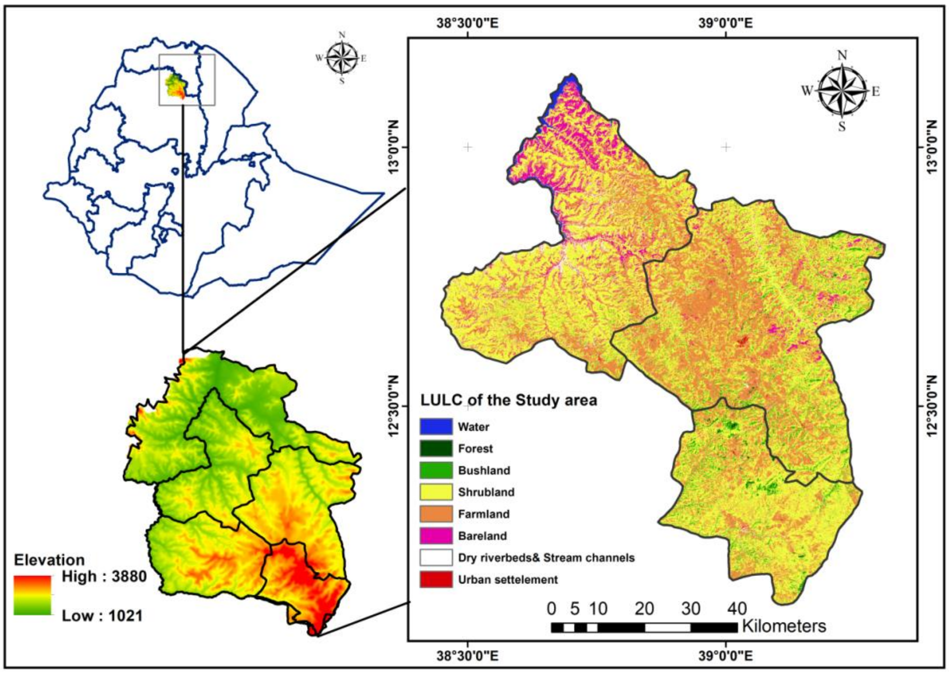

Fig. 4.1 Location of the study area: a) in Ethiopia, b) in Waghimra Adminstrative Zone c) studied sub-basin showing LULC

The study area receives much of its annual rainfall in the Ethiopian main rainy season (June–September), locally known as “*Kiremt*”". This season contributes more than 70% of the annual precipitation in north and northwest Ethiopia, including in Waghimra zone. In almost all parts of Tekeze basin, the *Kiremt* rain ceases around the end of August (Bisrat & Berhanu, 2019). Unimodal and erratic rainfall patterns characterize rainfall in Waghimra zone. The mid and high-altitude areas receive rainfall from late June to early September. The rainfall distribution of the lowland part of the area extends from early July to mid of August. The primary crop production system is based on the summer season. About 63 % of the annual rainfall is in July and August. At the beginning of the rainy season, June, only 6.57 % of the annual rain falls. The area's minimum and maximum annual temperatures are 12.8 ^{o}C and 28^{o}C, respectively (Wubet et al., 2020).

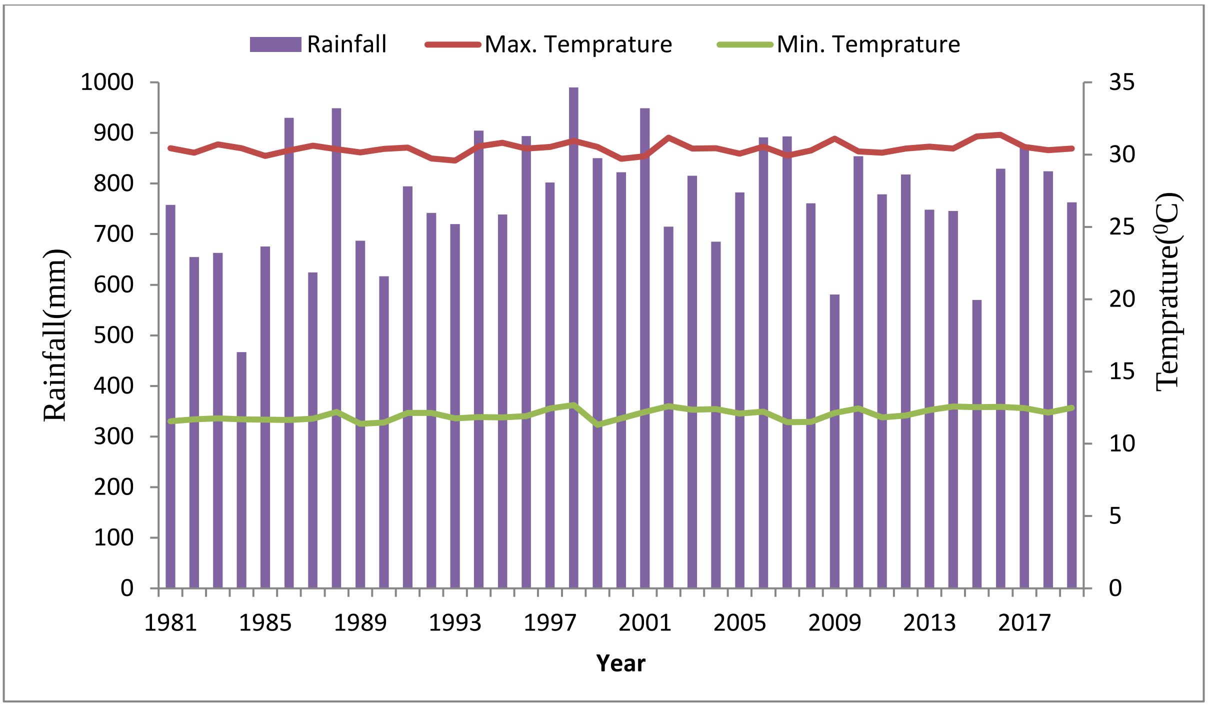

Fig. 4.2 Annual rainfall, minimum and maximum temperature time series of the study area from 1981 to 2021 (derived from monthly CHIRPS-v.2)

Most of the study area is semi-arid and arid according to the United Nations Environment Programme (UNEP) aridity classification. While the northern and northeastern part of the basin is dry sub-humid and non-dryland, the central and northern holds semi-arid and arid land characteristics. Fig. 4.3 shows the spatial distribution of aridity over the study area as calculated for the years 2011 to 2020.

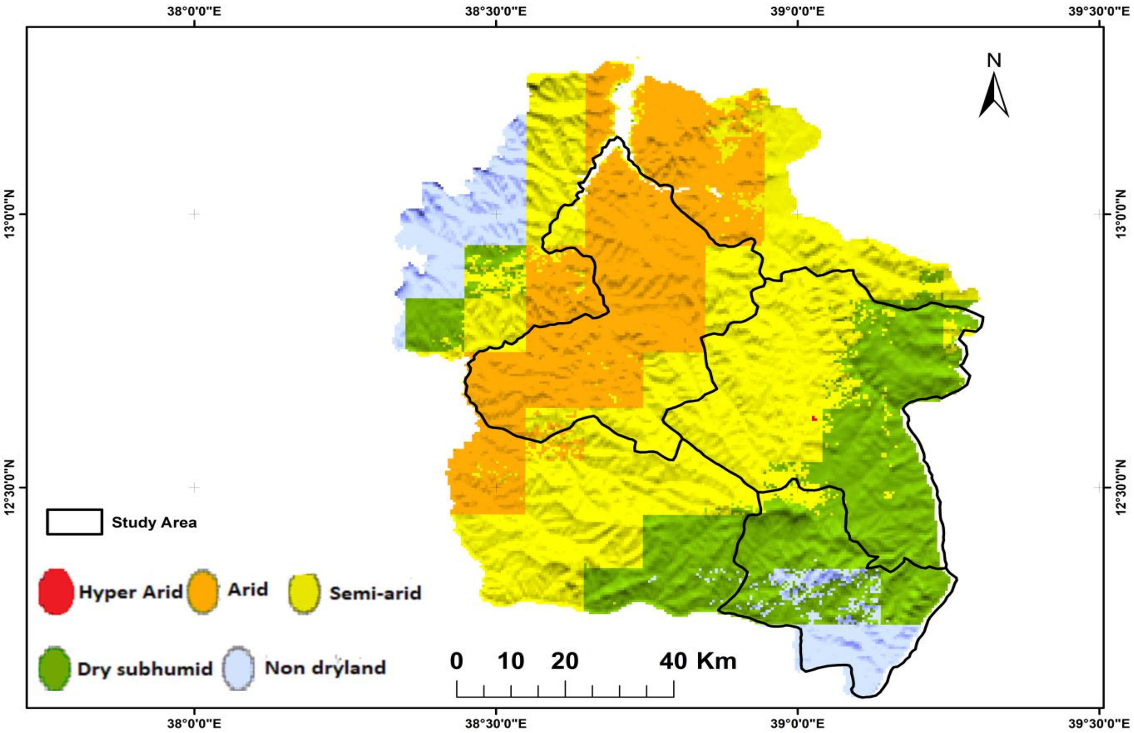

Fig. 4.3 The spatial distribution of aridity over Tekeze Basin in Waghimra zone as calculated for the years 2011 to 2020 (Source: https://earthmap.org).

Over 90 percent of households throughout the Wag-himra Zone live on smallholder farming with landholdings of less than one hectare. The agricultural activities are rain-fed, with the main harvest from September to November. Farmers produce mainly cereals (sorghum, teff, barley, and wheat), pulses, and vegetables. The region is characterized by severe land degradation, climate variability, and high population density (Rosell & Holmer, 2007; Hermans-Neumann et al., 2017). The zone has been one of the most drought-affected areas in the past. High vulnerability to drought and famine, growing population pressure, and land degradation have reduced agricultural production. People residing in the study area are frequently in immediate need of food assistance. Seasonal migration t has been a common livelihood for the poorest in Waghimra zone.

4.2.2. Data Used

CHIRPS is used for rainfall analysis, has been suggested for its good applicability over the Horn of Africa, and has been validated in Ethiopia by Dinku et al. (2018). Moreover, in stationed based data scarce areas such as in Ethiopia CHIRPS-v.2 has good applicabilty in drought studies (Mariano et al., 2018). CHIRPS precipitation at 8-day temporal resolution and 1 km spatial resolution was obtained from GEE for 41 years (1981 to 2021). This datasets were used to derive SPI-1, SPI-3. MODIS Terra 16-days NDVI and EVI composite of 250m resolution (MOD13Q1) for 22 years (2000 to 2021) was used to develop monthly NDVI and EVI time series. This dataset was also used to derive NDVI and VCI time series. Before computing DI, pixel reliability band 'SummaryQA' flags of MOD13Q1 and 'QC_day' flags of MOD11A2 were used to remove cloudy pixels. The monthly, seasonal, and yearly DI were composited by using 16-day index. The DI was calculated for the main growing season (*Kiremt*). From July-September (Julian dates of 183 to 273. MODIS/061/MOD11A2 LST data was used to obtain the LST value in the Kelvin unit. This data was obtained from the GEE platform at a spatial resolution of 1 km from 2000 to 2021. The LST values were rescaled by 0.02 and converted into degree Celsius (°C).

4.2.3. Methods of Data Processing and Analysis

Rainfall, LST, and NDVI data were accessed through GEE platform. Image filtering, cloud masking, computation of VCI, and TCI, NDVI trend analysis were processed in GEE API. Then, we used the R open-source (R- 4.2.2) statistical software platform (R Core Team, 2019) to generate the VCI, TCI, time series maps. In addition, the SPEI package in the R software platform was used to analyze the SPI index. The general schematic presentation of the methods and procedure has been presented on Fig. 4.4.

Pearson Correlation and Non-parametric trend analysis

The Pearson correlation coefficient was applied to examine the correlation between NDVI, TCI, and SPI, with LST and rainfall.

Using the NDVI time series from 2000 to 2021, we computed vegetation greeness trends based on the Mann-Kendall (MK) non-parametric test. The year 2000 was selected as starting year for the NDVI analysis to align with the drought indices based on MODIS data. The non-parametric test is an approach to examine trends in time series data by estimating the rate of change in vegetation greenness for each pixel. This approach is reliable and is being used to analyze climatological datasets. MK coefficient ranges from −1 to +1, with values greater than 0 indicating an increasing trend and less than 0 indicating a decrease (Akinyemi, 2021; Neeti & Eastman, 2011). MK method is a covenant in the case of a trend of the time series on data that does not obey a specific distribution. MK has been widely used in meteorological fields (Liang et al., 2021; Luo et al., 2020; Wu et al., 2020), and it is resilient to outliers, non-normality, missing values, and seasonality (Liou & Mulualem, 2019).

The non-parametric MK test detects monotonic trends in environmental, climate, or hydrological data. The MK test is calculated according to (Kendall, 1975);

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(X_j - X_k\right) \tag{4.1}$$

and

$$sgnX = \begin{cases} 1\ if\ x > 0 \\ 0\ if x = 0 \\ -1\ if\ x < 0 \end{cases} \tag{4.2}$$

The mean of S is $E[S] = 0$ and the variance σ^2

$$\sigma^2 = \left\{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j\left(t_j - 1\right)\left(2j_t + 5\right)\right\}/18 \tag{4.3}$$

Where p is the number of the tied groups in the data set, and t_j refers to the number of data points in the jth tied group. S is normally distributed provided that the following Z-transformation is employed:

$$Z = \begin{cases} \frac{s-1}{\sigma}\ if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{s+1}{\sigma}\ if\ S < 0 \end{cases} \tag{4.4}$$

A positive Z value indicates increasing trends, and negative Z signifies decreasing trends. Sen's slope estimator then calculated the magnitude of the linear trend. It was computed as (Sen, 1968):

$$Sen's\ Slope = Meadian\left\{\left(X_i - X_J\right)/(i-j)\right\}, i > j, \tag{4.5}$$

Where x_i and x_j are the changing values of the variable at time steps i and j, respectively. A value close to zero means there is no variation through time. A negative value indicates a decreasing trend, whereas a positive value represents a positive trend. This method is recommended for remote sensing time series analysis and has been used for vegetation trend analysis. The trend analysis described above was applied to pixel-based NDVI values using the GEE API.

4.2.4. Identification of Drought Indices

The Spatio-temporal variation of drought from 1981 to 2021 was characterized using SPI (Guttman, 1999; Hayes et al., 1999; Livada & Assimakopoulos, 2007; McKee et al. 1993, 1995), VCI (Kogan & Guo, 2016; Liu & Kogan, 1996; Jiao et al., 2016), TCI (Kogan & Guo, 2016; Kogan, 1995). The combination of these DI can detect and spatial distribution, and frequency of agricultural and meteorological drought.

Drought assessment using SPI

The SPI is a well-known meteorological drought indicator that is based on precipitation. This indicator was designed by McKee et al. (1993) to measure the precipitation deficit across multiple time scales. It has since become one of the most important indices for quantifying meteorological drought on different time scales. The calculation of SPI is based on the probability of precipitation for any given time scale, making it a reliable indicator for monitoring drought conditions (Guttman, 1999; Dutta et al., 2013; McKee et al., 1993). SPI represents the standardized deviation of the observed cumulative precipitation relative to the long-term precipitation average (Eq.4.6).

$$SPI = \frac{X_{ij} - X_{im}}{\sigma} \qquad (4.6)$$

Where "X_{ij}" is the rainfall for the ith station and jth observation "X_{im}" is the mean rainfall for the ith station, 'σ' is the standard deviation for the ith station. However, because precipitation usually does not follow the normal distribution, SPI calculation reqsuire fitting a gamma distribution as proposed by (Edwards & McKee 1997; Guttman, 1999) (Eq. 4.7). (Guttman, 1999; Sandeep et al., 2021) (Eq. 4.7). Thus,

$$g(x) = \frac{x^{x-1}.e^{-y/\beta}}{\beta^{x}.\tau(\alpha)} \qquad (4.7)$$

Where α> 0 is a shape parameter, β > 0 is a scale parameter, x is the precipitation amount, and τ (α) is the gamma function. SPI is categorized by different temporal scales, e.g., 1, 3, 6, 12-month. SPI-1 represents the 1-month precipitation condition, whereas SPI-3 represents three months average precipitation condition. This study calculated the SPI on 1, 2 and 3-month time scales. These time scales reflect the soil moisture conditions (Livada & Assimakopoulos, 2007).The classification of the SPI is according to (McKee et al., 1993), holding four categories of drought condition; mild drought (0 to -0.99), moderate dry (-1.00 to − 1.49), severe dry (-1.5 to −1.99) and extreme dry (< -2.0).

Drought assessment using VCI

VCI is particularly useful for agriculture drought detection (Akinyemi, 2021; Liu & Kogan, 1996). It is a better indicator for vegetation response to precipitation impact and monitoring water stress conditions than NDVI (Dutta et al., 2015; Yang et al., 2020). VCI is used to find vegetation conditions at a specific pixel location by considering the mean multi-annual variability and the minimum and maximum NDVI (Eq. 4.8).

$$\mathrm{VCI} = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \times 100 \quad (4.8)$$

Where $NDVI_i$ represents the mean values for the main growing season in the study period, $NDVI_{min}$ and $NDVI_{max}$ are the multi-year minimum and maximum NDVI values calculated for each pixel.

VCI values range from 0 to 100; the larger the VCI value, the better the vegetation growth and the lower the degree of drought (Kogan, 1995; Liu & Kogan, 1996; Sandeep et al., 2021). According to Kogan, (1995) 20% reduction in corn yield during drought years was associated with 0 to 35 values of VCI. This range has been suggested as a drought severity classification scale (Kogan, 1995; Dutta et al., 2015). In this study, we slightly modified this range (Dutta et al., 2015; Jiao et al., 2016; Liang et al., 2021; Qian et al., 2016). Accordingly, we sub-divided it into five grades; no drought ($VCI > 70$), mild drought (MiD) ($50 < VCI \leq 70$), moderate drought (MD) ($30 \leq VCI \leq 50$), and severe drought (SD) ($20 \leq VCI \leq 30$) and extreme drought (ED) ($VCI < 20$).

VCI Anomaly

The anomaly of VCI is used to analyze historical variations in the VCI (Eq. 4.9; Liang et al., 2021).

$$\mathrm{VCI_A} = \frac{VCI_{i\_}VCI_{av}}{VCI_{av}} \quad (4.9)$$

Where AVCI is the VCI anomaly, VCI_i is the VCI value in a specific period, and VCI_{av} is the average VCI over the research period. A positive AVCI indicates improved vegetation conditions and a negative AVCI indicates below long-term average VCI. The AVCI is vital to quickly identify the years or months of exceptional dry or wet years below.

Drought assessment using TCI

High temperature in the middle of the season indicates drought conditions, while low temperature indicates primarily favorable conditions. The TCI assumed that higher temperature tends to cause drought during the vegetative growth period. Low temperatures are largely favourable for vegetation during its development. TCI is expressed by the following equation (Kogan, 1995).

$$TCI = \frac{T_{max} - T}{T_{max} - T_{min}} * 100 \qquad (4.10)$$

Where T, T_{max}, and T_{min} are actual LST of the observed week, multi-year maximum, and minimum temperature, respectively. The drought classification through TCI; grades are similar to VCI classification scales.

Drought assessment using VHI

VHI represents the overall health of the vegetation and is used to identify drought (Karnieli et al. 2006; Zeng et al., 2022). VHI is estimated as a weighted sum of VCI and TCI, computed by combining the TCI and VCI as proposed by Kogan (1995).

$$VHI = a \times VCI + (1 - a) \times TCI \qquad (4.11)$$

The weights for α is assigned 0.5. However, according to recent studies by (Bento et al., 2020; Zeng et al., 2022), we employed α =0.68 to give more role to VCI. VHI range from 0 to 100, similar to the VCI and TCI as well as the classification is also common for these three indices, which have five classes, extreme drought (0–20), severe drought (20–30), moderate drought (30–50), mild drought (50–70), and no drought (70 –100) (Kogan, 1995; Sandeep et al., 2021).

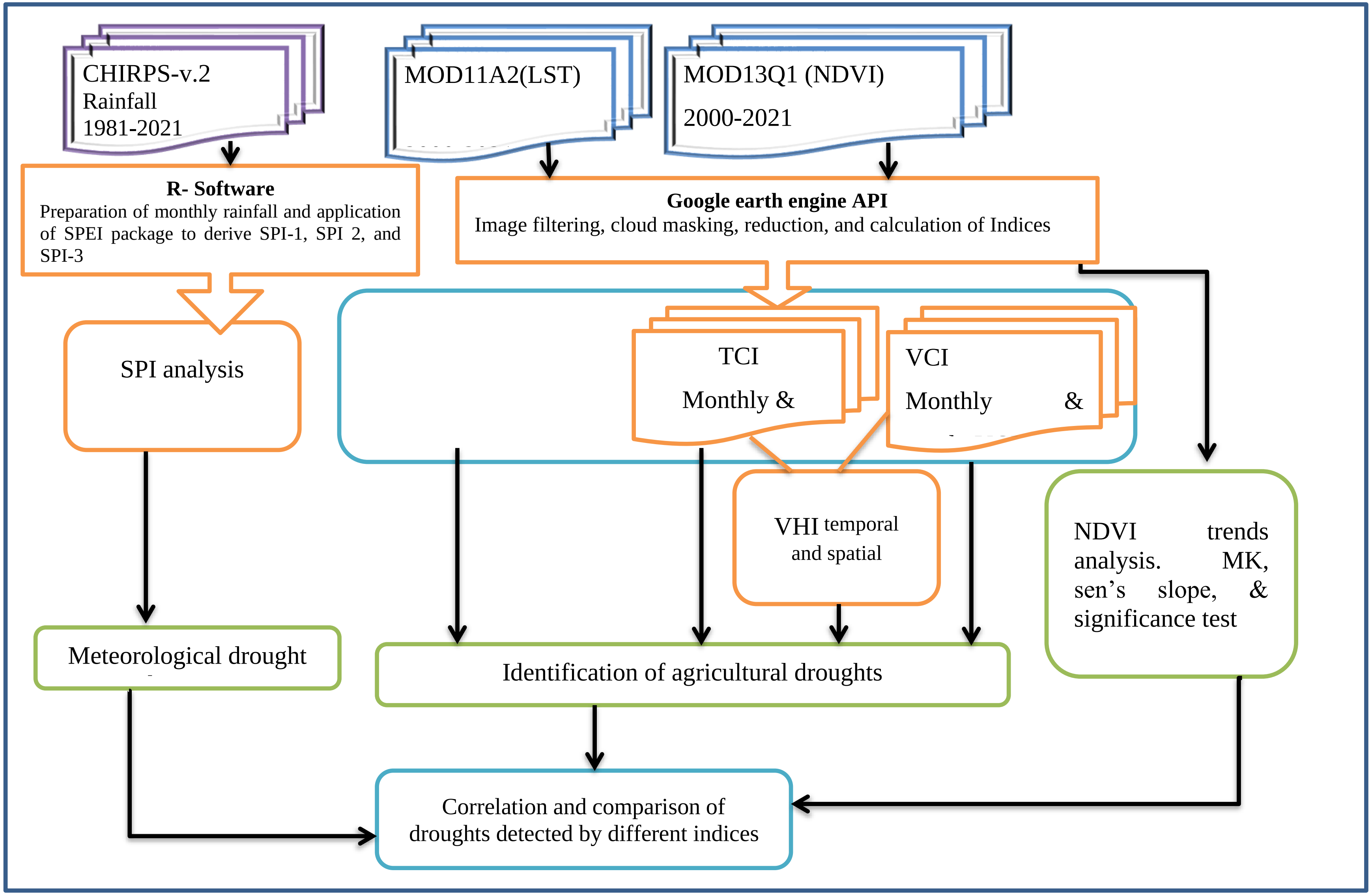

Fig. 4.4 Methodological flow chart of modelling spatial and temporal drought in the upper Tekeze basin, Ethiopia

4.3. Results and Discussion

4.3.1. NDVI Trend in the Upper Tekeze Basin

NDVI datasets for the main growing months of the study period were analysed to examine the spatial-temporal distribution of vegetation dynamics. The highest values of NDVI were observed in the southern highlands and midland watersheds of the study areas. The Northern part of the basin following the course of Tekeze River has the lowest VI, indicating that this part of the study area is arid and has low vegetation cover. The mid and low-altitude part of the basin has low mean annual values of the VI due to variability of in climatic factors and recurrent droughts that affect the distribution and growth of plants. Man Kendall's non-parametric trend analysis has shown that the majority of the study area has experienced a change in the NDVI value over the past 22 years. As clearly seen in Fig. 4.5, most of the pixel showed a decreasing trend. A significance test was also carried out to check whether these changes were significant. Pixel-based Kendall trend and its significance level is shown in Fig. 4.5.

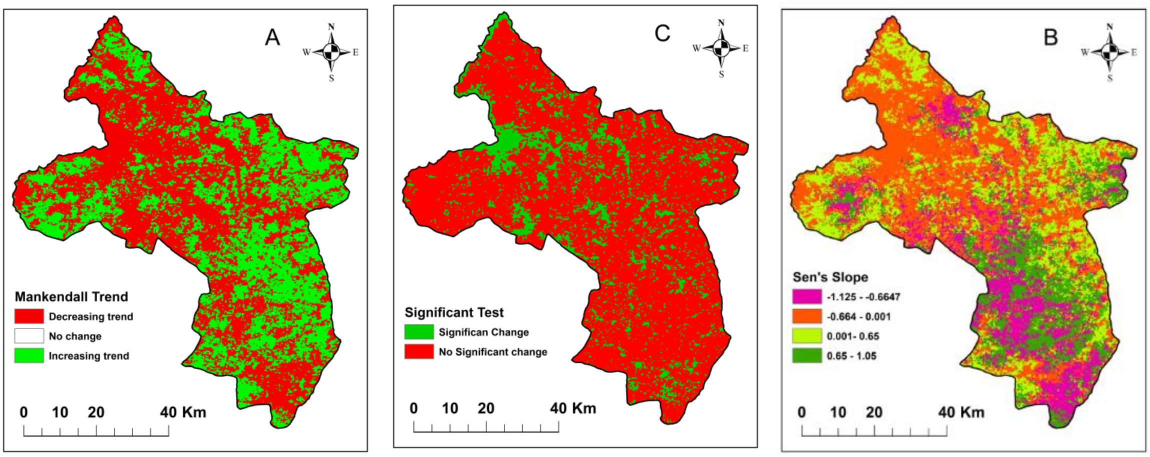

Fig. 4.5 Man-Kendall non-parametric test of NDVI trend over the study area from 2000 to 2021; MK trend (A), Sen's Slope magnitude (B), and Significance level (C)

The test showed that the majority of the increasing or decreasing trends were not statistically significant. Only about 72500 ha land area showed statistically significant increasing or decreasing trend (p=0.05) (Fig. 4.5). Since the Man-Kendall test is based on the historical time series of the data itself, very recent positive changes in NDVI around watersheds and area closure might be insignificant statistically. Likewise, recent cleared land surfaces, farmlands, and urban area expansions that decrease the surface's NDVI value are not significant.

4.3.2. Drought Monitoring Using SPI

SPI helps depict the meteorological drought patterns spatially and temporally. The primary livelihood of the smallholder farmers in the study area depends on rain-fed agriculture. This rain-fed agriculture also depends on the rains during the main growing season. Thus, SPI-1, SPI-2, and SPI-3 were estimated to show the drought condition during this season. Both dry and wet years were observed in the temporal analysis of the SPI. The SPI-3 (June - August) represents the deviation of rainfall below or above the mean rainfall in the same period throughout the study period (Fig. 4.6). As the rainfall in these three months is critical for the germination, growth, and maturity of crops, the SPI best explains the severity of the drought condition. The year 1984 was the driest year in the study period with SPI-3 = -2.72 for the months from June to August and SPI-3 = -3.06 of August through October. The 1984 drought began to emerge from April to June with SPI-3 of -2.67. After the 1984 drought, the 2015 drought was the second driest year in the study period. During this year, the severe rainfall deficit starts in July SPI-3= -2.34, and extends to August SPI-3= -1.78 and September (SPI-3= -1.68). The SPI-3 from July through September had been recorded -2.69 in 1984, -1.57 in 1987, -1.65 in 1993, and -1.68 in 2015. Furthermore, on the SPI 3 timescale, SPI values less than -1 were recorded during 1987, 1985, 1993, 2009, 2015, and 2019 (Fig. 4.6). The SPI pattern shows frequent dry conditions in the upper Tekeze basin in Wag-himra Zone. The SPI value in the study area for months from June to July (SPI-3) reached -2.72 (extreme drought).

In addition to SPI-3, SPI-1 tells us the anomaly of the rainfall in a given month compared to the average rainfall of the same month throughout the study period. It is not only the shortage of rainfall but also the distribution of rainfall among each planting and growing month that causes droughts. If drought exists at the beginning of the planting period, it creates agricultural drought. Thus, studying each month's drought condition separately helps to understand the drought's beginning, duration, and intensity. In the study area, rainfall in July is highly demanded to plant crops, and if there exists a rainfall deficit in this month, the occurrence of drought in the following months is highly likely. As compared with SPI 3, SPI-1 of the study area showed less drought conditions. Higher drought frequency was in SPI-3.

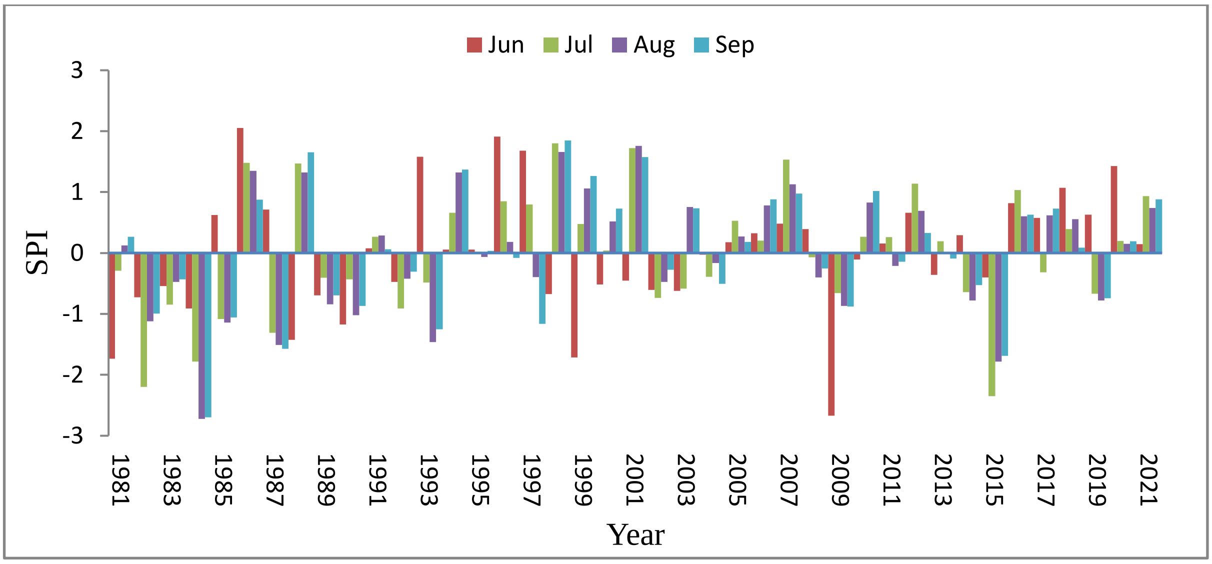

Fig. 4.6 SPI-3 time series of the growing season (June- September) from 1981-2021

Drought frequency

Drought frequency is the return period between drought events with severity values of SPI ≤ −1(Thompson, 1999; Mekonen et al., 2020). SPI-1 of the main rainy months is indicated in table 4.1. Amongst all the months in the season, more frequent drought was observed in August, followed by September and July. The SPI-3 analysis in the month of August indicated that seven (7) drought years (17% of the total study period) were recorded as drought years (Table 4.1). Generally, moderate to extreme drought events (SPI< -1) happen at every 5-8 years interval in the study area. There are also 11 mild drought or SPI values ranging from 0 to -0.99. If we count the negative signs of SPI (-0.99 to -0.1) under the mild drought category, the recurrence time will be lowered to 2 to 3 years. Regarding the frequency of drought events in the neighboring district of North Wollo, Gebre et al. (2017) reported the recurrence at every 2- to 3-year interval. Irregular rainfall and dry condition during July and August is highly responsible for crop failure and leads to agricultural drought.

Table 4.1. Frequency of drought years (SPI< -1) under different SPI time scale

Months	**Drought frequency in different SPI Time scale**		
	SPI-1	SPI-2	SPI-3
Jun	3	6	5
Jul	5	6	5
Aug	6	5	7
Sep	5	6	6

4.3.3. Drought Analysis Using VCI

VCI is a good tool for detecting drought and measuring the time of its onset, intensity, duration, dynamics, and impacts on vegetation (Kogan, 1995). Specifically, VCI is appropriate for monitoring agricultural drought (Bento et al., 2020; Kogan, 1995; Quiring & Ganesh, 2010 & Singh et al., 2003). The VCI drought severity and its spatial distribution from 2000 to 2021 are depicted in Fig. 4.7. Since June is a dry month over most of the study area, the study considered only three consecutive months (July to September) to analyse the dynamics of VCI as an indicator of agricultural drought. Because of the aridity of most of the study area, NDVI values of dry seasons are lower than the growing seasons during which crops are present. This helps VCI identify the condition of crops in relation to rainfall and crop health in the growing season. Spatially, the northern and northeastern parts of Waghimra are drier than the southern areas. A high frequency of low VCI has been observed in the northern part of the basin. Other studies have also indicated that this part of the basin is highly moisture-stressed. Due to this, agricultural production is low; only goat production can support the people's livelihoods. The time series map of VCI (Fig. 4.7) shows that the study area experienced mild to severe drought during 2004, 2004, 2015, 2017, and 2018. Significantly, below-average VCI was recorded in 2004, 2009, 2015, and 2016. During the wettest year (2007), the study area experienced excellent greenness, and no land area was under extreme and severe drought conditions. The area of land that falls under different drought categories is presented in Fig. 4.9. A tiny portion of the study area (919 hectares) experienced moderate drought in 2007. During the driest year 2015, 150,077 hectares land was under extreme and severe drought conditions. The total area of land under 30% VCI was 286,163 hectares (Fig. 4.9). All *Kiremt* months in 2015 experienced negative AVCI due to the drought, which is claimed to be one of the worst droughts Ethiopia experienced in more than 50 years (Hermans & Garbe, 2019; Roop et al., 2016). During this year, up to 50% rainfall deficit has caused severe crop failures (FAO, 2016). In 2015, most AVCI values were less than the mean, and the yearly mean VCI trend line decreased (Fig. 4.8). After the severe impact of the 2015 drought, the 2017 drought also affected the condition of vegetation and crop growth. Most of the *Kiremt* months from 2015 to 2019 experienced below-average VCI. The linear trend of average yearly VCI showed a decreasing trend, particularly from 2015 onward, dragging the trend line downward (Fig. 4.8).

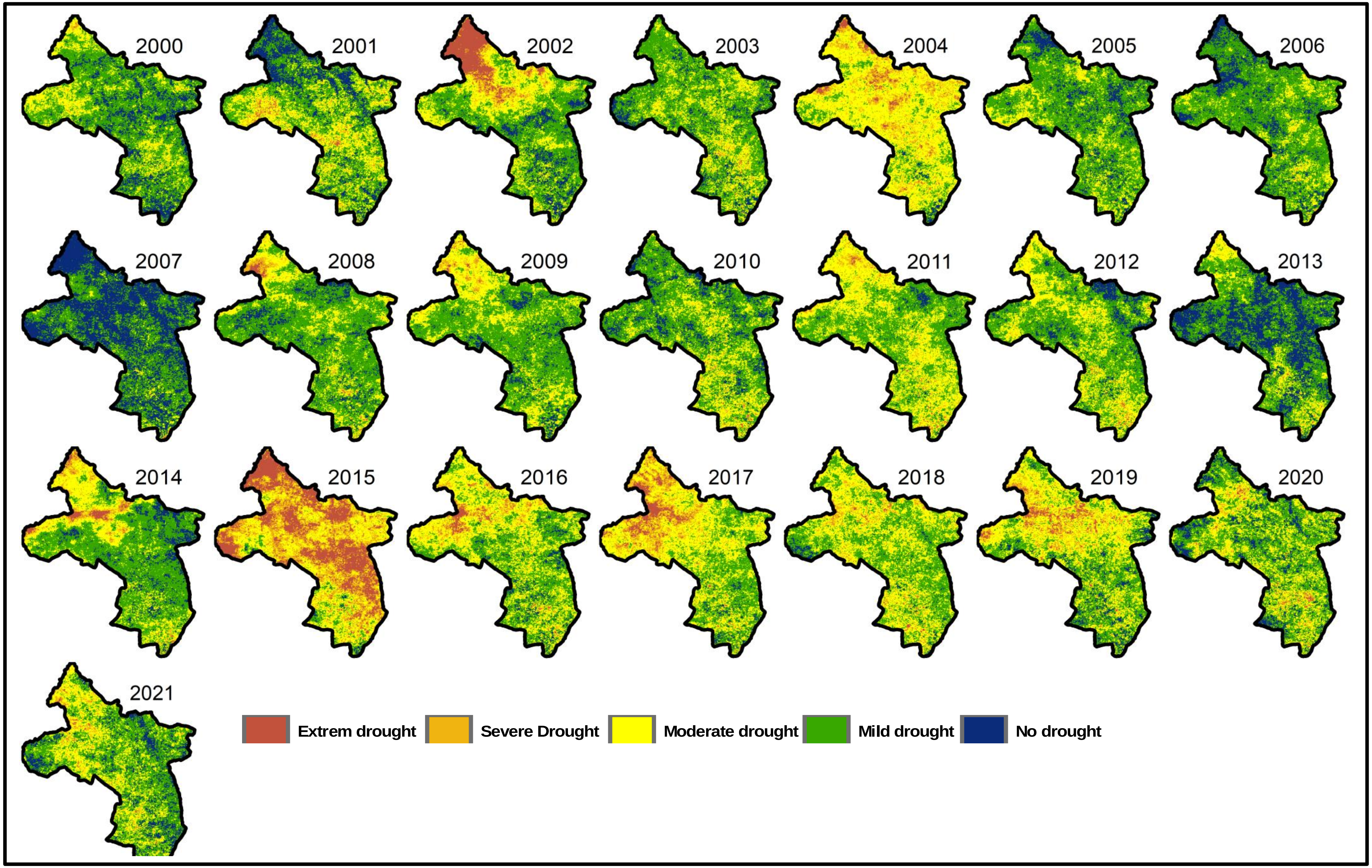

Fig. 4.7 Spatio-temporal patterns of mean VCI of the main growing seasons over the study area from 2000 to 2021.

