



**MEKELLE UNIVERSITY**  
**COLLEGE OF DRYLAND AGRICULTURE AND NATURAL**  
**RESOURCES**  
**DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS**

**Impact of War on Physical Soil and Water Conservation Structures,  
Vegetation Cover, and Community Livelihoods in Raya Azebo District,  
Tigray, Ethiopia**

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**A Thesis Submitted in Partial Fulfillment of the Requirements for the Master  
of Science Degree in Agro-Ecology and Sustainable Development**

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## **ABSTRACT**

*Decades of human pressure on agricultural lands have led to significant environmental degradation, particularly in the Tigray region, where erosion has resulted in an annual loss of 1.5 billion tons of soil. Despite efforts in soil and water conservation (SWC) and landscape rehabilitated, the conflict in Tigray has exacerbated environmental damage, affecting forest cover and conservation structures. This study evaluates the impact of war on soil and water conservation (SWC) structures and vegetation cover in the Raya Azebo district, Southern Tigray, Ethiopia. Data were collected from two conflict-affected kebeles, Hawelti and Ebo, through household surveys, key informant interviews (KIIs), focus group discussions (FGDs), field observations, and satellite imagery. The study employed satellite data from Landsat 7, 8, and 9 to assess vegetation cover changes between 2000, 2020 and 2022 using the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). 267 households were selected through random sampling method, four focus group discussion purposively selected and five key informant interviews were conducted, and the data were analyzed using SPSS version 20 and ArcGIS 10.8.1. The study shows that male is dominance in land management, and agriculture as the primary livelihood. War has exacerbated socio-economic vulnerabilities, limiting the adoption of sustainable practices. The findings underscore the urgent need for post-conflict rehabilitation to restore SWC structures, promote sustainable land management and improve agricultural productivity. The results show significant war-induced damage to SWC structures, with 46.9% of systems in Ebo and 53.2% in Hawelti partially or fully destroyed. This led to increased soil erosion, reduced agricultural productivity, and heightened food insecurity. Vegetation cover analysis from revealed improvements in Ebo exhibited improvement until 2020, but faced post-war setbacks, while Hawelti showed pre-war progress and post-war challenges. These results stress the need for customized management strategies. Ebo's NDVI values ranged from -0.3 to 0.33 in 2000, peaking at 0.50 in 2020, but dropping to 0.484 in 2022 due to wartime activities. Similarly, EVI rose from 0.387 in 2000 to 0.432 in 2020, declining slightly to 0.412 in 2022.*

## **BIOGRAPHICAL SKETCH**

The author, Atakilti Eyasu, was born on May 22, 1992, G.C in Mehoni town, Raya Azebo district, in the Southern zone of the Tigray Regional State of Ethiopia, from his father Eyasu Bayru and his mother GodifeyWedajo. He attended his primary, secondary, and preparatory education at Degol Elementary School, Mehoni Secondary School, and Fenkil Preparatory School, respectively. In 2013 G.C, he joined at Wolayta Sodo University and graduated from the Department of Natural Resource Management in June 2015 G.C. Following his graduation, he secured employment at the Raya Azebo Woreda Office of Agriculture as a natural resource management (NRM), forestry, and watershed expert, where he served for over six years.

In October 2020/21 G.C, he joined the Postgraduate Program at Mekelle University to pursue his M.Sc. Degree in Agro-ecology and Sustainable Development.

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The word of God says, “All things came into being through Him, and without Him not one thing came into being. What has come into being in Him was life, and the life was the light of all people (John 1<sup>13-4</sup>).” The Lord has given me opportunities and ordered success in my life. Therefore, I would like to say, “to the King of ages, immortal, invisible, the only God, be honor and glory forever and ever (1<sup>st</sup> Tim 1<sup>17</sup>).” Amen.

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## **ABBREVIATION AND ACRONYM**

a.s.l	Above Sea Level
ADLI	Agricultural Development-Led Industrialization
BOARDO	Bureau of Agriculture and Rural Development Office
DAs	Development Agents
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization
FGDs	Focus Group Discussions
Ha	Hectare
HH	Household
Hv	Healthy Vegetation
ILO	International Labor Organization
IPCC	Intergovernmental Panel on Climate Change
KII	Key Informant Interviews
Km	Kilo Meters
Mhv	Moderately Healthy Vegetation
NDVI	Normalized Difference Vegetation Index
NRM	Natural Resource Management
SCRP	Soil Conservation Research Programme
SPSS	Statistical Package for Social Sciences
Sqkm	Square Kilometers
SWC	Soil and Water Conservation
PSWC	Physical Soil and Water Conservation
SWCPs	Soil and Water Conservation Practices
UN	United Nations
UNDP	United Nations Development Programme
UTM	Universal Transverse Mercator
Uv	Unhealthy Vegetation
VCC	Vegetation Cover Change
WB	World Bank
WoARD	Woreda Raya Azebo Office of Agriculture and Rural Development
NGO	Non-Governmental Organization
SLMP	Sustainable Land Management Program
PSNP4	Productive Safety Net Program
CRGE	Climate Resilience Green Economy
EFDRE	Ethiopian Federal Democratic Republic of Ethiopia
TPLF	Tigray Peoples Liberation Front
GPS	Geographical Information System

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# 1. INTRODUCTION

## 1.1 Background of the Study

In Northern Ethiopia, growing human pressure on agricultural land and forests over the last 50 years has accelerated the degradation processes along hill slopes, leading to higher sediment loads delivered to streams (Gebresamuel and Kibret, 2019). Despite its mountainous and rugged topography, the Tigray region has been used in traditional agriculture for millennia. The mountains and riverbanks alike are exhaustively cultivated in traditional agriculture. Estimates showed that about 1.5 billion tons of soils are lost from the highlands annually (Tamene, 2022). Efforts made by national stakeholders and local communities to restore the degraded landscape of Tigray in northern Ethiopia over the last three decades have had notable success. Various interventions in soil and water conservation practices, sustainable land management strategies, a forestation and re-forestation programmes were implemented in the period 1991 to 2020 to restore degraded land in Tigray (Gebrehiwot *et al.*, 2022; Gebremeskel *et al.*, 2018; Noulekoun *et al.*, 2021).