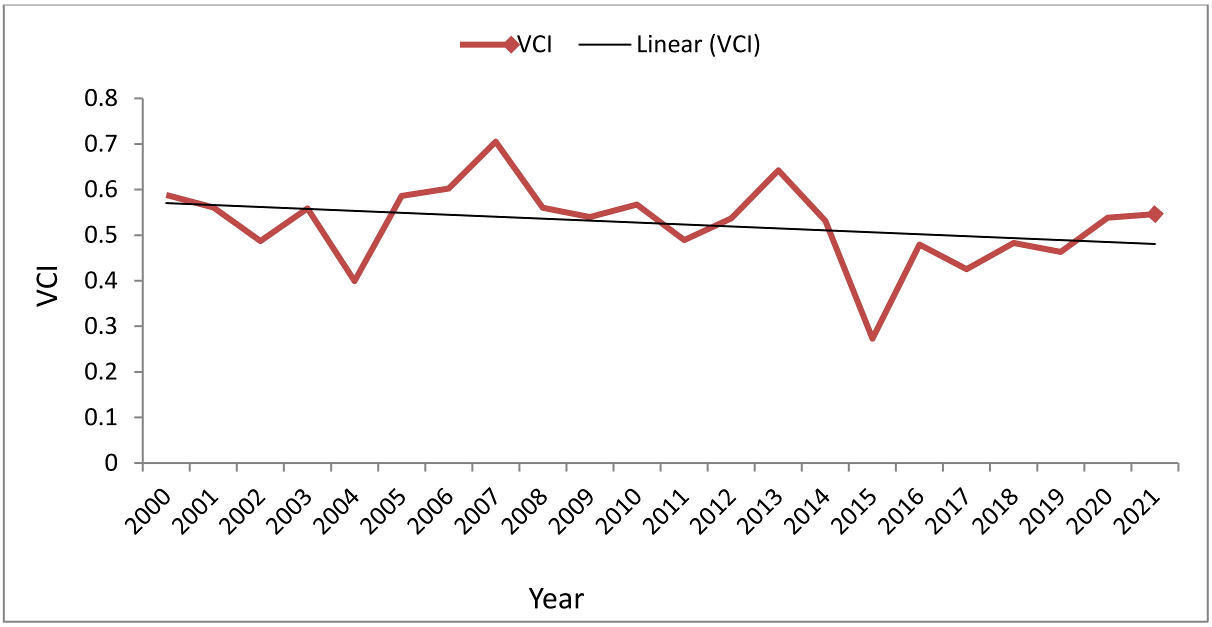

Fig. 4.8 Trend of mean annual VCI in the study area from 2000 to 2021

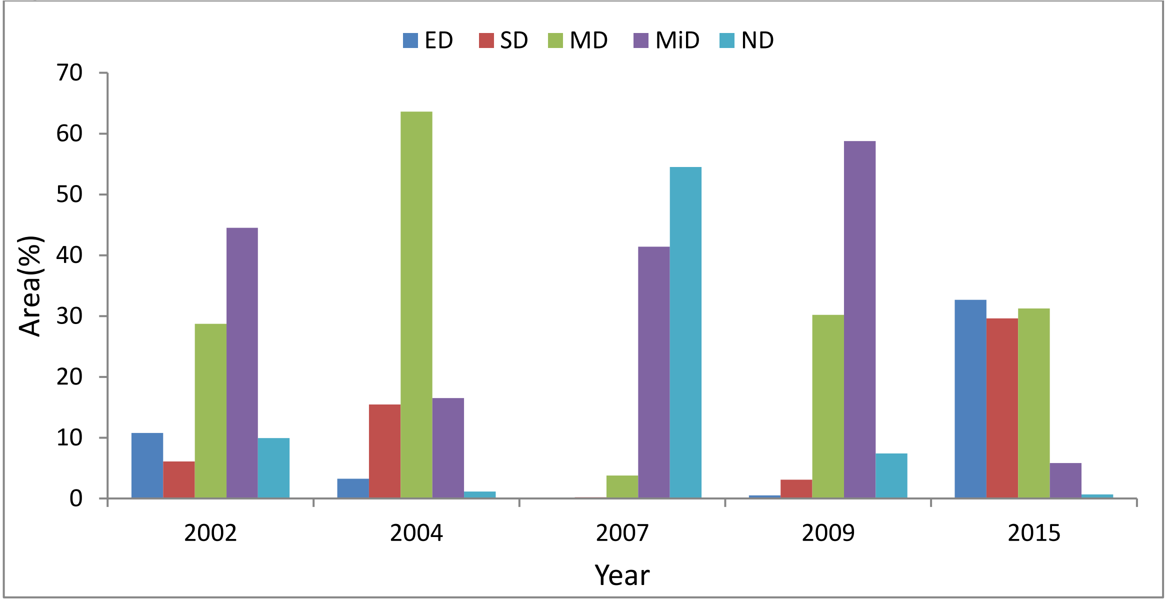

Fig. 4.9 The area under different categories of droughts for the major drought years (2002, 2004, 2009 and 2015) and the wettest year (2007) (area in percentage); (ED=extreme drought, SD=severe drought, MD = Moderate drought, and MiD= Mild drought and ND=No drought))

VCI anomaly

To analyze the long-term characteristics of drought in *the Kiremt* (summer) season, we have studied vegetation conditions anomaly in the study area. AVCI during the summer from 2000 to 2021 is shown in Fig. 4.10. The anomaly ranges from a 70% increase to an 80% decrease.

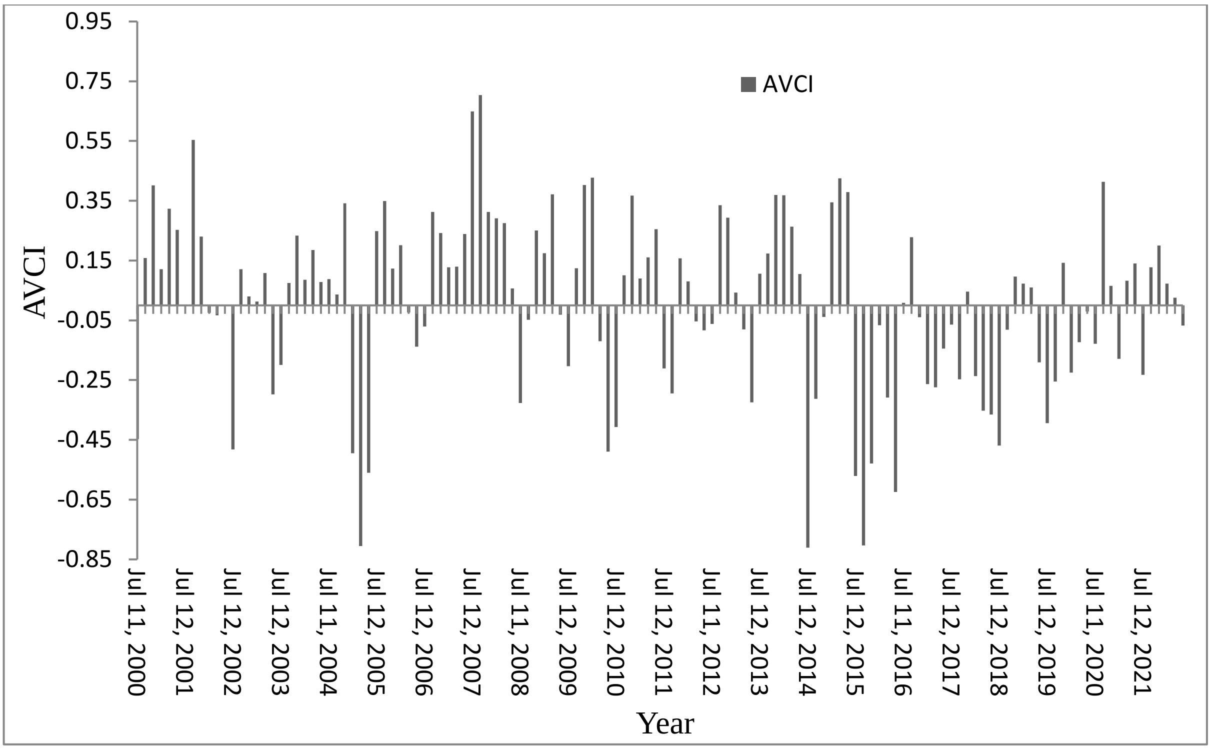

Fig. 4.10 Inter annual Anomaly of VCI (AVCI) for the main growing months from 2000 to 2001

The years 2000 and 2001 showed about 10 to 55% positive variation from the historical mean. However, July 2002 had a 48% reduction in VCI, and a negative coefficient of variation was observed for September that year. The implication of reducing VCI at the start of the major growing season and during the maturing season (September) is always the result of the late onset of rainfall and early exit of the rainy season. From 2002 to 2005, there was both positive and negative AVCI every other year alternately. The years 2006 and 2007 experienced positive AVCI. The highest AVCI (65% increase in VCI) in the time series (from 200 to 2021) was seen in July 2007 (Fig. 4.10). The Highest VCI in July is always related to the presence of healthy sorghum, wheat, and barley crops. These crops will be in good health and maturity when the late June and early July precipitation has a normal distribution. Except for the early July VCI, the growing months of 2008, 2009, and 2010 showed positive AVCI. However, 2011 and 2012 showed irregular increases and decrease in VCI. The AVCI varies positively and negatively from July to September. However, the overall VCI anomaly of these years is below the historical mean. The VCI values for 2011 and 2012 showed that most of the study area was below 40%, indicating the presence of moderate and above-moderate drought conditions. The highest negative AVCI (82% negative anomaly) was seen on July 2014. However, in August and September of the year 2014, were with positive AVCI. From 2015 onwards, this was the period of continuous negative AVCI in the study area. The AVCI during 2015 was also the highest in the time series, accounting 82% reduction from the historical average. Furthermore, the effect of the 2015 drought was observed in the subsequent years. Most of the months from 2015 to 2021 have experienced below-average VCI (Fig. 4.10).

4.3.4. Drought Analysis Using TCI

High LST and decreases in soil moisture adversely affects vegetation healthy (Cowles et al., 2018). According to Kogan, (1995), TCI identifies if vegetation stress is happening due to high temperature (Singh et al., 2003). If VCI is solely used to identify vegetation stress, it cannot reveal if it is due to excessive -wetness. In this case, VCI fails to tell what exactly cause the drought during over-wetness rather than dryness is a leading cause for low NDVI . However, TCI indicates whether stress is due to dryness (Singh et al., 2003). Like VCI and TCI produced a consistent and accurate spatial and temporal drought map of the study area. Years 2002, 2004, 2009, 2015, 2016, and 2017 experienced moderate to extreme drought (Fig. 4.11). Like in the results using the other DI, 2007 was also a wet year using TCI. During this year, no land area fell under severe and extreme drought conditions. Only 89 hectares of land was found under moderate drought condition. However, during the most drought-affected year (2015), 88407 hectares of land were affected by severe and extreme drought. Moderate drought was observed over 391007 hectares of land (Fig. 12).

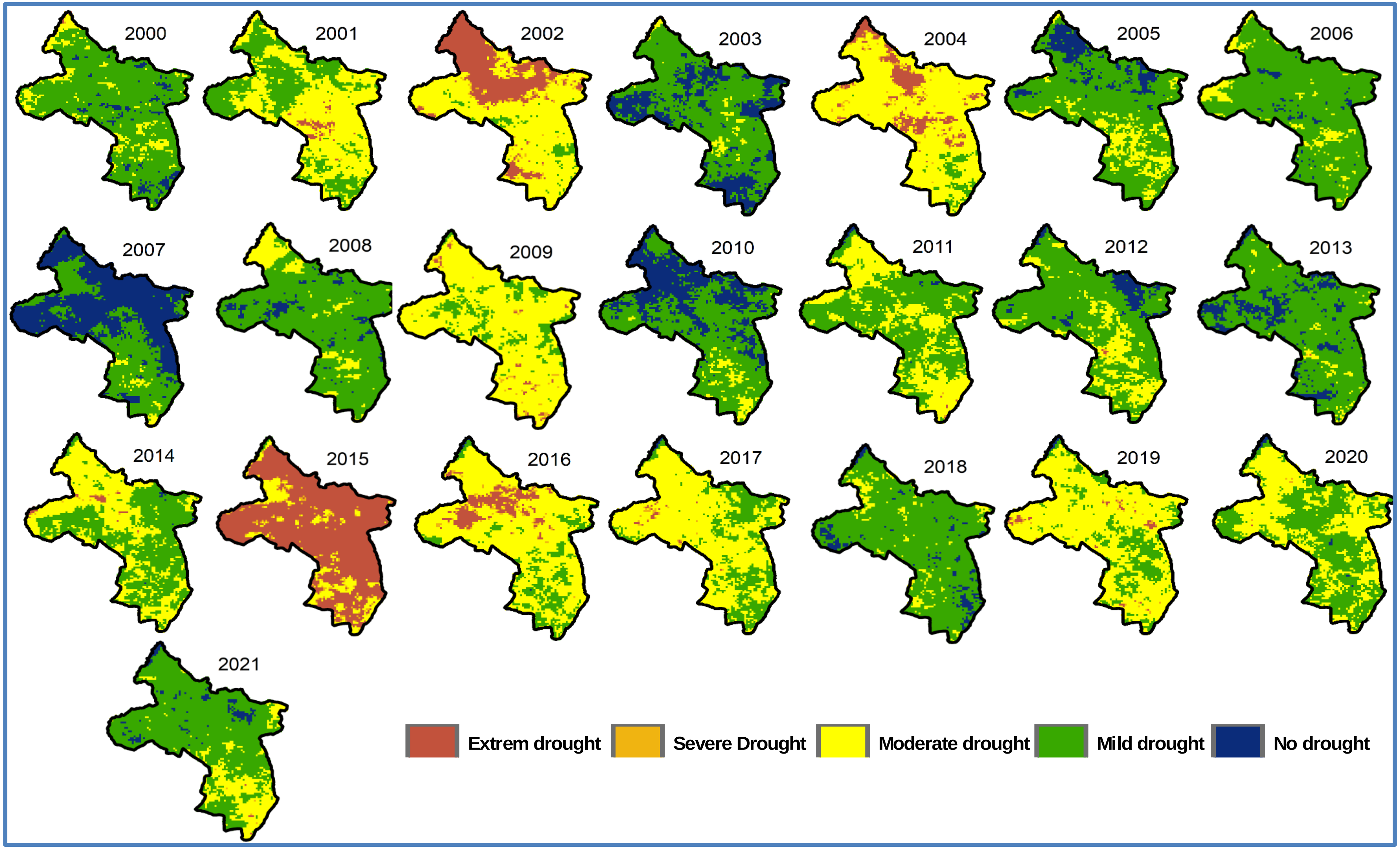

Fig. 4.11 Spatio-temporal patterns of mean TCI of the main growing seasons over the study area during the period from 2000 to 2021

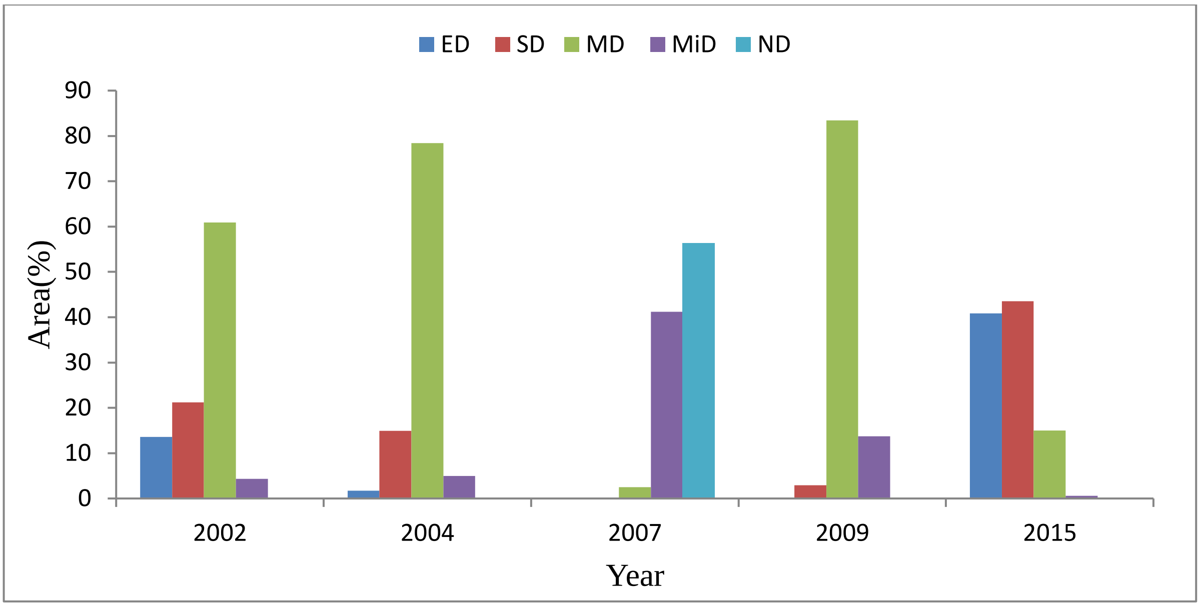

Fig. 4.12 Area under different categories of TCI-based droughts 2000, 2004, 2007, 2009, and 2015(area in ha). (ED=extreme drought, SD=severe drought, MD = Moderate drought, and MiD= Mild drought and ND= No drought)

4.3.5. Drought Detection Using VHI and the Role of VC and TCI

When estimating the mean annual TCI and VCI of the study area, both indices produced significant correlations and can be used to detect drought comparably. However, difference was observed while detecting the portion of the basin that falls under extreme and severe drought (Fig.s 4.11 and 4.12. TCI can detect extreme and severe drought in the study area only during an extreme drought year (2015). VCI accurately detected extreme and severe drought throughout the study periods. The result suggested that TCI tends to underestimate drought conditions in some parts of the basin and cannot detect extreme and severe vegetation drought. Applying TCI alone could underestimate the drought severities in the study area. Contrary to the findings by other studies, TCI tends to detect more moderate and mild droughts.

The effect of LST on NDVI is different across latitude, vegetation type and climatic nature of a place (Bento et al., 2020; Hakam et al., 2022; Wassie et al., 2022;Tian et al., 2019). Much literature reported that rise in LST leads to a declining NDVI, as it exposes vegetations to extreme heat and moisture deficiency (Gidey et al., 2018). However, in high-altitude ecosystems where the temperature is a limiting factor for vegetation growth, rising temperature positively affect NDVI. Depending on the question, which factor, temperature or precipitation, is the most limiting for vegetation greenness, the measurement of drought have to consider what should be the weight for each limiting factors. Dry land regions are more sensitive to the lack of moisture than to temperature stress; vegetations in this region are more sensitive to the rise in rainfall and hence NDVI (Bento et al., 2020). Furthermore, even the contribution of temperature and rainfall is not the same throughout the vegetation-growing period. For instance. Hakam et al.(2022) suggested that yield is most affected by decreased moisture (expressed in VCI) during planting and early growing. However, near the harvest stage, high LST affect vegetation health, decreasing yield. The study area is characterized by moisture stress, and rainfall is the primary limiting factor for crops and vegetation.

The traditional VHI considers equal weight to TCI and VCI while classifying droughts; however, because VCI dominates the vegetation health, using $\alpha = 0.68$, as suggested by Bento et al. (2020), can produce a better result. VHI estimated at $\alpha = 0.68$, giving more share to VCI is presented on Fig. 15 Comparison of conventional VHI (a= 0.5) and VHI (a=0.68) based on area coverage (%) of different drought classes is also shown on Fig. 16. VHI with a= 0.5 detected slightly lower area of land under extreme and severe droughts than VHI (a=0.68).

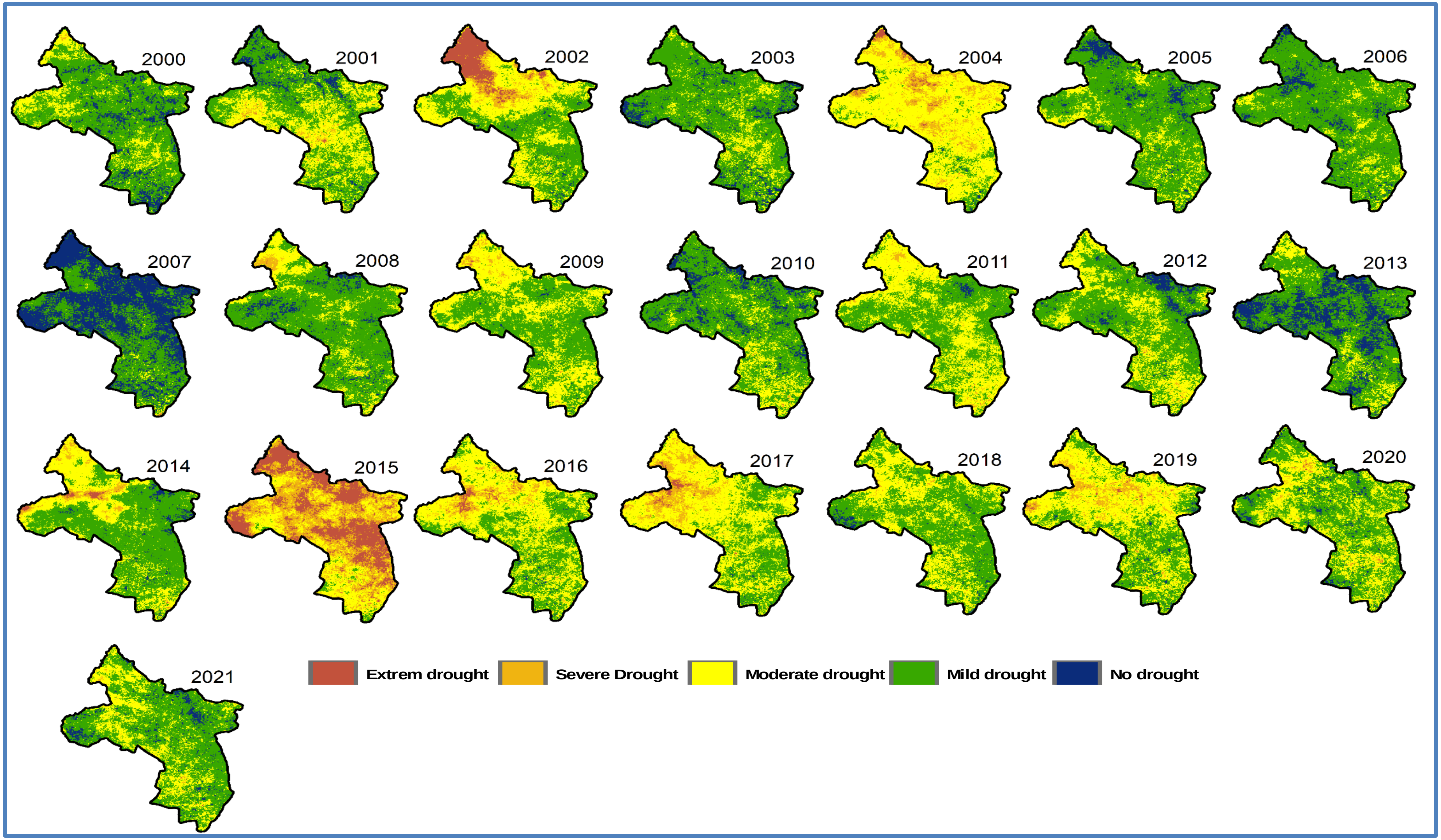

Fig. 4.13 Spatio-temporal patterns of mean VHI of the main growing seasons over semi-arid and arid land of upper Tekeze River Basin from 2000 to 2021

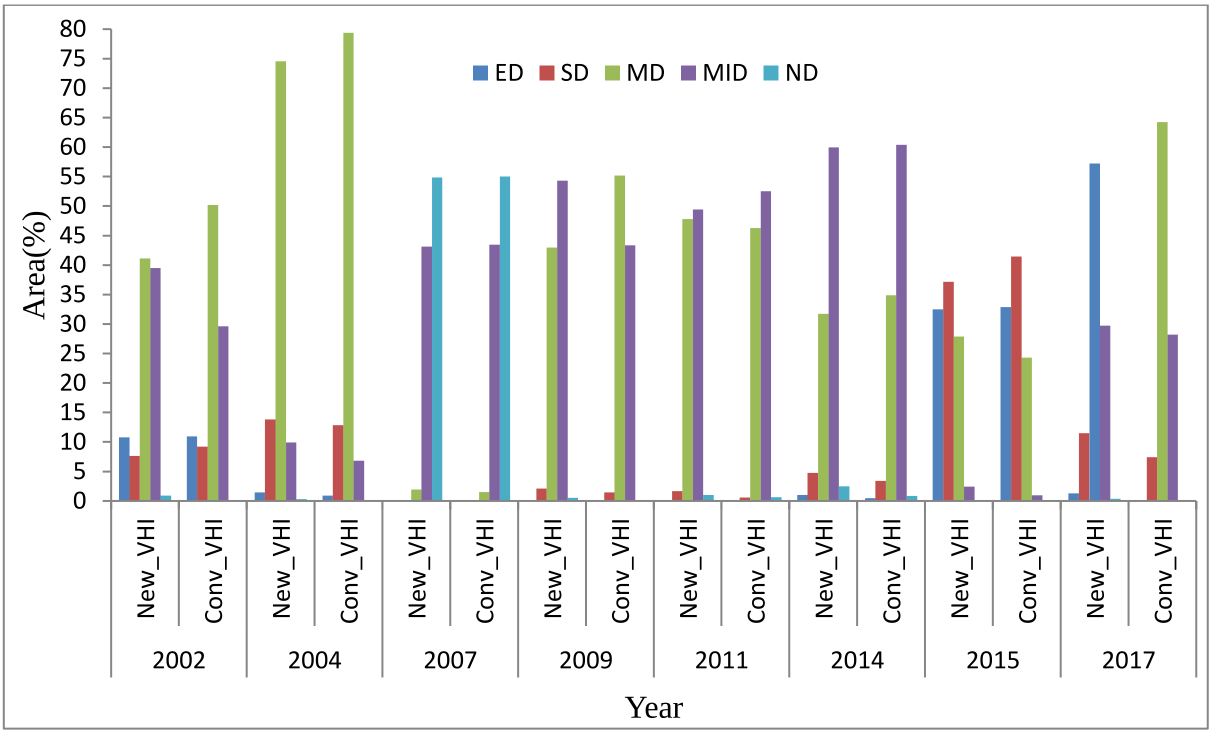

Fig. 4.14 Comparison of conventional VHI (a= 0.5) and VHI (a=0.68) based on area coverage (%) of different drought classes. (Note: ED=extreme drought, SD=severe drought; MD=moderate drought; MID= mild drought; and ND= no drought)

4.3.6. Pearson Correlation Test Results: Agreement of Each of the Indices

In order to study the relationship between NDVI, rainfall, LST, and DI over the growing season, we conducted a Pearson correlation test. A correlation test was employed in order to see the association between precipitation of the rainy months (July, August, and September) with NDDVI and LST, as these two variables have been used to derive VCI and TCI, respectively. July rainfall strongly correlated with July NDVI (r=.853; significant at 0.01) and August NDVI (r=.533; significant at 0.05). Similarly, SPI-1 of July was correlated with August NDVI (r=.59; significant at 0.01) and July NDVI (r=.835; significant at 0.01). In a neighboring district, a study by Wassie et al. (2022) reported that increased water availability due to precipitation results in an increasing trend of NDVI. Rainfall during July negatively correlates with July LST (r=-.705; significant at 0.01) and August LST (r=0.45; significant at 0.05). However, SPI was more correlated with LST than the unit rainfall of the month. SPI-1 is correlated with the LST of July and August (r = -.759 and -.484 respectively). July rainfall is vital for the NDVI and LST in the two consecutive months. As explained by (Bento et al., 2020), semi-arid and arid lands are moisture stresses, and vegetation greenness is highly sensitive to rainfall than LST. LST itself is affected by the soil moisture and availability of green vegetation. August rainfall and SPI-1was not correlated with August and September NDVI. However, a significant negative correlation was obtained between August rainfall and August LST (r= -.464). Still, it confirms that the LST at a given month highly depends on that month's rainfall and the prior month's NDVI and rainfall. Table 4.3 shows that precipitation in July correlates with the next two months' NDVI.

The study has also examined the association between each month LST with the NDVI of the growing months. A significant negative correlation was obtained between July LST and NDVI of the month. Besides, after one-month lag, it also correlated with NDVI in August. LST in August is also correlated with NDVI in August and September. LST in September is also strongly negatively correlated with NDV of the month (r= -0.842, $p<0.01$). Besides, there exists a moderate negative significant correlation between NDVI of August and September LST (r=-0.428, $p<0.05$) (Table 4.3). Precipitation being the primary limiting factor, it determines both soil moisture and NDVI and hence the LST record of each month. In northern Ethiopia study by (Gidey et al., 2018; Wassie et al., 2022) found strong negative correlation between NDVI and LST.

Finally, we tested the correlation of each month's rainfall, LST, and SPI with the seasonal VCI, and TCI. Since not only the amount of rain in the season equally determines the meteorological and agricultural drought conditions, it was important to examine which month's climatological condition mostly affects the vegetation conditions at a given year. Although the rainy season is believed to begin in June in Ethiopia, Waghimra receives much rainfall starting in early July. The correlation test result indicated that July rainfall significantly correlated with July TCI(r=0.44) and August TCI (r=0.77). A strong correlation was also observed in SPI -1 of July and August with July TCI. Although the LST is high in the season, the precipitation during the months improves the soil moisture and vegetation growth, leading to low LST recoding. Another strong correlation was observed between September SPI-3 and TCI of July, SPI-1 of July, SPI-1 of August, and SPI-3 of July and August. Similar climatological and topographic settings (Gebrehiwot et al., 2011) found that VCI values strongly correlated with precipitation and indicated that VCI could detect drought conditions.

In order to see the contribution of precipitation for VHI, we have examined the correlation with SPI of the 3 months. The result showed that a higher association was obtained between the July SPI with modified VHI ($\alpha=0.68$) (r=0.72) than the conventional VHI ($\alpha=0.5$) (r=0.69). However, both VHI was not significantly correlated with August and September SPI-1. This is because July VHI or VCI is the primary determinant factor for the seasonal VHI. The VCI determines the drought condition in August and September in July and early August. Drylands are characterized by moisture stress and rainfall variability.

Table 4.2 The Pearson's correlation coefficient matrix computed among the four DI based on their annual mean value for the main growing season.

DI	LST	TCI	VCI
LST	1		
TCI	-.975**	1	
VCI	-.834**	.838**	1

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

Pairwise correlations among SPI, NDVI, TCI and LST were examined to know the correlation of one of the indices over the other and check the agreements among each other. The correlation was tested on the average value of indices on a yearly base. The correlation between LST VCI, and TCI was statistically significant, as indicated in Table 4.2. The drought conditions studied by the VCI and TCI showed strong agreement; Gidey et al., (2018), also reported similar finding.

Table 4.3 Correlations between monthly precipitation, LS and NDVI

Precipitation (PPT) and NDV						
	July PPT	August PPT	September PPT	July NDVI	August NDVI	September NDVI
July PPT	1	-	-	-	-	-
August PPT	.266	1	-	-	-	-
September PPT	-.140	.025	1			
July NDVI	.853**	.184	-.179	1	-	-
Auguts NDVI	.533*	-.086	-.077	.470*	1	-
September NDVI	.258	.167	.445*	.005	.502*	1
Precipitation and LST						
	July LST	August LST	September LST	July PPT	August PPT	September PPT
July LST	1	-	-	-	-	-
August LST	.576**	1	-	-	-	-
September LST	.365	.559**	1	-	-	-
July PPT	-.705**	-.447*	-.174	1	-	-
August PPT	-.319	-.464*	-.171	.266	1	-
September PPT	.086	.039	-.516*	-.140	.025	1
LST and NDVI						
	July NDVI	Auguts NDVI	September NDVI	July LST	August LST	September LST
July NDVI	1	-	-	-	-	-
Auguts NDVI	.470*	1	-	-	-	-
September NDVI	.005	.502*	1	-	-	-
July LST	-.699**	-.628**	-.292	1	-	-
August LST	-.378	-.576**	-.434*	.576**	1	-
September LST	-.022	-.428*	-.842**	.365	.559**	1

* . Correlation is significant at the 0.05. and **. Correlation is significant at the 0.01.

4.4 Discussion

Drought indicators that account for rainfall and temperature effects and the combination of standardized SPI with remote sensing-based indices are better for quantifying agricultural and meteorological droughts. This study uses SPI, TCI, and VCI indices to evaluate droughts during the main growing season from 1981/ 2000 to 2021. The man-Kendall non-parametric trend analysis showed that the overall NDVI trend exhibited a decreasing trend. Cyclic drought conditions and irregular alternate of wet and dry years might be the primary cause of decreasing NDVI. Spatially, the largest percentage of the NDVI decreasing trends are concentrated in the eastern, northern and northeastern part of the basin. The area exhibited high aridity over extended exposed rocks. On the other hand, pocket areas of watershed management, plantation, and irrigation sites are prime reasons for positive NDVI changes.

The SPI analysis showed that there were 7 years (17% of the study period) where the SPI fell below -1.0, indicating moderate to extreme drought. During 1984, 2002, 2004, 2009, 2015, 2016, and 2017, the study area experienced moderate to extreme drought. The result showed less severe and extreme drought coverage than mild and moderate droughts. Furthermore, some drought years that SPI did not detect were found dry in TCI and VCI. For instance, TCI and VCI indicated that 2019 was drier in the central part of the basin. All indices, including SPI, equally detected the 2015 severe drought. The reported drought years are in line with reports of other studies in Ethiopia (Bayissa et al., 2018; Degefie et al., 2019; Viste et al., 2013; Segele & Lamb, 2005; Zeleke et al., 2017), who reported that years 1984, 2002, 2004 and 2009 were dry in most parts of Ethiopia. Although (Bayissa et al., 2018; Mera, 2018) reported that all regions of Afar, Amhara, and Tigray were under severe drought in 2002, this study resulted that only the dry land area of the northern part of the study area was under severe and extreme drought. In 2004, drought conditions from mild to extreme drought grades affected almost all of the study area. As reported by (Bayissa et al., 2018), 2004 was drier in most of Ethiopia. In this study, although the SPI-3 did not detect drought conditions in 2009, VCI and TCI revealed that the Northern and southern parts of the basin were under moderate drought. A national-level study by Viste et al. (2013) reported widespread drought in most parts of Ethiopia in 2009.

Regarding the distribution of drought conditions across the different agrological zone, the Northern parts of the basin represent the *Kolla* (dry hot) low-altitude agrology. When traveling to the southern part, the climate exhibited middle and high-altitude agro-ecology with more vegetation greenness and relatively favorable rainfall conditions for crop cultivation. The VCI, and TCI have shown slight differences across these different agrological zones. The northern part of the basin was more frequently under drought than the rest. Vegetation is very sparse and rare in the northern tip of the basin. A previous SPI study by Senamaw et al. (2021) revealed that northern part of the study area was found to be frequently affected by severe agricultural drought while the southern and central parts were affected by severe to moderate drought conditions. This part of the basin is where the annual potential evapotranspiration is greater than the annual rainfall; thus, the aridity is high in this area. Given deficient annual rainfall in the region, a slight change in the amount and timing could lead to a series drought. Frequent drought condition caused by variation in rainfall aggravates surface aridity through increased land surface temperature affecting the shrubs and croplands in the northern part of the basin. Furthermore, this frequent drought poses a greater risk to crop and cattle production. Short-maturing crops, the primary crops grown in this short growing season, are at greater risk every year.

Slight difference was observed in the performance of the DI while detecting drought in the study area. SPI is a good indicator of the rainfall variation and drought severity across the studied months. Precipitation correlates with LST and NDVI. Among the three main rainy months, precipitation in July was more correlated with NDVI and LST in July and August. This relationship indicates more about the causal effect of rainfall and LST. Vegetation health in the study area is more sensitive to rainfall.

Moreover, the observed strong correlation between LST and PPT also explains the association between NDVI and LST. Since VCI is derived from NDVI and TCI from LST, and the amount of precipitation determines LST on the given month, VCI is the primary indicator of vegetation health or drought conditions in the arid and semi-arid land of Wag-himra. In deriving VHI, more weight should be given to VCI as it may underestimate the effect of precipitation on NDVI when giving equal weight for TCI. As it has been observed on Fig. 7, more land under extreme and sever drought was detected by TCI, showing that the capacity of TCI in estimating severe and extreme droughts were less than that of VCI.

4.5 Conclusions

Accurate drought forecasting and preparedness are at the core of drought risk management. Particularly in a country with significant discrepancies in the geographical conditions, climatic variables, and infrastructural developments, accurate information and understanding of the local level drought magnitude and frequency has significant advantage for immediate drought risk management and planning sustainable land and water management. This study is the first to formulate the spatial and temporal magnitude and variation of drought in the semi-arid and arid land of upper Tekeze basin in Waghimra administrative zone, where high rainfall variability and low agricultural productivity are critical challenges for food security.

Except over pocket areas of managed watershed management, plantation, and irrigation sites, where positive NDVI changes were observed, the overall NDVI trend experienced a decreasing trend. According to the SPI analysis (from 1981 to 2021), the study area was affected by sever and extreme drought in 1884, 1985, 1987, 1993, 1997, and 2015. The TCI and VCI revealed that in 2002, 2004, 2009, 2015, 2016, and 2017 the majority of the study area was hit by severe and extreme drought. In 2007, exceptionally wet conditions were observed in all three MODIS-based DI.

Compared to SPI, VCI and TCI produced more years of drought. The slight variation in SPI that is not regarded as a drought by the SPI scale were having a greater negative effect on the condition of the vegetation and was easily detected by VCI and TCI. Strong agreement was seen in between rainfall, SPI, NDVI, TCI and LST in the study area. When looking at the distribution of drought conditions across different agrological zones, the northern part of the basin that represents the *Kolla* (dry hot) low-altitude agro-ecology is frequently affected by drought. The southern part of the basin exhibited middle and high altitudes with green vegetation and relatively favorable rainfall conditions for crop cultivation. Given lower annual rainfall, frequent drought and other socio-economic disadvantages in Wag-himra, any policy and strategy towards ecosystem and livelihood development should put drought at the core of its action plan. As the diversity of topography, microclimates, and the nature of farming is highly diverse and complex, this local-level drought analysis is more valuable to design and plan drought prevention and SLM that can address drought's cause and effects.

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CHAPTER FIVE

SOIL EROSION ASSESSMENT AND IDENTIFICATION OF EROSION HOTSPOT AREAS USING RUSLE-GEE FRAMEWORK IN THE UPPER TEKEZE BASIN, NORTHERN ETHIOPIA[4]

Abstract

Soil erosion is a major environmental problem in Ethiopia, reducing topsoil and agricultural land productivity. Soil loss estimation is a critical component of SLM practices because it provides important information about soil erosion hotspot areas and prioritizes areas that require immediate management interventions. This study integrates the Revised Universal Soil Loss Equation (RUSLE) with Google Earth Engine (GEE) to estimate soil erosion rates and map soil erosion in the Upper Tekeze Basin, Northern Ethiopia. SoilGrids250m, CHIRPS-V2, SRTM-V3, MERIT Hydrograph, NDVI from sentinel collections and land use land cover (LULC) data were accessed and processed in the GEE Platform. LULC was classified using Random Forest (RF) classification algorithm in the GEE platform. Landsat surface reflectance images from Landsat 8 Operational land imager (OLI) sensors (2021) was used for LULC classification. Besides, different auxiliary data were utilized to improve the classification accuracy. Using the RUSLE-GEE framework, we analyzed the soil loss rate in different agroecologies and LULC types in the upper Tekeze basin in Waghimra zone. The results showed that the average soil loss rate in the Upper Tekeze basin is 25.5 t ha^{-1} yr^{-1}. About 63% of the basin is experiencing soil erosion above the maximum tolerable rate, which should be targeted for land management interventions. Specifically, 55% of the study area, which is covered by unprotected shrubland is experiencing mean annual soil loss of 34.75 t ha^{-1} yr^{-1} indicating the need for immediate soil conservation intervention. The study also revealed evidence that this high mean soil loss rate of the basin can be reduced to a tolerable rate by implementing integrative watershed management and exclosures. Furthermore, this study demonstrated that GEE could be a good source of datasets and a computing platform for RUSLE, in particular for data scarce semi-arid and arid environments. The results from this study are reliable for decision-making for rapid soil erosion assessment and intervention prioritization.

Keywords: Revised Universal Soil Loss Equation; Google Earth Engine land use, agroecologies, land management; Upper Tekeze Basin; Waghimra administrative zone

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5.1. Introduction

Almost all over the world, water availability, biodiversity, and agricultural productivity are threatened by land degradation processes (Arneth et al., 2019; IPBES, 2018; Reed et al., 2011, 2015). Although land degradation has many components and definitions, in ecological perspectives, it includes several processes that may cause biodiversity loss and a decline in ecosystem functions and services (Pandit et al., 2020). Soil erosion by water is among the primary forms of land degradation, causing grave environmental problems and food insecurity (Eniyew et al., 2021; Panagos et al., 2014). It decreases soil mass, depletes soil nutrients, and increases down-stream river sedimentation and siltation of reservoirs (Abdelsamie et al., 2023; Eniyew et al., 2021). In sub-Saharan Africa, especially in East Africa, with its degraded complex topography accompanied with high rainfall intensity, soil erosion and nutrient depletion threaten food security and sustainable agricultural production (Doherty et al., 2010; Eriksen et al., 2008; Fenta et al., 2019; Volkova et al., 2019). Although it seems very difficult to establish the exact time when soil erosion in the history of agriculture was considered a problem in Ethiopia, many SWC interventions were introduced following the rising global awareness of land degradation and after the severe drought of Ethiopia in 1974 (Haregeweyn et al., 2015; Hurni, 1988; Hurni et al., 2010). Nevertheless, soil erosion is still a significant challenge in Ethiopia (Haregeweyn et al., 2015, 2017; Mathewos et al., 2023), particularly in the country's highlands due to high rainfall erosivity, intensive agricultural practices, and high population pressure (Ewunetu et al., 2021b; Negese et al., 2021). Northern dry land areas of Ethiopia are more susceptible to soil erosion because their ecology is considerably damaged attributed to easily degradable soils, highly variable temperature and rainfall, cultivation on steep slopes, deforestation, and dense and rapidly growing economically marginalized populations (IPBES, 2018). As a result, the country's backbone of the economy, agriculture, is severely affected by persistent soil erosion in the northern highlands of Ethiopia (Gebreselassie et al., 2015; Hurni et al., 2010). It has been suggested that soil erosion in this area could be worsen because of increased population and predicted rise in precipitation (Haregeweyn et al., 2015; Niang et al., 2014). The country has implemented short- and long-term plans to reverse and minimize land degradation through different community-based strategies. Both in its Growth and Transformation plan (GTP) and Climate Resilient Green Economy (CRGE), the Ethiopian government adopted strategies to address the effects of land degradation caused by soil erosion and build a climate-resilient green economy by 2025 (FDRE, 2011; Fenta et al., 2021; MoFED, 2010). However, given the economic and technical limitations to the conservation of all areas affected by soil erosion, targeting areas with high soil loss rates is required for effective and proper allocation of limited resources (Fenta et al., 2021; Haregeweyn et al., 2015; Tamene et al., 2017). For this purpose, scientifically investigated, organized, and mapped soil erosion severity status, at a basin-level, is prerequisite to identify priority areas of conservation.

In Ethiopia, there are regional differences regarding efforts made to understand soil erosion processes (Haregeweyn et al., 2015). For example, Tekeze basin located in the Tigray highlands was among the major basins of Ethiopia that has got much attention from researchers. However, most of the previous studies were plot-scale, or small-scale at small-watershed; and were fragmented. Recently, majority of the sub-basin and basin-based soil erosion assessments studies are conducted in Blue Nile Basin (Balabathina et al., 2020; Duguma, 2022; Getnet & Mulu, 2021; Kebede et al., 2021; Liu et al., 2020; Sinshaw et al., 2021), and Rift Valley Basin (Dananto et al., 2022; Mathewos et al., 2023; Tamire et al., 2022; G. Taye et al., 2023; Wolde et al., 2023; Yirgu, 2022), while data on soil erosion status in the Tekeze River basin in Waghimra administrative zone is scarce. Since the basin is home to millions of rural farmers whose economy mainly depends on rain-fed agriculture, estimating soil erosion rates and identifying erosion hotspot areas at basin level is critical for land and water resource management. Moreover, this basin is ecologically and historically vulnerable to soil erosion due to degraded forest cover, high population pressure, and complex topography that aggravate soil erosion.

According to Karydas et al. (2014) more than 80 erosion models have been developed for different purposes in half a century. Among those models, Universal Soil Loss Equation (USLE, (Wischmeier & Smith, 1978)), Modified Universal Soil Loss Equation (MUSLE, (Williams & Berndt, 1977)), European Soil Erosion Model (EUROSEM, (Morgan et al., 1998)), and Water Erosion Prediction Project (WEPP, (Flanagan et al., 2001)) are commonly preferred by researcher around the world. Above all, USLE and its revised version; RUSLE (Renard et al., 1997) are the most frequently used models in soil erosion studies (Panagos et al., 2017; Panos Panagos, Borrelli, Meusburger, et al., 2015). RUSLE is used to estimate annual average soil loss rate by accounting for rainfall erosivity, soil erodibility, slope, land use, and land management attributes (Renard et al., 1997; Wischmeier & Smith, 1978). Since soil erosion assessment as well as sustainable land and water management are increasingly requiring big-data-driven policymaking and management strategies; Remote sensing (RS) and Geographic Information System (GIS) tools are facilitating the development of soil erosion models (Hagras, 2023; Karydas & Panagos, 2018; Ugese et al., 2022). However, RS and GIS based soil erosion models require extensive field soil data collection, which is expensive and time-consuming constraining soil erosion assessment for present priority use. Furthermore, the increasingly available high-resolution gridded soil and other vegetation-related data are not well utilized to estimate soil loss rates (Balabathina et al., 2020).

GEE has recently become a popular cloud-computing platform for retrieving and analyzing geospatial data (Gorelick et al., 2017; Kumar & Mutanga, 2018). GEE offers cutting-edge technologies and unrestricted access to various remote sensing data, fostering the formation of transformative research issues. GEE has been used for a variety of applications, such as drought assessment (Fentaw et al., 2023; Sazib et al., 2018) and land use-land cover change (LULCC) and vegetation mapping (Aghababaei et al., 2021; Tsai et al., 2018; Wu et al., 2020). However, there are very few attempts to estimate soil loss estimation through the RUSLE-GIS-GEE framework by integrating ArcGIS and GEE interface (Petito et al., 2022), for example, studies by Elnashar et al. (2021) and Wang and Zhao, (2020). Implementing RUSLE in the GEE environment minimizes data filtering and image correction time. It facilitates accurate estimation of soil erosion at global, regional, and watershed scales by increasing readily available soil, precipitation, and topographic variables (Elnashar et al., 2021). Using common datasets in the GEE could also help produce comparable results among different studies by minimizing data-related errors and uncertainties. The increasing availability of open data sources, for example, Multi-Error-Removed Improved-Terrain (MERIT) Hydrograph, SoilGrids250m, and high-resolution sentinel images in GEE have also increased the suitability of this cloud-based platform for soil erosion studies. Particularly time-series data management for Normalized difference vegetation index (NDVI) and spatio-temporal rainfall analysis could be much easier in the GEE environment. Furthermore, integrating the classification algorithm, primarily the RF algorithm, could improve land cover classification for RUSLE.

Methodologically, this study aims to contribute to soil erosion assessment based on RUSLE-GEE framework. In addition, the study applied the upslope contributing area approach in order to derive the slope length (L) factor. This approach is more appropriate in basin-based studies because the upstream contributing area is a more determinate factor than slope length in those areas (Desmet & Govers, 1996; Panagos, et al., 2015; Tamene et al., 2017). In addition, most of the available studies in Ethiopia used LULC as a proxy measurement for the C-factor. However, in semi-arid and arid land areas, land cover classification is complicated due to the similarity of reflectance from the different LULCs. In these cases, NDVI is decisive in differentiating surface reflectance. Furthermore, the current study fills the gap in the LULC classification system by implementing RF algorithm and adding 5 Axillary data (NDVI, Normalized difference witness index (NDWI), Tesseled Cap indices, slope and elevation) to achieve higher accuracy.

Therefore, the overall objective of this study was to provide an up-to-date basin level soil loss severity map and implication of estimated soil loss severity for suitable land management practices in the upper Tekeze basin using RUSLE–GEE framework. The specific objectives were to: 1) estimate and map the extent and severity of soil loss by water erosion in the Upper Tekeze Basin, 2) analyse soil loss estimates in relation to land cover types and agroecological zones of the basin, and 3) identify soil erosion hotspot areas of the basin for watershed management interventions.

Since land management practices depend on land cover types and agroecology (Fenta et al., 2021), the result from this study can solve the scarcity of soil loss data as well as help land degradation control and land resources management practices by raising awareness among policy makers and land managers on the extent and severity of soil loss by water erosion. The result could also serve as feedback for the long-term conservation works implemented in the basin over the past three decades.

5. 2. Methods and Datasets

5.2.1. Study Area Description

Tekeze River is one of the major tributaries of the Nile River. The river originates from the highlands of North Wollo, from Mount Abune Yosef, drains to Waghimra, Tigray, and finally enters Sudan to join the Nile River. Tekeze river basin is situated in the north-western part of Ethiopia and forms the most northern part of the Nile Basin within Ethiopia. The basin covers about 66,541 km^2, extends from 35.87º to 39.87º East, and 11.52° to 14.8° North (Tesfaye et al., 2019). The basin is surrounded by the Blue Nile (Abay), Angereb and Mereb Rivers, and the Afar Rift escarpment. The current study is conducted on the river's upper basin in Waghimra Administrative Zone. Geographically the study area extends from 12.11 to 13.13^0 N latitude and 38.40^0 to 39.30^0 E longitude (Fig. 5.1). The study area includes 4 rural administrative districts in Waghimra zone, namely Gazgibla, Sekota Zurya, Zquala, and Tsagbji. In this part of the basin, there exists very diverse and rugged topography. While the altitude of Tekeze basin in Ethiopia ranges from 500 m in its western lowlands to over 4600 m in the central highlands, in the current study district, the elevations range from 1021 to 3880 m above sea level (Fig. 5.1). Based on Hurni's (1998) agroecological classification which considers elevation, three different agroecological zones dominate the study area. The *Kolla* agroecological zone (warm, semiarid lowlands; covering 17.5%), followed by Weyna-dega (cool, humid highlands; covering 68%), and Dega (temperate cool sub-humid highlands; covering 14.5% of the study area). Most of the study area is semi-arid and arid according to the United Nations Environment Programme (UNEP) aridity classification (Fentaw et al., 2023). While the northern and northeastern part of the basin is dry sub-humid and non-dryland, the central and northern holds semi-arid and arid land characteristics.

Unimodal and erratic rainfall patterns characterize rainfall in Waghimra zone. The basin receives much of its annual rainfall from June to September (locally known as "*Kiremt*") when the Inter Tropical Convergence Zone (ITCZ) is located north of Ethiopia (Hagos et al., 2015). This rainy season contributes over 70% of the annual precipitation in north and northwest Ethiopia, including in the Waghimra zone. While the annual rainfall of the Tekeze basin reaches up to 2000 mm in the Ras Dashen Mountains (Hagos et al., 2015), it is less than 1000 mm in the upper river basin in the Waghimra administrative zone (Fig. 5.2).

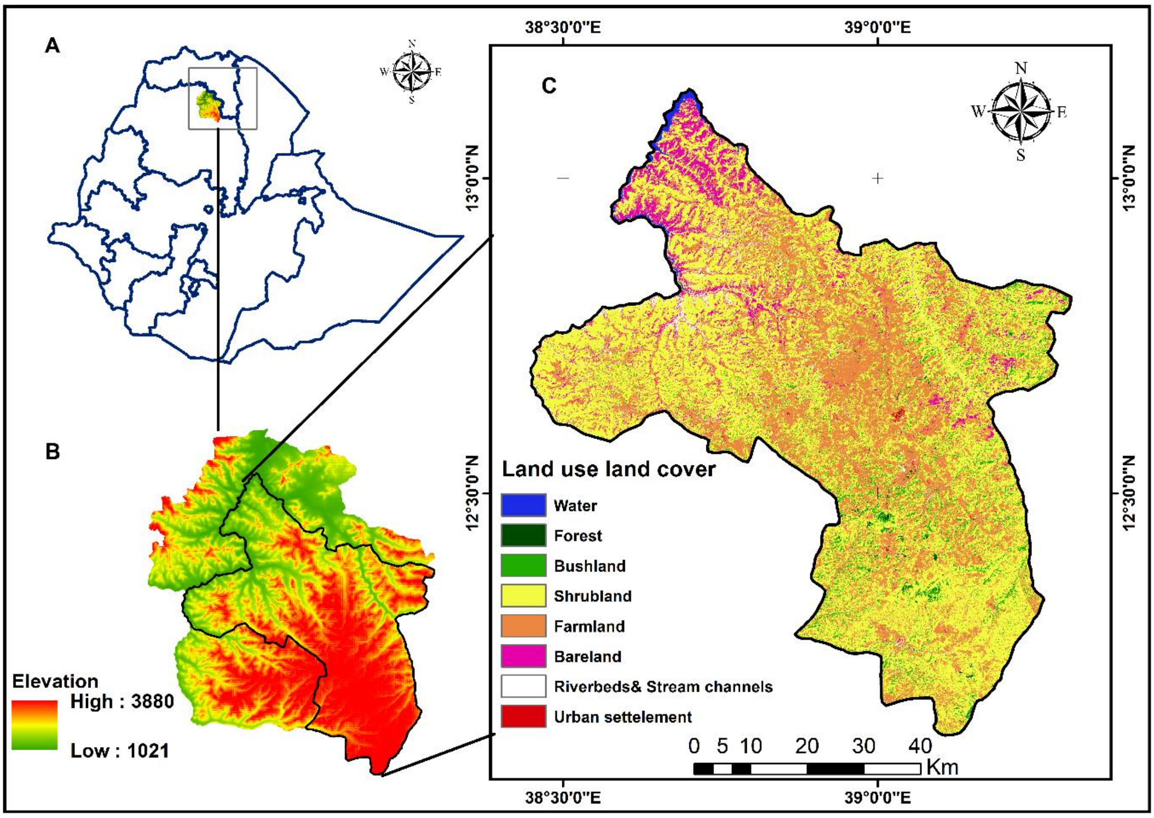


Fig. 5.1. Location of the study area: a) in Ethiopia, b) in Waghimra Adminstrative Zone c) studied sub-basin showing LULC

In almost all parts of the Tekeze basin, the summer (*Kiremt)* rain ceases around the end of August. The mid and high-altitude areas receive rainfall from late June to early September. However, rainfall distribution of the lowland part extends from early July to mid of August. About 63% of the annual rainfall is in July and August (Fentaw et al., 2023) (Fig. 5.3). The area's annual minimum and maximum temperatures are 12.8 °C and 29 °C, respectively (Fig. 5.2). The primary crop production system is based on the summer season.

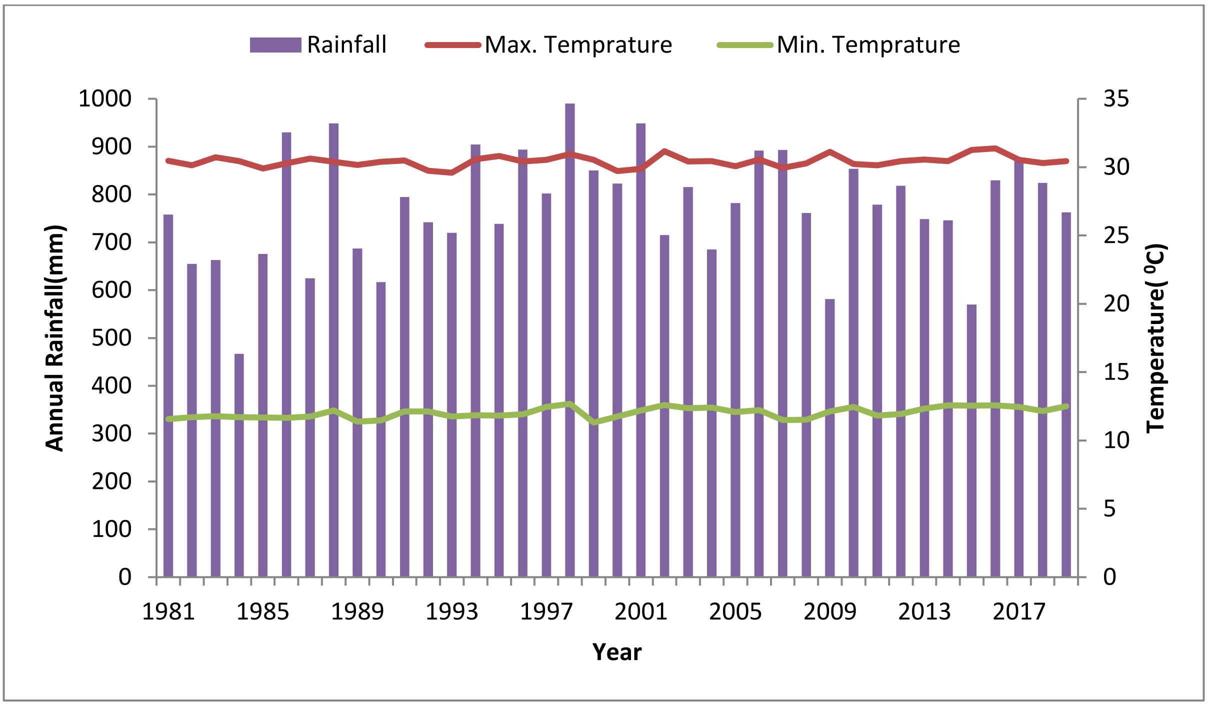


Fig. 5.2. Annual rainfall, minimum and maximum temperature time series in the study area from 1981 to 2021 (derived from monthly CHIRPS-v.2)

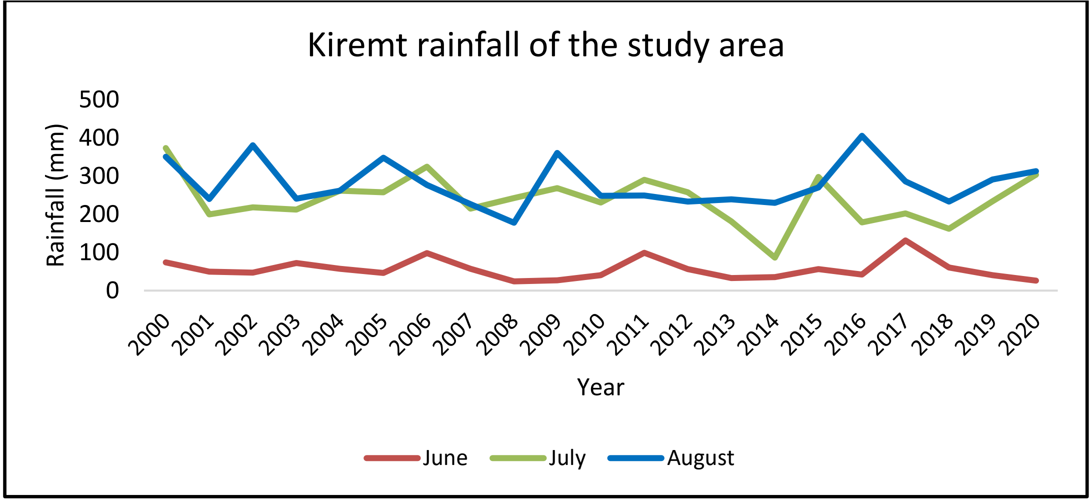


Fig. 5.3. Seasonal (Kiremt or Summar) rainfall time series in the study area from 1981 to 2021 (derived from monthly CHIRPS-v.2)

Over 90 percent of households throughout the Wag-himra Zone live on smallholder farming with landholdings of less than one hectare. The agricultural activities are rain-fed, with the main harvest from September to November. Farmers produce mainly cereals (sorghum, teff, barley, and wheat), pulses, and vegetables. The region is characterized by severe land degradation, climate variability, and high population density (Hermans-Neumann et al., 2017). The zone has been one of the most drought-affected areas in the past. High vulnerability to drought and famine, growing population pressure, and land degradation have affected agricultural production.

5.2.2 Datasets

Data used in this study includes i) Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) precipitation, ii) SoilGrids data, iii) LULC data, iv) NDVI, and v) Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM). The general overview of flow of the methology applied to assess soil erosion by water in RUSLE–GEE framework is depicted on Fig. 5.3. Detailed description of the different data used in the study is presented in the following subsections.

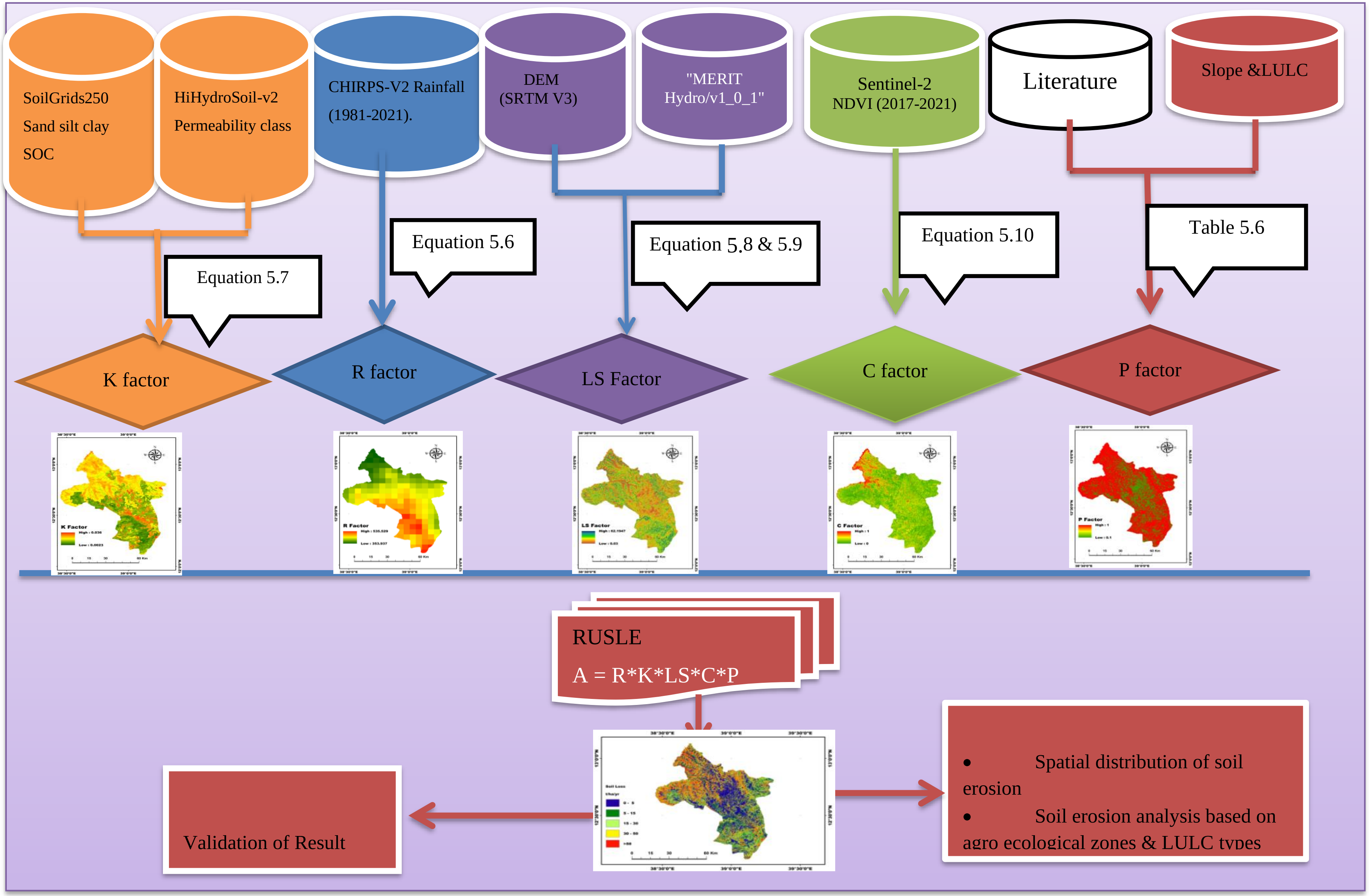


Fig. 5.4. Schematic presentation of the methodological framework of the study

5.2.2.1. Precipitation data

CHIRPS precipitation data were used to estimate the erosivity factor. CHIRPS was chosen for its long-term data availability and relatively high spatial resolutions as compared to most other satellite rainfall products**.** This product has good applicability over the Horn of Africa and has been validated in Ethiopia by Dinku et al. (2018). Moreover, in ground-station data-scarce countries such as Ethiopia, CHIRPS-v.2 is good alternative for climatological studies (Mariano et al., 2018). CHIRPS precipitation at 8-day temporal resolution and 1 km spatial resolution was obtained from GEE for 42 years (1981 to 2021). This data set was used to generate long-term mean annual rainfall in order to derive R-factor.

5.2.2.2. Land Cover

LULC map (Fig. 5.4) was generated from Landsat surface reflectance images (Landsat 8 Operational land imager (OLI) sensors). LULC classification was done for the year 2021 image in order to represent the current biophysical status and observed changes after 2010 area exclosure and ecological restoration policy of Ethiopia (Mekuria et al., 2018; MoFED, 2010). The image after 2021 is less reliable to represent biophysical changes due to the war in the north Ethiopia and the damage it might caused on the land resources.

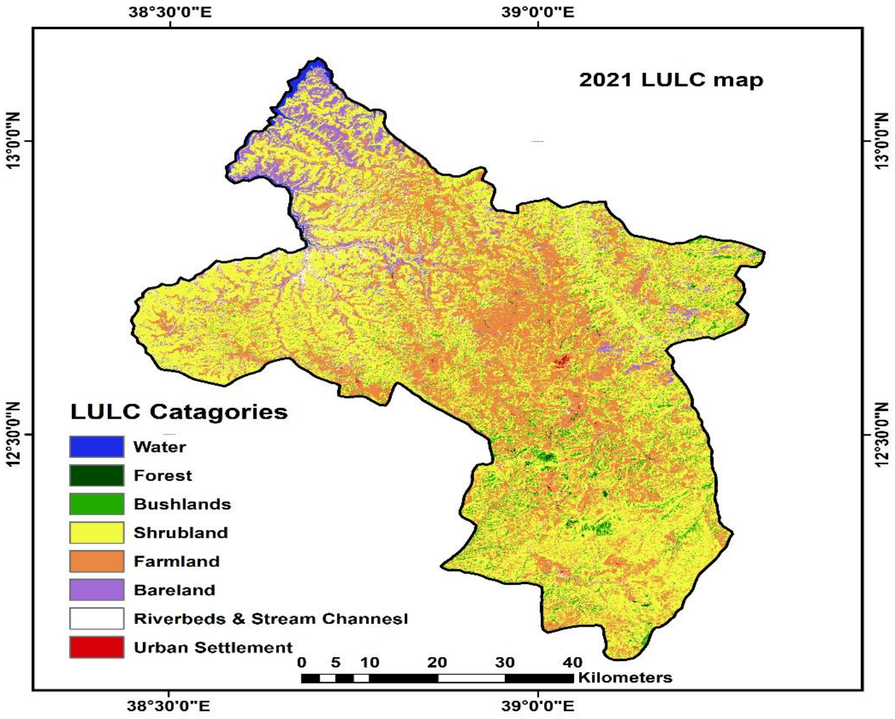


Fig. 5.5. LULC types of Tekeze sub-basin of the Waghimra zone in Amhara region, North Ethiopia

Table 5.1 presents the major LULC classes identified in the study area. LULC was classified using the RF classification algorithm in the GEE code editor. In order to improve the classification LULC classification, axillary data such as elevation, NDVI, Tasselled Cap brightness, dryness and wetness index, NDWI, and NBI (Normalized Burning Index) were utilized.

Table 5.1 Description of LULC classes in the study

No	LULC classes	Description
1	(W)	An area of land covered with surface water such lakes, and rivers.
2	(F)	Areas covered by dense natural trees mainly grow naturally in the reserved land, church compounds, riverbanks, and plantations.
3	(BL)	Areas covered with small trees, woody bushes. Sparse canopy trees and dense vegetation grown in protected areas and hillsides.
4	(ShL)	Areas covered with short shrubs and bushes with little valuable wood, usually stony with a very rugged micro relief. A mix of tiny clusters of plants or single plants dispersed on open grassing land.
5	(FrL)	Cultivated land, crop fields, and fallow lands. Rural settlements fenced with trees that are commonly found around homesteads
6	(BrL)	Areas of rock or soil with very sparse to no vegetation; large areas of sand, rock, and deserts with no to little vegetation
7	(RbSc)	Dry riverbeds, stream channels, gullies, and sandy flooded areas.
8	(UrS)	The urban settlement, residential, commercial and services, industrial, and mixed-use.

Note: W = water body, F = forest, BL= bush land, Shl= shrub land, FrL= farmland, BrL= bareland, RbSc= dry river beds and stream channels, and UrS = urban settlements

Tasselled Cap indices are used to distinguish the presence and density of green vegetation, total reflectance, and soil moisture (Qu et al., 2021). The accuracy evaluation (Table 5.2) was performed using indices including the user's accuracy (UA), producer's accuracy (PA), overall accuracy (OA), and kappa coefficient (Fonte et al., 2020a; Sharma et al., 2018). These accuracy indices are calculated by constructing confusion matrix using GEE syntax. The GEE inbuilt code for construction of error matrix and calculation of LULC accuracy was done following Stehman. (1997). Eqs (5.1, 5.2 and 5.3), presents the calculations of UA, PA, and OA, respectively;

$$\mathbf{UA}_{\boldsymbol{i}} = \frac{\boldsymbol{C_{ii}}}{\sum_{k=1}^{n} \boldsymbol{C_{ik}}} \tag{5.1}$$

$$\boldsymbol{PA_J} = \frac{\mathbf{C_{jj}}}{\sum_{\mathbf{k=1}}^{\mathbf{n}} \mathbf{C_{kj}}} \tag{5.2}$$

$$\boldsymbol{OA} = \frac{\sum_{\mathbf{k=1}}^{\mathbf{n}} \mathbf{C_{kk}}}{\mathbf{n}} \tag{5.3}$$

Where c_{ij} = the value of the cell in row i and column j in the confusion matrix; n = the number of classes in the map.

The kappa coefficient was estimated using Eq. 5.4.

$$\mathbf{K} = \frac{\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+}.x_{+i}}{N^2 - \sum_{i=1}^{r} x_{i+}.x_{i+}} \qquad (5.4)$$

Where N = total number of pixels used in the matrix, r = number of classes in the matrix, x_{ii} = correctly classified pixels in the matrix, x_{i+} = sum of pixels described in ith row, x_{+i} = sum of pixels described in ith column.

Table 5.2 shows the details of the accuracy evaluation of the RF classification. The classified map was obtained after the RF algorithm achieved high accuracy, 0.88 and 0.82 overall accuracy and Kappa values, respectively. The final classified map is shown in Fig. 5.4. This LULC map was used to identify croplands and other LULC classes for the purpose of support practice (P) factor mapping and for aggregation of erosion rate in different LULC classes.

Table 5.2 Accuracy of the RF classification algorithm

Year		LULC classes									
	Accuracy	W	F	BL	Shl	FrL	BrL	RbSc	UrS	OA	Kappa
2021	UA	1	0.74	0.82	0.84	0.91	0.86	0.91	1	0.88	0.82
	PA	0.93	0.81	0.85	0.86	0.90	0.91	0.89	0.82		

Note: AU= user's accuracy, PA = producer's accuracy, OA = overall accuracy, W = water body, F = forest, BL= bush land, Shl= shrub land, FrL= farmland, BrL= bareland, RbSc= dry river beds and stream channels, and UrS = urban settlements

5.2.2.3. Soil

The most recent and improved version of the 250 m spatial resolution SoilGrids250m dataset developed by International Soil Reference and Information Centre (ISRIC) (Hengl et al., 2017) was used for soil erodability estimation. The SoilGrids250m data is generated based on machine-learning methods including RF, gradient boosting, and multinomial logistic regression. Geo-referenced soil profile data generated by World Soil Information Services (WSIS) have been used for the prediction of SoilGrids250m data (Hengl et al., 2017). Previous studies have used this product for RUSLE studies (Elnashar et al., 2021; Ewunetu et al., 2021b; Fenta et al., 2021).

5.2.2.4. Elevations and flow accumulation

The Shuttle Radar Topography Mission (SRTM V3) product was used for LS factors, slope, and elevation data. This dataset has 30 m spatial resolution and undergone a void-filling process (Farr et, al., 2007). The flow accumulation (FA) area is a relatively downslope area (pixel) where all the upstream areas are draining into. We used the openly available FA dataset of MERIT Hydrograph dataset ("MERIT/Hydro/v1_0_1") for LS factor estimation (Yamazaki et al., 2019). This dataset was initially generated from error-corrected and highly improved DEM. This data set has both flow accumulation pixel and flow contributing area as a distinct band and is freely available in GEE. After importing the data to the GEE code editor using ee.Image ("MERIT/Hydro/v1_0_1") script, its resolution has been rescaled from a 90 m to a 30 m to match the SRTM V-3 30 m DEM and the LULC map. The rest of the LS components, i.e., slope and aspect, were derived from 30 m resolution SRTM V-3 available in GEE.

5.2.2.5. Vegetation

The NDVI for C factor was computed from a cloud-masked sentinel that has been masked for water, clouds, heavy aerosols, and cloud shadows. This product is provided at 10 m spatial resolution. We used the mean NDVI of the basin from 2017 to 2021. The baseline date is taken based on data availability of the Sentinel collection ('COPERNICUS/S2_SR').

5.2.3 Methods of Soil Loss Estimation Using RUSLE-GEE

Summary of data type, data source, and processing software for estimating RUSLE parameters presented in Table 5.3. RUSLE is an empirical model that estimates the long-term average soil loss rate by taking into account six factors that affect soil erosion: rainfall erosivity, soil erodibility, slope length and steepness, cover management, and conservation practices (Renard et al., 1997; Wischmeier & Smith, 1978). RUSLE has been very popular mainly for its easy integration with GIS. This study uses GEE, an open-source platform for analyzing geospatial data to estimate parameters of RUSLE and soil loss rates. GEE has been used worldwide for retrieving and processing earth observation data.

Table 5.3 Summary of data type, data source, and processing software for estimating RUSLE parameters

Parameters	Input data	Source and processing environment
R	CHIRPS-V2 rainfall data 1 km Spatial resolution for the past 42 years (1981-2021)	Obtained from GEE datasets using Javascript code ee.ImageCollection ('UCSB-CHG/CHIRPS/PENTAD')
K	SoilGrids250m Soil organic matter, soil textural class, and soil bulk density data HiHydroSoilv2_0 (Simons et al., 2020) Permeability class, and Hydrologic group and saturated hydraulic conductivity	Filtered and computed in GEE after the data is imported from SoilGrids as (ee.Image ("projects/soilgrids-isric/--") HiHydroSoilv2_0 accessed through GEE
LS	DEM: SRTM V3 30 m resolution Flow accumulation: MERIT Hydrograph dataset	STRM DEM is freely available in GEE and imported as (ee.Image ("USGS/SRTMGL1_003") MERIT Hydrograph dataset is available in GEE and imported as ee.Image ("MERIT/Hydro/v1_0_1")
C	NDVI from sentinel collections	Accessed and processed in GEE
P	LULC and Slope data	Image accessed and processed in GEE

There is an attempt to integrate RUSLE with GEE because of the computation power of GEE and availability of geospatial data allows the estimation of RUSLE parameters. This approach is now a days mentioned as GEE-RUSLE framework (Elnashar et al., 2021; Petito et al., 2022). The popular RUSLE formula is presented in Eq. 5.5;

$$A = R.K.LS.C.\ P \qquad \textbf{(5.}5)$$

Where A is annual average soil loss rate (t ha^{-1} yr^{-1}) at pixel level; R is a rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K is erodibility (t ha h (ha^{-1} MJ^{-1} mm^{-1})); LS factor is a dimensionless topographic factor accounting slope length (L) and slope steepness (S). C is the land cover factor, and P is a factor for erosion control support practice.

Derivation of parameters and retrieval of all the datasets were carried out in GEE (Fig. 5.3) and most of the model's input parameters were adjusted for the study area’s specific context. The details of each parameter are presented in the following subsections.

5.2.3.1 Rainfall erosivity factor (R)

The rainfall erosivity factor (R) measures the power of rainfall to cause soil erosion. The major factors which cause soil erosion by causing detachment of particles are rainfall amount and intensity (Panagos et al., 2017; Wischmeier & Smith, 1958). Rainfall erosivity can be calculated based on kinetic energy (E) and the maximum 30-minute rainfall intensity (Wischmeier & Smith, 1958, 1978). Although several formulas are suggested by different researchers (Ghosal & Das Bhattacharya, 2020) to calculate rainfall erosivity, this study adopted Eq. 5.6 developed by Hurni (1985), considering the Ethiopian highland arid and semi-arid region where rainfall is concentrated in a few months while the rest of the year experience deficient rainfall. Previously the equation has been used by several studies in Ethiopia (Ewunetu et al., 2021; Tadesse & Tefera, 2021; Tamene et al., 2017; Wolde et al., 2023).

$$R = -8.12 + 0.562(Pa) \tag{5.6}$$

R is rainfall erosivity in (MJ mm ha^{-1} h^{-1} yr^{-1}), and Pa is long-term mean annual rainfall (mm). We used 42 years (1981 to 2021) of annual rainfall for deriving the R factor.

5.2.3.2 Soil erodibility factor (K factor)

The K-factor represents the erodability of soil particles by water. The level of resistance of soil particles to erosion is determined by the soil's physical and chemical properties, including organic matter, texture, structure, and permeability (Renard et al., 1997; Wischmeier & Smith, 1978). The significant methodological variation of RUSLE application globally comes from the presence of several equations to estimate K factor (Panagos et al., 2017).

Scholars have developed different formulas to determine soil erodibility. These are mainly based on parameters such as soil grain size and the degree of saturation (Dangler & El-Swaify, 1976), particle size, amount of organic matter content, molecular bonding, structural class, and the rate of permeability (Foster et al., 1981; Wischmeier & Smith, 1978), and soil color (Hurni, 1985). In this study, we applied a model that considers the particle size, organic matter, structural class, and rate of permeability developed by Wischmeier and Smith (1978) and adopted by Renard et al. (1997). The formula is presented in Eq. 5.7.

$$\mathbf{K} = \left[\frac{2.1*10^{-4} * \mathrm{M}^{1.14}(12-\mathrm{OM})+3.25(\mathrm{S}-2)+3.5(\mathrm{P}-3)}{100}\right] * \mathbf{0.1317} \qquad (5.7)$$

Where M is the particle size parameter and is estimated as $(\mathbf{silt}_{\%} + \mathbf{very\ fine\ sand}_{\%}) * (\mathbf{100} - \mathbf{clay}_{\%})$, OM is th**e** organic matter content (%), S is the soil structure code, P is the soil permeability class, and 0.1317 is a factor to convert K unit from US metric system to the international metric system unit. Not all the required data for Eq. 5.7 were directly available in SoilGrids250m dataset, for example, there is no very fine sand fraction in the dataset layer, and we estimated the very fine sand fraction as 20% of the sand fraction following Panagos et al. (2014). The upper limit of very fine sand plus silt contents was set to 70%, and the maximum limit of OM was set to 4% to prevent an underestimation of K values following Wischmeier and Smith, (1978).

5.2.3.3 LS Factor

LS is a measure of the topographic effect in the RUSLE model. It is a function of two components, slope length (L) and slope steepness factor (S) (Renard et al., 1997; Wischmeier & Smith, 1978). Slope length is the horizontal distance from the origin of the erosion to the point where the slope gradient decreases and overland flow concentrates. S factor is also the effect of slope gradient on soil erosion by water. Different equations are available to calculate LS factor (Wischmeier & Smith, 1978). For this study, a more explained formula based on the contributing area concept has been used. In order to measure the slope length (L), the upslope contributing areas is preferred over the combined slope-length approach since the upstream area of a pixel is the key determinant factor of runoff to a given point (Desmet & Govers, 1996; Tamene et al., 2017). The techniques of calculating L factor were given by Desmet and Govers, (1996) as presented in Eq. 5.8.

$$\boldsymbol{L_{ij}} = \frac{\left(A_{ij}+D^{2}\right)^{m+1} - \left(A_{j,j-in}\right)^{m+1}}{D^{m+2} * \left(x_{ij}{}^{m}\right) * 22.13^{m}} \qquad 5.8)$$

where; Ai,j−in is contributing area to the grid cell (i, j) in m², D is the grid cell size (30 m) , $\boldsymbol{X_{i,j}^{m}} = \boldsymbol{sina_{i,j}} + \boldsymbol{cosa_{i,j}}$, $\boldsymbol{a_{i,j}}$ represents the aspect of the cell (pixel).

where m (Eq. 8.1) is related to β (Eq. 8.2), the ratio of the rill to interill erosion suggested by (Foster et al., 1977) and later adopted by (Renard et al., 1997);

$$\boldsymbol{m} = \frac{\beta}{\beta+\beta} \qquad (5.8.1)$$

and $$\boldsymbol{\beta} = \frac{sin\beta/0.896}{3.0(sin\beta)^{0.8}+0.56} \qquad (5.8.2)$$

Where θ is the slope angle in degrees.

In order to solve the error related to the overestimation of soil erosion in larger streams and make an ideal erosion estimate over extremely low-laying areas, we have limited the upslope contributing area to 4000 m^2 (which is almost equal to 4.5 pixels) as suggested by Zhang et al. (2017). In this study, limiting the upslope contributing area to 4000 m^2 has sustainably decreased the mean soil loss from ca. 195 to 25.5 t ha^{-1} yr^{-1}.

In order to estimate the slope steepness (S) factor**,** the original formula from McCool et al., (1987) and later Renard et al., (1997) adopted an algorithm for the S-factor estimation based on two slope gradient intervals (slope < 0.09 and slope > 0.09) (Eqs. (5.9.1 & 5.9.2)) as follow:

$S = 10.8 \times \sin \theta + 0.03$, where slope gradient < 0.09 (5.9.1)

$S = 16.8 \times \sin \theta - 0.5$, for slope gradient ≥ 0.09 (5.9.2)

Where θ is the slope angle in degree.