The Tigray region, over the past three decades, showcased remarkable progress in restoring degraded lands through robust community-led conservation efforts. Notable achievements include a significant increase in vegetation cover, facilitated by widespread implementation of soil and water conservation techniques, and the establishment of exclosures to promote natural regeneration. The community of Abreha We Atsbeha stands as a prime example, earning the UNDP's Equator Prize in 2012 for their successful integration of sustainable land management practices, which led to improved groundwater levels and increased agricultural productivity (UNDP, 2012).

The watershed approach adopted in Tigray since the 1990s has helped restore degraded farmland, improve soil water holding capacities, increase woodlot cover, and improve the productivity of pasturelands (Gebremeskel *et al.*, 2018; Tefera and Sterk, 2010). Since the 1990s, Tigray has also been undergoing landscape restoration and natural resource management program for soil conservation and land rehabilitation (Nyssen *et al.*, 2009ab, 2015) which has contributed to food security and the provision of other ecosystem services (Abera *et al.*, 2020; Babulo *et al.*, 2009; Weldetnsae, 2021). This refers to Tigray's conservation-based Agricultural Development-Led Industrialization (ADLI) strategy. This strategy caused reduced sheet and rill erosion rates, enhanced infiltration and spring water discharge, and higher values of vegetation through enhanced

vegetation cover and crop production (Gebremedhin *et al.*, 2003; Hagos *et al.*, 1999; Kumasi and Asenso-Okyere, 2011).

War has profound negative effects on forests, as armies may intentionally burn or clear wooded areas, and forests might be utilized as cover for guerrilla warfare and secluded bases (Van Dexter, and Visseren-Hamakers, 2020). The war help in Tigray, Ethiopia, has notably contributed to a substantial decrease in forest cover and ecosystem resources since November 2020 (Negash *et al.*, 2023). Deforestation driven by conflict can impede the provision of crucial ecosystem services, including carbon sequestration, the supply of food and fibers, and pollination, with enduring implications for food security, environmental sustainability, and regional stability. As a result, the study focuses on the effects of war on soil and water conservation and vegetation cover change in Raya Azebo district, Southern zone of Tigray, Ethiopia.

## **1.2 Statement of the Problem**

The war in Tigray, Ethiopia, has left a lasting impact on the environment, leading to severe environmental degradation (Birhane *et al.*, 2024). The debilitated government's capacity to set up and keep control, coupled with a need for community mindfulness, has impelled a surge in different unlawful and harmful exercises. Strikingly, the pressing issue of charcoal generation as a wood-based fuel worsens the decrease in the country's woody biomass (Kassahun *et al.*, 2021).

War-induced challenges, such as forced migration, enduring refugee issues, and widespread infrastructure destruction, further compound the environmental crisis. The war has triggered unsustainable harvesting of timber and fuel wood, culminating in severely degraded landscapes, pervasive soil erosion, and extensive areas denuded of vegetation cover (Olsson *et al.*, 2019).

The impacts of war on conservation are intricate and multifaceted, and existing knowledge gaps persist regarding how conflicts have affected biodiversity in numerous regions (Hanson, 2011). Hishe *et al.* (2023) further uncovered that frequently war-affected areas in Tigray faced various destructions of soil and water conservation structures aggravated by military trenches and extensive cutting of forest lands. More over a study by Emnet *et al.* (2023) indicates the human and environmental consequences of the war conflict in Tigray particularly, the vegetation coverage changes, deforestation and desertification. He concludes the magnitude of the devastation is high.

Nonetheless, recent studies (Emnet *et al.*, 2023; Hishe *et al.*, 2023) in Tigray have primarily employed remote sensing techniques, Google Earth, and secondary data. The current study utilized household surveys, key informant interviews (KII), and focus group discussions (FGDs), and field or ground observation and survey. The study covered two case study sites in Raya Azebo district, Tigray region. Additionally, the study examined the socio-economic consequences of the war, which have not received sufficient attention in previous research.

Overall, there is a lack of comprehensive data to track temporal changes (before and after the war) and spatial variations. This deficiency hampers our understanding of the impacts of the war on conservation efforts across diverse landscapes. The objective of this research is to address these critical gaps and provide a better understanding of the war's impact on soil and water conservation (SWC), vegetation cover change, and socio-economic aspects in Raya Azebo district, Southern zone of Tigray, Ethiopia.

### **1.3 Objective of the Study**

#### **1.3.1 General Objective**

The general objective of the study is to evaluate the impact of war on physical soil and water conservation structures, vegetation cover, and community livelihoods in Raya Azebo district, Tigray, Ethiopia

#### **1.3.2 Specific Objective**

- To identify the specific types of physical soil and water conservation (SWC) structures affected by war in the study area;
- To measure and analyze the extent of war-induced changes in vegetation cover in the study area;
- To evaluate the socio-economic implications on communities resulting from damages of both physical soil and water conservation (SWC) structures and vegetation cover caused by war in the study area:
- To assess the community's perception about the effect of the war on natural resource.

### **1.4 Research Questions**

1. What types of soil and water conservation structures have been affected by war in the study area and to what extent?

2. How has war influenced the magnitude of vegetation cover change in the study area?
3. What are the socioeconomic implications of damage SWC and vegetation cover for the affected communities?
4. How do local communities perceive the impact of war on natural resources in the study area?

## **1.5 Significance of the Study**

The significance of this study is multifaceted, encompassing both localized environmental restoration and the formulation of global policies. Firstly, by identifying the impact of war on soil and water conservation structures, the research provides essential insights for developing strategies to restore these crucial resources in the Raya Azebo district. Understanding the specific types and extent of these impacts is fundamental for sustainable land management, thereby enhancing the resilience of communities grappling with the aftermath of conflict. Furthermore, the findings can inform local policies and serve as a framework for effective environmental restoration initiatives.

Secondly, the assessment of the war's influence on vegetation cover change holds far-reaching implications. The knowledge gained from this research can guide local conservation efforts and contribute to the global discourse on the environmental consequences of armed conflict. This knowledge is invaluable for policymakers, aiding in the formulation of evidence-based strategies to mitigate the long-term effects of conflict on landscapes.

Thirdly, evaluating the socio-economic impact on communities resulting from war-induced damages extends beyond immediate concerns. The study establishes a foundation for community empowerment and awareness, fostering a sense of ownership and resilience. Additionally, the research makes a significant academic contribution by adding to the discourse on the intricate interplay between conflict, environmental degradation, and socio-economic consequences. As a foundational piece, it not only informs future research endeavors in the field but also supports the development of global policies aimed at addressing the environmental fallout of armed conflicts.

## **2. LITERATURE REVIEW**

### **2.1 Overview of the Environmental Impacts of War Globally**

The environmental impacts of war are extensive, encompassing long-term degradation across multiple ecological spheres. Modern conflicts, with their reliance on advanced weaponry,

contribute significantly to soil and water contamination through the dispersion of heavy metals and toxic chemicals, disrupting agricultural productivity and posing severe health risks (Machlis and Hanson, 2008). Deforestation and habitat destruction often employed as strategic tactics, result in substantial biodiversity loss and the destabilization of ecosystem services (Dudley *et al.*, 2002).

Furthermore, military activities exacerbate air pollution and contribute to climate change through the release of greenhouse gases and the destruction of carbon sinks (Austin and Bruch, 2000). The disruption of conservation efforts and direct mortality of wildlife further compound these impacts, leading to enduring ecological vulnerabilities. Addressing these complex and interconnected challenges necessitates international cooperation and a commitment to environmental remediation and sustainable resource management.

## **2.2 Impact War on Physical Soil and Water Conservation Structures**

The effects of war on physical soil and water conservation (PSWC) practices are profoundly disruptive, undermining long-term environmental sustainability. Direct destruction of infrastructure, such as terraces, contour bunds, and water harvesting systems, through military operations and heavy vehicle movement, leads to immediate degradation of soil and water resources (Nyssen *et al.*, 2009). The abandonment of agricultural lands due to conflict-induced displacement further exacerbates soil erosion and reduces water infiltration, as maintenance of these crucial conservation structures ceases (Mekonnen *et al.*, 2014). For example, conflicts often lead to the collapse of local governance structures, which are vital for enforcing and maintaining PSWC practices, resulting in widespread environmental damage. This is further complicated by the use of explosives and other weaponry, which can directly alter soil structure and contaminate water sources (Gleick, 1994).

Soil and water conservation (SWC) measures, such as terracing, check dams, and water diversion structures, are critical for maintaining soil fertility and water availability in Ethiopia's drought-prone regions (Nyssen *et al.*, 2007). During times of conflict, these structures often suffer from neglect, intentional destruction, or abandonment due to displacement of local communities. Additionally, conflicts can hinder the rehabilitation of SWC structures post-conflict, exacerbating soil erosion and water scarcity issues (Tesfaye and Belay, 2021). Tilahun *et al.* (2021) explored the effects of political instability on SWC structures in the highlands of Ethiopia, finding that war

and conflict lead to the destruction of essential SWC structures, resulting in significant soil erosion and water loss. Girma *et al.* (2020) provided an overview of the degradation of SWC measures in Tigray, focusing on the impacts of armed conflict on community-based conservation projects and the collapse of institutional support for such programs.

Addressing the impacts of war on PSWC requires a multi-pronged approach that focuses on both immediate rehabilitation and long-term resilience. Post-conflict reconstruction efforts must prioritize the restoration of damaged PSWC infrastructure, alongside the re-establishment of effective governance and community-based management systems (Nyssen *et al.*, 2009). Investing in capacity building and knowledge transfer to revitalize agricultural practices and promote sustainable land management is essential. Furthermore, integrating PSWC into broader peace building and development initiatives can help to ensure long-term environmental security and contribute to the sustainable recovery of war-affected regions. The international community should support programs that provide technical assistance, financial resources, and policy guidance to facilitate the restoration and enhancement of PSWC practices in conflict-affected areas (Gleick, 1994).