However, due to the limitation of this method in estimating S in steeper slopes (>10 degrees) and due to the evidence that the S-factor calculated using this method is lower by around 20% (B. Liu et al., 2002; Panos Panagos, Borrelli, & Meusburger, 2015), we used the method of Liu et al.,(2002) to account for slope gradient effect greater than 10^0 (Eq. (5.9.3)). This S factor calculation method has been applied by previous studies (Elnashar et al., 2021).

$S = 21.91 \times \sin \theta - 0.96$ (5.9.3)

5.2.3.4 Cover management factor (C)

The cover management factor (C) represents the effects of vegetation cover on soil loss rates. The cover management factor is the dimensionless parameters of the RUSLE model. The cover and management factor is defined as the proportion of soil loss from land with particular vegetation (Wischmeier & Smith, 1978). C factor can be changed over time and has a significant role in soil erosion management planning. Land cover change has the most substantial influence on the C-factor, leading to a significant increase in the C-factor and soil loss. Other studies in Ethiopia used land cover as a proxy measurement for the C-factor (Eniyew et al., 2021; Kebede et al., 2021) by assigning values from 0 in covered land surface to 1 in bareland. However, NDVI, which helps to assess the actual ground vegetation cover in every LULC type, can quickly assess the C factor (Thakuriah, 2023). Several empirical studies have proved that NDVI is a good measure of cover management factors, particularly in large-scale soil loss assessment studies (Elnashar et al., 2021; Thakuriah, 2023).

For this study, a C-factor map of the basin was generated based on the following empirical relationship of NDVI and C factor (Eq. 5.10) (Van der Knijff et al., 2000).

$$C = \exp\left(-\alpha\, x\, \frac{NDVI}{\beta - NDVI}\right) \quad (5.10)$$

where α and β determine the relationship between NDVI and C factors, and value of 2 and 1 was assigned for them, respectively, based on Van der Knijff et al. (2000). This method of C estimation has been used by (Balabathina et al., 2020; Elnashar et al., 2021; Hagras, 2023; Sinshaw et al., 2021; Thakuriah, 2023). The lower C factor values close to 0, represent well-protected soil, while the value approaching 1 is for bare surface.

5.2.3.5 Support practice factor (P)

The P in RUSLE is a human-made practice to reduce soil erosion by water and designate the effect of soil conservation and management efforts made to overcome soil erosion and runoff (Eniyew et al., 2021; Wischmeier & Smith, 1978). The P-factor represents the ratio of the soil loss rate in a field with a given conservation practice to the soil loss rate where no conservation practice is applied. For this study, we produced a P-factor map based on land cover, where only contour tillage on croplands was considered. In this case, P-factor values were assigned to croplands based on slope classes following the recommendation of Wischmeier and Smith, (1978). In order to derive the P factor, the land cover classes are grouped into two main classes: cropland and non-cropland (Karydas & Panagos, 2018; Tamene et al., 2017). The minimum value approaching 0.1 was assigned to cropland assuming that SWC practices were applied in all croplands. For land cover types other than cropland, a P-factor value of 1 was assigned. The classification of cropland into different slope classes and assigning values (Table 5.4) was suggested by (Wischmeier & Smith, 1978). P values proposed for agricultural and non-agricultural landscapes were used by (Elnashar et al., 2021; Fenta et al., 2019; Mathewos et al., 2023).

Table 5.4 Slope classes for assigning P value for farmlands

Slope in percentage	P factor values
0–5	0.10
5–10	0.12
10–20	0.14
20–30	0.19
30–50	0.25
50–100	0.33

5.2.4. Validation of Model Results

Model validation is an important and common task in soil loss assessment studies. Validating result with field or plot-based data is one and preferable validation technique, however field measured soil loss rate data is scarce in our study area for this purpose. Furthermore, comparison of our result with field or plot scale data, or with averaged soil loss rates from large geographical region may not be appropriate (Fenta et al., 2020). Due to these reasons, we followed scientific model validation by comparing our model result with previous works carried out in the study area and outside the study area. This method of model validation in soil erosion studies is commonly applied in previous studies (Gashaw et al., 2020; Kebede et al., 2021; Mathewos et al., 2023; Yesuph & Dagnew, 2019).

5.3. Results and Discussion

5.3.1 Spatial Distribution of RUSLE Parameters

This section discusses the spatial distribution of RUSLE parameters in the basin (Fig. 5.5). The parameters showed spatial variation in the study area and varying influence on the estimated soil loss rates.

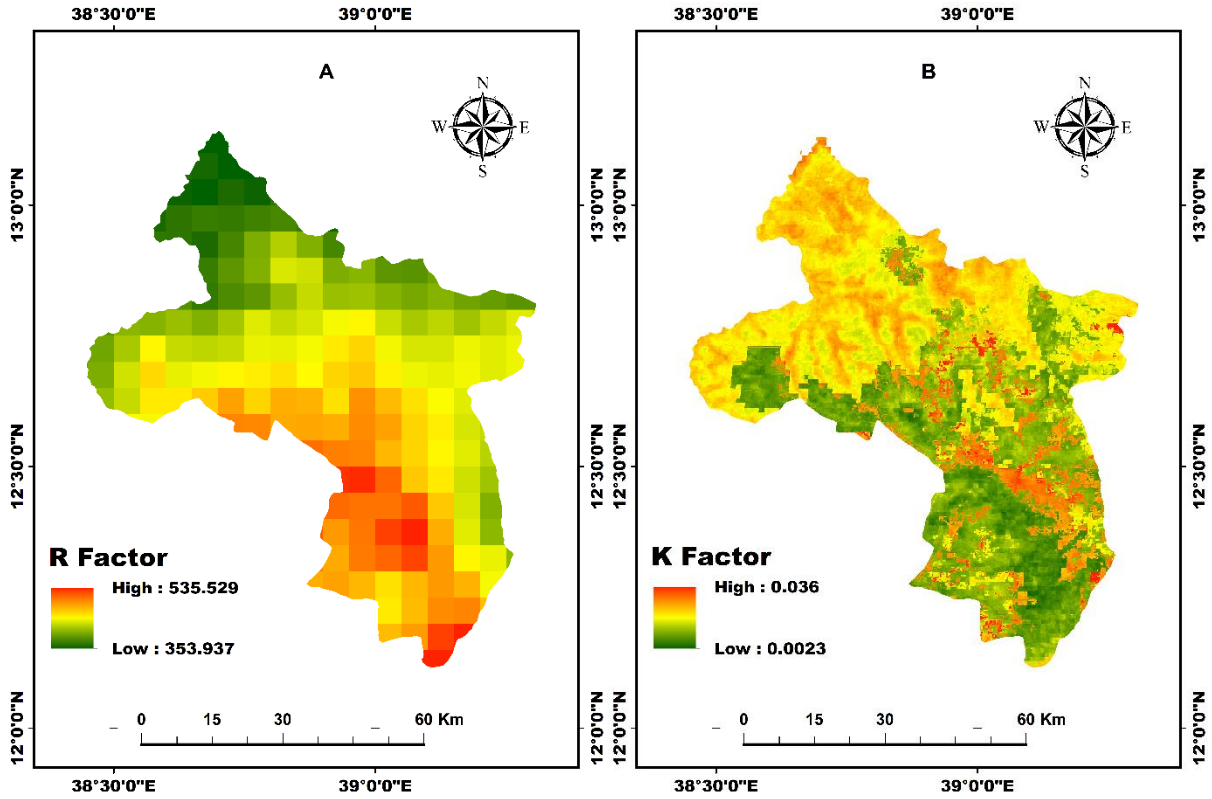
R factor ranges from 353 to 535.5 MJ mm ha^{-1} h^{-1} yr^{-1} (Fig. 5.5A). Higher erosivity is spatially distributed in the southern and southwest part of the study area. Erosivity increases to the southern part of the basin, which it's most part is highland agroecology being the origin of most of highland streams. The erosivity ranges from 535 in the highland southern part of the basin to 354 MJ mm ha^{-1} h^{-1} yr^{-1} in the northern part (Fig. 5.5A). The relatively higher R-value is associated with more rainfall power to erode the soil particles and, thus, high vulnerability to erosion

K-factor values range from 0.002315 to 0.036 t ha h (ha^{-1} MJ^{-1} mm^{-1}) (Fig. 5.5B). The mean K factor in the highland agroecology is 0.00995, while it is 0.013861 and 0.017766 in the midland and lowland agroecology, respectively. The K factor distribution was the opposite of rainfall erosivity distribution. The highest K factor values were observed in the lower part of the basin, where there is a lower erosivity factor, but coincided with higher C and P factor.

The LS-factor map is shown in Fig. 5C, and ranges from 0.03 to 62.2. Higher LS factor values are located on the basin's high slope and hillside areas (Fig. 5.5E) both in western and eastern, and the lower and upper part of the basin. The mean LS factor is 10.013. The Dega agroecology has a higher mean LS factor of 12.34. The Weyna-dega and *Kolla* agroecologies have 9.3, and 8.4, respectively.

The C-factor ranges from 0 to 1 (Fig. 5.5D). The highest C factor values are found in the northern part of the basin where there is poor vegetation cover, eroded floodplain, and bare grounds. The lower C values are distributed in the basin's central, western, and southern parts over conserved forests and managed watersheds. These areas are relatively less vulnerable to soil erosion. Pocket areas of dense forest on less human-accessible mountainsides, church forests, and area exclosures and successful cases of integrated watershed managements were found to have lower C factor values. Generally, the C factor map (Fig. 5.5D) shows that the north and north-western part of the basin exhibited higher C factor values indicating lower vegetation cover. Low rainfall and aridity of rainfall contribute to the absence of vegetation cover in this part of the study area. The lower C factors are located in the southern highland of the basin. This part of the basin is where the Tekeze River and most of its tributary streams originate. In this part of the basin vegetation cover is relatively better because of relatively better annual rainfall. Despite high erodabilty factors, the area has lower C factor.

P factor is a means to measure the impact of erosion management practices on erosion rate, particularly the erosion control strategies implemented on agricultural lands. The P factor in the study area ranges from 0.1 to 1 (Fig. 5.5F) and the slope map that is used for classification of croplands by different slope class for the assignment of P factor values is shown on (Fig. 5.5E). Lower P factor is spatially distributed in the central part of the study area over the croplands. However, higher P factors area almost evenly distributed in the basin over the vast spare shrub lands and degraded wood and bush lands (Fig. 5.5F).



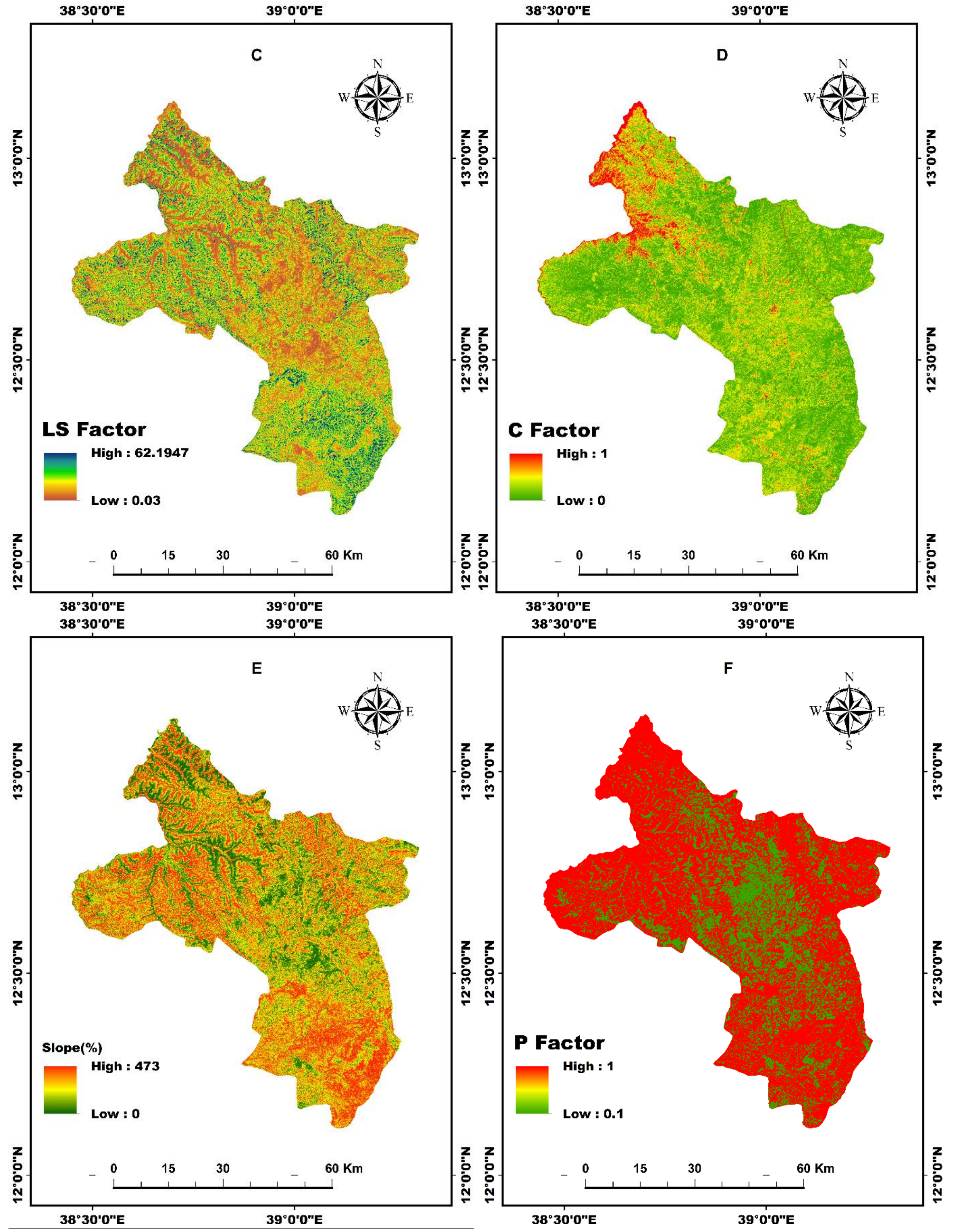


Fig. 5.6. Spatial distribution maps of RUSLE parameters; R factor (A), K factor (B), LS factor (C), C factor (D), Slope (E), P-factor (F)

5.3.2. Assessment of the Extent and Severity of Soil Loss by Water Erosion in The Upper Tekeze Basin

The spatial variability of soil erosion severity rates in the upper Tekeze Basin are presented in Fig. 5.6. Highly eroded areas are clustered in the highland regions of the basin and over the mountainous shrub lands of the northern part of the basin mainly because of steeper slopes and higher soil erodabilty (Fig. 5.5B). While the rainfall erosivity is low in the northern lowland agroecology of the basin, low cover factor combined with poor management factor make the region more prone to erosion. On the other hand, a lower soil loss rate was seen in the vast middle parts of the basin due to the lower LS factor and better cover management and support practice factors. The central midlands and the southwest part of Waghimra zone have relatively low soil erosion rate than the north and northeast part of the study area (Fig. 5.6).

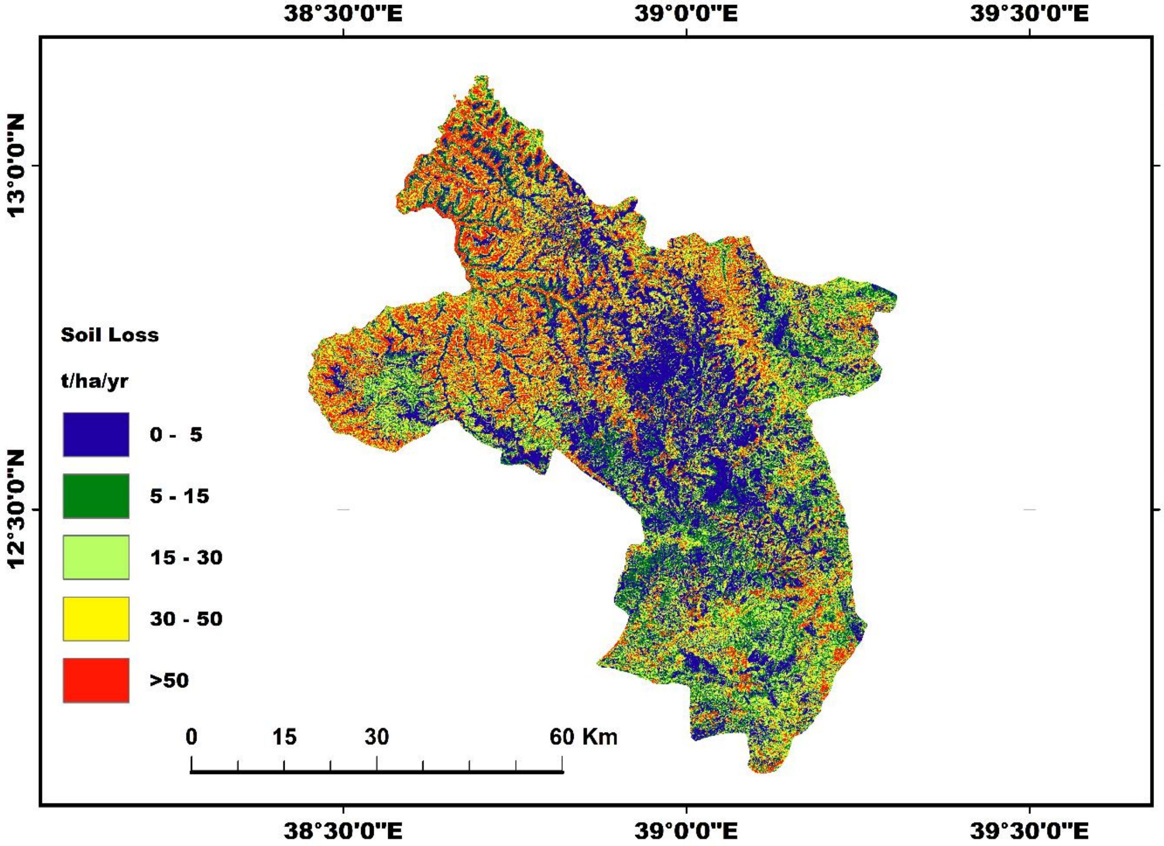


Fig. 5.7. Spatial distribution of soil loss rates severity in the upper Tekeze basin, (0-5; very slight), (5-15: slight), (15-30: moderate), (30-50: severe), (above 50: very sever)

The mean soil erosion rate in the study area is 25.46 t ha^{-1} yr^{-1}. This estimate was higher than estimates by Fenta et al., (2020) (16.9 t ha^{-1} yr^{-1}) for Ethiopian Basins. The result agrees with Sonneveld et al. (2011) estimate of mean soil loss rates for northwestern and central highlands of Ethiopia (more than 20 t ha^{-1} yr^{-1}). But lower than some other watershed base studies by

Yirgu et al. (2022) (30.6 t ha^{-1} yr^{-1}) for Upper Domba watershed in southern Ethiopia, and by Eniyew et al., (2021) who reported 576 t ha^{-1} yr^{-1} for Telkwonz Watershed in northwestern Ethiopia. However, since the study was conducted over a large spatial scale, basin and sub-basin scale comparison is more appropriate and meaningful. Regarding this, the estimated mean annual soil loss rate can be considered generally consistent with estimates by Elnashar et al., (2021) for the Blue Nile basin in general (39.73 t ha^{-1} yr^{-1}) and lower than, estimates for upper Blue Nile (57.98 t ha^{-1} yr^{-1}). Similarly, the result is in agreement with mean soil loss rates estimate by Haregeweyn et al., (2017) (27.5 t ha^{-1} yr^{-1}) and Fenta et al., (2021) (32.5 t ha^{-1} yr^{-1}) for upper Blue Nile basin.

We have classified the soil erosion rate into five classes; less than 5 t ha^{-1} $yr^{-\mathbf{1}}$ (very slight), 5-15 t ha^{-1} yr^{-1} (slight), 15-30 t ha^{-1} yr^{-1} (moderate), 30-50 t ha^{-1} yr^{-1} (sever) and above 50 (very severe erosion). This classification was according to soil erosion literature in Ethiopia (Haregeweyn et al., 2017).

Areas under very slight soil loss (< 5 t ha^{-1} yr^{-1}) cover 24.4% of the basin. Slight soil loss (5-15 t ha^{-1} yr^{-1}) is also observed over for 22.5% of the total basin area. Moderate soil loss rate is also seen in over 21.7% of the basin. Both severe and very severe soil loss rates are observed over 31.3% of the basin (Table 5). The very slight and slight soil loss rate classes covering 47% of the basin contributed more than 9% of the total soil loss. Severe and very severe soil erosion classes contributed 25% and 47% of the total soil loss in the basin, respectively (Table 5).

The result showed that the soil erosion severity distribution in terms of area coverage of the basin is gradually decreasing from 24.4% very slight to 22.5% slight, 21.7% moderate, 16.1% severe and then to 15.2% very severe. However, the more significant part of the total soil loss in the basin was generated from the moderate, severe and very severe erosion classes contributing 18.25, 25.06 and 47.43% of the total soil loss, respectively. The second and third contributors to the total soil loss are from severe and moderate soil erosion classes that cover 16.1 and 21.7% of the basin. The severity class distribution implies that the majority of total soil loss is generated from the 15.2% of the basin, which experiences very severe soil erosion and moderate to high erosion rates. The general pattern of the soil erosion severity distribution indicates that a high amount of soil loss rate is observed in a very large basin area. Geographically, the sight and very slight soil losses are concentrated in the middle part of the basin, with a relatively gentle slope and terraced agricultural lands. Slight erosion classes were also observed on upslope areas in highly protected watersheds (Bella-Wuleh watershed). Moderate erosions are almost evenly distributed through the basin on hilly, bare, and moderately protected area exclosures. However, the severe and very severe erosion classes are observed dominantly in the northern high-slope areas of the basin. Spares shrubs cover this part of the basin dominantly.

Table 5.5 Soil erosion severity classes and respective total soil losses in the basin

Severity classes ($t\ ha^{-1}\ yr^{-1}$)	Description	Area (Km^2)	Area (%)	Mean soil loss rates ($t\ ha^{-1}\ yr^{-1}$)	Std	Total soil loss by the class ($t\ yr^{-1}$)	Contribution to the total soil loss (%)
<5	Very slight	1122	24.4	2.13	1.24	2960612.1	2.33
5-15	Slight	1033	22.5	9.60	3.0	8779632.1	6.90
15-30	Moderate	996	21.7	22.0	4.0	23159069.78	18.25
30-50	Sever	741	16.1	38.85	5.7	31,815,573.14	25.06
>50	Very severe	700	15.2	77.80	28.8	60,195,744.64	47.43

5.3.3 Soil Erosion Analysis Viz-À-Viz Land Cover Types

The share of different LULC classes to the total soil loss in the study area is presented in Table 6. The largest share of total soil loss comes from soil erosion over shrubland, 99,950,272.9 t yr^{-1}, which counts for 79.9% of the total soil erosion from basin. The mean annual soil loss rate from this land cover class is also the highest of all land cover (34.7 $t\ ha^{-1}\ yr^{-1}$). The higher soil erosion rate over shrublands could be due to the spares vegetation and higher LS factor. The LULC classification of the basin showed that most shrublands are very sparsely distributed with bare and sandy exposed surfaces. Vegetation is dry most of the year and is highly vulnerable to soil erosion during intense rainfall. This finding was consistent with Elnashar et al., (2021), who reported that the highest erosion in the Blue Nile basin comes from shrublands. Low soil loss rate was found on farmland contribution being 4.25% to the total soil loss in the study area with mean annual soil loss rate of 3.56 $t\ ha^{-1}\ yr^{-1}$. Mean soil loss from this study is lower than reports from studies by Fenta et al., (2020,2021), Yirgu, (2022), and Haregewoyn et al., (2017). In these studies, higher mean soil loss rates were reported on cropland than other land cover types. Furthermore, reduction in cropland mean soil loss rate in this study is due to the method applied to limit the maximum contributing area while deriving L factor. This study has limited the upslope contributing area to 4000 m^{2} ⁽which is almost equal to 4.5 pixels), this has resulted lower mean soil loss rate. Besides, the study area is known for its ridged topography that hinders expansion of agricultural land. Furthermore, the most available agricultural land lies in the relatively gentle slope are with low annual rainfall, thus low erosivity. In most of the croplands, stone bunds are constructed to protect soil erosion. Besides, biological measures such as grasses and Aloe vera are common SWC mechanism (Fig. 5.7A).

Due to the relatively gentle slope of farmlands and conservation structures on them, the soil erosion rate of farmlands is lower in most of the agricultural lands. However, due to the shortage of the cultivable land, some high slope areas are being converted to cropland. In these high slope areas soil erosion is extremely high. During intense rainfall, it totally damages the crops. Fig. 5.7B shows a photo of a mountainside newly converted to farmland. The crops are eroded by soil erosion and the soil conservation works could not withstand the force of the erosion accelerated by the slope gradient and land use conversion. Forestland is also the second that contributes lower soil erosion in the study area. Forestlands have 7.2 t ha^{-1} yr^{-1} and 0.13% to the total soil loss in the study basin. Forests area located in the relatively high slope and elevation remote area where there is less human access. Rehabilitated watersheds with good forest cover are also found in this LULC category and contribute low soil erosion. However, bush and woodlands exposed to higher soil erosion (22.66 t ha^{-1} yr^{-1}). They are found over the complex topography and in areas with high LS factor. Most of the wood and bushlands are found in community-based watershed conservation sites where exclosures are currently established. Their erosion rate is not yet reduced down to the acceptable soil erosion rate.

Bare land with a mean annual soil loss rate of 31.7 t ha^{-1} yr^{-1} contributes 9% of total soil loss in the basin. Most of the bare lands are found in the lower part of the basin behind the Tekeze hydroelectric dam. The topography in this part of the basin is highly diverse, ranging from low deposition areas to high slop mountainsides. This area is constantly vulnerable to erosion, so soil development is challenged, and regeneration of vegetation cover is almost impossible.

Table 5.6 Mean soil erosion rate and total soil loss from different LULC categories

Land cover	Mean soil loss rates (t ha^{-1} yr^{-1})	Std	Total soil loss rate (t yr^{-1})	Contribution to the total soil loss (%)
Forests	7.2	10.4	147505.78	0.13
Bush and woodlands	22.66	19.65	5,763,929.86	4.6
Unprotected shrub lands	34.75	27.88	99,950,272.9	79.9
Farmland	3.56	7.78	5,316,081.33	4.25
Bare lands	31.68	34.46	11382931.34	9.0
Dry river beds and streams channels	27.6	28.93	2477398.37	2.0
Settlement areas	12.95	13.97	60320.578	0.05

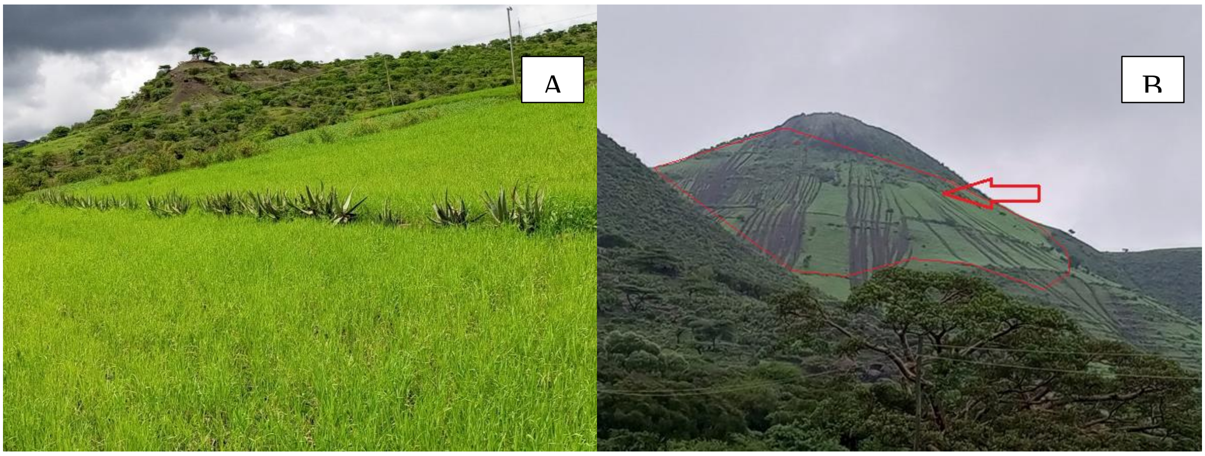


Fig. 5.8. Soil and water conservation mechanism implemented on croplands
(A: Aloe vera strip, Photo taken around Tiya village and B: farming on steep slope areas expose to sever soil erosion. Photo taken outside of Agewmariayma watershed, July, 2022).

5.3.4. Soil Erosion Analysis Viz-À-Viz Agroecological Zones

The agroecological classification of the Ethiopian farming system and ecosystem has great implications for SWC practice (Fenta et al., 2021; Hans Hurni, 1998). Soil erosion management should also consider these agroecologies since there is distinct rainfall distribution, runoff production, vegetation cover, and cropping practice. Elevation is the prime determinant of agricultural land use in Ethiopia because it influences the temperature and rainfall distribution. Generally, crop production also exhibits a distribution mosaic in Ethiopia. Some crop types are found within several zones, while others are restricted to single agroecology. This distinct crop distribution also has different runoff production, erosion vulnerability, and management requirements. In the study area, we classified the agroecology into three dominant agroecological zones. While the majority of the basin is Weyna-dega (midland) and *Kolla* (lowland), small portion is found in Dega (highland) agroecology (Table 5.7).

Table 5.7 Agroecological distribution of soil erosion risks in the upper Tekeze Basin

Agroecology	Altitude (m)	Area (km^2)	Area (%)	Mean soil loss rate ($t\ ha^{-1}\ yr^{-1}$)	Total soil loss rate ($t\ yr^{-1}$)
Dega (Highlands)	Above 2,300	668	14.54	19.8	28137689.82
Weyna-dega (Midland)	1,500- 2,300	3125	68	24.3	85877094.56
Kolla (Lowland)	below 1,500	799	17.5	37.6	28137689.82

Most of the basin (68%) is characterized by midland (Weyna-dega) agroecology. This is the part of the basin where the most extensive cropland is found. As seen in Table 5.7, the mean soil loss in this agroecology is 24.3 t ha^{-1} yr^{-1}. The Weyna-dega agroecology experienced higher mean soil loss rate than the high land agroecology. The Dega agroecology is the high slope area and the origin of the major Tekeze River and its tributaries, so one might expect higher soil loss in this zone. However, this agroecology has good vegetation cover and low soil erodabilty. The *Kolla* (lowland) agroecology, which covers 17.5% of the basin, experienced 37.6 t ha^{-1} yr^{-1} soil loss rate. This zone is characterized by high aridity, complex topography, and low rainfall. High K factor values, low vegetation cover characterize this agroecology.

5.3.5. Evaluation of Model Results by Comparing with Other Assessments

This result of the RUSLE–GEE estimate of soil erosion was compared with findings of previous studies in Ethiopia, mainly in the Tekeze basin and the Upper Blue Nile River Basin. The mean soil erosion rate from this study (25.5 t ha^{-1} yr^{-1}) is comparable with other studies in the Ethiopian highlands by Sinshaw et al.,(2021) (25.52 t ha^{-1} yr^{-1}); and by Haregeweyn et al., (2017) (27.5 t ha^{-1} yr^{-1}). Unlike these comparable reports, as presented in Table 5.8, higher estimates were also reported by some studies in different parts in Ethiopian highlands. For example, Elnashar et al., (2021) estimated 57.98 t ha^{-1} yr^{-1} erosion rate for the upper Blue Nile basin; Ewunetu et al., (2021) estimated 46 t ha^{-1} yr^{-1} for North Gojjam sub-basin of Upper Blue Nile River; and Tamene et al., (2017) estimated 45 t ha^{-1} yr^{-1} in Adikenafiz, Gerebmihiz and Laelaywukro watersheds in Nothern Ethiopia. Lower estimation of mean soil loss was also reported by Kebede et al., (2021) **(**9.1 t ha^{-1} yr^{-1}**),** and Ayalew, (2015) (13.2 t ha^{-1} yr^{-1}) for Zingin (Blue Nile) and upper Beles in the Blue Nile basin, respectively.

Besides the difference in land use management, difference in methods of estimation and datasets could result in different model results. Since the estimation was carried out in the GEE platform, different equations, and dataset for LS factor and C factor, the estimated soil loss rate is reasonable and comparable with results of previous studies, particularly with GEE-RUSLE framework and basin and sub-basin studies. Variations in time, space, assessment scales, input data, and methods followed could lead to difference in results. This is because erosion is a process with significant variation in time and space (Haregeweyn et al., 2015).

A recent review of soil erosion assessment studies in Ethiopia by Tamene et al., (2022) reported that the soil loss rate in Ethiopia varies between 0 and 220 t ha^{-1} yr^{-1}, and the national average gross soil erosion rate is estimated to be 38 t ha^{-1} yr^{-1}. Studies implementing RUSLE give the highest soil loss (51 t ha^{-1} yr^{-1}), while the field-survey approach gives the lowest (20 t ha^{-1} yr^{-1}). Compared with this report, the current study estimated 25.5 t ha^{-1} yr^{-1}, slightly higher but close to the field survey approach but lower than the country average estimation using RUSLE.

Table 5.8 Comparison of the estimated mean soil loss rates by this study (25.5 t ha⁻¹ yr⁻¹) with previous studies conducted in different basins in Ethiopia

No	Basin /watershed	Slope & topographic characteristics	Dominant LULC	Mean soil loss rates (t ha^{-1} yr^{-1})	References
1	Rib Watershed	Dominated by gentle slope	Cultivated & grasslands	25.52	(Sinshaw et al., 2021)
2	Zingin (Blue Nile)	Moderate slope	Cultivated	9.1	(Ayalew, 2015)
3	Beshillo (Blue Nile)	Dominated by high slope terrain (>30%)	Farmland & grasslands	37	(Yesuph & Dagnew, 2019)
4	Upper beles (Blue Nile Basin)	flat to very steep slope	Cultivated & Bushlands	13.2	(Kebede et al., 2021)
5	Upper Blue Nile Basin	Moderate slope	Cultivated land	27.5	(Haregeweyn et al., 2017)
6	Adikenafiz, Gerebmihiz & Laelaywukro	About 12^0 mean slope	Cultivated & grazing land	45	(Tamene et al., 2017)
7	Upper Blue Nile Basins	From low to high slope	Dominated by Shrub and cultivated	57.98	(Elnashar et al., 2021)
8	North Gojjam sub-basin (Upper Blue Nile)	Gentle to moderate slope	Cultivated land & settlement	46	(Ewunetu et al., 2021b)

However, our result is highly comparable and within the average soil erosion rate range in the sub-moist (23.6 ± 2.7 t ha^{-1} yr^{-1}) and the arid zone (28.8 ± 6.5 t ha^{-1} yr^{-1}) of Ethiopia. More importantly, the estimate from this study is highly in agreement with field experiment-based soil erosion rate in the Agewmariayam watersheds, in the current basin. Girmay et al., (2020) estimated the mean soil loss rate at 25.00 t ha^{-1} yr^{-1} in Agewmariayam watershed**.** According to this comparison, we can say that our estimation of soil erosion rate using GEE-frame work produces reasonable results that can be used as input for land and water conservation policies.

5.3.6. Erosion Hotspot Areas for Management Interventions in Soil Erosion Reduction

This study will benefit policymakers in exploring the extent and severity of soil erosion and identify hotspot areas of soil erosion in the upper basin of the Tekeze River in the Waghimra administrative zone. The spatial pattern of the soil erosion risk map (Fig. 5.6) shows that the entire basin experience from very slight to very severe erosion. However, because conservation efforts are economically expensive, it is impossible and economically inefficient to implement conservation measures in all areas that are affected by erosion. One of the aims of soil erosion assessment is to identify erosion hotspot areas and prioritize immediate conservation (Fenta et al., 2021; Haregeweyn et al., 2017). The soil erosion severity analysis in this study indicated that about 36.9% of the basin is within the acceptable soil loss tolerance. Soil loss tolerance is the maximum tolerable soil erosion rate that that will allows crop productivity to be sustained and does not significantly affect land productivity (Hans Hurni, 1985; Wischmeier & Smith, 1978). The tolerable mean annual soil loss of 10 t ha^{-1} yr^{-1} was used to evaluate the potential risk of soil erosion in the basin following previous studies in the highland of Ethiopia and the Blue Nile River basin (e.g., (Elnashar et al., 2021; Fenta et al., 2020, 2021; Girmay et al., 2020)). According to this threshold, 36.9% of the study area affected is exposed to mean annual soil erosion of less than 10 t ha^{-1} yr^{-1} which can be considered as acceptable soil erosion rate. The remaining 63% of the study area, which is affected by moderate, severe, and very severe erosion, is above the tolerable soil erosion rate, contributing 90.74% of the total soil erosion, and hence needs an immediate soil conservation measure in order to halt this severe and very severe erosion rate. The very severe soil erosion rate alone, which covers 15.2% of the basin, contributes 47.43% to the total soil loss. This area is very critical and a hotspot of very severe erosion in the basin. Therefore, land management intervention should prioritize this area to reduce severe erosion. Moderate and severe erosion contribute 18.25 and 25.06% of soil loss, respectively. The government and any natural resource conservation stakeholder, including policymakers, should immediately consider these hotspot areas for soil conservation measures. Over the past two decades, watershed management practices such as the construction of stone bunds and the establishment of exclosures have been implemented in the semi-arid highlands of northern Ethiopia to reduce soil erosion (Fenta et al., 2016). Regarding the effectiveness of the implemented conservation measures, studies in the highland of Ethiopia reported that physical, biological and integrated conservation measures are very effective (Gebrernichael et al., 2005; J. Nyssen et al., 2009). In the northern highlands of Ethiopia, there is ample evidence that land management measures such as stone bunds, soil trenches, check dams afforestation, and areas exclosures are effective practices for controlling runoff and soil erosion (Fenta et al., 2021; Teka et al., 2020). For example, Taye et al., (2018) showed that stone bunds, trenches, and stone bunds with trenches in rangeland and cropland are successful protection measures. Similarly, Ebabu et al., (2019) demonstrated that soil bunds, combined with grass enclosure with trenches effectively reducing soil loss and runoff in the Upper Blue Nile Basin. Fenta et al.,(2021) reported that land cover and agroecology-specific land management practices such as level bunds, graded bunds, trenches, and exclosures could reduce the national mean soil loss rate by about 68%. A study in north-west part of Ethiopia (Mustefa et al., 2020) reported that implementing conservation practices such as contour ploughing with terracing could reduce the mean annual soil erosion by 62%.

For the identified erosion hotspot areas in the study area, suitable land management practices, including soil or stone bunds and exclosures should be implemented to minimize soil erosion. Mainly focus should be made on the vast shrublands vulnerable to natural and human-made degradation. SWC practices have been implemented in Waghimra administrative zone for the last two decades. However, the effectiveness of these interventions varies from place to place. Substantial portion of the shrublands is open to human and animal intervention, hence vulnerable to degradation and overgrazing. Combined with the frequent drought and surface aridity, vegetation cover is unable to regenerate and protect soil from erosion. Despite challenges that hinder the effectiveness of soil conservation measures, few watersheds that achieve soil erosion under a tolerable threshold show how erosion management could be possible in the upper Tekeze basin. To compare and investigate the role of conservation measures in reducing soil erosion rate, we purposely selected four sub-watersheds in the basin and studied the mean soil erosion rate. We compared shrub land where there are poor erosion-controlling efforts with the managed watersheds and shrublands (Table 5.9 & Fig. 5.8A-D). The four examples of sub-watersheds are featured as follows: Bella-Wuleh (Fig. 5.8B) is under exclosure and integrated watershed management; Hamuset-Chochorba (Fig. 5.8C) is under SWC practices; Asketeam (Fig. 5.8D) is under area exclosure; while Ziquala shrubland (Fig. 5.8A) is unprotected. All areas are found in relatively similar topographic settings. Mean soil erosion rate in the unprotected shrubland is about 54.58 t ha^{-1} yr^{-1}. The most successful case in soil erosion management is Bella-Wuleh watershed, showing erosion rate of 7.5 t ha^{-1} yr^{-1}. This management practice has reduced the soil erosion rate by 86.3% from that of unprotected shrubland. In this watershed, previous study by Gebrernichael et al., (2005) has confirmed that watershed management has positively transformed the upland of Bella-wuleh watershed; evidence of increase in vegetation and water has been observed after implementation of integrated watershed management. High, low, and moderate slopes characterize the area and are an upslope area susceptible to soil erosion. However, due to the continuous effort of soil and land management, the mean soil loss has dropped to 7.5 t ha^{-1} yr^{-1} (Table 5.9 & Fig. 5.8A), which is within the range of an acceptable soil erosion rate. Similarly, in the Asketema area exclosure of mountain area, protection of the area from animal grazing and human use alone has reduced the soil erosion compared with unprotected areas. The mean soil loss is reduced to 10 t ha^{-1} yr^{-1}, and is less than its nearby unprotected mountain ridges.