### **2.3 Environmental Consequences of War**

Ethiopia's history of conflict has resulted in significant ecological degradation, which can be traced back to both political instability and the direct impacts of warfare. Large-scale environmental damage in conflict zones includes deforestation, loss of biodiversity, and changes to the hydrological cycle. These changes hinder agricultural productivity and exacerbate food insecurity in post-conflict periods. Mekonnen *et al.* (2022) reviewed the environmental consequences of civil unrest and warfare in Ethiopia, documenting the long-lasting effects on the environment, particularly the destruction of vegetation and soil erosion in conflict-affected areas. Bennett *et al.* (2019) assessed the ecological recovery post-conflict in the Horn of Africa, arguing that long-term rehabilitation efforts are needed to restore ecosystems and SWC structures in conflict-ravaged regions.

In Tigray, the consequences of the war on the environment have been devastating. Forests have been cleared for military and strategic purposes, and agricultural practices have shifted to unsustainable methods due to the displacement of populations (Birhane, 2023). The environmental

degradation in these areas will likely continue for decades, with recovery efforts requiring significant resources and time (Mekonnen and Gebreselassie, 2022).

## **2.4 War and Vegetation Cover Changes**

The effects of war on vegetation degradation are substantial, leading to both immediate and long-term ecological consequences. Direct military actions, including the use of heavy machinery, bombings, and the deployment of chemical defoliants, result in the immediate destruction and fragmentation of vegetation cover (Machlis *et al.*, 2020). For example, the use of napalm and other incendiary weapons can cause widespread forest fires, leading to significant vegetation loss and soil degradation (Dudley *et al.*, 2020). Beyond direct destruction, the use of military vehicles and the construction of fortifications disrupt natural vegetation patterns and soil structure, hindering natural regeneration.

Armed conflict leads to severe disruptions in ecosystems, primarily through deforestation, destruction of habitats, and changes in land use. Armed forces and rebel groups often clear forests for fuel wood or as a tactical measure, contributing to the depletion of local vegetation. Moreover, displacement of local populations leads to unsustainable agricultural practices and further encroachment into forested areas. Leech *et al.* (2020) analyzed the consequences of conflict on vegetation cover in East Africa, noting that both direct human activity and indirect impacts, such as soil erosion due to the removal of vegetation, play significant roles. Similarly, Karsenty (2018) highlighted how conflicts in Sub-Saharan Africa, particularly in forested areas, contribute to irreversible vegetation cover changes, focusing on the role of militarized groups in altering land use.

War significantly disrupts socio-ecological systems, exacerbating vegetation degradation. Displacement of populations and the breakdown of environmental governance lead to increased pressure on remaining natural resources (FAO, 2021). Refugee camps and displaced communities often rely on unsustainable practices, such as excessive firewood collection and uncontrolled grazing, resulting in severe deforestation and vegetation loss (FAO, 2021). Furthermore, the abandonment of agricultural lands and the disruption of traditional land management practices contribute to the proliferation of invasive species and the loss of biodiversity (Machlis *et al.*, 2020).

The disruption of conservation efforts and the diversion of resources away from environmental protection further compound these impacts.

Addressing vegetation degradation in post-conflict environments necessitates a comprehensive approach that integrates ecological restoration with socio-economic recovery. Reforestation and afforestation programs, coupled with sustainable land management practices, are crucial for restoring degraded ecosystems (FAO, 2021). Strengthening local governance and community-based natural resource management can ensure the long-term sustainability of restoration efforts. Integrating ecological restoration into broader peace building and development initiatives is essential for fostering resilience and promoting long-term environmental security (Dudley *et al.*, 2020). The international community should support programs that provide technical assistance, financial resources, and policy guidance to facilitate the restoration and enhancement of vegetation cover in conflict-affected areas.

In the case of Tigray, the prolonged conflict has led to substantial reductions in vegetation cover across large portions of the region. Satellite imagery before and after the conflict shows noticeable deforestation in areas that were once rich in vegetation.

## **2.5 The Impact of War on Natural Resource Damage**

The impact of war on natural resource damage is a profoundly complex issue, marked by both immediate and long-term environmental consequences. Direct military actions, such as bombings and the deployment of heavy machinery, cause immediate destruction of habitats, soil degradation, and contamination of water sources (Omar *et al.*, 2009). For example, the deliberate targeting of industrial facilities, oil reserves, and agricultural lands releases toxic substances, leading to widespread pollution and lasting ecological damage (Westing, 1983). The oil well fires during the Gulf War serve as a stark illustration of this, demonstrating the extensive atmospheric and terrestrial pollution resulting from targeted destruction (Omar *et al.*, 2009). Similarly, the widespread use of defoliants during the Vietnam War resulted in extensive deforestation and long-term soil contamination (Lacombe *et al.*, 2010; Orians and Pfeiffer, 1970; Westing, 1983). The current war in Ukraine vividly illustrates the devastating effects of modern warfare on natural resources, exemplified by the destruction of dams and the contamination of farmlands.

Beyond the immediate physical destruction, war generates significant indirect environmental consequences. The displacement of populations, the disruption of environmental governance, and the diversion of resources away from conservation efforts exacerbate existing environmental problems. Refugee camps place immense pressure on local ecosystems, often leading to deforestation and resource depletion (Westing, 1983). The breakdown of regulatory frameworks and the proliferation of illicit activities, such as illegal logging and wildlife poaching, further degrade natural resources. Additionally, the increased greenhouse gas emissions from military equipment contribute to global climate change, compounding existing environmental challenges. The consequences of these indirect impacts are visible in numerous conflict zones, including regions in Africa and the Middle East, where environmental degradation exacerbates existing social and economic vulnerabilities.