Table 5.9 Comparison of protected and unprotected watersheds in terms of soil erosion rate

Sampled sub-watersheds	Conservation level	Dominant LULC	Agroecology	Mean slope (%)	Mean soil loss rate (t ha^{-1} yr^{-1})
Bella-Wuleh sub-watershed	Area exclosure & Integrated watershed management	Cultivated & woodland	Weyna-dega	25.18	7.5
Hamuset-chochorba	Area exclosure with SWC practice	Shurbland	Weyna-dega	45.73	17.2
Asketeam -area closure	Area exclosure	Wood & bushland	Dega	65.65	10
Ziquala shrubland	Unprotected	Shurbland	*Kolla*/Lowland	53.64	54.6

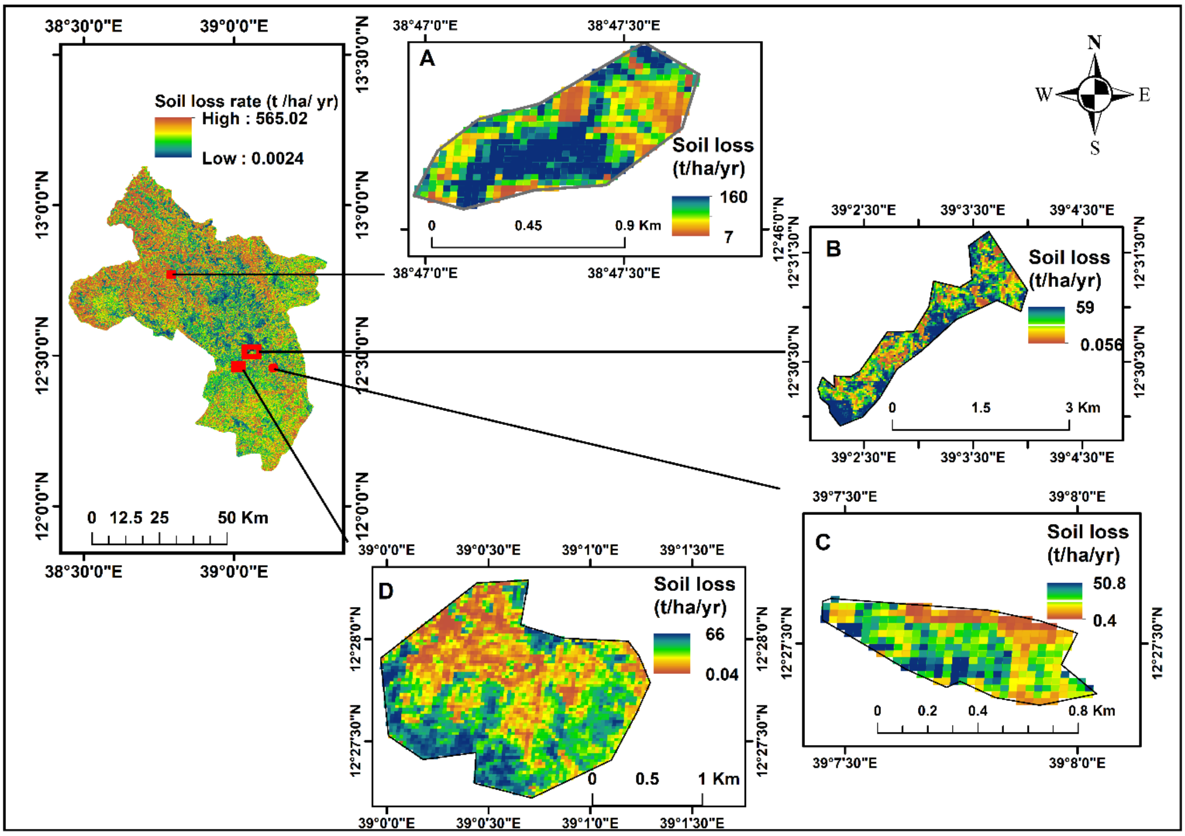


Fig. 5.9. Location of the sample sub watershed in the study area and their soil loss rates (t ha−1 yr−1) (A: Ziquala shrubland, B: Bella Wuleh sub-watershed, C: Hamuset-Chochorba, D: Asketema area exclosure)

Recent study by Fenta et al., (2021) showed that implementation of land cover and agroecology specific management practices in the upper Blue Nile and Tekeze basin would reduce total soil loss by 50%. Furthermore, managing erosion-prone areas in Dega and Weyna-dega agroecologies can lead to 70% total soil loss reduction. Watershed-scale studies in northern Tekeze basin demonstrated that implementation of soil/stone bunds and exclosures reduced soil loss (Fenta et al., 2016; Jan Nyssen et al., 2009). According to these empirical evidences and the observed erosion rate reduction over area exclosure and managed watersheds, it is clear that soil erosion reduction is possible if proper management and conservation is implemented on properly identified erosion hotspot areas. SWC structures on previously degraded shrub lands have been implemented in the study area (Fig. 5.9A). It is evident that promising results have been obtained in protecting the soil loss and helping vegetation regeneration (Fig. 5.9B).

Fig. 5.10. Soil and water conservation structure on degraded shrub lands (A: Stone bund on previously degraded shrubland, and B: Soil retention and vegetation growth along the constructed stone bunds)

5.3.7. Limitation of the Study

Validation of the model estimation in this study is carried out by comparing it with previous studies conducted in the highlands of Ethiopia. While such validation is common and possible in the literature, using measured soil loss data to validate the soil erosion rate would have been more appropriate. Furthermore, we could not get spatially comparable prior studies in the area to triangulate with the current study; the result was compared to the studies conducted by different scholars on another sub-basin of the Blue Nile in Ethiopia. In addition, these estimates form this study are on the annual time scale; however, future studies are needed on soil erosion estimation on seasonal and monthly time scales in order to identify the risk of soil erosion in the rainy seasons, as the rainfall is highly unevenly concentrated on the three (June, July, August) months in the basin. Finally, since RUSLE-GEE depend on free and open data sources, error also might arise from the lack of a very fine sand layer in the SoilGrids250m dataset. Due to the absence of very fine sand data in the SoilGrids250m dataset, we used very fine sand as 20% of the sand fraction, as suggested by (Panagos Panagos et al., 2014). Finding an alternative data source or adding the very fine sand layer to the SoilGrids250m dataset is necessary for future studies to improve the estimation of soil erosion rate in GEE.

5.4. Conclusions

As soil resource is increasingly vital with the growing food demand of the increasing world population, a practical soil erosion assessment framework is desired for conservation and management practices. This study assesses soil erosion by water using the RUSLE model in the GEE platform in the Upper Tekeze basin in Waghimra administrative zone, one of the oldest settlement areas of Northern Ethiopia. This study used all required data from GEE freely available datasets. Besides, all the computation and analysis of the RUSLE parameter and the final soil erosion statistics were performed inside GEE code editor. Our RUSLE-GEE model estimates 25.5 t ha^{-1} yr^{-1} mean annual soil loss rate in the study area. On about 1939.5 km^2 (36.9%) area of the Upper Tekeze Basin rate of soil loss by erosion is with an acceptable soil erosion rate below 10 t ha^{-1} yr^{-1}, whereas about 63% of the area showed above acceptable rates, ranging from 10 to over 50 t ha^{-1} $yr^{-1.}$ Soil loss analysis by land cover type demonstrated that the highest soil loss rates are found in sparsely vegetated shrub lands; contributing about 80% of the total soil loss of the basin. Both in terms of mean soil loss rate and contribution to the total soil loss, bare lands are the second most erosion hotspot areas in the Upper Tekeze basin. Croplands have significantly lower mean erosion rate of 3.56 t ha^{-1} yr^{-1} and contribute a lower percentage (4.25%) to the total soil loss of the basin. The result showed that about 63% of the study area requires immediate soil conservation measures. Particularly, the focus should be given to shrublands that have the highest mean soil erosion rate and significant contribution to the total soil erosion rate in the study area. Wood and bush lands located in high slope area are also among the highest vulnerable LULC classes to soil erosions that need SWC measures. Area exclosures and adoption of different soil erosion controlling mechanisms such as terracing, and stone and soil bonds on exposed shrublands have good reputability in minimizing soil erosion in the highlands of Ethiopia. Few watersheds in the study area that achieve soil erosion within the tolerable threshold show how erosion management could be possible in the climatologically harsh and topographically complex region of upper Tekeze basin. We compared shrub land where there are poor erosion-controlling efforts with the managed watersheds and shrub lands. Mean soil erosion in the unprotected shrubland was found being the highest, about 54.58 t ha^{-1} yr^{-1}. However, on managed watershed, due to the continuous effort of soil and land management, the mean soil loss has dropped within the range of the acceptable soil erosion rate. Area exclosure from animal grazing and human use has reduced the soil loss rates. Therefore, this study concludes watershed management using area exclosure and SWC practices can help to reduce soil erosion and to rehabilitate and protect the ecosystem, and also to protect croplands from sever erosion.

The study also highlighted that using RF algorism has improved land cover classification for RUSLE model; using freely available datasets in the GEE, SoilGrids250m, and high-resolution sentinel images in GEE are the greatest benefits of GEE-RUSLE framework for soil erosion studies.

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CHAPTER SIX

INTERPLAY OF SEASONAL RURAL OUT- MIGRATION AND FARMLAND MANAGEMENT: AN EXPLORATION OF THEIR LINKAGE ON SMALLHOLDER FARMERS OF NORTHERN ETHIOPIA[5]

Abstract

In the less productive semiarid and arid land regions of Waghimra zone, Northern Ethiopia there is growing trend where members of farm households spend parts of the year working in cities and other agriculturally high potential rural areas to generate additional income. Yet, no research has examined the impacts of this seasonal migration on farmland management. This study explores the role of seasonal migration and remittances on SLM practice in drought-affected Waghimara district of Northern Ethiopia. Data was collected through household survey, semi-structured interviews, and focus group discussion (FGD). We found drought and rainfall irregularities during the planting season are initiating migration by interacting with non-environmental factors, such as land shortage, landlessness, and lack of oxen. Remittance is primarily invested in basic household consumption, rather than agricultural inputs. This qualitative study showed that seasonal migration through its remittance does not contribute to improved farmland management and the use of agricultural inputs like fertilizer, pesticides, and improved seeds. Seasonal migration has transferred the already degraded and less productive farm to left-behind women. However, labour, input, and skill limitations are challenges for women. The changed role of women did not benefit farmland management; however, it has brought additional workload for women. This study recommends that SLM policies consider mobile households who portioned their labor between farm and seasonal migration. Moreover, understanding of land management in the context of decisions made by left-behind women and mobile male household heads whose remittance is invested in other than soil and agricultural inputs is essential.

Keywords: Seasonal migration; farmland management; Sustainable land management (SLM); Waghimra; Northern Ethiopia

6.1. Introduction

Population mobility is one of the significant demographic change phenomena in the twenty-first century. Individuals are geographically mobile today than ever before, with an about 232 million moving globally (Radel et al., 2019). Most migrants are from poor, subsistence agricultural countries to rapidly industrializing, economically advanced regions. Rural-to-urban migration is a practical approach to support rural livelihoods and adapt to climatic risks (Adger et al., 2015; Bhandari & Ghimire, 2016; Gray, 2009). While migration is considered one of the positive adaptation options available to households (Adger et al., 2015; Sobczak-

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[5] Impact of Seasonal rural out- migration on SLM adoption and uses in resource poor marginal communities of Northern Ethiopian. (Submitted to Journal of Rural studies)

Szelc & Fekih, 2020), it is also conceptualized as a decision made when in-situ adaptation fails (Gray & Mueller, 2012; Etana et al., 2022; Caulfield et al., 2019). Rural-urban migration is strongly associated with agriculture and farming practices in response to the opportunities and challenges brought by migration (de Haas & Solé-benet, 2001; de Haas, 2006; Jaquet et al., 2016). Furthermore, rural out-migration affects rural household’s actions to manage resources, determine land use, and land management by affecting the interaction of labour and remittances (Milbourne & Kitchen, 2014; Radel et al., 2019; Caulfield et al., 2019). Households' migration decisions are made based on multifaceted sets of push and pull factors. Adverse climate conditions have been considered as the underlying causes of migration. However, migration decisions are shaped by a complex interaction between climate and other contextual drivers of migration, including economic, social, demographic, environmental, and political push and pull factors (Black et al., 2011). Most notably, disruption of agricultural productivity due to climate extremes significantly increases migration from developing countries (Falco et al., 2019). Among extreme climate events, droughts have significant adverse effects on smallholder farmer agricultural production and can potentially lead to livelihood losses and subsequent migration out of rural areas (Falco et al., 2019; Hermans & Mcleman, 2021). In developing countries, where agriculture is the primary livelihood source, migration and remittance will affect it positively or negatively (Huy & Nonneman, 2016; Tong et al., 2019; Nguyen et al., 2019; Abebaw et al., 2019). Improving agricultural productivity also requires agricultural technology adoption and sustainable conservation and management of natural resources (Williams & Paudel, 2020; Mendola, 2007; Kassie et al., 2010). Adopting and investing in SLM is crucial in reversing and controlling land degradation. Several studies (such as; Adgo et al., 2013; Asrat & Simane, 2017; Kassie et al., 2010; Kirui & Mirzabaev, 2019; Sileshi et al., 2019) acknowledge the role of SLM in rehabilitating degraded and improving productivity in Ethiopia. However, smallholder farmers' investment in modern agricultural technologies is affected by factors such as liquidity and credit constraints (Abate et al., 2016; Teklewold et al., 2013; Holden & Shiferaw, 2004). Other studies in Ethiopia showed that farm labour, social capital, and labour sharing institutions affect SWC practice adoption (Asrat & Simane, 2017; Teshome et al., 2016). Contrastingly, NELM theory and empirical studies (Stark & Bloom, 1985; Taylor, 1999; Huy & Nonneman, 2016) showed that labour migration could increase investment in agriculture by easing capital and risk constraints on local production of migrant-sending households. However, the effect of migration on agricultural production and diversification depends on the remittance transfers to rural households (Nguyen et al., 2019). Furthermore, the impact of migration and remittance on agriculture and farmland management depends on the sending areas' societal context, decision priorities, and cultural and demographic contexts. Several studies in developing countries confirmed that remittances are invested in basic consumptions.

There is a gap in the literature on how migration affects SLM practices. Moreover, the available studies on migration and the environment have been limited by both disciplinary boundaries and a lack of an appropriate framework (Gioli et al., 2016). While migration research is often focused on those who migrate or where they migrate to (Black et al., 2011; Piguet, 2013), land management studies, on the other hand, tend to consider land user families as a stable unit (de Graaff et al., 2008). Additionally, SLM studies treat migration as part of the factors determining the adoption and use of SLM technologies and as a coping mechanism in times of crop failure. While SLM implementations are labor demanding, and migration necessarily causes the loss of labor (Greiner & Sakdapolrak, 2013; Zimmerer, 1993). When people migrate away from rural areas, there are fewer labour days on their farms (Brauw, 2010), small engagement in SLM activities (Caulfield et al., 2019), and local knowledge of traditional practices gradually diminish and disappears (Schwilch et al., 2013).

Internal migration remains among the most significant phenomena in Ethiopia. Particularly, seasonal migration is a major component of land and livelihood nexus. However, the potential importance of seasonal out-migration for land management and agricultural investment in Ethiopia remains under-researched (Abebaw et al., 2019). On the other hand, labour migration is the most common in Waghimra. Particularly in land scares – dry lowland areas of the zone, migration is the most familiar experience for every family. The most common type of migration is seasonal migration, by which the migrant return to their village after 2 to 6 month of labour work in the destination areas. The study districts are selected based on three factors: (1) large migrant populations participating in seasonal migration; (2) impacted by frequent environmental/climate extremes, particularly drought; (3) degraded soil fertility, vegetation cover, and water resource, being difficult to sustain on the subsistence farming without relief aids. Therefore, this paper explores the nexus between rural out-seasonal migration on household farming practices and sustainable farmland management. Specifically, the paper examines factors of migration, the relationship between rural out-migration and SLM, how drought contributes to seasonal migration decisions and how far remittance and migration earnings contribute to SLM practice and benefit land management. Finally, the study sheds light on how left behind women modify the gender role in farmland management and shows its implication to SLM practice and agricultural yield.

6.2. Rural Out-migration, Agriculture, and Land Management Nexus

Agricultural and labour migrations are important livelihood sources in developing countries. Diverse views exist concerning the impacts of migration and remittances on rural livelihood. In the traditional view, rural out-migration creates a dependency on labour migration, undermining local livelihoods and creating social and economic inequalities. However, the new economics of labour migration (NELM) hypothesize that migration and remittances positively affect incomes in migrant-sending households by easing capital and risk constraints and diversifying income sources (Stark & Bloom, 1985; Taylor, 1999). Nevertheless, the effects of migration on rural livelihoods are context-dependent and heterogeneous across space, socio-ethnic, and gender groups and tend to change over time; hence, no easy generalizations could be made (Nguyen et al., 2019; de Haas, 1999; de Haas, 2007). NELM is only supported in the case of available remittances because the remittances help rural households to compensate for the lack of labor and to specialize in more efficient income-generating activities.

There is a longstanding debate on the effects of rural out labor migration on agricultural change in migrant sending rural areas (Gray & Bilsborrow, 2014; Jokisch, 2002; Qin, 2010). One side of the argument is that agricultural production is diminished because of labour shortage due to rural out-migration (Rozelle et al., 1999; Williams & Paudel, 2020). A study in Nepal by Williams & Paudel (2020) showed that farm households face labour shortages due to out-migration. Furthermore, Jaquet et al. (2016) reported that migration led to land abandonment and increased land degradation and exposure to flooding. An earlier study conducted in Zimbabwe found that labour migrant households had less average farm labor input and lower production efficiency than non-migrant households (Mazambani, 1990).

Contrastingly, the other side of the argument states that remittances from labor migration can compensate for the reduction in labor input and provide capital resources for agricultural productivity (Stark, 1980; Taylor, 1999; Taylor & Lopez-Feldman, 2010). There are ample empirical evidence from different regions to support this argument. For instance, case studies from China found that migration increases labour shortage, but remittances compensate for that loss to improve productivity (Li et al., 2013). A case study in Nepal by Ghimire et al. (2021) showed that the amount of remittances received from household migrants in a year was substantially associated with lower odds of exit from farming. McCarthy et al. (2006) found that remittance increased access to capital and improved agricultural yield despite reduced labour due to rural out-migration in rural Albania. Similarly, De Haas (2006) showed that international migration remittances positively affect investment in hiring agricultural labour in

Morocco, thus leading to increased agricultural production. Redehegn et al. (2019) suggest that remittance has increased crop income and land and livestock holdings in northern Ethiopia.

Beyond the labour loss effect of migration on agricultural production, several studies examined the influences of migration on farmers' agricultural technology adoption and use. The literature on this aspect is not conclusive. An earlier study by Brauw and Rozelle (2008) argued that remittance is spent on consumption expenditure and housing rather than yield improving agricultural inputs and practices. Similarly, Jaquet et al. (2016) showed that remittances are used mainly for food and goods and much less for agriculture. They further reported that migration led to land abandonment and increased pressure on the land and exposure to flooding. Jaquet et al. (2019) also stated that migration exposed rural landscapes to land degradation as many terraced landscapes disappeared and increased overgrazing. Another study by Williams & Paudel (2020) found no direct impact of remittance on the intensity of SWC practices adoption in Nepal. Similarly, Caulfield et al. (2019) also reported decreased household labour availability associated with decreased use of physical SWC techniques in rural Andes. C. Zhang et al. (2021) also reported that rural-urban migration experience is associated with reduced fertilizer use in rice production. More broadly, H. Zhang et al. (2020) in China showed that labour force left behind is of low quality and does not care much about the sustainable use of cultivated land.

However, a more optimistic perspective on the impacts of labour migration on agricultural technologies and SWC practice declares that remittance contributes to better farmland management and agricultural technological improvement and hence improved agricultural productivity. Studies in different parts of the world confirmed this perspective. For instance, Gray (2009) argued international remittances have investment-promotion effects that result in increased maize production. Similarly, Davis and Lopez-carr, (2014) and Kapri and Ghimire, 2020) demonstrated that remittance drives agricultural productivity. Li et al. (2013) also reported that migration could lead to investing remittances in capital-intensive and profitable cash crop production. Caulfield et al. (2019) also found, despite the reduced use of SWC mechanism, financial resources of sending farming families leading to investments in potato cropping and hence greater use of agro-chemicals and mechanized tillage. In Rural Vietnam, Nguyen et al. (2019) conclude that migrant-sending households could increase their land productivity if remittance transfers occur.

6.3. Materials and Methods

6.3.1 Study Area Description

The study is conducted on the upper Tekeze basin in Waghimra administrative zone of Amhara Region, Ethiopia. It is located between 38^o 15’ 0” E to 39^o 15 0 E and 12^o 25 0” N to 13^o 250 N. Based on the 2007 Ethiopian census, this zone had a total population of 426,213, which showed an increase of 54.64% over the 1994 census, with an area of 9,039.04Km^2.

The elevation of the area ranges from 989 to 4043m above sea level. The minimum and maximum elevations are 997 and 4005 meters above sea level. The area is characterized by undulated topography with severe land degradation. The slope of the area ranges from flat plains to very steep escarpment. The average slope of the zone is 19.17%. Based on the elevation, the zone has three different climatic divisions (zones). These climatic zones are the *Kolla* (Tropical zone, elevation < 1830 m), Woina Dega (subtropical zone, elevation ranges between 1830-2440 m), and Dega (cool zone, elevation >2440).

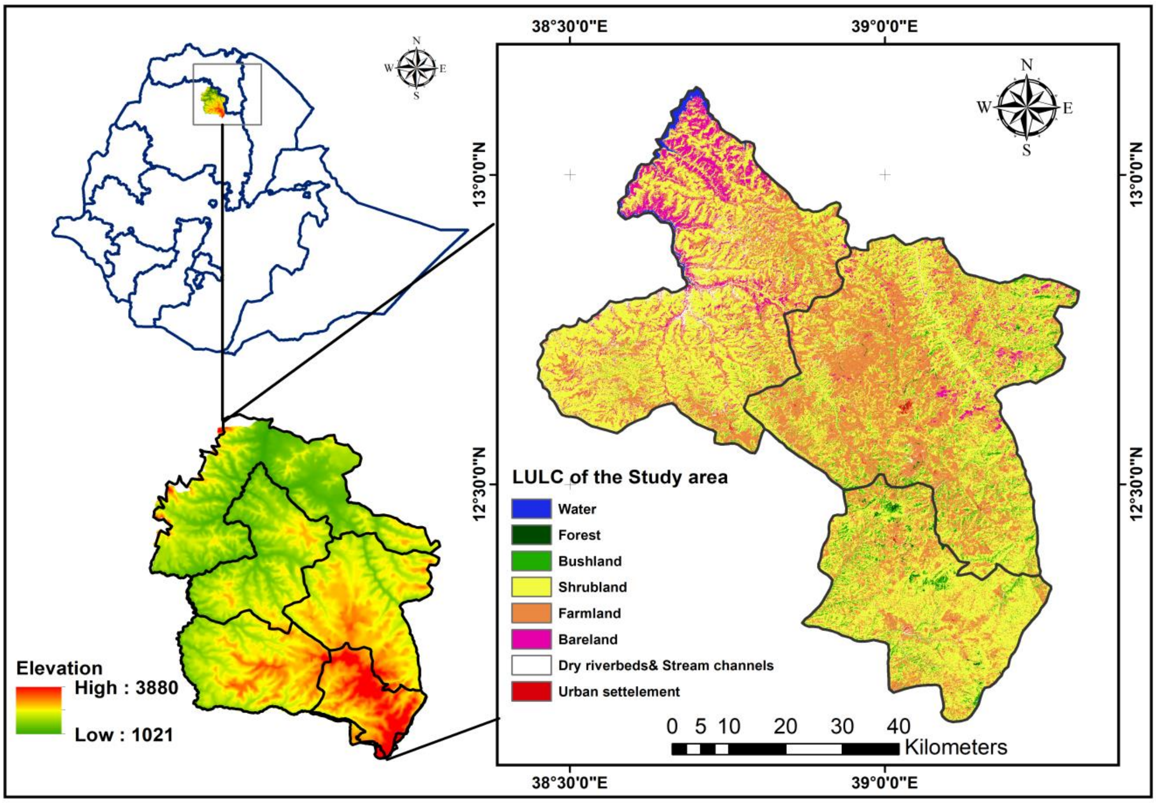


Fig. 6.1. Location map of the study area.

Waghimra receives its rainfall during the main rainy season, which runs from June to September. Unimodal and erratic rainfall patterns characterize rainfall in Waghimra zone. The mid and high-altitude areas receive rainfall from late June to early September. The rainfall distribution of the lowland part of the area extends from early July to mid of August. About 63% of the annual rainfall is concentrated in July and August. At the beginning of the rainy season, June, only 6.57 % of the annual rain falls. The minimum and maximum annual temperatures of the area are 12.8 °C and 28°C, respectively (Wubet et al., 2020).

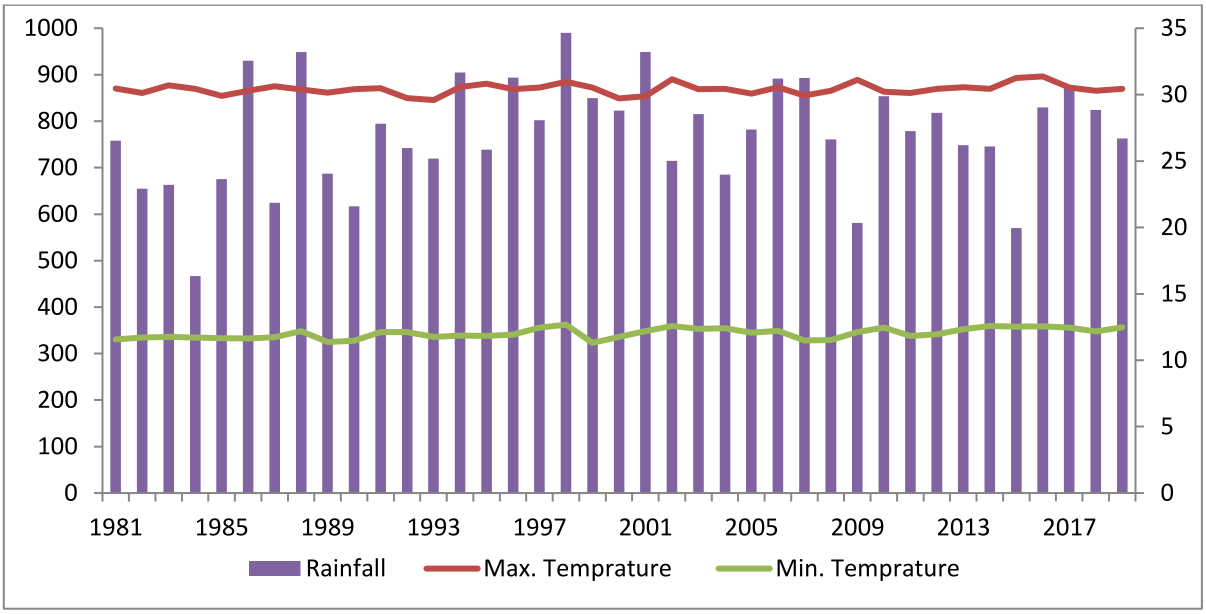


Fig. 6.2 Annual rainfall time series of the study area from 1981 to 2021

Over 90% of households throughout the Waghimra Zone live on smallholder farming with landholdings of less than one hectare. The agricultural activities are rain-fed, with the main harvest from September to November. Farmers produce mainly cereals (sorghum, teff, barley, and wheat), pulses, and vegetables. Livestock, like cattle, donkey, sheep and goat, chicken and bees, are kept for the consumption of their products, plowing, sale, and as savings mechanism to cope with economic stress.

The region has severe land degradation, climate variability, and the highest population density (Rosell and Holmer 2007; Hermans-Neumann et al. 2017). The zone has been one of the most drought-affected areas in the past. High vulnerability to drought and famine, growing population pressure, and land degradation have reduced yield per capita. People residing in the study area are frequently in immediate need of food/relief assistance. Migration for short-term employment has been a feature of the livelihoods of the poorest in Waghimra. Due to the consequences of climate change, and low and erratic rainfall patterns, the food system's capacity to provide decent livelihoods is critically restrained in the upper Tekeze basin.

6.3.2. Data Source and Data Collection Methods

We employed a qualitative research approach in three districts in the upper and middle catchments of Tekeze River basin of Waghimra zone. These regions have the highest population mobility in the form of seasonal migration. The study villages are distributed across different agroecology and topographic characteristics. The first case study, Shimedir Kebele, is located where there is a protected watershed (Agewmariam watershed) supported by Sekota agricultural research centre. The rest of the study villages, Sirel, Zuna, and Qeba kebele, are laid in relatively lowland altitudes where the upper catchment streams meet. Tsagbji is the northeast and northern part of Waghimra zone. This district is known for its large-scale population mobility. The district is characterized by low productivity and degraded mountainous topography and exhibited frequent drought and crop failure experiences and hence the worst food insecurity prevalence.

The study is based on primary data collected through semi-structured interviews and FGD. The cross-sectional data for this study was from June to August 2021. The principal method of data collection was semi-structured interviews and FGD. The semi-structured interviews allowed for a flexible approach for recoding respondents' experiences and perceptions.

Besides the qualitative data, household survey was used to collect data on the intensity and adoption of SLM practice, perceptions on the status of plot slope, soil erosion, and soil fertility status were also gathered through the questionnaire. The questionnaire included demographic, reasons for migration, allocation of remittances, application of SLM strategies, e.t.c. It also included land users' perceptions on the status of soil erosion and fertility status. The sampling procedure and sample size of the respondets for questionnary surves is discussed unde chapter 7 section 7.2.2. The reliability and validity of the questionnaire were checked based on preliminary key informant interview and FGD with selected farmers and agricultural extension workers, and input from local government and non-government organizations which work with farmers in the zones.

Interview was conducted with returnee migrant and sending households. The number of respondetns are 13, 12, 7, and 5 farmers in Tsagbji woreda, Shimedire, Sirel, and Tiya Keble, respectively. We interviewed women alone to give them more freedom in expressing ideas. Interviews were conducted with migrant, non-migrant households. In addition, Three FGDs were held with farmers and elders in the three study villages. The FGD consisted of from six to eight individuals. One FGD was in Wuleh IDP centre with older farmers who were displaced due to the TPLF and Ethiopian federal government conflict. In the IDP, we systematically selected farmers who were more than 36 years old and had migration experience and farming. These farmers were residents of Tsagbjii district, kebele 06 and 09. The second FGD was held in Shimedir Kebele, where a model watershed is located. Thirdly, we made FGD in Sirel Kebele. This district is relatively on the low-laying landscape along the middle part of the basin. The theme of the FGD was the reason for seasonal migration; land degradation, land management in their village, the role of women during male out-migration, etc. In general, the

FGD was very important in understanding the history and trend of seasonal migration, its relationship with land management and the reasons, timing, and trend of migration.

Fig. 6.3 Photos from the data collection (A; with FGD participant in Sirel, B with interview in Wuleh, C with elders in Agewmariyam Watershed and C with farmer in Tiya)

The village development agents (DA) helped arrange a gathering of farmers and provided space for FGD and interviews. Data collection through the interview was a face-to-face interview. Interview questions were initially prepared using Amharic language. However, for some participants who do not speak Amharic, translation to the respondent's language (Himtigna) was done with the help of a translator. The data collection schedule was on the month of the farmers' busiest days of the year. Getting farmers' idle time during the regular working days was impossible. Finally, with the help of DAs in the village, it was agreed to conduct interviews and FGD on monthly and weekly religious holidays (sacred) days. The farmers are adherent to the Ethiopian Orthodox Christian church and do not work on specific days in the month. For example, every weekend Sunday, the 21st (Saint Merry), the 29th (Baele egziyabher), the 12th

(Siant Michael) of the month etc., are holy days on which farmers do not work labour-intensive agricultural work on these days.

6. 4. Results and Discussion

6.4.1. Livelihoods and Environmental Stress

The major livelihood in the study areas is mixed agriculture where both, rainfed agriculture and livestock are basic source of income. A very small number of households have access to irrigation and agroforestry because of their location around river valley. The dominant environmental stresses consist of irregular and reduced amount of rainfall in major planting and growing seasons. Intensive rainfall also creates devastating floods on hillside farmlands (for example in Shimedir and Sirel kebele). Such flood not only damage crops but also wash away topsoil and leads to reductions in soil fertility.

FGD and interview participant reported that there is perceived shift or change of the surrounding climate and ecosystem. Land productivity has declined in the past 20 years. Besides, they noticed clear change of land cover in their village in terms of that indigenous trees, forests bushlands and uncultivated land has changed to other land use/cover type. While respondents reported that rainfall amount and pattern had been a problem every 2 and 3 years, they also explain that drought is much-feared environmental problem due to its impact of cattle and human being.

In addition to the respondents account and FGD, we have examined the magnitude and frequency of drought using meteorological data. Standard precipitation Index (SPI) was used to detect the drought events. Both dry and wet years were observed in the temporal analysis of the SPI. On the SPI 3 timescale, SPI values less than -1 were recorded during 1984, 1987, 1985, 1993, 2009, 2015, and 2019. The SPI pattern shows frequent dry conditions in the upper Tekeze basin in Wag-himra Zone. The SPI value in the study area for months from June to July (SPI-3) reached -2.7236 (extreme drought).

Drought frequency, the return period of the magnitude of the drought event corresponds to the cumulative water deficit below SPI-values ≥ -1 (Thompson, 1999; Mekonen et al., 2020) was investigated to detect frequency of drought in the study area. The SPI-3 analysis in the month of august indicated that seven (7) drought years (31% of the total study period) were recorded as drought years. Irregular rainfall and dry condition during July and August is highly responsible for crop failure and leads to agricultural drought.

In addition to what appears to be an increasingly adverse rainfall regime, and drought, shrinking land holdings significantly shape livelihoods in Ethiopia. Due to the national land policy, people cannot acquire land other than through inheritance from parents. Under conditions of population growth, the condition through which land is redistributed to inheritance redistributions have generated increasingly fragmented landholdings, so that individual household plots are now very small (Admassie, 2001) or do not have land at all.

Under conditions of land shortage and unpredictable rainfall and frequent drought, the majority of respondents described their production shortfalls of under 6 and 9 months of food every year. Consequently, most households have observed reduction in their livestock ownership due to either lack of grazing, or sold to cover consumption expenses including purchase. As the result of prevalence of food insecurity Waghimra zone is among the top administrative zone which receive food aid and productive saftynet. Besides, farmers engage in various coping strategies including seasonal migration to nearby sites.

6.4.2. Migration Push Factors and Motives

Who migrates from rural areas for seasonal work, and why do they migrate?

Migration not only takes place under historically and culturally specific social-ecological conditions but also in ecological circumstances (Hummel, 2016). These ecological circumstances could affect the livelihood of the community as a whole. However, even if ecological factors, migration networks spread in the community, not all households have equal migration decisions, and not all migration push factors immediately translate to migration. We conducted in-depth interviews and FGD to understand the context of migration decisions, the magnitude of seasonal migration, and which section of the community is participating in the phenomena. To start with, an interview account of a 62 years old farmer who was asked about the magnitude and participant of seasonal migration in his village *says: "More people are seasonally migrating than any old days in my life; they migrate to fill the agricultural income shortage."* This account tells that migration is, for those who can move, the way of getting additional income to fill the gap in agricultural income. However, the quickest response of most respondents about the cause of migration is “drought”. The majority of interview responses cite drought as a common problem that causes migration. However, what the respondents usually call "drought" is rainfall irregularities, delayed onset, and reduced amounts of the summer rainfall. Key informant farmers explained that “extreme drought have occurred in our villages, these days were terrible even to remember. We were praying, crying to God during the rainy seasons, but we could not get rain that year”. The same informant was asked about the regular nature of rainfall in their village; “this day we cannot be sure about the amount and timing of rain; there is a problem (rainfall irregularity) every year.” We can understand that both drought and rainfall irregularities are very common in the study area. When they (respondents) were made to remember the known drought years, for example, 1985 and 2015, they explained that these years were sadness of God and they could not forget the severity. The study area exhibited dry land characteristics, and annual rainfall was minimal. Given such conditions, a very slight change in the amount and timing of rainfall significantly and negatively affects agricultural practice.

Many interviewed respondents and FGD discussants highlighted the role of land shortage or landlessness in their participation in seasonal migration. Since other livelihood sources, such as off-farm sources of income, are limited, small land holding combined with low soil productivity is a creeping cause of migration decisions. A narrative by a priest supports landlessness as a significant cause of migration: *‘Those who are migrating are the young who have not owned land. Almost all farmers below age 35 do not have land unless they have inherited it from their parents*. Another exemplary account of farmer in Tsagbiji district (kebele 09) supports the narrative about the land shortage and low soil fertility as a cause of migration. *“…land shortage is the primary reason. The second reason is that the land is not fertile; moreover, it needs labours to work every year. This forces them to decide to migrate…”*
A large number of respondents complained about inequality in land ownership. They explained that some households have a considerable land size of up to 3 hectares, while others own below one hectare. Given the large family size in the district, inherited land could not support the new households. In most newly established households, it was not only small land- holdings but also an absolute lack of any land that had shaped their decision to move. Owning land is very limited due to the State’s prohibition on the transfer of land by private sale. How young households can attain land is only through either inheritance from their parents or from the local administrator, who can distribute the land of deceased farmers with no next of kin. Land distribution is impossible because land holdings are already too small to support existing and new households. An old man FGD discussant in Shimedir Keble expressed the severity of the land shortage by saying, *"A plot of land that is owned by four households used to be owned by one farmer before the land redistribution and decades ago, the land is too small, but we are too many”.* The latter option is limited because it is rare for households not to have children of their own or other immediate families who can inherit the land. For the above reasons, younger males in households frequently migrate and return home with some earnings. Many young

farmers who do not want to leave the rural area struggle to pay land rent and secure crop sharing to produce grain.

In general, most of the reasons for migration among the respondents revolve around the problem of landlessness and small landholding. For example, during the survey and described by informants, food shortage arising from scarcity of farmland was identified as an important factor driving rural-out migration. This finding is similar to a study conducted by Asfaw et al., (2010), who reported that land shortage was the major cause of migration in the Amhara region. In addition to landlessness, the lack of oxen affected the farmer's mobility decision. The following interview account shows the importance of ox ownership in determining migration decisions. *"Those who have oxen do not migrate. They frequently prepare the land; rotate the crops to get enough grain. Even though they may not have excess, they can feed their family." (G/ egziyabeher Kassaye, aged 62).* However, the upper hand of the interview accounts still cites landownership and land productivity as prime factors in determining migration decisions**.** It was also understood that debt repayment is the other push factor among some respondents. When the grains and cattle are not enough or absent to pay debts, the head of the household migrates to earn income and pay the debts. KII in Shimedir and Sirel Kebele explained that some farmers took loans from ACSI (Amhara Credit and saving association) to buy sheep, goats, and oxen. However, the loan would not be paid unless those who do not have cattle to sell and pay the debt migrate.

Regarding gender aspects of migration, the data indicated that almost all migrants are male. Of our respondents, only a handful of women reported a migration history. These women are either single or divorced in terms of their marital status. However, unless the whole family decides to migrate temporarily, it is unlikely that women alone involve in seasonal migration. In the study community, males are prime decision-makers in household livelihood activities. There is no possibility that the wife alone could migrate to other cities to earn money. The whole family may leave the village until the next planting season in extreme drought and crop failure conditions. In the lowland area of Waghimara, specifically in Tsagbiji district, children and women too are part of the migration due to continuous crop failure, low productivity, and shortage of land. Against the findings of (CSA, 2021;Tegegne & Penker, 2016), women were less involved in migration in this study

The interview accounts demonstrate multiple but interacting factors determining the migration decision in the study area. These multiple factors do not act independently; environmental factors (drought, soil degradation, and crop failure) and shortage of land interact mediated by the socioeconomic and demographic factors to determine migration decisions. For example, the earlier account from 62 old farmer interview, *"We who are old are who do not have the option to move, the young are frequently migrating to get additional income to support their family,"* show how demographic factor. Age determines the decision not to move, even if the productivity is low and poverty is a problem in the family. It hinders mobility, with many older respondents describing how they could not migrate as they had no livelihood prospects in the urban areas. This finding was corroborated by a study conducted in northern Ethiopia (Morrissey, 2013).