Addressing the environmental damage caused by war requires a comprehensive and multifaceted approach. This includes integrating scientific assessment, legal frameworks, and international cooperation. Methodologies such as the US Natural Resource Damage Assessment (NRDA) can provide a structured approach to quantifying environmental injuries and informing restoration efforts (Omar *et al.*, 2009). Furthermore, strengthening international laws and mechanisms to hold perpetrators accountable for environmental crimes is crucial for deterring future conflicts and promoting environmental protection (Westing, 1983). The international community must prioritize the remediation of war-torn environments to ensure the long-term health and sustainability of affected ecosystems, recognizing that environmental security is intrinsically linked to human security (Lacombe *et al.*, 2010).

## **2.6 Socio-Economic Consequences of War**

The war in Tigray has led to widespread socio-economic disruption, impacting both urban and rural communities in profound ways. Agricultural production, the backbone of the Tigrayan economy, has suffered significantly due to the destruction of farmland, loss of livestock, and the displacement of farmers. Many households that relied on farming as their primary source of income now face severe food insecurity, as ongoing conflict has interrupted the planting and harvesting cycles, leaving communities unable to produce or access food. Additionally, the destruction of infrastructure, such as roads and markets, has further isolated communities, limiting trade and access to essential goods and services (World Bank, 2021; Mekonnen, 2022).

The conflict has also triggered a humanitarian crisis marked by rising unemployment, poverty, and loss of livelihoods in Tigray. Many local businesses have been forced to close, and job opportunities have diminished, especially in urban areas where economic activity has ground to a halt. Displacement has further strained resources in host communities, while those who remain in conflict-affected areas often face economic hardship due to inflation and rising prices of basic goods. Furthermore, education and healthcare services have been severely disrupted, limiting access to essential social services and exacerbating the long-term economic challenges for families and communities in Tigray (UN OCHA, 2021; Getachew, 2023).

### **3. MATERIAL AND METHODS**

#### **3.1 Description of the Study Area**

##### **3.1.1 Location**

The study was conducted in the Raya Azebo district of the Southern zone of Tigray, specifically in two kebelles, namely Hawelti and Ebo, which are located near Mehoni town. These kebelles are situated approximately 7 km away from the town, along the Mekoni-Mekelle main road. Raya Azebo is positioned between 12°17' and 12°15' North and 39°22' to 39°25' East. The district experiences a mean annual temperature of 21.5°C and is located approximately 666 km from Addis Ababa and 125 km from Mekelle. It shares borders with the Afar region and Raya Chercher district

in the East, Wajirat district in the Northwest, EmbaAlaje and Enda-Mehoni district in the West, and RayaAlamata district in the South.

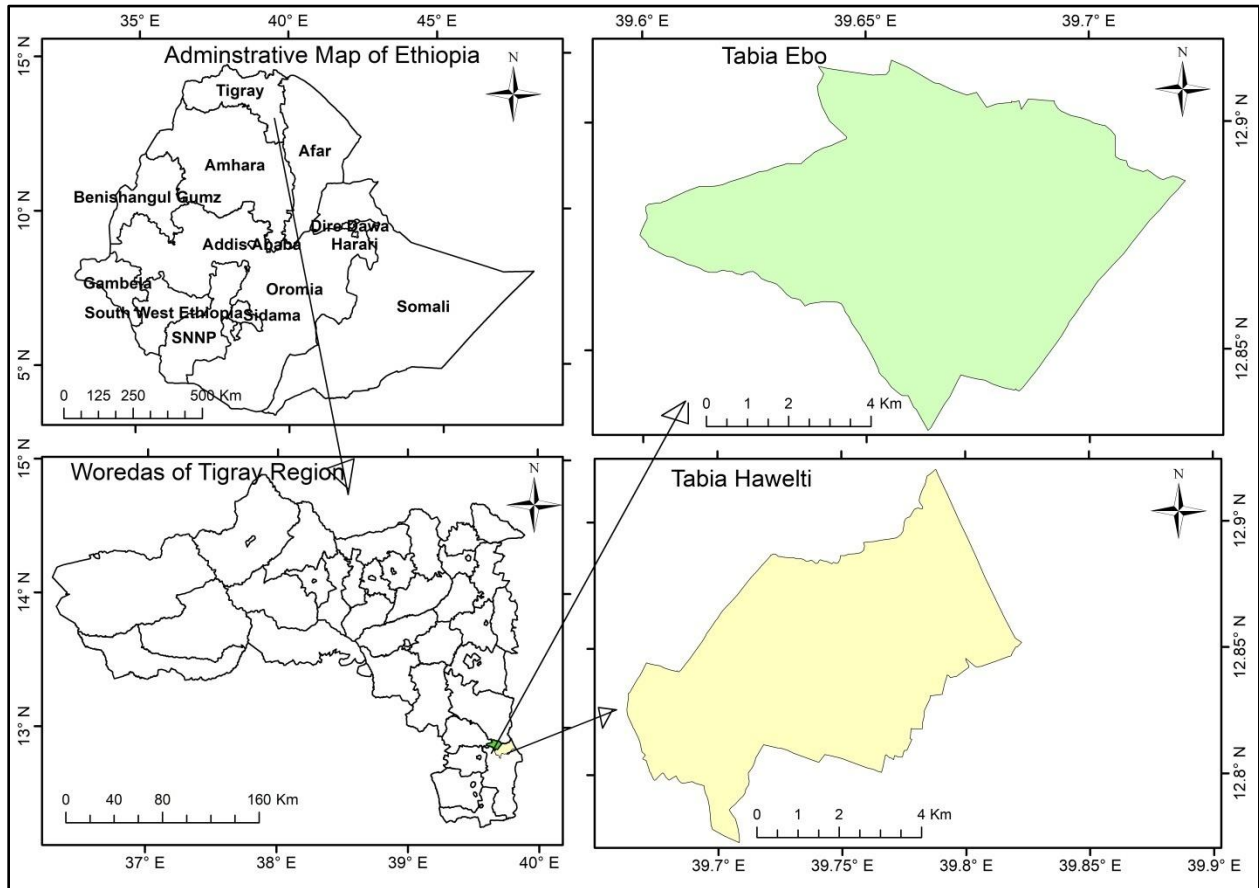


Figure 3.1 Location map of study area

### 3.1.2 Topography

The Ethiopia climate condition is determined by altitude. The same is true, large part of Raya Azebo is characterized by rugged topography that consist very high mountains, deeply incised canyons, gorges, valley, plain and plateaus. However, the climate under condition slightly varies from rural Tabia to Tabia, due to a difference in the nature of the relief (topography). Therefore, the strong relief difference, anthropogenic activities have led to extensive degradation. Generally, Raya Azebo is found in north lowland of Ethiopia. Elevation of the district ranges from the highest point of 2300 m a.s.l to the lowest point of 1200 m a.s.l (WoARD, 2011).

### **3.1.3 Climate**

The mean annual rainfall in Raya Azebo district is 779 mm. The rainfall follows a bimodal pattern, occurring from February to April and from July to September. The area experiences high potential evapo-transpiration rates (Bewket, Radeny, and Mungai, 2015). The agro-climatic conditions in the area are characterized as 85% midland and 15% lowland (Lemlem, 2013).

The majority of the Raya Azebo district is located in the Kola Agro-Ecology zone. During the warm season, the maximum temperature reaches approximately 33.33°C, while the minimum temperature during the cold season is around 12.07°C. The average temperature in the area is about 22.7°C. The maximum temperature 33.33°C was recorded in June, while the lowest 19.44 °C was recorded in December (WoARD, 2011).

### **3.1.4 Land Use and Vegetation Cover**

In Raya Azebo district, there is a variety of natural vegetation species. The major indigenous vegetation in the area includes Woira (*Lippia abyssinica*), Endod (*Phytolacca dodecandra*), Girar (*Excoecaria bussei*), Wanza (*Cordia africana*), Beles (*Ficus carica*), Aris (*Ficus sycomorus*), Kitkita (*Dodonea angustifolia*), Yabeshatid (*Juniperus procera*), Agam (*Acacia abyssinica*), Asta (*Erica arborea*), and Kulkal (*Euphorbia abyssinica*). Additionally, there are other indigenous plants that have adapted to the local climate conditions, including various grasses, Warka, Tukurenchet, Selansa, Shelean, Rowey, Mantaro, Kinchebte, and other short trees and desert plants (xerophytes). Furthermore, various exotic plants have also adapted to the local climate in the study area. Generally, the vegetation cover in the study area varies from one rural kebele to another, with some areas exhibiting relatively better status (AzeneBulwla, 2007; BORDO, 2024).

### **3.1.5 Soil Type**

Various soil types commonly found in the area include Vertisols, Nitisols, Cambisols, and Luvisols. The dominant soil type is Vertisol, characterized by black soil with swelling and shrinking characteristics. Vertisols cover over 70% of the study area, contributing to the relative fertility of the region (WoARD, 2011).

### **3.1.6 Population Size**

Based on the information provided from the Bureau of Agriculture and Rural Development Office (BOARDO, 2024), the population size of Raya Azebo district is 151,912. Out of this total

population, 77,474 are females. At the household level, there are 30,378 households, with 10,717 of them being female-headed households.

Table 3.3 Population size of the study area

№	Kebelle Name	Total Population Size			Total Household Head		
		Male	Female	Total	Male	Female	Total
1	Hawelti	10609	11042	21651	2414	1894	4308
2	Ebo	5475	5698	11173	1233	1186	2419
<b>Total</b>		<b>16083</b>	<b>16740</b>	<b>32823</b>	<b>3647</b>	<b>3080</b>	<b>6727</b>

### 3.1.7 Farming System

The farming system of the area is mixed (crop and livestock). Mainly Sorghum and Tef are continuously cultivated, and the minor crops are maize, wheat, barley and legumes like chickpea rotation are also cultivated. It is divided into two belts of cropping systems, Tef and Sorghum belt, respectively. Tef and Sorghum rotation is the most common practice in the area. Maize and Wheat are also practiced where some fields are used for crop rotation with Wheat (WoARD, 2016).

## 3.2 Data Sources and Methodology

### 3.2.1 Household Survey Data Sources

To assess the impact of the war on physical soil and water conservation structures, vegetation cover change, and socio-economic implications a combination of primary and secondary data was utilized, employing various methods and approaches. Qualitative data was collected through questionnaires, focus group discussions (FGDs), key informant interviews (KIIs), and field observations. Secondary data was primarily generated through a literature review encompassing books, articles, and reports from relevant stakeholders (district and kebele rural agricultural development agents and forest security guards) in the study areas.

FGDs was conducted at the local level, involving selected groups that represent leaders of traditional institutions (both men and women) within the relevant communities, as well as local peace and community-based organizations. These FGDs was help gather diverse perspectives from individuals who have been affected by the war. Information was collected regarding the history of each conflict, its impact, and community perceptions surrounding it.