The finding from this study was in line with the findings in Ethiopia and other developing countries. Several studies reported Land scarcity, poverty, lack of oxen, perceived food insufficiency, household-head age, and household size as determinants of migration (Redehegn et al., 2019; Tegegne & Penker, 2016; Asfaw et al., 2010; Ezra, 2001; Morrissey, 2013). In Ethiopia, earlier studies such as by (Abate, 1989; Ezra, 2001) showed that lack of access to sufficient farmland and severe environmental degradation has been among the significant factors forcing people to abandon their farms and move to towns.

Table 6.1 Reasons for migration in Waghimra zone.

Categories of reasons for migration	Reason for migration
Environmental	Drought
	Pest breakout and crop failure
	Rainfall absence during planting seasons; delay of rainfall from its regular pattern
Farming	Low productivity, increased surface aridity, high erosion on the farmland, fragmented land on marginal area
	Shortage of land; the family land is too small, and could not support the household
	No access to land/ landlessness
	I do not have oxen, so I could not farm my land.
	I do not have goats, unable to access manure to fertilize my farm
	The land is not productive; it is exposed to erosions (located on the hillside)
Livelihood	To earn income by working in nearby cities
	Absence of livestock as an immediate coping strategy during crop failure,
	Migration is regular livelihood to compensate for crop shortfall
	Debt repayment
	Because agricultural wage is higher in highly fertile areas (Humera, Wolkite, Rraya)

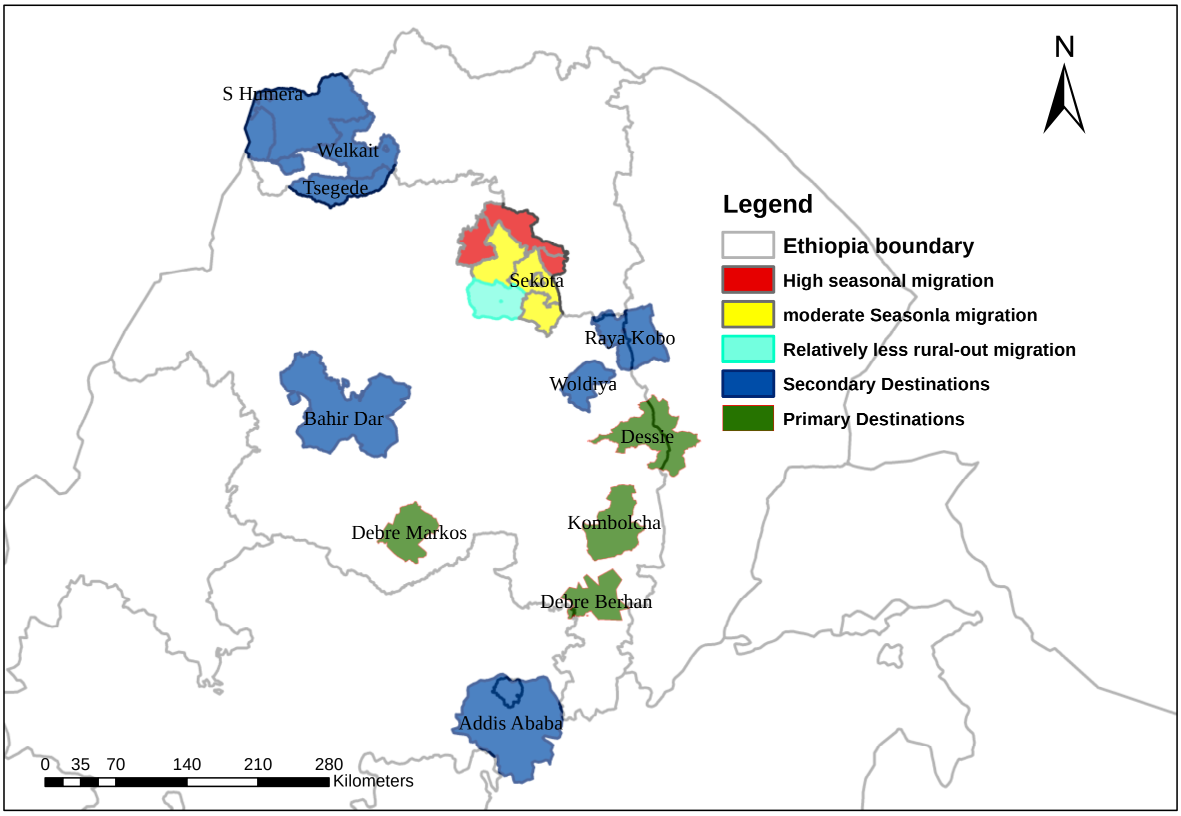


Fig. 6.3. Majore sending areas and destination of seasonal migration from Waghimra zone (map prepared based on participant response

The role of environmental problems in initiating migration decision

As we go beyond the reason for migration, we have documented the description of the migrant's immediate moment of migration decision. The interview data concluded that the reason for migration involves more than single interrelated factors for individual migrants to consider migration decisions. These factors may occur suddenly or appear over time. Given the experience of frequent drought in the study area, we postulated that drought, low and irregular rainfall patterns, and low soil fertility might be a factor for migration and are the major cause of migration decisions. In doing so, we determine what makes the farmers sit down and immediately decide to migrate. The interview and FGD data analysis demonstrate that the combination of personal, socioeconomic, and environmental problems initiates migration decisions. The narrative from a resident of Tsagbji district responds as follows when he was asked about his first experience of migration decision.

"My first decision of migration was due to drought and pest invasion of my sorghum. Drought occurs at the time of maturity, and suddenly pests appear and destroy the already unsatisfactory sorghum. During that year, I consider migrating for the first time." He adds, *"During that season, i did not produce enough for the next year's seed. For a farmer, not producing at least for his seed is a total loss. I had no option rather than deciding to migrate."*

According to this account, drought and pests caused crop failure and further pushed farmers to migrate. This also implies that in the absence of immediate alternative coping strategies, environmental factors are the immediate cause of migration. Environmental factors, notably drought, happens at frequent time interval in the study area and is a common problem for all farmers. However, the degree to which drought causes migration decisions depends on other non-environmental factors. This finding supports the arguments that "environmental and non-environmental factors interact to shape mobility decisions" **(**Morrisse, 2012). However, in the context of the study area, which is frequently food insecure and does not have in-Suita coping strategies such as selling cattle, assets, and remittances, their only option at disposal is migration.

Regarding the manner of interaction among environmental and non-environmental factors, what has been understood from the data is that "land alone" and "drought alone" is rare migration determinant factor. Age, family composition, oxen ownership, and family size play different degrees of roles in determining whether to migrate or stay on the farm. For example, an account of a father of daughters explains his story: *"After I lost my wife, my economy was weakened, and I sold all my oxen. The last six year was difficult. I support my family by seasonal migration. I have given some of my farms for crop sharing. If I had oxen, I could produce enough grain on my farm. I think I have enough land compared with other farmers."* The religious and traditional prayer ceremony when someone loses his family requires a large amount of money, and families will sell their assets or cattle to cover the cost of the feast. This, in turn, leads to an economic shock. Hence, the family remains in the vicious migration cycle once economic shock happens. Despite having land, this family does not have oxen, and all the children are female girls, so the father must migrate every year to fill the consumption gap. Having a young son determines whether the head of the household (the father) must seasonally migrate or stay home. The son will manage the land or migrate instead of his father; at least, they would have planted their entire farm.

Migration networks play role in mobility decisions as well as provide information on where to find work and what work is available. They disseminate information about migrant wages, types of works in the destination areas, and possibilities of change through migration. Most migrants from Qeba kebele migrate to northwestern Ethiopia as Humera, and Wolkite, and some go further to neighboring Sudan. This migration pattern mainly seeks agricultural labor in large-scale commercial farming. Migrants from Tsagbji also mainly migrate to towns and cities in central Ethiopia, such as Addis Ababa, Dessie, Bahirdar, etc. Migrants who plan to migrate with their families (children and wives) prefer migration to these areas. A migration network for such migrants is vital to locate where good paying labour work is available and where chip rental house is available for their temporary stay. What is notable is that while networks appeared important for shaping where migrants went, the decision whether to migrate solely depends on the household's economic background and exposure to low yield due to environmental factors. This finding is corroborated with Morrissey, (2013) who also reported that migration network has less effect on determining whether rural farmers decide to migrate.

6.4.3 Land Management in the Context of Seasonal Migration

Many studies on land management consider rural households as stable entities. However, land management also happens in the context of highly mobile populations where the head of the household and other household members seasonally migrate. Given the age and gender selectiveness of migration patterns, it has substantial implications for land management practice. Many empirical quantitative studies have produced varied findings regarding the effect of age, gender, and land ownership association on land management practice. As observed in this study, the younger men tend to leave the village for seasonal work. The productive age group and the men are away from the village for at least 3 to 6 months, and, in some households during drought, they migrate for more than a year. In a large household, elder sons migrate, while the household head (HH) stays on the farm and organizes the labour to manage the land. Nevertheless, in small family size, the head of the household involves in the migration leaving the task of land management for children, and women. Few respondents argue that husband out-migration does not affect farmland management and that left-behind families are enough to manage the land during male/husband out-migration. Still, some migrant families believe that the majority of farmland management task is done when the head of the household come back from migration. Other respondents also reported that few and less labour-intensive farmland management tasks are done during seasonal migration. Responses such as, "The head of household himself when he comes back from migrant, "*wife*", "*children*," "*my elder son*," " *my relatives*," "*crop sharing*," and "*my neighbor*" have been frequently cited for the question "who manage your land during the months of seasonal migration?" (Fig. 6.3). To give detailed insights, the following interview accounts also answer the question of who will manage the farmland during seasonal migration.

"Most household heads, including me, leave the land to our wife when we migrate for seasonal work,"

In the case of migration of the head of the household, the account of G/r Kassaye explains as follows**;** ‘*No one was left to manage the farm. Rather I came back to the village after months of daily labour work. I returned home when I earned money equivalent to the price of one ox (nearly 10000 at that time). Immediately I returned to the village, I bought an ox and began plowing the land."* The narratives of priest G/Slassies also evidenced crop sharing case**;** “*when I was in Kemmise* (a town about 430km far from his village)*, I give my land for crop sharing. Because the land does not produce enough grain even if I work all year, I decide to give it to crop sharing. ....most people migrate in the winter/ January/ and return in May. They come back in May to plow the land. However, those who do not have enough land would spend the summer in other areas working there*.”

While in most households, only the household head or members of the family migrate, some cases were reported that there is a condition where the whole family participates in the migration. In the last scenario, the family either leaves the land for their relative or gives it for crop sharing. Farmland management, fertilizer application, SWC, and other things are decided by the farmer who rented it or by the relative willing to farm.

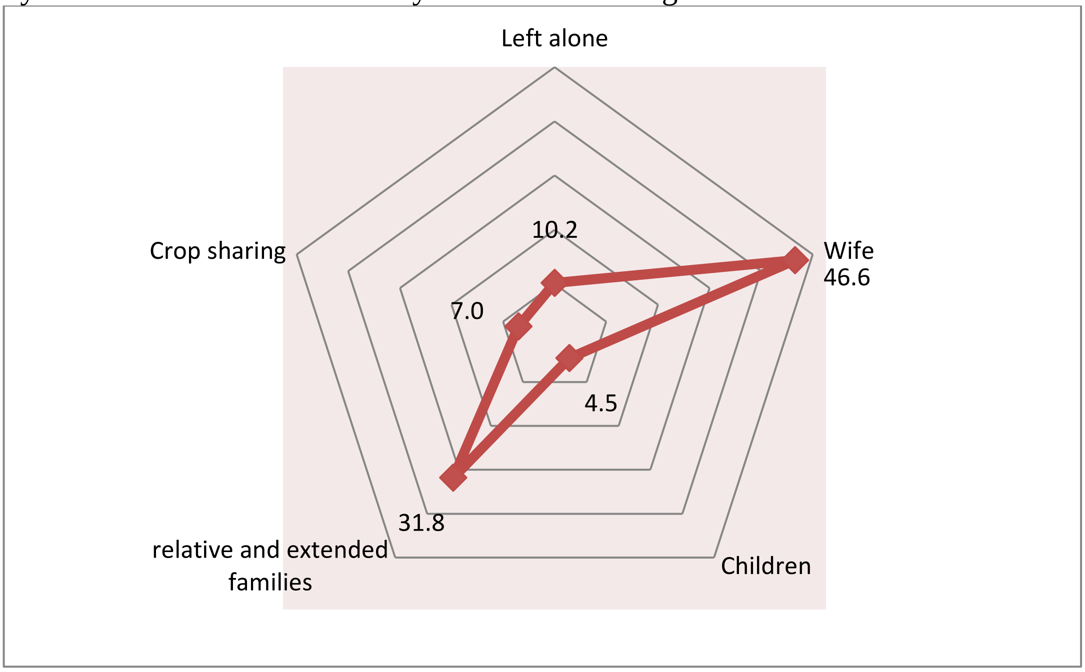
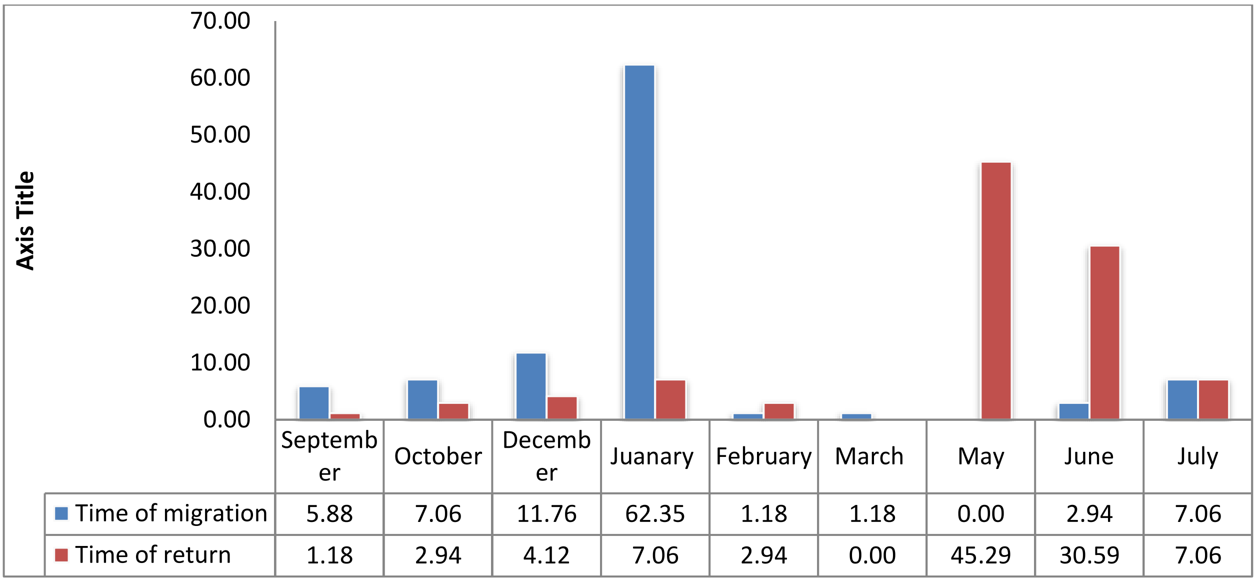


Fig. 6.4. The condition of land management during outmigration (units are in percent of response)

It is also necessary to mention that FGD and KI reported that households with large family size labour availability and land management are not highly affected by the migration of one or two young sons. The head of the household will mobilize the remaining labour and relatives for land, soil, and water conservation works, plowing, weed collecting, fencing homestead crops, and harvesting yield. In this case, migration would increase access to additional income to purchase farm inputs.

Not only who manage the land but also the season of migration have implication to sustainable farmland management. From September, onwards some farmers began migrating to other agriculture potential areas. These migrants usually migrate to fertile areas to work on weeding and harvesting as daily labourers. This migration is determined by the wage difference between their village and the destinations. During December and January, seasonal migrants have harvested their farm and beginning seeking other jobs in other urban areas. Most seasonal migrants are away from their village during from December to May. In this season, most of the land preparation and SLM practice will be managed by the family member who stayed at home or otherwise will be idle until the head of the household come back from the migration. Finally, in June, most seasonal migrants will return to their village after hearing the rainfall news. The months July-August are the rainy and growing months. Most farmers will be in their village planting/sawing, weeding etc. Still, some farmers will be out of the village as a daily labourer. However, this depends on the migrants' land holding and their land productivity status.



	Septemb er	October	Decemb er	Juanary	February	March	May	June	July
🟦 Time of migration	5.88	7.06	11.76	62.35	1.18	1.18	0.00	2.94	7.06
🟥 Time of return	1.18	2.94	4.12	7.06	2.94	0.00	45.29	30.59	7.06

Fig. 6.5 Seasonal migration timeline (months of migration and return) in the study area

September
Some farmers began migrating to other agriculture potential areas.
These migrants usually migrate to fertile areas to work on weeding and harvesting as daily

December, January
During these months, seasonal migrants have harvested their farm and began seeking other jobs in other urban areas.

December to May
December to May, most seasonal migrants are away from their village during these months. In June, most seasonal migrants will return to their village after hearing the rainfall news.

July-August
This is the rainy and growing season. Most farmers will be in their village planting/sawing, weeding and etc. Still, some farmers will be out of the village as a daily labourer.

Fig. 6.6 Seasonal migration timeline (months of migration and return) in the study area. This time line is prepared based on the selected migrant life history interview; it is believed to be representative of the migration time line of most seasonal migrants in the study area

Land abandonment and seasonal migration in Waghimra

Despite emerging studies examining the magnitude and degree of relationship between labour migration and farmland abandonment, there are no qualitative studies, particularly in developing countries with fewer urbanization rates and limited non-farm employment. We tried to understand the degree of land abandonment due to seasonal labour migration. Our study produced a result that contrasts the finding of emerging papers from developed countries such as by (Terres et al., 2015) and developing countries in Southeast Asia (such as Xu et al., 2019; Jaquet et al., 2019). This study's findings suggested no cropland abandonment is observed in the study area. The migration patterns in the study area do not lead to cropland abandonment. We have requested our participants about any probability of land abandonment during labour rural out-migration, especially when the whole household decides to migrate to escape crop failure or drought. The participant reported many ways the land would not leave idle; crop sharing, and rental are among the common ways the migrants' farmland would be transferred temporally to the non-migrant farmers. In the case of a single household member or HH migration, the wife, children, and relatives would farm, and manage the land. Instead of farm abandonment, this finding indicates that if the magnitude of the current migration increase, farmland management, not land abandonment, would be a problem in the area. Furthermore, in the long-term, the massive rural out-seasonal migration would make the land at the hand of few non-migrant farmers. The remittance and wage earned by the migrant is not enough to force rural migrants and their families to abandon the crop and exit from the farm. Even though the land is not abandoned due to seasonal migration, further studies should investigate the level of SLM of farmers who own through rent and crop sharing, as land tenure is determinant of the application/ adoption and investment of SWC technologies and/or practices.

Goat ownership in the lowland of Waghimra; co-determining migration and farmland management

What relations do goat ownership and agricultural yield have explained more by FGD and interviews. Manure has become the most popular and preferable farmland fertilizer in most Waghimra zone. Manure application and goat ownership have a critical positive relationship in the community. Our participant explained that goats have multiple benefits for households. In the lowlands of Waghimra, goat ownership has been the major determinant of food security and migration decision. Generally, goat has a dual purpose: 1) as copings strategies, insurance during crop failure due to drought, 2) Manure production for farmland fertilization. Beyond food security and livelihood strategies, households buy even a few goats for their children. They are also an asset that keeps children happy in the village. If the family does not have goats, the children would be idle and unhappy and consider migrating to nearby towns. KI told us, "*Children should not stay at home in rural areas; to stay out all day; they should have goats to follow and look after."* They firmly believe that goat ownership determines the probability of young boys migrating out of the village.

In addition to determining migration in terms of creating assets and inspiration for children to stay in the village, goat ownership also determines access to manure fertilization. Farmers built a shelter for their goats on their farms and let them stay for weeks on a given arc of land. After a week, they also move to the adjacent portion of the plot, and they repeat this multiple times until the plot gets urine and goat dung. This cyclic fertilization of plots by goat manure is common among goat owner farmers. According to the DA and elder farmers, the manure from the dung is the preferable fertilizer for the farm; even after applying the whole farm in one season, the farm might not need fertilizer for the next two years.

Moreover, the time at which goat manure is required is very critical for the health of the soil, according to the farmers. They believe that if goats spend the nights during September and October, the urine and the dung will get enough time to fertilize with the soil up to the next April and May. Farmers who do not have enough goats also do not apply as frequently as those who own goats. However, there is a mechanism through which poor farmers could access goat manure; they lend their relatives; families goat and let spend in their plot.

6.4.4 The Role of Women in Farmland Management; Are They Left Behind or Female Farmers?

Migration affects the family structure by bringing "improved autonomy" and " increased responsibility" for left-behind women (Choithani, 2019). Moreover, when her husband is away, she has to manage the land and make decisions instead of her husband. Rural out-migration in the study area is creating a new trend where women take responsibility for deciding on the farm, at least partially for up to 3-6 months. We interviewed women to analyze their family migration history and labour management. Their accounts lead to the question of whether migration is putting much pressure on women in terms of land management during land preparation seasons. The result unequivocally tells us that women hold additional roles during the season when the male out-migrates. Land preparation, plowing, pesticide spraying, irrigating, drainage preparation, digging water-harvesting holes, fencing home yards, and planting crops are commonly assigned to men. At the same time, women help the husband with weeding, transplanting, and harvesting. Due to male out-migration, if the women decide to farm the land with the help of her family and other labour in the house, she usually engages her time and labour in land preparation, pulling out weed roots while other male plow, and maintaining biological and physical SWC structures. Even women who usually participate in weeding with their husbands, their involvement, and responsibility increase during the male absence in the village. Traditionally, the decision on crop choice, time of planting, labour mobilization, and the overall decision on the farm is given to the husband. However, seasonal migration is changing the conventional norm by giving those decision roles to women. Both migrant families and non-migrant farmers believe that women hold the responsibility of deciding whether the cattle to be sent to relatives[6] or kept at home; whether the farm should be given to crop sharing or planted with the help of neighbours and relatives; and labour mobilization to harvest crops. Nevertheless, as reported by (Bacud et al., 2021), this responsibility is not entirely independent; wives exchange information with their migrant husband, their sons, her or her husband's family, and their neighbors. In the literature, there is evidence that migration increases women's decision-making role and capacity. Some trending studies call these phenomena the concept of 'feminization of agriculture.' A study by Radel et al. (2012) reported that women with migrant husbands in Mexico participate more in decision-making on the farm, autonomously or jointly with their spouses, and are responsible for supervising the hired male labour. Gender differences in access and use of assets are pervasive in the agricultural sector, and agricultural development interventions are likely to have gender-differentiated impacts (Meinzen-dick et al., 2014). Some find that women are doing more agricultural work than before their husbands migrated and compared to their non-migrant (Mu and van de Walle 2011) and male out-migration is pushing women to hold new agricultural duties and increasing household labour responsibilities (Paris et al., 2009; Spangler & Christie, 2020). Against some findings such as by (Jaquet et al., 2019), women in the study are do not feel comfortable to work alone in the farm. They explained that although women have always-highest domestic and agricultural work, the burden increases in the agricultural peak season when the male migrate. They believe the decision to farming and other social activities are good if when performed by their husband. *"I want to help him in weeding and harvesting, these*[7] *roles are good when men decide them"*

Farmers work closely with agricultural extension experts to scale up and implement SLM practices. Due to the nature of gender differentiation in many conventional communications and relations of DAs, male migration has affected the benefit that would be obtained from the

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[6] Some families sent their cattle to their relatives to take care of them. However, these relatives share the newborn livestock according to their deal. This newborn livestock sharing is preferred in households with labour shortage.

[7] Type of crop to plant, dates of planting, harvesting e.t.c and other village level affairs

frequent contact and established network with agricultural experts and male household heads. Although the DA believe they have the necessary contact and communication with women household heads as they have with male household heads, women FGD discussant and male participants believe that the frequent consultation and informal communication about SLM practice, fertilizer access, etc. are not as much as it was with the male household head.

We have asked all migrant households if any land management practice is implemented on the farm when the head of the household is not at home. Not all migrant families implement farmland management during husband out-migration, and some households do not do land management on their farm until the male returns from migration. Particularly physical infrastructures like, maintenance of stone bonds, farmland terraces, biological bonds (Aloe Vera bund), compost preparation, manure storage, collection and application on the farm, and preparation of drainages are not possible. What has been observed from the logical evidence of these farmers is that the above-mentioned land management mechanisms are already done before the male household head leaves for migration or would be implemented after his return. They insist that women only look after the planted crops, protecting them from damage by cattle, pests, and birds. However, many studies argue that land management is not a one-time job of farmers; it should be planned, implemented, and maintained throughout the year.

Given that it is difficult for women to access labour through organizing non-migrant farmers and left-behind families, this scenario is not without its disadvantage. For instance, a woman explained that " *when there is a bad flood on the farmland due to torrential rainfall this year (august, 2022). I was not able to quickly construct some flood controlling structures. Most of my neighbours were also busy doing on their farm".* We cannot deny the cumulative skills and strength of male doing physical SWC structures on their farm.

Table 6.2 Agricultural activities and SLM practices and corresponding impact of migration

Land management decisions	**Season of implementation**	**Impact of seasonal migration on the task**
Deciding on fertilizer accesses and purchase	May to June	Highly impacted[8]
land preparation (stone clearing from the farm, fancing, and making ready for plowing)	Starting from February in the highland and May and June in the lowland	Very high [9]
Breakdown of consolidated dirt on farm	Starting from February in the highland and May in the lowland	Moderately affected
Compost preparation		Almost impossible[10]
Searching and transporting feed for cattle	Throughout the year	Moderately affected
Frequent ploughing before the rain arrives	May and June	Highly affected
Paving runoff way, preparing drainage, installing of in-suta runoff collection system	May and August	Highly affected
Maintenance of farmland terrace	June	Moderately affected
Searching and applying manure on farmland	It starts from October for the next June to July planting season	Moderately affected
Community level Watershed management and SLM mobilization		Not affected

Challenges of Women's Access to labour during male out migration

Women hold multiple responsibilities, including motherhood and domestic work, so spending all day doing physical SWC work is challenging to achieve (Nchanji et al., 2021). Indigenous labour mobilization institutions are common in the study community. *Wobera***,** for example, is an indigenous institution through which farmers come together and work labour intensive agricultural tasks. Rather than doing independently for a more extended period, the farmers form a team of up to 15 or 20 people and work rotationally on every team member's farm.

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[8] Fertilizer access is very limited to a particular class of farmers. Despite the skyrocketing price, availability is also minimal. Given the absence of the HHH, it is undoubtedly difficult for women/wives to penetrate the male dominated social network to get prior access to fertilizer.

[9] Most plots are on a steep slope and stony topography; this is very difficult for women to do alone given their difficulty of access to labour.

[10] Compost is not familiar SLM tool for most farmers. It is observed in a few model farmers whose primary livelihood is farming and livestock. It would be impossible for the migrant family, given their labour shortage and less time in the village.

Women can participate on *Wobera* days once their husband or younger son joins *Wobera* team. However, if the household head or physically abled socially active son is outside the village, forming the *Wobera* or *Wonfel* team might exclude women. This is not because the women are not fit for or discriminated against from participating in such labour accessing institutions. However, it is due to the way these institutions are formed. These institutions are formed in the time-space geography of males; most agricultural discussions are decided when men meet in church, on wedding days, and during leisure time. This is the effect of the traditional social structure that creates agricultural associations and farm cooperatives predominately under the domain of men (Peterman et al., 2014; Rola-rubzen et al., 2020).

Finally, it was important to explore whether women managed farmlands are productive and well managed. As crop yield is partially dependent on the personal traits of the HH, it is appropriate to expect women-managed lands to differ from men-managed lands. However, when the HH decides to migrate, it confirms that the yield from the land by working the whole year is less than the migration earning. In other words, farmers risk the yield reduction incurred by the opportunity cost of migrating. A review of studies by Kawarazuka et al. (2022) argued that when a man migrates off a marginal farm, even if nothing changes on the farm, his move will decrease the productivity of land, or women might switch to less labour-intensive crops. Furthermore, female-headed farm households are underserviced concerning the provision of credit, inputs, facilities and equipment, and the effective dissemination of information (Satyavathi, Bhar- adwaj, and Brahmanand 2010; Rola-rubzen et al., 2020).

In the study area, given the short rainy season and frequent rain failure, the unavailability of the head of the household on critical agricultural tasks such as land preparation, sawing, and weeding, affects the crop yield. Moreover, changing the conventional crops and switching to less labour-intensive crops could reduce crop diversity, leading to weak adaptability during environmental disasters. Women informants reported that compromising sawing days while waiting for other farmers to finish their tasks and come to help inevitably reduced crop yield. When women ask for help from neighbors and families, given that every farmer rush to saw and weed on critical days, they miss the most decisive soil moisture to saw/plant their crop. Findings from this study indicate that the already unproductive, labour-intensive farming is hampered when the management is role is shifted to less empowered and resource poor women. Compromising the sawing, weeding, and harvesting dates due to the absence of male out migration and lack of enough labour- could reduce the agricultural yield and productivity. Data from the FGD, interview, and KI showed that except for the additional burden on women brought by male migration, the land productivity, number, and types of SLM practices do not benefit from changed gender roles due to seasonal migration.

This finding corroborated with studies (such as Aguilar et al., 2014; Backiny-Yetna & Mcgee, 2015; Croppenstedt et al., 2013; Muricho et al., 2020; Padmaja et al., 2019; Quisumbing, 1996; Tavenner et al., 2019; Rola-Rubzen et al., 2020) that reported women farmers lack access to inputs, and services to implement improved agricultural practices. Let alone the already degraded land transferred to left-behind women; female-headed farm households generally underserviced with the provision of credit, inputs, facilities and equipment, and the effective dissemination of information (Brahmanand et al., 2010: Rola-rubzen et al., 2020). Comprehensive review by Peterman et al. (2014) finds that men use more improved seed, fertilizer, and extension services than women do. Men generally have higher input measures than women (Kawarazuka et al., 2022; Meinzen-dick et al., 2014). Another finding in Nepal indicated that the feminization of agriculture due to migration has lowered farm production and worsened food insecurity (Pandey, 2019). Bacud et al., (2021) also argued that women are working more but are getting low yield.

4.4.5. Migration Earnings and Remittance Investment on SLM

The biggest on-going academic debate and discussion is the financial effect of remittance on how it compensates the labour loss of rural households and how it is invested on SLM. NELM provides a theoretical explanation that remittance positively affects SLM and agricultural yield by easing financial constraints. The majority of interview account from seasonal migrant tends to give less value for either staying in the village during the whole year or to the benefit of SLM practiced during the winter season. Most migrants believe the land management or care given when they return from seasonal migration is enough for their farm. Frequent seasonal migrant farmers seem to reduce their attachment and effort on the farm slowly. On the other hand, it was much visible in the interview and FGD that non-migrant households are more emotionally and physically attached to the farmland. Although it is not observed currently, slow exit from the farm might be a future phenomenon if the seasonal migrant shifts to permanent migration.

Seasonal migration and the flow of remittance have been one of significant sources of financing in developing countries. However, little is known about the role of remittance receipt by households on the adoption of SLM practices (Williams & Paudel, 2020). We explore how remittances were allocated to different expenses. Almost all the KII and participants reported that remittance and migration earnings are predominantly invested in basic consumption, such as purchasing grain, spices, and clothes for children. Some informants reported that they had bought livestock, particularly oxen and goats, after returning from their migration. Very few reported that they sometimes buy chemical fertilizer using their migration earnings.

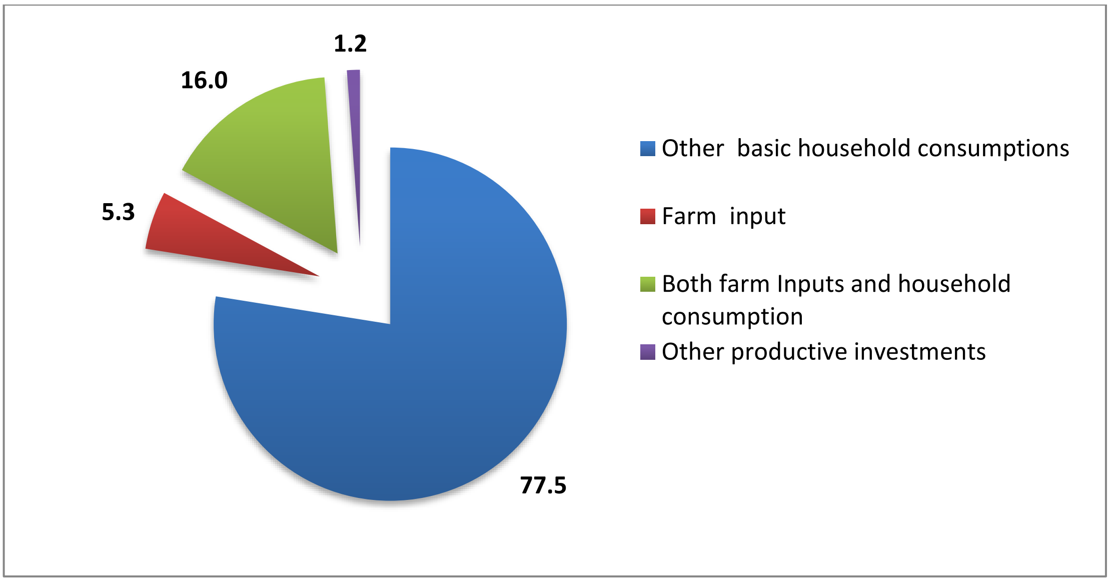

Fig. 6.7. Patterns of remittance allocation in the study area

Reasons for not investing their remittances on yield improving inputs and SWC practices are categorized into two main categories. 1); the remittance and earnings are not enough to cover beyond fulfilling the grains and clothes for their kids, 2); the second group argues that their farmland is either too small or located on a steep slope; they believe application of fertilizer would not bring significant yield improvement.

It was also understood from the interview that some respondents already labeled themselves poor and fertilizer and manure application is not affordable for them. The following account from farmer and Priest (G/ Slassies*)* support this view.

"*I only manage my land by working terracing/stone bund. The richer farmers will apply manure and fertilizer. People with low incomes would only work terracing to halt erosion. Improved seeds and fertilizer are only affordable by the richer family."*

Besides labelling fertilizer and improved seeds for wealthy farmers, it was observed that there are types of SLM packages that the poor and the migrant could not afford due to time and financial constraints. In the above account, terracing is only affordable to this household.

FGD in Shmedir kebele also explained that fertilizer is being inaccessible for all affording farmers. An old farmer expresses his grievance as "*they (the local administrators) made us to be dependent on fertilizer….but they made it difficult to access it now. Fertilizer is accessed through personal network and kinship with administrators".*

Regarding manure application, the critical importance of goat ownership comes here to determine farmers' access to manure. Responses like “*If I had goats, I would apply manure, and even I would not migrate seasonally at all”* appear in the narratives of seasonal migrant farmers.

Another respondent, Gishe Belay, frequent seasonal migrant, was asked if he has any biological SWC structure on his farm, such as grass, Aloe Vera, e*tc. He said, "There is a stone bund on my farmland, and I do not use biological structures*."

Due to the topographic nature of the district, most farmlands lie on sloppy land. Terrace or stone bund is widely used and is important in halting farmland erosion. These stone bunds are constructed long ago and may need maintenance that is not difficult for migrant farmers to maintain at given time intervals when they come back from migration. Biological SWC methods are common in Waghimra farmers; *Aloe vera* bund is particularly popular as a soil and water protector. Farmers in Tiya, Agewmariam, and Sirel have good experience of Aloe vera bund. Experienced farmers from Shimedir kebele explained that *Aloe Vera bund* is more important than stone bund because it has roots, holds much soil, and produces fertile soil around its root after. They also prefer it because it resists soil erosion than stone bunds. However, biological structures need frequent follow-up, trans-locating roots from nearby shrublands to the farm; this is challenging for a farmer whose time is portioned between seasonal migrations and farming.

The FGD and KII showed that migration and SLM are co-determined by the household's economy. Farmers frequently categorized themselves and other farmers as “the rich" and "the poor". We attempt to know what constitutes being “a rich farmer" and “a poor farmer” in the community and how it determines SLM. The agricultural experts in Shmedir and Sirel were interviewed on the economic background difference between migrant and non-migrant HH. They respond that the non-migrant families have at least optimum grain production yearly unless extreme environmental shocks happen in the district. However, the migrants have less grain every year. Even though they might have cash earned from migration, grain prices are increasing, making purchasing difficult. According to the possible remittance flow, we expected that seasonal migrants could have more cattle, build iron roof houses, and generally have a better living standard than the non-migrant who only depends on rain-fed agriculture. The interview result disproves this postulation. Almost all the migrant key informants supported that the non-migrant farmers are better off, particularly the number of goats they owned reflects their economic status. A 42-year-old women mother of two told that “*the more productive farmers are who stay the whole year in their village, follow the DA guidelines and* *recommendations of farming and SLM application*". She added, "*farmer who stayed the whole year in the village can rent the migrant farmlands to produce additional grains*." In support of her account, the local DA explained that, since the land is degraded and ploughed for the century without fallow, it needs much time and labour to produce optimum yield. Waiting the rainy days and planting the right crop according to the amount and timing of rain require a farmer who is always actively working on the farm. Following strict farming guidelines and the seasonal working calendar is a very important aspect of farming in the study area. Fulfilling this requirement is also difficult for seasonal migrants since they are out of the village. For example, let us look at the following response to the question.

In support of the views of FGD discussants and the above accounts of women, a farmer explains in an interesting statement, *"The land gives only to his caregiver! Those who plow well, who work the whole year get a good yield."*

The above accounts and the general perception observed from our participants concluded that the non-migrant farmers produce more grain than the migrant farmers do. This leads us to the argument that given the migrant give less attention/effort to the land; their yield might also be minimal. This situation probably creates a vicious circle in that a migrant will remain poor, and land will be redistributed (in terms of crop sharing and rent) to the non-migrant farmers who are relatively better off.

Given that our methodology is different, the findings from this study contrast with studies by (Brauw, 2015 & Abebaw et al., 2019). Brauw, (2015) reported that there is an increase in production among migrant-sending households relative to non-migrant households. Abebaw et al. (2019) showed that the out-migration of a household member has significantly increased household spending on herbicides and livestock. This qualitative study does not imply any agricultural yield increment or increased agricultural input among migrant families.

6.5. Conclusions

This paper has attempted to contribute to understanding the role played by land degradation: manifested in low productivity, and environmental factors (mainly drought) in determining mobility decisions in terms of seasonal migration. This study explores the relationship between seasonal migratory pattern of smallholder farmers with the practice of SLM that are response for the existing land degradation and declining agricultural production in the upper Tekeze basin of Waghimara administrative zone in Ethiopia. The study extends its analysis from the cause of migration to the impact of remittance on SLM investment and practices to increase crop yield.

The study revealed that seasonal migration is a pronounced and continuing phenomenon both in the relatively fertile midland and degraded lowland areas of the basin. The study shows that land shortage, lack of immediate coping strategies during environmental shock, declining fertility, and landlessness are the dominant cause of migration in Waghimar zone. Reduction of land productivity and increase in labour and input requirement of the farm has also been reason for migration. Younger farmers have limited possibilities to stay in rural areas while they do not have land. On the other hand, the land is degraded and unable to support large family size. Moreover, drought and rainfall irregularities during the planting season are initiating migration decisions. This finding supports earlier evidences that argue that environmental factors shape migration through its impact on migration drivers (Black et al., 2011; Lilleør and Van den Broeck, 2011; Morrissey, 2013). Our finding showed that drought does not cause migration equally for all households. However, it exacerbated the economic problem and forced farmers to seek other coping mechanisms. There are limited non-farm and off-farm livelihood strategies, and household is short of alternative coping strategies such as asset sale and savings. As a result, migration is an immediate response to crop failure due to drought, irregular rainfall, and pest invasion.