KIIs were carried out at district and kebele levels, involving selected representatives from natural resource management (NRM), social affairs, kebele leaders, forest area security guards, kebele DAs, and kebele SWC foremen (HirshaKadire). Concurrently, quantitative data was collected through structured household surveys conducted at the household level in both kebelles.

### **3.2.2 Remote Sensing Data Collection and Analyzing**

The Landsat satellite imagery was used to assess and analyze changes in land use and vegetation cover in the forest area before and after the armed conflict. This analysis aims to identify significant alterations in vegetation cover within the study area. Specifically, satellite images from the years 2000, 2020 and 2022 was acquired, utilizing Landsat 7 and 8, to analyze the land use and vegetation cover changes before the armed conflict. For the year 2022, after the armed conflict ceasefire agreement, Landsat 9 imagery was utilized. NDVI was used to analyses and measure vegetation cover changes from 2000 to 2022. As a result, Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and spatiotemporal analysis of forest change using NDVI was analyzed as consulted Laksono *et al.* (2020). Accordingly, NDVI classes was classified using the pixels in to non-vegetated and vegetated, i.e., -1 up to 0.00 as no vegetation; 0.01-0.30 are slightly dense vegetation; 0.31-0.60 are moderately dense vegetation; 0.61-1.00 are highly dense vegetation. As a result, an area of each class was computed to analyze the vegetation cover trends of the study periods.

The digital satellite image processing operations and analysis was carried out using ArcGIS 10.8.1 software. The images were geo-referenced to a common coordinate system using the Universal Transverse Mercator (UTM) map projection (Zone 37) and WGS 84 datum in ArcGIS 10.8.1.

#### **Reference Sample Size and Accuracy Assessment**

There is no universally agreed-upon standard for the ideal sample size of reference data points. However, a general guideline suggests collecting at least 50 samples per land cover class when dealing with fewer than 12 classes, especially for maps covering areas less than 4000 square kilometers (Lillesand *et al.*, 2008). Based on this guideline, four primary land cover classes were selected for each time period (2000, 2020, and 2022), and at least 60 samples were gathered for each NDVI category. Consequently, this study compiled a total of 800 reference data points for each year, allocating 560 for classification and 240 for accuracy assessment.

To evaluate the accuracy of the classification results, a comparison with ground truth data was conducted. Classification is considered incomplete without an accuracy assessment (Lillesand *et al.*, 2008). Accordingly, an error matrix, also known as a confusion matrix or contingency table, was used to quantify classification accuracy (Equation 1). Here, reference and classification data were organized as columns and rows, respectively, within an Excel pivot table. From this matrix, classification accuracy metrics namely, user and producer accuracies were derived in percentage terms (Equations 2, 3). Additionally, thematic errors, such as omission and commission errors of pixels, were calculated.

Following the computation of accuracy for each classification result across the selected time periods, further agreement analysis was performed using the Kappa coefficient (Khat) to assess both the overall and chance-corrected agreement between reference and classified data (Equation 4). The Kappa coefficient helps evaluate the extent of actual versus expected agreement. User's and producer's accuracies were determined by dividing the number of correctly classified pixels in each category (diagonal entries) by the total classified pixels in each specified row or column category, respectively. Overall accuracy was calculated by summing the correctly classified pixels (diagonal values) and dividing this by the total pixel count. Additionally, Kappa coefficients were computed to measure NDVI classification accuracy and assess statistical significance across different matrices for each selected time period.

$$OAC = \frac{\sum X_{ij}}{N} * 100 \quad (1)$$

$$Khat = \frac{N \sum_{i=1}^r X_{ii} - \sum_{i=1}^r (X_{i+} * X_{+i})}{N^2 - \sum_{i=1}^r (X_{i+} * X_{+i})} \quad (2)$$

$$UAC = \frac{X_{ii}}{X_{+i}} * 100 \quad (3)$$

$$PAC = \frac{X_{ii}}{X_{i+}} * 100 \quad (4)$$

Where: **OAC** represents overall accuracy, **UAC** denotes user accuracy, **PAC** stands for producer accuracy, Khat refers to the Kappa statistic, **N** is the total number of samples,  $X_{ij}$  represents the diagonal values,  $X_{i+}$  is the column total, and  $X_{+i}$  is row total, **r** denotes the number of categories.

Reference data for classifying NDVI images from 2000, 2020, and 2022 using relatively high-resolution satellite imagery were collected through historical images from Google Earth for each

respective year. This process was further supported by targeted field observations and GPS measurements, when needed, to enhance accuracy and validation.

### **3.3 Sampling Techniques**

To focus on areas highly affected by the armed conflict, a purposive sampling technique was employed to select two kebelles. For the purpose of the study; two kebelles have been purposely selected based on the severity of the armed conflict in the study area. This sampling approach allows for a focused examination of the impacts on the forest area and local communities in areas that experienced significant consequences, based on their specific characteristics and their representation of the severe impact of the armed conflict.

- Household (HH) survey: This survey was conducted to gather essential information such as demographics, attitudes, and perceptions of the beneficiaries regarding socioeconomic aspects, soil and water conservation structures, and changes in vegetation cover.
- Focus group discussion (FGD): FGDs were conducted to obtain vital information such as demographics, attitudes, and perceptions of beneficiaries regarding socioeconomic aspects, soil and water conservation structures, and changes in vegetation cover. The FGDs was used to compare the findings from the household survey and remote sensing satellite image analysis.
- Key Informant Interviews (KII): KIIs was conducted with selected individuals who possess specific activity required for this survey.