It is worth mentioning that communities are well-informed about land management concepts and committed to spending their time and labour on their farm. However, on the other hand, it is also observed that the younger landless are spending less time in the village, and doing less physical soil and water conservation practice on their farm. In addition, migration earnings and remittances are not benefiting the SLM application and investment in farming; almost all remittances are allocated to basic consumption. Furthermore, in the long-run, if men migration persists and left-behind women and elders dominate the village, the migration may affect the community level SWC practice by decreasing labour availability.

This article argues that there are distinct relations between migration, and land management. The interactions among these is mediated by several endogenous and exogenous factors such as the availability of remittances, loss of labour, socioeconomic status of households, gender, and land and cattle ownership. The impact of migration on the effort of SLM can be seen from two points of view; 1) migration season overlaps with the season of SLM practicing season, even considerably seasonal migration is happening during the time major planting seasons. This directly affects the SLM's labour and time allocation, leading to low SLM application performance and reduced productivity. 2) The current seasonal migration is a coping strategy for environmental degradation, fertility loss, drought, and landlessness for younger household heads. The remittances are rarely used for SLM investments such as the purchase of fertilizer, additional labour, improved seeds, etc. The central point of argument in this paper is that land management, land degradation, and migrations do not have a straightforward relationship; they are context-specific based on the demographic and socioeconomic characteristics of the household and its member.

Finally, this paper argues environmental problems with economic and demographic factors are causing male out-migration. Remittances are not invested in agricultural inputs and SLM practices. Left behind women are deciding on farmland management, however, input and skill limitations are challenges for women. Furthermore, the changed role of women did not benefit farmland management. However, it has brought additional workload for them, not empowerment in the sense of feminization of agriculture. Seasonal out-migration could provide non-migrant farmers with more land for rent. However, whether these farmers would manage the rented land remains a question as land tenure is determinant of SLM practice and adoption.

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CHAPTER SEVEN

IMPACT OF SEASONAL RURAL OUT- MIGRATION ON SLM ADOPTION AND USES IN RESOURCE POOR SMALLHOLDER FARMERS, NORTHERN ETHIOPIA

Abstract

Seasonal rural out migration is one of the major livelihood strategies for resource poor farmers in developing countries. However, little is known about the links between seasonal migration and adoption of SLM practices. We use two-stage least squares (2-SLS) regression and PSM to examine the impact of migration on the adoption of SLM practices. Data was obtained from questionnaire surveys of 376 households in Waghimra district of Northern Ethiopia. The study found that poor land fertility, perceived high soil erosion on farmland, lack of cattle, participation in off farm livelihood, increased education level, and male gender significantly positively influence migration in the study area. Our analysis show that migration has significantly negatively affects the number of SLM adoption intensity. Furthermore, other variables such as participation in extension trainings, larger livestock ownership, size of land owned and land owned through rent and crop sharing significantly positively influence SLM adoption intensity. Similarly, participation in indigenous local labour sharing institution positively affects SLM adoption intensity. However, poor perceived land fertility significantly discourage SLM adoption intensity. PSM result confirmed migrant households have adopted 1.51 unit of SLM than the non-migrant households indicating that engagement with migration significantly reduce the number of SLM adopted by households. Farm households facing labor shortage resulting from out-migration should be part of policy focuses and the resource access, skill, and quality of left behind households should be considered in SLM policy and strategies.

Keywords: Seasonal migration; determinants of rural out migration, Sustainable land management (SLM); 2-SLS, PSM, Waghimra; Northern Ethiopia

7.1. Introduction

Rural-urban migration is connected to agricultural dynamics, presents both opportunities and challenges, particularly in the context of resource management, land use, and ecological processes (Caulfield et al., 2019; Radel et al., 2019). Migration decisions among households are influenced by factors, adverse climate conditions often cited as a key driver in rural developing areas. However, these decisions are also shaped by economic, social, demographic, and political factors (Morrissey, 2013). Among the climate-related events, droughts stand out as having severe impacts on smallholder agricultural production, potentially leading to livelihood losses and subsequent migration (Hermans & Mcleman, 2021).

In sub-Saharan Africa, agriculture provides employment for over 70% of the population (World Bank, 2016).With a population exceeding 104 million, Ethiopia's economy heavily depends on agriculture, which accounts for 42% of its GDP and is the primary livelihood for more than 80% of its population (Dessalegn et al., 2023; Zeweld et al., 2018). However, Ethiopian agriculture is predominantly small-scale, traditional, and rainfed, facing significant challenges such as land degradation, and frequent droughts (Ewunetu et al., 2021a; Teklewold et al., 2013). To address these challenges, investments in SLM practices and improved farming techniques have been recommended (Ewunetu et al., 2021b; Quinn, 2009; Teklewold et al., 2013; Williams & Paudel, 2020).

SLM practices, such as soil bunds, stone bunds, and manure, compost, chemical fertilizer, crop rotaion e.t.c have been implemented in Ethiopia for decades, particularly in the Northern highlands (Ebabu et al., 2019; Eshetu & Abegaz, 2024; Haregeweyn et al., 2015). These practices have been widely recognized for their effectiveness in enhancing productivity and rehabilitating degraded environments (Adgo et al., 2013; Kassie et al., 2008; Pender et al., 2001; Hishe, Lyimo, & Bewket, 2017; Amare et al., 2014). Since the mid-1970s, the Ethiopia has made major investments in soil loss reduction and agricultural production improvement techniques (Sileshi et al., 2019). However, the increasing trend of rural-urban mobility creates both obstacles and opportunities for implementing SLM.

Rural–urban migration is an important livelihood strategy for rural households to increase their income (li et al., 2013; Nguyen et al., 2019). Migrant remittances contribute significantly to development and living conditions in sending countries (De Haas, 2005). Migration, often driven by economic necessity, can have significant effects on agricultural production, both positively and negatively (De Haas, 2005; Kapri & Ghimire, 2020; li et al., 2013; Redehegn et al., 2019). While some argue that rural out migration produce the flow of remittances that are invested on agricultural productivity (Kapri & Ghimire, 2020; Quinn, 2009), others also argued that it leads to a loss of labor and negatively affect farm productivity (Nguyen et al., 2019; Rozelle et al., 1999; Shi, 2018; Taylor, 2010). Given mix of findings regarding the casual relationship of migration and agricultural development through sustainable farmland management, the complex interaction between migration and agricultural practices is not yet fully explored, particualarly in less urbanized regions like sub-Saharan Africa, where agriculture remains the dominant livelihood.

Traditionally much of the literature on migration has focused on whether or not migration has positive effects on the welfare of migrants or the economies of migrant destinations (Borjas, 2003; Ghatak, Levine, & Price, 1996). The interaction of migration and farming in developing countries is not well studied as opposed to the increasing available literature in the developed and highly urbanizing developing countries such as China. Moreover, biased focus on migrant receiving regions has shadowed the understanding of migration impact on the sending areas (De Haas, 2005). The New Economics of Labor Migration (NELM) literature has placed new emphasis on understanding the effects of migration on the development of sending areas (De Brauw & Rozelle, 2008). Both positive and negative impact of migration in sending areas is presented in the NELM framework. NELM provides new insights about impact of labor migration on the agricultural activities in rural areas. NELM argues that migration is household decision in order to maximize economic gains and to cope with the risks associated with income constraints and agricultural shocks (Stark & Bloom, 1985; Taylor, 1999). Similarly, remittance ease the credit constraint of rural and enable them to invest in new agriculture technology, and SLM practice which helps enhance their agriculture productivity.

When a household decides to send out a migrant, it makes simultaneous decisions about its labor allocation and other input. Upon arrival of remittance from migration, the household also makes decision about investment in household resources such as hired labour and adoption and purchase of improved farming inputs and mechanisms (Taylor et al., 2003; Kapri & Ghimire, 2020). However, this decision can either exacerbate or alleviate constraints on production (De Brauw & Giles, 2018; li et al., 2013; Williams & Paudel, 2020). In the NELM framework, in areas where a household relies on family labor, maigration causes lost labour effect which a decrease in the number of family workers. In this context, it is difficult to replace the lost family labor by hired labor (Atamanov and Van den Berg, 2012). This negative lost-labor effect has been shown in several empirical studies (de Brauw, 2010; Rozelle et al., 1999). Even when remittance compensate the lost labour effect, it is necessary to question the productivity of left-behind elderly and women, who have been often limited by skill and power (Shi, 2018).

The available literature particularly on the impact of migration and remittance on SLM is not conclusive. For example, study by Brauw and Rozelle (2008) argued that remittance is spent on basic consumption expenditure rather than yield improving agricultural inputs and practices.

Similarly, Jaquet et al. (2016) showed that remittances are rarely used for agriculture improvement. Migration without remittances decreases farm labor productivity and crop diversification of rural households (Nguyen et al., 2019). Even worse, migration exposed rural landscapes to land degradation as many terraced landscapes disappeared and increased overgrazing (Acquit et al. , 2019). Another study by Williams and Paudel, (2020) found no direct impact of remittance on the intensity of SLM practices adoption in Nepal. Similarly, studies reported decreased use of physical SWC techniques (Caulfield et al., 2019), reduced fertilizer use in rice production (C. Zhang et al. (2021) and low quality left behind labour with less attention about the sustainable use of cultivated land. Migration generates economic and environmental losses for on-farm production (Ren et al., 2023) However, a more optimistic perspective on the impacts of labour migration on agricultural technologies and SWC practice declares that remittance contributes to better farmland management and agricultural technological improvement and hence improved agricultural productivity. For instance, (Caulfield et al., 2019; Gray, 2009; Li et al., 2013) reported remittances investment-promotion effects that result in increased maize production, greater use of agro-chemicals and mechanized tillage; agricultural productivity (Kapri & Ghimire, 2020; Nguyen et al., 2019).

Given the conflicting findings in existing literature on the impact of migration and remittances on agriculture, this study contributes to a better understanding of these dynamics in the Ethiopian context, shading lights on how migration influences agricultural practices and sustainability in rural areas. This study aims to explore the impacts of seasonal rural out-migration on SLM adoption and use, focusing on the upper basin of the Tekeze River in northern Ethiopia. This region, characterized by erratic rainfall and poor infrastructure, represents farming systems in environmentally disadvantaged areas. The study seeks to estimate the impact of migration on the intensity of SLM practices, such as soil and water conservation mechanisms and the use of improved agricultural inputs. Specifically, the study aims to estimate the impact of migration on SLM adoption and use intensity and improved agricultural inputs such as fertilizer, manure, pesticide, improved seeds, stone and soil bund and biological conservation structures. It will also examine whether remittances are primarily used for yield-improving mechanisms or basic household consumption and how the lost-labor effect influences farmland management and productivity. There are four main contributions in this paper. First, we analyze the impact of migration and remittance on agricultural productivity at the household level, demonstrating that remittances have a significant positive impact on agricultural productivity

7.2. Methods and Study Area Description

7.2.1 Study Area Description

This study was conducted in Northern Ethiopia, hotspots of rural out migration, land. The study was conducted on the upper basin of Tekeze river, which is part of the Nile Basin in Ethiopia. Tekeze River found in northern Ethiopia between 11040’ and 14051’ N latitude and 36040’ and 39050’ E longitude. It is bounded by the Blue Nile (Abay), Angereb and Mereb river basins and the Afar Rift. The river originates from the high lands of North Wollo, from mount Abune Yosef and drains to Waghimra, Tigray and finally enter to Sudan to join the Nile-Ababy River. While the Total drainage basin of Tekeze basin in Ethiopia is about 45694 km^2 covering part of Amhara and Tigray administrative regions, the current study is conducted on the upper basin of the river in Waghimra Admisntrative Zone. In this part of the basin there exists extremely diverse topography (Fig 7.1). While the altitude of Tekeze basin in Ethiopia ranges from 500 m in its western lowlands to over 4600 m in the central highlands, in the current study districts, the elevations range from 1021 to 3880 m above sea level (Fig. 7.1).

Based on Hurni’s (1998) agroecological classification which considers elevation, three different agroecological zones dominate the study area. The *Kolla* agroecological zone (warm, semiarid lowlands; covering 17.5%), followed by Weyna-dega (cool, humid highlands; covering 68%), and Dega (temperate cool sub-humid highlands; covering 14.5% of the study area). Most of the study area is semi-arid and arid according to the United Nations Environment Programme (UNEP) aridity classification (Fentaw et al., 2023). While the northern and northeastern part of the basin is dry sub-humid and non-dryland, the central and northern holds semi-arid and arid land characteristics.

Unimodal and erratic rainfall patterns characterize rainfall in Waghimra zone. The baisn receives much of its annual rainfall in the from June to September (locally known as “*Kiremt*”") when the Inter Tropical Convergence Zone (ITCZ) is located north of Ethiopia Gemechu, 1977; Hagos et al., 2015). This season contributes more than 70% of the annual precipitation in north and northwest Ethiopia, including in Waghimra zone. While the annual rainfall of Tekeze basin reaches up to 2000 mm in the Ras Dashen Mountains (Hagos et al., 2015), it is only under 1000mm in the upper basin of the river in Waghimra a dmisntrative zone.

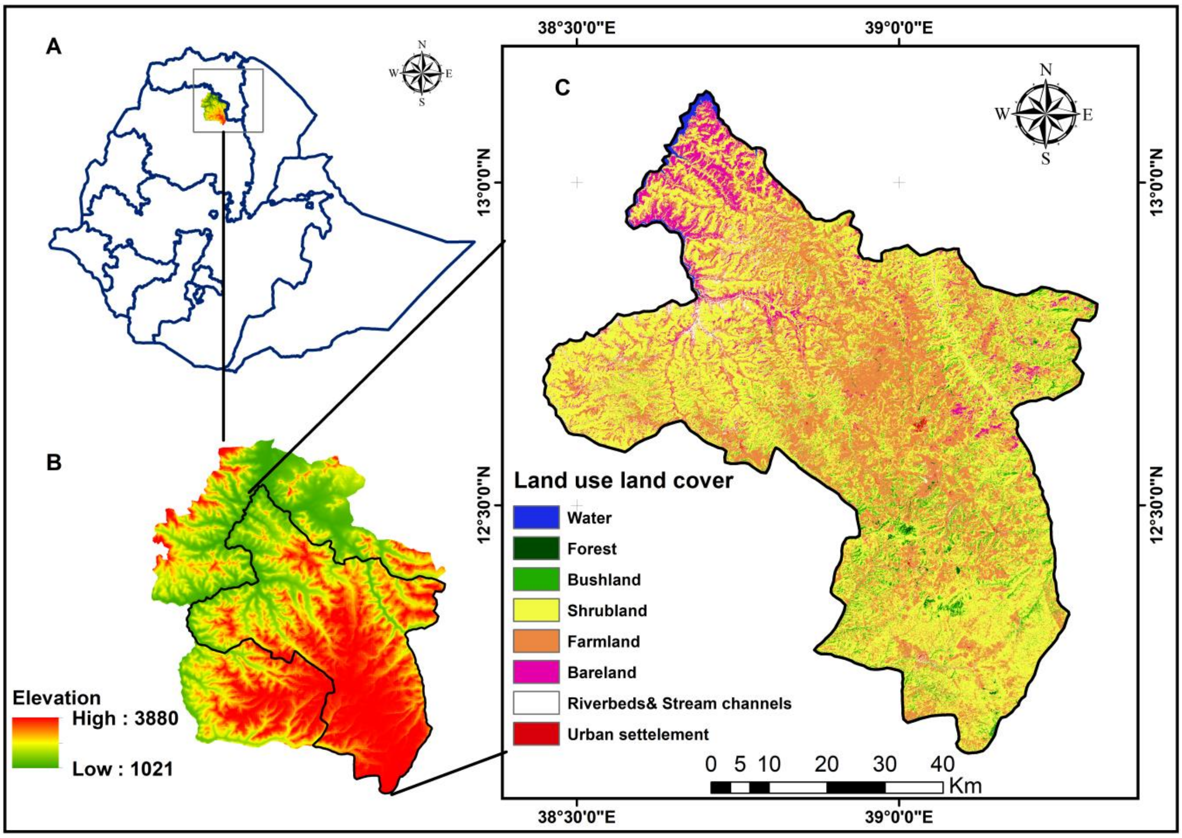

Fig. 7.1. Location of the study area: a) in Ethiopia, b) in Waghimra Adminstrative Zone c) studied sub-basin showing LULC

Summer (*Kiremt)* rain ceases around the end of August in the stusy area. The Deaga and Woynadega areas receive rainfall from late June to early September. However, rainfall distribution of the *Kolla* agroecology extends from early July to mid of August. About 63% of the annual rainfall is concentrated only in July and August (Fentaw et al., 2023). The area's annual minimum and maximum temperatures is shown on Fig. 7.2.

Waghimra zone in is exposed to recurrent drought. It has been affected by the devastating droughts of 1973, 1984, and 2015 (Fentaw et al., 2023). Crop pests, livestock disease and human health epidemics are common shocks that affect the life and livelihood of the population. Furthermore, land degradation as a series problem and manifests in the form of soil erosion, soil infertility, and insufficient rainfall.

Trend of seasonal rural out migration in Waghimra

Commonly, destination areas for migrants from Waghimra districts are Metema, Quara, Humera and Dansha, Mai-Kadra, and neighbouring Sudan regions. Due to the presence of large agricultural investment farms, there is great demand for daily labourers during agricultural peak seasons. Most of the labour is for activities weeding, and harvesting. The work arrangement in these areas is both contract and daily casual based for both weeding and harvesting of cash crops such as sesame, and cotton (Kibrom et al., 2019).

The other corridor of rural out migration is towards the southeast and south of Waghimra Ethiopia. This migration is mainly both for works in urban areas and for agricultural jobs in high agricultural potential districts of the Amhara region. Among these areas, Raya areas hire considerable large number of migrants during harvest and weeding seasons. Besides, urban areas including Woldia and Dessie are among the destinations of migrants from Waghimra zone. Furthermore, migrants from the study are could migrant far up to Addis Ababa, Bahir Dar and Debre Markos for searching jobs.

7.2.2 Data Sources, Sampling and Data Collection Methods

The cross-sectional data for this study were collected using both open and close-ended questionnaires from June to August 2021. Guided by NELM that argues miration decision is at household level and is a family strategy, the sampling units were farming households. The questionnaire included demographic, plot charcterstics, and institutional characteristics. It also included farmers perceptions on the status of soil erosion and fertility status. SLM adoption and intensity was also collected through questionnaire survey. The reliability and validity of the questionnaire were checked based on preliminary key informant interview and FGD with selected farmers and agricultural extension workers, and input from local government and non-government organizations that work with farmers in the zones. Based on the feedback obtained from extension workers and other key informants, some questions were omitted, amended, and restructured. The questioner was administered using the local language (Amharic). Where there were farmers who do not understand Amahric, the assistant data collector was served as translator to Himtagna, their language. Well-trained enumerators under the close supervision of the researcher administered the questionnaire. In addition to the questionnaire survey, FGDs and in-depth interviews were conducted to complement and contextualize the quantitative data. In each FGD meeting, 6–8 members were participated.

With regard to sampling procedure of the study, multi-stage sampling procedure was used to select sample Woreda, Kebeles and respondents from each district. The multi-stage sampling involving purposive and random sampling methods. Although there is known lack of migration data at district and regional levels in Ethiopia, reports, and census data at national level registered migration hotspot area. The drought prone area of Waghimra has both historically and culturally driven migration history, and is well documented in government and humanitarian agencies reports. For this reason, Waghimra is the ideal context to study the link between migration and land management. In order to select the study villages in the zone, zonal level experts and development agents were consulted. In the first phase, secondary data was gathered in the zonal level regarding agricultural production, seasonal migration, exposure to land degradation and drought. In consultation with the expertise in the zonal administrative organs, among the five sub districts of the zone one representative woredas was selected purposely for its proper representation of the two dominant agro ecology in the zone, *Kolla* and Woynadega. In the second phase, Kebeles[11] in these districts were ranked based on their agricultural production, SLM implementation, watershed management while keeping seasonal migration at least common in the Kebeles. Finally, we have selected four Kebeles purposely that fulfil the criteria. Our pull of sample provide reasonable proportional sample of migrants and non-migrants and at the same time farmers who implement SLM on their farmland. Finally, simple random sampling were used to select respondents from the selected Kebeles.

Then on the bases of the established sample frame, the sampling size is determined based on Kothari (2004). The total sample of 385 households were selected using the formula by Kothari (2004) which is given in equation below:

$$n = \frac{z^2 p(1-p)}{e^2}$$

In which “n” represents the sample size of the study households distributed proportionally to each Kebele. Whereas, “z” represented the inverse standard cumulative distribution that corresponds to the level of precision level “e” in which in this study which takes the value of 5%. “P” represents the estimated proportion that is present in the study population. When, we don’t have information about the proportion of variability of the study population in terms of migration status, SLM practice and level of agricultural technology utilization; it is advised to use the value to p = 0.5 which is assumed to be most conservative sample size (Kothari, 2004). The distribution of the sample based on the sampling procedure is presented in table 7.1. From the total sample, 20(5%) households of contingency sample is added so that the total sample size of the study reached 405 households. However, the final refined number survey on which the quantitative analysis depends on is 376. The remaining questionnaires were incomplete and do not have adequate data to be included in the model.

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[11] The lowest administrative units in Ethiopia

Table 7.1 District wise distribution of respondents

Kebele name and code	Male	Female	Total household	Sample household
Tiya (02)	805	255	1060	78
Shimedr (08)	965	276	1241	91
Sirel (020	1148	528	1676	123
Qeba (023)	987	289	1276	93
Total	3905	1348	5259	385

7.2.3. Data and Variables

The outcome variable in this study, SLM adoption intensity expressed as the number of SLM practices that households utilized during the study period. After conducted preliminary field survey and detail discussion with agricultural extension workers, it was made possible to prepare the list of the very commonly applied SLM practices. We primarily collected the response in the form of dummy variable and computed the count the number of SLM practice adopted/used by the farmer. The total number of SLM practices included in the survey were of 11 including, improved seeds, chemical fertilizer, manure, crop rotation, soil bund, stone bund, biological SWC structures, planting trees and shrubs around the farmland, and drainage for flood prevention.

The treatment variable used in the study is participation of the household head or member of the household in seasonal migration. Migration was defined as the absence of the head of the household or active labour force of the household from the village at least for greater than 2 months. This definition is consistent with previous studies on seasonal migration. After defining the outcome and treatment variables, we identify the control variables grouped as social-economic, demographic, and regional characteristics of the respondents. Specifically, the variables representing the age, gender, and education level of the respondents, household size, land size, land size owned by rent, Tropical livestock Unit, labour sharing, credit, perceived land fertility, slope and erosion severity and ecological dummies were used in the models. Migration network and extension training access were also used as instrumental variable in order to explicitly explain migration and SLM, respectively.

Expected relationship between dependent and explanatory variables

Most of the factors that affect adoption of SLM are context specific that varies with geographical locations, and socio-economic background. However, there are explanatory variables that influences adoption with expected signs. We expect age to influence the number of conservation practices used positively; age may indicate the level of farming experience, knowledge of natural resources, and level of participation. We expect income, size of land owned, poor soil fertility, farmer’s perception of high soil erosion on their farmland and farmlands on high slope to encourage farmers to adopt many SLM practices. Previous studies in Ethiopia find that land size owned have positive influence on SLM adoption (Mekuriaw et al., 2018; Wolka & Negash, 2014). On the contrary, land size is expected to discourage seasonal migration. Access and participation in trainings on SLM application and maintenance and construction of soil and water conservation practices obviously would have positive relationship to increased intensity of SLM adoption and use. Credit constraint is one factor that discourages farmers not to invest in yield improving agricultural inputs. The rural poor have less access to income and credit, due to this, they are often unable and unwilling to invest in natural resource management (Frost et al. 2007; Ahmed and Rayhan 2012; Mgbenka et al. 2012). Therefore, access to credit as well as income from off farm livelihood will have significant positive influence on farmers’ adoption of SLM as well as have negative influence on migration decision.

Some studies found that education has a positive effect on technology. Contrarily, it is also possible that increased education levels have a negative effect on technology adoption as well (Adeola et al. 2011). It may be easier for more educated individuals to use technology, however, they may also spend more time earning an off-farm job income. We expect the size of owned land through crop sharing and rent to have a negative effect since the agreement is usually short term. Farmland renter and sharecroppers have minimum incentives to conserve land unless the agreement is long-term (Paudel et al. 1998; Paudel et al. 2000; Gartaula et al. 2012. Maharjan et al. 2012). Labour intensive conservation practices such as biological SWC structure, soil and stone bund, compost preparation are expected to be affected by migration.

'Table 7.2 Outcome, treatment and explanatory variables used in the econometric model

Variables	Description
Outcome variables	
SLM intensity	Number of SLM practice used or adopted by the household
Treatment variables	
Migration	Dummy; 1 if the household has at least one seasonal migrant member
Explanatory variable	
Gender	Gender of the household head
Household head age	Age of the head of the household (number of years)
Household size	Number of members in the household
Land ownership	Dummy; 0 if the HH does not have land and 1 if otherwise
Land size	Land size in *Timad*
Off farm livelihood	Dummy variable; 0 if the household do not have off farm livelihood
Off farm income	Amount of income from off-farm livelihood excluding remittance
No of oxen owned	Number of oxen owned by the household
Household's livestock size (TLU)	Total Tropical Livestock Unit of the household
Farmland slope	Perceived farmland slope
Land fertility	Perceived farmland productivity
Erosion	Perceived level of erosion on farmland
Credit accesses	Access to credit in the local institutions (0/1)
Instrumental variable	
Migration network	The number of migrant that the respondent has known before in his village (number of migrant contacts)
Training access	If the respondent has gain training on SLM practice (0/1)

7.2.4. Empirical Methods

7.2.4.1. PSM method

Because household participation in seasonal migration is not random decision, a simple comparison of migrant and none migrant households based on their SLM intensity leads to biased estimation. The decision of household heads and its members to migrate or to stay in the village could be affected by unobserved factors that may also influence the adoption of multiple yield-enhancing SLM techniques. Consequently, directly comparing these groups could lead to selection bias and endogeneity. Thus, estimating the effects of seasonal migration requires creating comparable observations from the treatment and control groups.

To address this, we consider migration (Mi) as the treatment variable. Migrant is defined as an individual member of the household living outside the village for at least two consecutive months for employment purposes during one calendar year. Therefore, migration (Mi) =1 if the household has at least one member who engage in seasonal migration during the year before the survey or at least have a family member who returned form seasonal migration and Mi=0 otherwise. Our primary outcome variable is SLM adoption intensity. Given that the decision to migrate is influenced by various non-random factors, we apply the PSM approach to estimate the causal effect of migration on SLM adoption intensity while accounting for the potential self-selection bias. Following Rosenbaum and Rubin (1983, 1984), we employ PSM to match households with similar characteristics, but different migration statuses. This method allows us to construct comparable groups of in households with participation in seasonal migration and without participation in seasonal migration, thereby lead to a more accurate assessment of the impact of seasonal migration engagement on SLM adoption.

PSM is widely recognized in impact evaluation for creating comparable groups by balancing observed covariates. In our study, it enables us to estimate the causal effect by comparing the differences in SLM adoption intensity between matched migrant and non-migrant households. The propensity score, P(X), summarizes these characteristics and represents the probability of a household participating in migration, conditional on observed covariates X:

$$P(X) = \Pr[D=1|X]=E[D|X] \tag{7.1}$$

The treatment effect (τi) on SLM adoption intensity is estimated as:

$$\tau i=Y1_i-Y0_i \tag{7.2}$$

where $Y1_i$ represents the SLM adoption intensity for households with seasonal-migration (treatment group), and $Y0_i$ represents the SLM adoption intensity for households without seasonl migration (control group). After matching to construct comparable groups, considering MD= {0,1} as a binary indicator (where MD=1 for migrant households and MD=0 for non-migrant households), the Average Treatment Effect (ATE) can be expressed as:

$$\tau ATE= E[Yi|MDi=1]-E[Yi|MDi=0] \tag{7.3}$$

However, ATE may not fully capture the true impact of migration if selection into migration and other factors are correlated with unobserved variables that affect SLM adoption intensity. Since we can only observe SLM adoption intensity under either migration or non-migration for each household—not both simultaneously—we focus on the Average Treatment Effect on the Treated (ATT), defined as:

$ATT=E[Y1|D=1]-E[Y0|D=1]$ where $E[Y1|D=1]$ is the expected SLM adoption intensity for migrant households, and $E[Y0|D=1]$ is the counterfactual outcome, which is not directly observable. Simply substituting $E[Y0|D=0]$ (the outcome for non-migrant households) would not yield an accurate estimate due to systematic differences between the treatment and control groups. The true treatment effect is only identified if: $E[Y0|D=1] - E[Y0|D=0]=0$

This approach allows us to evaluate the impact of migration on SLM adoption intensity more accurately, ensuring that our findings reflect the causal relationship between these variables. Previous studies in migration, agricultural technology, and SLM impact assessment has used PSM (Alemu et al., 2023; Kibrom et al., 2019; Ren et al., 2023).

7.2.4.2. Instrumental variable method 2SLS

Previous studies have shown that there is a need to consider selection bias when modelling migration with any yield improving technology adoptions including SLM adoption decision (li et al., 2013; G. Liu et al., 2016; Quinn, 2009; Shi, 2018; Williams & Paudel, 2020). Neglecting of self-selection bias and endogeneity of rural-urban migration experience would produce biased and inconsistent results (C. Zhang et al., 2021). Selectivity bias is a problem because not every household sends out migrants (li et al., 2013; Quinn, 2009).

Based on NELM theory, migration decision is made at the household level as a family strategy to achieve certain family goals including fulfilling household consumption and reduce credit constraint for agricultural investment. So do seasonal migration is decided at household level to send the head of the household or other members to urban areas or high wage rural areas for months within a year. A decision is made due to low agriculture output resulting from drought and lack of liquidity constraints. When deciding to seasonally migrate; reduced labour from the farm lead to reduced use/application or incomplete adoption of a SLM practices with an individual spending part of the year as a labour migrant and the rest of the year on the farm (Taylor and Martin, 2001). However, remittance and earnings from migration might compensate the labour loss as well as increase agricultural input purchasing power of the household. Moreover, allocating their labour to the farm depends on the worth fullness of return from non-migration and adopting/ applying SLM.

On the other side, household with seasonal migrant member can reduce the liquidity and risk constraints through remittances. Moreover, the lost labour from the household can be compensated by incoming remittance, household may hire local labour or improve its performance in labour sharing in the village. At the same time, the lost family labour can be substituted for by hired labour so that migration could not negatively affect SLM adoption. Furthermore, a household can invest in high-productivity technology to offset the yield reduction brought by labour withdrawal. In large family reduced labour may not have significant effect, but the remittance from the migrant member may be invested in chemical fertilizer, improved seeds, manure (through increasing livestock ownership) and other farmland management inputs and practices. The estimation of impact of migration and remittance on

SLM involves two interrelated equations. Household's use and practice of SLM is (S_i) is a function of migration (M), and other household and farm characteristics (X_m). First, the explanatory variables, we model migration from the sample households. Migration is a function of individual, household and community characteristics X_m .

$$M = \beta_0 + X_m \beta_1 + \varepsilon_m \tag{7.4}$$

Finally, adoption and intensity of adoption of SLM practice of a household (i) is a function of migration (M) and household, plot and economic characteristicsX_m , as follows:

$$Si = \beta_0 + X_S \beta_1 + M_S \beta_1 + \varepsilon_S \tag{7.5}$$

Where $\acute{M}_S$ is predicted value of migration from the equation 7.4

Due to endognouty of migration, and SLM adoption, instrumental variables was introduced into the model. Instrumental variable identifies only M but do not correlate with the adoption function SLM (Si). The single equation ordinary least square (OLS) method will be biased because all variables on the right side are endogenous. Solution for this estimation problem is to use the 2SLS approach. This model can estimate the impact of migration on adoption of SLM, by deriving migration coefficient using the instrument identified. Previous studies applied 3-SLS approach in order to estimate both migration and remittance on different agricultural productivity outcomes (li et al., 2013; Quinn, 2009; Redehegn et al., 2019; Williams & Paudel, 2020; R. Zhang et al., 2022). However, in this paper, the role of remittance is not included due to the minimal contribution of remittance to SLM and very few respondents reported that they use the remittance other than fulfilling basic consumptions. Furthermore, we were unable to get strong instrument for identification of remittance function.

Instrumenting migration

In order to eliminate issues associated with simultaneity and endogeneity biases related to migration (M) in equation (1), instrumental variable was included in the 2SLS model. Ideally, a good instrument should be strongly correlated with the endogenous variable without affecting the dependent variable. While different variables including migration index (by indexing Villages according to their proportion of migrant) were tested to be a candidate for instrumenting migration, only migration network was found strong enough to instrument migration without correlating with SLM adoption intensity. Therefore, migration network at respondent level expressed as reported number of migrant contacts of the interviewed respondent (usually the available head of the household). Migration network has been used as instrument in previous studies and fulfil the theoretical requirement to be a best instrument for migration (li et al., 2013; Quinn, 2009). We assume that the proportion of migration network of the household has a strongly influence on the decision to migrate for seasonal work. However, migration network do not necessarily and directly affect the adoption decision and number of SLM adopted.

7.3. Results and Discussion

7.3.1. Demographic Characteristics of the Respondents

The demographic characteristics and descriptive statistics are shown in table 7.3 and table 7.4. Results show that, among the total respondents 38.6 % of households sent at least one family member to work as seasonal migrant. The remitted amount was, on average, 2961.832 per one season, and farmers adopted, on average, five conservation practices. The average off farm income of a household is 4276.908 ETB[12]. Table 3 shows distribution of migrant and non-migrant households across the study villages.

Table 7.3Distribution of migrant and non-migrant respondents across the study villages

Kebele		Migration		Total
		NO	YES	
	Shimedr	71	35	106
	Tiya	53	21	74
	Sirel	72	53	125
	Qeba	35	62	97
Total		231	171	402

The majority of the respondents were male-headed (83%), while 17% of them were female-headed. The average age of the respondents was 41 years, while the minimum and maximum age observed in the data were 18 and 73 respectively. The mean family size was six with the maximum family size of 11. The survey result indicates that about 33.7% of respondents were illiterate, while 33.4% can read and write. About 28.9 % of the respondents also have primary education. Very small number of respondent (4%) also reported that they have secondary education. The average land holding size was 2.8 Timad (1 Timad = 1/4 hectare). A maximum of 9 Timad land was observed in the samples households. Farmers who are landless or have inadequate land owned through rent and crop sharing. Average land size owned by rent and crop sharing was recorded as 0.88 Timad. However, some households reported more than 10 Timad (up to 2 hectare) land owned by rent and crop sharing. The distribution of rental/crop

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[12] Ethiopian birr, (1 US dollar was approximately 52 Ethiopian birr during the time of data collection)

sharing land was not uniform among migrant and non- migrant households. The average land holding through crop sharing was 1.15 among non-migrant households while it was only 0.46 for migrant households, implying that the non- migrant households own more land through crop sharing and rent in order to fill their land shortage.

While evaluating farmland characteristics, on average, about 21% of respondents perceived that their farmland was steep, 43% moderate, and 36% of the land had a plain slope. About 35% of respondents perceived that their cultivated land was fertile. The majority of farmlands were perceived by the land users to have moderate to very severe erosion status.

We have observed mean difference on various variables among migrant and non-migrant households. The mean age of non-migrant households was slighter younger than the migrant ones. While the maximum age observed in migrant household was 67, the maximum age observed among the non-migrant was 73 years old. Still non-migrant households have higher family size than the migrant groups (5.8 and 4.8, respectively) (Table 7.4).

Table 7.4 Comparison of means of major variables among migrant and non-migrant households

	None Migrant		Migrant	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
SLM intensity	5.54	2.869	1.845	1.967
Credit	0.4	0.490	0.1032	0.305
Age	42.9	10.12	37.638	10.056
Family size	5.80	2.154	4.8193	2.199
Education	1.8	0.83	2.4709	0.885
Perceived land fertility	1.93	0.60	2.75	0.488
Off farm livelihood	0.46	0.4998	0.245	0.431
Off farm Income	4657	8692	3673.5	9687
Oxen ownership	1.33	0.857	0.703	0.765
Cattle ownership	0.89	0.307	0.645	0.480
Land size	3.19	1.578	2.154	1.3960
Rental land size	1.14	1.969	0.4645	1.158

There was also great mean difference on income from off farm livelihoods. Non- migrant households have higher income (4657 ETB) than migrant households (3673.5 ETB). Similarly, non-migrant household TLU have more than twice higher than migrant households do. Particularly non-migrant households have more oxen than their counterpart does. Finally, we have seen great mean difference in terms of SLM use and application intensity between the two groups. Non-migrants apply 3.7 more SLM than migrant households and this mean difference was statistically significant at less than 1%.

7.3.2. The Status of SLM Practice in the Upper Tekeze Basin

Farmers in Waghimra zone of upper Tekeze basin apply various SLM technologies on their farmland. A total of eleven SLM technologies were considered in this study, including, soil bund, stone bund, drainage maintenance, and construction, agroforestry, manure, compost, inorganic fertilizer, improved seed, intercropping, crop rotation, and biological structures such as alovera bund (Table 7.2).

The most commonly adopted SLM practice is crop rotation where 68% of respondent have applied it. Alternating between crops to increase soil fertility by nitrogen fixing plants, and switching from cereals to long stalk crops such as sorghum is common in the study area.

Stone bunds are popular soil and water conservation structure in the local farmer due to the high slope gradient of farmlands and the previous public awareness and practice mobilization efforts. Stonbund was implemented by 52% of the respondent. While stone bunds are most common on high slop and stony areas such as in Sirel, Shimdir Kebele, soil bunds and biologically SWC structures area predominantly common in Tiya and low laying farmlands in Sirel villages. Soil bunds were used by 41.7% of respondents. Biological SWC methods mainly Aloe Vera stripe is the most common across Waghimra district. Among our respondents 36% of them reported that the have Aloe Vera stripe on their farmland. Chemical fertilizer was also found to be used by 53% of the respondents. 40.3 and 34.2 % of the respondents, respectively also use manure and improved seeds. While most farmers' interview and FGD discussant reported that they usually use improved for wheat seeds, whereas other crops seeds are local seeds. The awareness about the application and benefits of manure is very appreciable in the upper Tekeze basin of Waghimra administrative zone. Unlike in other areas reported by previous studies in Ethiopia, the use of manure was not only limited around the homesteads. A small number of respondents (12%) used compost. In depth interview with farmers revealed that, they do not have enough labour to prepare compost however some reported that it is time consuming and require skill. Furthermore, some farmers have also fear that compost preparation will lead to sickness. Extension workers reported that compost is less favoured and less familiar SLM practice to most of the farmers due to lack of awareness. The use of agroforestry practice on farmland appears to remain low in the upper Tekeze Baisn of Waghimra administrative zone. Only, 20 respondents (4.8%) were practicing agroforestry during the survey year.

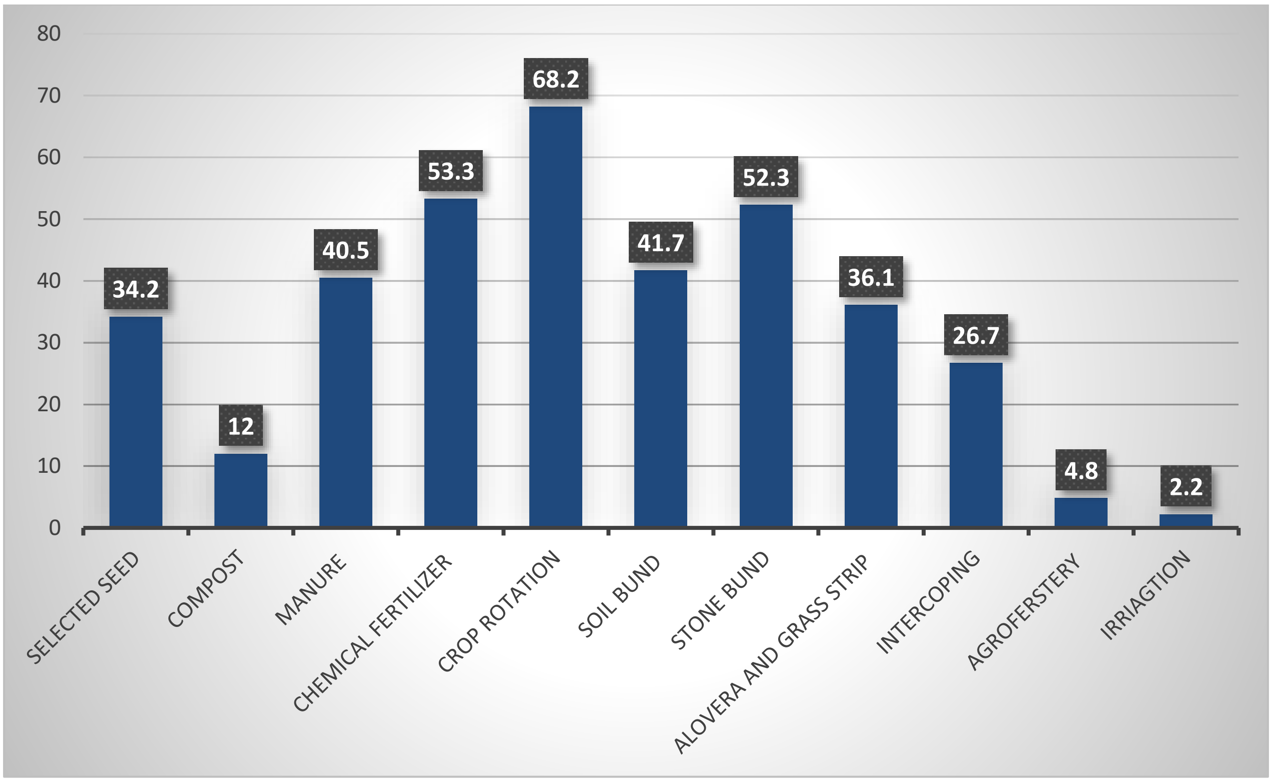

Fig. 7.2 Frequency of SLM practices used by respondent in the study area

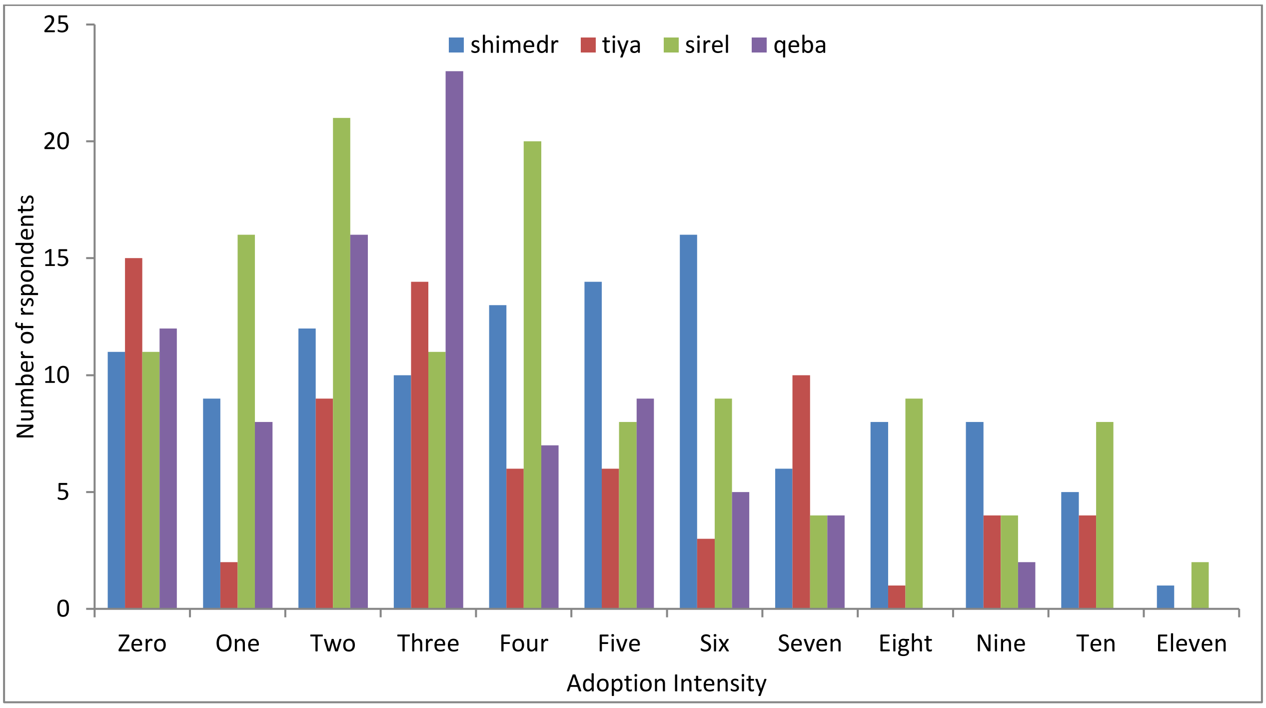

Fig. 7.3 Number of SLM technologies adopted/used by respondents in the study area

7.3.3. Impacts of Migration on SLM Adoption Two-Stage Least Squares (2SLS) Method

Testing for endogenueity and Instrument Validity

Several tests are conducted to determine the necessity of employing 2SLSL, the overall model fitness and the validity of the instrumental variable. The estimated R-squared (0.765) was strong indicating that approximately 76.5% of the variance in the outcome variable (SLM) is explained by the independent variables included in the model. Similarly, the model produced lower Root MSE suggesting a better fit. In order to check weather Migration and SLM are endogenous in the data we have tested the correlation between the residuals from migration equation and the SLM equation.

As hypothesised in the methodological part the endogeneity test using Hausman–Wu supported that migration and remittance are endogenous. The Wu-Hausman statistics obtained a coffiecetn of 2.383 with the (p = 0.102). Althouth t-statistic looks small migration should not be viewed as exogenous to SLM adoption intensity. The test suggest that the null hypothesis of exogeneity of migration in the SLM regression can be rejected at the 90% confidence level. The instruments in the 2SLS are tested for validity. The test of significance of the instruments in the migration equations yields R-square and adjusted R-square in the first stage regression is 0.6386, 0.6194 respectively. The F statistics of 63.47, which is much far than 10 was also reported by the model. This indicates that the null hypothesis that the value of the instruments is zero can be rejected at the 99.99% level of significance (p-values = .000).

7.3.3.1 Determinants of seasonal migration in Waghimra zone

The model performs reasonably well in explaining migration and SLM. R-square of migration 0.61 was significant. Table 3 shows the coefficient and P statistics of migration with their explanatory variables. Migration is significantly related with male household indicating the fact that female seasonal migration is not common in the study area. Regarding age and migration, the result illustrates that the younger household heads have a higher likelihood of seasonal migration. This finding corroborated with the national migration assessment report that rural migrants in Ethiopia young adults (CSA, 2021). However the result contradicts with studies like by (Tegegne & Penker, 2016). Meanwhile, household head education was found positively significantly influencing the probability of seasonal migration. Households with better-educated members are more likely to participate in migration.

As hypothesized based on previous literature, migration network significantly positively related with migration. A single unit migration contact would increase the probability of migration by 8%. Positive relation between migration network and migration decision is consistent throughout migration studies in (li et al., 2013; Quinn, 2009; Williams & Paudel, 2020). Establishment of migration culture in the community would increase greatly the flow of information, and ease of migration decision and destination of migrations (Morrissey, 2013; Quinn, 2009; Williams & Paudel, 2020). In Waghimra administrative zone, migration is common livelihood that have historical and ecological factors. However, there is great variation, in terms of migration experience, in the different districts due to their productivity potential and topographic factors. Particularly in Ethiopia migration network have great role in helping migrant in determining destinations (Morrissey, 2013).

Table 7.5 Determinants of migration; probit regression result

Migration	Odds Ratio	Std. Err.	z	P>|z|
Gender	2.414	0.969	2.2	0.028**
Age	0.994	0.019	-0.32	0.746
Family size	1.089	0.091	1.02	0.307
Education	1.877	0.334	3.54	0***
Perceived farmland slope	0.841	0.203	-0.72	0.473
Perceived erosion on farmland	1.917	0.541	2.3	0.021**
Credit	0.471	0.187	-1.9	0.057**
Perceived land fertility	8.865	2.591	7.47	0***
Off farm Livelihood	0.332	0.133	-2.75	0.006***
Off-farm Income	1.000	0.000	1.85	0.065*
Oxen Ownership	0.946	0.227	-0.23	0.818
TLU	0.383	0.165	-2.22	0.026**
Land size	0.985	0.124	-0.12	0.902
_cons	0.000	0.001	-5.84	0

*** denotes significant at 1%, ** denotes significant at 5% and * denotes significant at 10%

In terms of gender as determining migration participation, the data showed that male headed households are more migrant than female headed households. Having male gender increase the odds ratio of favouring migration decision by a factor of 2.41 at less than 5% probability level ($p< 0.05$). This indicates that males are more migrant for seasonal work in the study area. The results indicate that men’s labor migration increases with drought and if they have less/no land at all (Gray & Mueller, 2012). Previous studies in Ethiopia show that female are more migrant than male headed households (Abebaw et al., 2019; Kibrom et al., 2019; Tegegne & Penker, 2016). Recent survey of Ethiopian mobility also reported that female are more migrant than male (CSA, 2021). However, these studies were not specific to seasonal migration and do not separate marriage related migration from work related migration.

The other variable with strong influence on migration was household head education. Education level of the household head has the 1.87 factor of odds ratio for migration and this was significant at P value less than 1% (Table). This clearly shows educated household heads are more participating in seasonal migration. This result was in line with previous studies in rural Ethiopia such as by (Bundervoet, 2018; Tegegne & Penker, 2016). Survey of internal migration by world bank concluded that migrants in Ethiopia are younger and better educated compared to non-migrants from the same origin area (Bundervoet, 2018).

Although slightly less significant, credit was found reducing the odds ratio of migration. Farmer’s perception of soil erosion on their farmland also significantly influence migration. High soil erosion on farmland influences seasonal migration decision and the statistics was found significant (2.3 (0.021) at 0.05 level of significance. Households who feel that soil erosion is less on their farmland tends to be non-migrant households. Likewise, farmers who feel that their farmland has poor fertility are more likely to participate in seasonal migration. The statistics result indicated that land fertility is significantly affecting migration in the study area (7.4; p=0.00).

Participation of household in off-farm livelihood (excluding migration) was tested for its influence on the decision of seasonal migration. The binary logit output suggest that households who have at least one off farm livelihood have lower odds ration by a factor of 0.33 and was significant at P value of less than 0.01(P=0.006). However, the test revealed that as income from off farm livelihood increases the odds ratio for migration positively increase by factor of 1.0. However, this factor was slightly lower the significant level at 5% probability (p= 0.065).

The other variable that was affecting seasonal migration participation in the study area was cattle ownership. This variable was positively and significantly (p= 0.026) influencing migration among households in the study area. Although statistically not found significantly, oxen ownership has been reported that it reduce the participation of farmers in seasonal outmigration. According to FGD, discussant, oxen ownership is very vital aspect of farming in the study area. Economically poor farmers who do not have oxen look for seasonal migration to take as livelihood source or a means to own oxen through migration earnings.

Land ownership in most part of farming communities of Ethiopia is associated with social status and wealth. Access to productive, optimum size and on relatively gentle slope is a desired quality in order to fulfil food security. Other things remain constant, farmers who have enough, and productive land would have less likely to send the family member to seasonal migration. Although the statistical test does not confirm this, the FGD and interview support this argument in the study area. Many interviewed respondents and FGD discussants highlighted the role of land shortage or landlessness in their participation in seasonal migration. Small land holding combined with low soil productivity is a slow on set cause of migration decisions. A narrative by a priest supports landlessness as a significant cause of migration: Those who are migrating are the young who have not owned land. Almost, all farmers below age 35 do not have land unless they have inherited it from their parents. Another exemplary account of farmer in Tsagbiji district (Kebele 09) supports the narrative about the land shortage and low soil fertility as a cause of migration. "…land shortage is the primary reason. The second reason is that the land is not fertile; moreover, it needs labours to work every year. This forces them to decide to migrate…"

A large number of respondents complained about inequality in land ownership. They explained that some households have a considerable land size of up to 3 hectares, while others own below one hectare. Given the large family size in the district, inherited land could not support the new households. For young household heads, it was not only small land-holdings but also an absolute lack of any land that had shaped their decision to move. For the above reasons, younger males in households frequently migrate and return home with some earnings. Many young farmers who do not want to leave the rural area struggle to pay land rent and secure crop sharing to produce grain.

7.3.3.2. Impact of migration on SLM; Result from 2SLS

We present the estimation results and robust standard errors for Eq. (7.5) in Table 7.6. in previous literature two hypotheses are related to migration and technology adoption, credit hypothesis and risk hypothesis. According to NELM theory, despite rural labour out-migration that possibly affects the agricultural labour requirements and negatively affects land management, remittance provides the necessary fund needed to adopt a new agricultural technology and increase productivity (Castelhano et al., 2016; Quinn, 2009; Taylor, 1999, 2010). The risk hypothesis predicts that, holding remittance constant, the more the number of migrants in a household, the more likely that the household will adopt a new technology. The role of migration in farming households is, therefore, to overcome the risk of agriculture failure. In seasonal labour out migration, since the labour is not permanently removed from the farm, and the migrant come back every other season with migration earnings and new skills and experience, the more the number of migrants in a household, the more likely that the household will receive remittance to invest in yield improving agricultural inputs and SLM. The role of seasonal rural out migration in farming households is, therefore, to overcome the risk of agriculture failure (Quinn, 2009; Williams & Paudel, 2020).

Our result do support the risk hypothesis that migration positively affect SLM adoption and use intensity. After addressing the endogenouty of migration and SLM, our 2SLS model resulted that migration is negatively and significantly affecting the number of the intensity of SLM adoption and application among farmers in the study area. According to the statistics in Table 7.6 migration decreases by 1.41 coefficient and this was significant at p = 0.01. Specifically, the result indicated that an increase in migration leads to a 1.41 unit decrease in the total SLM adopted by each household. Different scenarios could contribute to the negative impact of migration on SLM adoption. The first is; that engagement with seasonal migration reduce the focus of the household or capacity for households to SLM strategies. Secondly, If the households experience loss of family labour through migration and remittance flow is minimal to compensate lost labour and promote investment in agricultural technology, they reduce adoption and use of multiple SLM practice. We assume that if remittance from seasonal migration is directed toward SLM and other farmland management investments we would have observed positive relationship between migration and SLM adopted by farming households. The other factor that discourages SLM adoption is perceived low land fertility. Households who perceive their land is unproductive adopt very few SLM technologies than who perceive their land is better productive. The coefficient of perceived land fertility is negative and significant (-0.418 significant at P=0.05). The finding from this study contradicts with (Asfew et al., 2023; Betela & Wolka, 2021) who reported that slope of the plot, and perceived severity of erosion had significant and a positive association with adoption SWC measures. While households with degraded farmland should be adopting the multiple SLM practice at their farmland, it was found that they were discouraged to adopt. Still, although the statistics was not significant high farmland slope has negative effect on SLM adoption intensity. Both perceived land fertility and slope suggest that household who have degraded farmland and high farmland slope do not have the need to invest their labour and cash rather they opt to engage in seasonal migration to fulfil the production trade-off.

Table 7.6. Impacts of migration on SLM adoption intensity; 2SLS result

	Coef.	**Std.Err.**	**P>|t|**
MIGRATION	-1.416	0.453	0.002***
SEX	0.499	0.252	0.048**
AGE	0.023	0.011	0.037**
Family size	0.002	0.049	0.966
Education	-0.113	0.111	0.309
Crop variety	0.333	0.106	0.002***
Training access	1.681	0.199	0.00***
Off farm livelihood	0.496	0.187	0.008***
Off farm income	0.000	0.000	0.268
Self sufficiency	0.268	0.215	0.213
Crop sharing/contracted land size	0.146	0.057	0.011***
Own Land size	0.198	0.078	0.011***
Land ownership(dummy)	0.058	0.453	0.897
Farmland slope	-0.132	0.135	0.33
Perceived Erosion on farmland	0.094	0.161	0.556
Perceived land fertility	-0.418	0.189	0.027**
TLU	0.288	0.051	0.00*
_cons	0.716	0.841	0.394

***Denotes significant at 1%; and ** denotes significant at 5%

Other than migration, other factors influence the SLM adoption intensity in the study area. Households engaged in off-farm livelihood activities are significantly more likely to adopt SLM practices, with a 0.49 unit increase in number of Adopted SLM practices. Surprisingly, although it is statistically insignificant, the effect of income from off farm livelihood on SLM is negative. This might suggest that the more the household began obtaining income from the off farm livelihood, their attention to SLM decrease or as it might be the beginning of exit from the farm. Looking the pattern of remittance allocation and the statistical relationship of off farm income with SLM adoption intensity, it appears that very little capital is being directed toward SLM implementation on farmland. Either this supports the trend that households in Waghimra are moving away from agriculture production, or farmers perceive agriculture is less profitable to invest much capital on it in the study area. Households with agriculture as the main source of income adopt significantly more conservation technologies than those that do not depend on agriculture production.

Larger landholdings are strongly associated with adoption of large number of SLM practices. A one-unit increase in land size corresponds to a 0.19 unit increase in the adopted SLM, suggesting that larger landowners may have adopted more SLM. Land size owned and land owned by crop sharing and rental have positive and significant influence on SLM intensity. The statistics is also positive and significant at 99% confidence level with coefficient of 0.19 and 0.145, respectively. The first stage regression of migration also showed that more land owned by rent and cash crop discourage the probability of migration, implying that non-migrant households are getting more land by crop sharing and rent and apply yield-improving mechanisms. This could indicate that once the household decide to stay in the village, by deciding not to engage in seasonal migration, they may be more motivated to implement SLM practices to maintain soil quality and improve productivity which in turn fil the income gap incurred by the opportunity cost of not migrating.

Other variables that have positive influence on SLM intensity are credit, labour sharing, and TLU. The data showed that most of economically better household have took loan from Amhara saving and credit institute. Credit access to credit significantly increase the adoption of SLM practices, with a 0.91-unit increase. This underscores the importance of credit access in facilitating the adoption of SLM by easing financial constraints to enable the purchase of agricultural inputs. Membership in indigenous labour sharing mechanisms was also positively affecting SLM adoption intensity. Generally, labour sharing was positively correlated with stable households who do not participate in seasonal migration.

Other characteristics of the respondents – including sex of household head, age, and family size were investigated to understand their relation with SLM adoption. Gender plays a significant role, with male-headed households being more likely to adopt SLM practices by 0.64 units. This could indicate gender deference in access to resources, skills and decision-making power related to land management. Age is positively associated with SLM adoption, where each additional year increases the likelihood of adopting higher number of SLM practice by 0.025 units. This can be due to greater experience in farming which provide them the capacity resilient not to be discourage by low productive but continuously apply multiple and different types SLM practice. This was supported by FGD discussant that although the younger are good at aspiring to get high yield from their small land, the only apply few and specific types of SLM practice. However, the older households spend much of their time in the farm and apply many SLM practice including agronomic, and mechanical soil and water conservation methods. This result was in line with finding by such as (Belachew et al., 2020) in Ethiopia have reported that age has positive influence on SLM adoption on the contrary studies like by (Asfaw & Neka, 2017; Asfew et al., 2023; Zegeye et al., 2022) reported age significantly negatively affect SLM adoption.

7.3.4. Treatment Effect of Seasonal Migration on SLM Adoption Intensity; PSM Method

Based on simple mean comparison, there is clear difference in the number of Adopted SLM among migrant and non-migrant households in the study area However, attributing this difference may not be only duet to the effects treatment (migration) but could be due to other attributes of the households. The result from 2SLS regression (Table 7.7) shows the coefficient of migration after considering endogeounity, thus, a PSM technique was used to control the observable household and plot level characteristics to determine the impact of migration on SLM adoption intensity. Propensity score of the control and treatment groups were calculated based on binary logit model. As a result, propensity scores were generated from the binary logit model using the covariates of the determinants of migration. Tests were carried out to check PSM model assumptions.

Table 7.8 Treatment effect of migration on SLM adoption intensity Using PSM

SLM5	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf. Interval	
ATET MIGRATION	-2.347	0.44	-5.34	0.00	-3.21	-1.485
(1 vs 0)						

We calculate the ATET to look at detail how migration affects SLM intensity. The results are presented in Table 7.8 and the estimated ATET was -2.347, suggesting that migration decreased SLM adoption and use intensity by unit of 2.347.

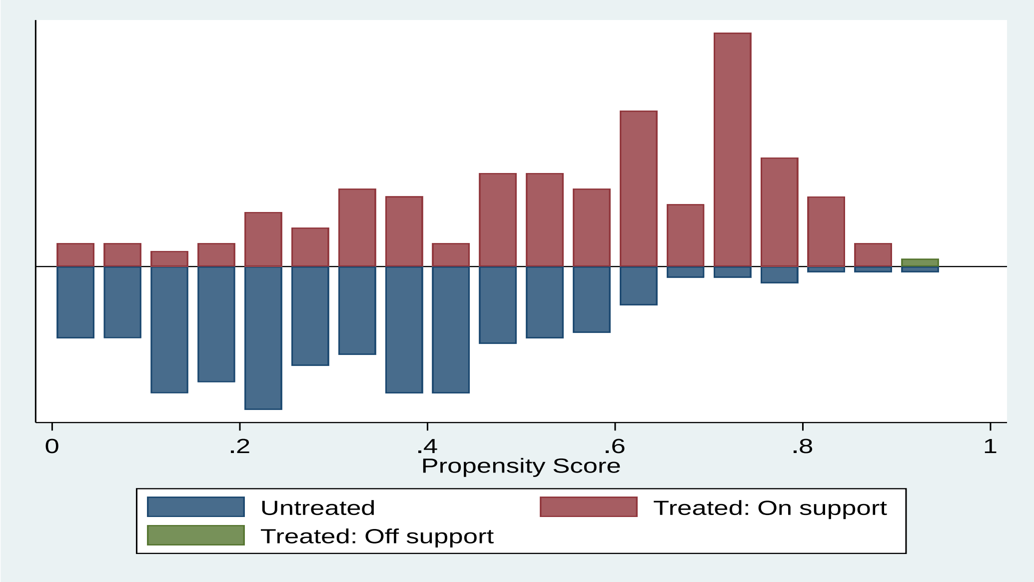

Fig. 7.4 The common support regions of the propensity scores after matching applied.

7.4. Discussion

Our findings from 2SLS and PSM appear in line with the NELM hypothesis and results obtained by Taylor et al. (1999, 2003). Although the NELM postulates migration as a strategy to overcome liquidity constraints and finance, consumption and investment at home, for the remittances to be invested in improving agricultural productivity there should be at least optimum surplus that can support basic household consumption requirements. Under the circumstance of unconducive economic and institutional environment where the possibilities of maximizing productivity of remittance and migration earnings is minimal, migration is more likely to have only a negative effect on SLM implementation including on agricultural technology adoption. Taylor and Martin (2001) have pointed out that migration’s effects on agricultural investments are likely to depend on local conditions. Likewise, farmers in Waghimra are resource poor, living in degraded environment and frequent drought causing crop failure, the lion share of remittance is allocated to support the basic household consumptions. In this case migration only appears to negatively affect SLM.

The finding from this study is against a study by Abebaw et al., (2019) in Ethiopia who found that rural out- migration has significantly increased spending on herbicide and livestock. However, the finding corroborate with Redehegn et al., (2019) who reported that for rise in months spent out of agriculture has a significant negative effect on crop income and asset accumulation. Furthermore, this study found an evidence that is line with Zhang et al.,(2020) who argued that labor force left behind for farming is of low quality and does not care much about SLM on farmland. Despite some different in model outcome, both models suggest that migration has negative impact on SLM application and adoption intensity. Therefore, both results are important for policy implication in this study.

7.5 Limitation of the Study

Previous studies used 3-SLS method for estimating the problem (li et al., 2013; Quinn, 2009; Williams & Paudel, 2020). However, in this study we only estimate the impact of migration on SLM using 2SLS. Due to minimal investment of remittance on agricultural inputs and SLM related investments, we do not included remittance in the model to simoultinouly study both migration and remittance in relation to SLM adoption intensity. Other reason for failing to include remittance was absence of strong instrumental variable that can explain remittance without correlating with migration. Adding remittance in the estimation may incur variation on the model result and general implication of migration to farmland management. Bias also might arise during data collection. We interviewed the defacto[13] head of the household; sometimes we collect data about the migrant from the non-migrant households. Similarly, we also collect information from the migrant him/herself, but after returning from the seasonal migration. This is the problem of most migration studies happening due to the dilemma of collecting migration data from origins or destinations.

7.6. Conclusion

We used cross sectional data from Waghimra Zone Northern Ethiopia, to examine the impact of seasonal rural out-migration on farm households conservation practices adoption intensity. To address endogeneity and selection bias in the regression model, we estimated a 2-SLS model and PSM. We found that a maximum of 11 conservation practices commonly adopted among many farmers in the study area. Crop rotation, chemical fertilizer, stone bund and soil bund are the among the commonly adopted SLM practise respectively. Irrigation, agroforestry and compost are also the least adopted SLM practices in the study area. Among the popularly adopted Practice, stone bund and soil bund are less capital intensive that can only be done with the household labour. There are also the least a farmers can do for their farm not to loss it through soil erosion and make is suitable for farming. The number of farmers adopting compost, and agroforestry, was too small although these practices are among SLM practices for agricultural yield improvement and SLM in general.

The data indicated that although remittance and money brought back from seasonal migration has not observed, but that migration has a significant and negative effect. Despite theoretical hypothesis that migration would ease credit constraint and investment in farm input and agricultural productivity, the data reveal that other factors remain constant migration resulted in low intensity of SLM application and did not improve investment on SLM and yield improving inputs.

Policymakers interested in increasing SLM adoption intensity need to target rural households and consider them as mobile households partitioning their labour into seasonal migrant and left behind. With growing numbers of households in Waghimra allocating a significant portion of their labor force to migration, labour scarcity during peak agricultural seasons may become constraining for SLM implementation. Moreover, without remittance directed to productive investment and to purchase of yield improving agricultural inputs such as chemical fertilizer, improved seeds, hiring labour, lost labour effect of migration could not be compensated.

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[13] Any of the family members acting as household head during the interview period

SLM is a holistic approach in which both productivity and the ecosystem could be benefited so that sustainable environmental management and food security can be achieved. SLM at household farm level includes practices such as such as improved crop varieties, application of compost, manure, chemical fertilizer, intercropping, physical and biological soil erosion and nutrient conservation mechanism, stone bund and agroforestry. Despite variation in the intensity of use, most of these practices were observed in the study. These SLM practices has the potential to mitigate the depletion of soil nutrients, increase crop yields, and conserve soil and water. Given the culturally and ecologically driven seasonal rural out-migration to agricultural high potential areas and urban centres, farmers in Waghimra can benefit greatly from adopting conservation practices by directing remittance towards agriculture productivity. The result from this paper showed that seasonal migration without remittance directed to support of SLM and agricultural, also while the lost labour and overlapping season of SLM and migration may hinder the adoption of SLM that would create the vicious circle of low agricultural production and the subsequent rural out migration. SLM including soil and water conservation should be beneficial to all farmers, however, those households who participate in seasonal rural out-migration should be targeted, and strategies should be put to direct migration earnings and remittances towards more adoption of SLM practices. With adequate policies to encourage conservation practices, agricultural development could converge with natural resource conservation, allowing migration and remittance to be a catalyst for SLM implementation and hence improved agricultural and ecosystem productivity. Adoption of drought smart SLM practices in semi-arid and arid land of Waghimra can mitigate future land degradation and improve households' resilience to vulnerabilities to drought and cycle of seasonal migration.

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CHAPTER EIGHT

SYNTHESIS, CONCLUSION AND RECOMMENDATIONS

8.1. Introduction

Land degradation, expressed in the form of unsustainable LULC change, drought, and soil erosion by water, is a grave environmental problem in Ethiopia, including the upper Tekeze Basin in Waghimra Administrative zone. Households in rural Waghimra respond to immediate environmental stress such as drought and slow onset land degradation problems including soil erosion and by engaging themselves in seasonal migration in search of better opportunities in other rural and urban areas. The complex dynamics between land degradation, migration, and SLM practices have great implications for the sustainability of agricultural systems, livelihoods and the environment at large in rural society. This chapter synthesizes findings from the previous chapters to explore these interconnections of land degradation, seasonal rural migration and SLM in the Dry land of upper Tekeze Basin.

8.2. Land Use/Land Cover Changes and Degradation

This study begins the assessment of land degradation in the upper Tekeze basin by investigating the LULC dynamics for the past three decades from 1990–2021. Advanced remote sensing tools such as RF classification algorithm and GEE platform have been used to study the change in LUCL and land degradation. The finding reveal significant LULC change pattern that highlight the ongoing land degradation in the study area. The study documented reductions in forest (12.2%), bushland (24.8%), and shrubland (1.2%). These areas have increasingly been converted into farmland, settlements, and dry riverbeds/stream channels, reflecting unsustainable land use practices and the ongoing environmental stress. The expansion of dry stream channels and sandy surfaces between 1990 and 2021, alongside a degradation of bushland since 2010, signals severe land degradation. Despite the continuous effort to restore degraded land in the upper Tekeze basin, in Waghimra administrative zone, no significant increase in vegetation cover was seen. Only pocket areas of managed watershed, church forests and agroforestry along river have been sustained without further degradation. Continuous alternative shift of high aridity and drought might have significant effect to the expansion of exposed shrublands and sandy surface along the side of dry riverbeds.

8.3. Drought Dynamics and Their Impact on Land Degradation

Droughts exacerbated by the ongoing climate change play a significant role in driving land degradation and rural out-migration. In the Tekeze Basin, spatio-temporal drought analysis using indices such as the Standard Precipitation Index (SPI), VCI, TCI, and VHI revealed recurrent moderate to extreme droughts. Key drought years identified included 1884, 1985, 1987, 1993, 1997, and 2015. Drought analysis using VCI and VHI showed that severe to extreme droughts have affected the basin in 2002, 2004, 2009, 2015, 2016, and 2017.

Droughts negatively impact vegetation health, as indicated by decreasing NDVI trends across most of the basin. Rainfall in July was found to be a critical determinant of NDVI, LST, TCI, and VCI values, highlighting the importance of timely precipitation for sustaining vegetation health. The strong correlation between VCI and precipitation underscores the need for drought monitoring tools that prioritize rainfall effect rather than temperature effect in drylands like in the study area. Effective drought management strategies can mitigate land degradation by providing information on nature and severity of droughts and identifying the drought hotspot areas for effective implementation of soil moisture and maintaining vegetation cover, which is in turn crucial for preventing soil erosion, and maintaining land productivity.

8.4. Soil Erosion and Land Degradation Management

Upper Tekeze Basin in Waghimra administrative zone is both historically and ecologically erosion hotspot area in Northern Ethiopia. Soil erosion by water is a pervasive issue in the upper Tekeze Basin, contributing significantly to land degradation and thus affecting agricultural productivity and the ecosystem at large. Using the RUSLE integrated with GEE, this study estimated soil erosion rates and identified erosion hotspots. The average soil loss rate in the basin is 25.45 t ha^{-1} yr^{-1}, with 63% of the area experiencing erosion above the tolerable threshold. Specifically, shrublands that cover 55% of the study area faced an average annual soil loss of 34.75 t ha^{-1} yr^{-1}. The study also revealed evidence that this high mean soil loss rate of the basin can be reduced to a tolerable rate by implementing integrative watershed management and exclosures. Watersheds and shurblands that were treated with area exclusure, have experienced significantly lower means soil loss rate as compared with unprotected shrublands. Documented evidences of lower mean soil loss over managed watershed management and area closures is an evidence that soil erosion reduction in arid and semi-arid regions should prioritize shrublands that are already degraded by the alternate impact of erratic rainfall and high surface aridity. This could be a strategy for promoting sustainable land use practices and combating land degradation. The study highlighted the utility of GEE as a platform for rapid and reliable soil erosion assessment, providing crucial data for decision-making in land management.

8.5. Seasonal Migration and Farmland Management: Implications for Land Degradation

The relationship between seasonal migration, remittances, and farmland management in the upper Tekeze Basin reveals a complex interplay that affects land degradation. Migration is often triggered by drought and irregular rainfall, compounded by socioeconomic factors such as land scarcity, degraded soil fertility and lack of agricultural resources. Remittances are primarily used for basic consumption needs rather than agricultural investments, leading to minimal contribution to the improvements of farmland management.

Seasonal migration results in the transfer of farm responsibilities to women, who face labor, input, and skill limitations. This gender shift does not enhance farmland management but rather increases the workload for women, potentially exacerbating the low adoption and practice of SLM and hence lead to further land degradation. The lack of investment in SLM practices due to migration can lead to further soil erosion and degradation, as degraded lands are less able to support crops and are more prone to erosion.

Finally, in order to compliment the qualitative exploration of migration and land management we used 2-SLS regression and PSM to examine the impact of migration on the adoption of SLM practices. Data was obtained from questionnaire surveys of 376 households in Waghimra district of Northern Ethiopia. The finding showed that poor land fertility, perceived high soil erosion, on farmland, cattle ownership, participation in off farm livelihood, increased education level, and male gender significantly positively influence migration in the study area. The 2-SLS result shows that migration has significant negatively affects the number of SLM adoption intensity. Furthermore, other variables such as participation in extension trainings, larger livestock ownership, and size of land owned and size land owned through rent and crop sharing significantly positively influence SLM adoption intensity. Similarly, participation in indigenous local labour sharing institution positively affects SLM adoption intensity. However, poor perceived land fertility significantly discourage SLM adoption intensity. PSM also confirmed migrant households have adopted 1.51 unit of SLM than the non-migrant households indicating that engagement with migration significantly reduce the number of SLM adopted by households.

8.6. Conclusion

The study focused on various aspects of land degradation and SLM in the upper Tekeze River basin in Waghimra administrative zone, Ethiopia. The focus of the study are land use and land cover change (LULCC), drought monitoring, soil erosion assessment, and the impacts of migration on SLM adoption nd practices. The findings revealed significant land degradation, with forest, bushland, and shrubland reduction in the last three decades. In contrast, there were notable increases in water bodies, farmland, dry stream channels, and urban settlements. The expansion of dry riverbeds, stream channels and sandy land surfaces from 1990 to 2021 indicates worsening land degradation. Drought assessment using multiple indices showed that the basin experienced frequent moderate to extreme droughts. SPI indicated that the basin was affected by moderate, severe, and extreme drought in specific years (e.g., 1984, 1985, 1993, 2015). Furthermore, VCI and TCI analyses revealed severe and extreme droughts occurred in 2002, 2004, 2009, 2015, 2016, and 2017. The NDVI showed a decreasing trend, with rainfall in July emerging as a critical factor in determining NDVI, LST, TCI, and VCI in July and August. The study concluded that although difference drought assessment indices are robust, VCI is more effective than TCI in detecting drought, especially in drylands where precipitation is crucial in determining vegetation health. This suggest that higher weight should be assigned to VCI than TCI in estimating VHI in dry land regions. Soil erosion assessment were also carried out to estimate soil erosion under different LULC classes and agroecologies. The results showed that the mean soil loss rate in the Upper Tekeze basin is 25.45 t ha^{-1} yr^{-1}, with 63% of the basin experiencing erosion rates above the maximum tolerable soil erosion rate. Specifically, shrublands in lowland agroecologies are particularly affected, with mean annual soil loss rates of about 37.6 t ha^{-1} yr^{-1}, highlighting the need for immediate soil conservation measures in erosion-prone areas. However, few watersheds in the study area, that achieve soil erosion within the tolerable threshold, due to the continuous effort of soil and land management treated with area exclosure and integrative watershed management, are evident that erosion management is possible in the climatologically harsh and topographically complex region of upper Tekeze basin. Therefore, this study concludes watershed management using area exclosure and soil and water conservation practices can help to reduce soil erosion and to rehabilitate and protect the ecosystem, and also to protect croplands from sever erosion.

The study found that seasonal migration was driven by factors such as land shortages, landlessness, and lack of resources. Remittance is primarily used for basic consumption rather than for farmland management and purchase of yield improving agricultural inputes. Women left behind faced significant challenges in managing farmland due to labor, input, and skill limitations, resulting in negative impacts on land management practices. The 2-SLS regression and PSM estimation indicated that migration negatively affects the number of SLM practices adopted. Factors such as participation in extension training, ownership of livestock, and land size positively influence SLM adoption intensity, while poor perceived land fertility discourages it.

In conclusion, these studies underscore the interconnectedness of land degradation, land management and migration in the upper Tekeze basin of Northern Ethiopia. The study reveal significant environmental challenges in the Tekeze River basin, including land degradation, increasing vulnerability to drought, severe soil erosion, and the negative impacts of migration on SLM. LULCC, driven by human activities and climatic factors, has led to significant losses in natural vegetation and the expansion of degraded lands. Drought monitoring shows a strong link between precipitation and vegetation health making the region vulnerable to agricultural drought. Soil erosion is identified as a severe problem, particularly in the extensive areas of shrublands. Furthermore, the studies highlight the complex relationship between migration and land management, where remittances are often insufficient to improve sustainable farmland management, and the burden on women left behind exacerbates land degradation. Addressing these challenges requires a holistic approach that integrates understanding of status of land degradation with the focus of LULC change dynamics, drought frequency and characteristics, and nature and factors of seasonal migration.

Methodologically, the study concludes that the use of advanced remote sensing tools and platforms like GEE is crucial for regular monitoring and assessment of land degradation, providing accurate and up-to-date data to guide SLM policies. Furthermore, this study suggests that while studying drought in dryland regions rainfall rather than temperature is the limiting condition for the vegetation growth and health, greater weight should be given to VCI. The traditional VHI assigns equal weight for VCI and TCI (a=0.5).

8.7. Policy Implications and Recommendations

Addressing land degradation and its consequence requires a multifaceted approach that integrates accurate land degradation monitoring, effective land management practices, and socio-economic considerations. By prioritizing sustainable land use and supporting communities in their SLM efforts, it is possible to mitigate the impacts of land degradation and enhance the resilience of rural livelihoods in semi-arid and arid land of upper Tekeze basin in Waghimra administrative zone. The recommendations from these studies include:

- Effective SLM and rural development policies must consider the dynamic nature of rural households that ingage in both farming and seasonal migration.
- Although there are SLM practice in the study are, it is only succeeded in small portion of the study area. Therefore, this study recommends more effective watershed

managements and area exclosures to reduce soil loss to tolerable levels. Immediate soil conservation measures should be prioritized in areas with high mean annula soil loss rates, particularly in shrublands and lowland agro ecologies where there is poor ground cover. Managing the shrublands is to manage the lowlaying farmlands and to reduce the runoff production from steep slope areas.

- Implementing and scaling up sustainable farmland management practices, afforestation, and reforestation in degraded and vulnerable areas to mitigate the negative impacts of LULCC.
- Drought management should prioritize the use of effective drought monitoring indices like VCI for early warning systems, particularly in drylands, and enhance water management strategies to mitigate the impact of drought on agriculture
- To combat further land degradation in the study area, policies should address the root causes of migration by improving local livelihoods and agricultural productivity. This could be possible by providing access to agricultural inputs, drought resilent agriculture, training, and resources to enhance SLM practices.
- By supporting communities in their adaptation efforts, it is possible to mitigate the impacts of land degradation and reduce the need for seasonal out-migration or otherwise direct remittance towards yield improving agricultural inputs and SLM.
- Recognizing the decision-making roles of women left behind and ensuring that remittances are directed towards sustainable farmland management are crucial for improving land productivity and mitigating land degradation through implementation of SLM.
- Policy interventions should support households affected by labor shortages due to migration by promoting low labor-intensive, cost-effective conservation practices.

8.8. Areas for Further Study

This study has focused on assessment of land degradation, and the link between rural outmigration and SLM. Although this study lies a foundation for understanding of the relationship between land degradation components susch as soil erosion, drought and LULC change with rural out migration and SLM, further studies in the following specific are could have further contribution:

- This study follwows expoloration of the interconnectedness of land degradation, rural out migration and SLM adoption, further studies could specifically use case studies and apply more precise mehtoldogy to study the casual relationship of these problems on farming household. Plot level experimental studies could be applied to comparison of the complete labour hour spent and agricultural input usage among a migrant and non migrant's farm plots so as to show the exact impact of migration on SLM

- Secondly, from methodological perspective, future studies could use panel data. By longitudinal survey, both the effect of land degradation in the form of drought and soil erosion and the subsequent descion of migration along with the change in the SLM adoption and practice could be documented.
- Thirdly, migration is the characterstics of less productive arid and semi arid regions, this study suggest more studies to be conducted on the visous circle of impact; land degradation- migration-SLM adoption and practice in the other parts of Ethiopia and other developing countries as well. This could provide the full picture of land degradation induced migration and the resulting nature of SLM practice.