#### **3.3.1 Sample Size Determinant**

Various methods exist for determining sample sizes, each with distinct approaches in defining error terms and precision levels. In the process of calculating sample sizes, Israel (1992) employed a formula established by Yamane (1967), using precision levels such as  $\pm 3$ ,  $\pm 5$ ,  $\pm 7$ , and  $\pm 10$ . Consequently, considering the flexibility in precision levels ranging from  $\pm 1$  to  $\pm 10$ , especially when dealing with a homogeneous target population, the researcher opts to utilize Yamane's (1967) formula with a specified precision level of  $\pm 6$ . This decision is grounded in the acknowledgment of different acceptable levels of precision and aligns with established practices in the field.

$$n = \frac{N}{1 + N(e)^2}$$

Where  $N$  = designates the total number of households in two kebele

$n$  = the sample size that the researcher used

$e$  = designates maximum variability or margin of error 6% (0.06), thus,  $N = 6727$ ,  $e = 0.06$

$$\text{Therefore, } n = \frac{N}{1+N(e)^2} = \frac{6727}{1+6727(0.06)^2} = \frac{6727}{1+6727(0.0036)} = \frac{6727}{25.2172} = 266.76 \approx \mathbf{267}$$

Table 3.2 Targeted sub-districts (kebele), their total population size and sample size

<b>N<sub>o</sub></b>	<b>Name of Sub-District (kebele)</b>	<b>Population Size (N)</b>	<b>Sample Size (n)</b>
1	Hawelti	4308	171
2	Ebo	2419	96
<b>Total</b>		<b>6727</b>	<b>267</b>

The study participants for the qualitative data were purposively selected based on their positions and their specialized knowledge of the issue. At kebele level, six officials from forest guards, agricultural extension, and kebele administrators were contacted. Additionally, two informants from the office of agriculture were interviewed at the level. A member of focus group discussions (FGDs) was recruited from community representatives, household heads with specific knowledge, and senior/elderly members of the community. Based on these criteria, two FGDs (one with women) were conducted in each kebele, total four separate groups. Kebele leaders, agricultural extension workers, and forest security guards were selected as group discussants. Each FGD were consisting of eight to twelve discussants. Furthermore, field observations, particularly the observer as a participant approach, were employed to investigate gender issues at the community level.

### **3.4 Ethical Considerations**

In research, ethics involve a set of norms and principles that researchers and data collectors must obey and apply (Babbie, 1990; Bernard, 2006). Accordingly, informed consent was explained to the study participants. The objective of the assessment was clearly communicated to the participants, and they were allowed to withdraw if they experience any discomfort during their involvement. The data collector refrained from using unnecessary terminologies that may displease the participants and avoided personal biases. Confidentiality and anonymity were ensured. The interests of the participants were given due attention and nothing was done to harm them physically, socially, or psychologically. The relationship was based on mutual trust, and the participants were not being exploited. All ethical concerns were respected. The participants were

informed that their involvement in the assessment was not incurred any cost or payment, and the information they provide was used to inform programmatic interventions.

### **3.5 Statistical Data Analysis**

The data analysis and interpretation involved a comprehensive presentation of both quantitative and qualitative findings were obtained from the questionnaires. Once the completed questionnaires are received from the respondents, the data were structured, organized, and tabulated systematically based on thematic similarities. Various statistical tools were employed for analysis and interpretation, depending on the nature of the questions in the questionnaires. This includes frequency counts and percentages to gain insights into the distribution and prevalence of different responses. Additionally, data obtained from interviews, focus group discussions, and field observations was integrated to enhance the robustness of the findings.

For the quantitative analysis, primarily focusing on objectives three and four, the study utilized the Statistical Package for Social Sciences (SPSS) version 20 software packages and Pivot Table. These tools facilitated a more efficient and accurate examination of statistical relationships and patterns within the dataset. By employing these software packages, the study aims to ensure a rigorous and insightful interpretation of the research findings.

Objective one employed a combination of qualitative and quantitative methods, along with the use of Google Earth satellite imagery. These approaches were aid in identifying changes in soil and water conservation structures in the study area. Objective two were involved the use of satellite imagery and remote sensing to measure vegetation index variables. This approach was helped identify changes in vegetation cover in the study area. Overall, the study employed a comprehensive analysis approach, integrating both quantitative and qualitative data sources, satellite imagery, and statistical software tools. This was enabled a thorough examination of the research objectives and provide valuable insights into the study area.

## **4. RESULT AND DISCUSSIONS**

### **4.1 Socio-Demographic Characteristics of the Household Respondents**

Table 4.1 provides insights into the demographic characteristics of respondents from Ebo and Hawelti, including their sex, marital status, educational level, and age. This analysis will delve into these characteristics to understand the socioeconomic context of the study population.

#### **Gender distribution**

The significant male majority observed in both Ebo (74%) and Hawelti (66.1%) (Table 4.1). This male dominance in land management can often lead to a short-term focus on agricultural yields, which may neglect sustainable practices necessary for preserving soil health and water resources (Smith and Johnson, 2019). Involving women in conservation efforts is crucial, as they typically manage household food production and resource utilization.

The gender distribution reflects a notable bias, with a more pronounced male majority in Ebo compared to Hawelti. This disparity may stem from various factors, including migration patterns, social structures, and labor demands in the region. The relatively low female participation suggests potential imbalances in household roles and workforce engagement, indicating that societal expectations might limit women's involvement in conservation initiatives. Promoting female-led conservation projects could enhance soil and water management practices and ultimately improve vegetation cover, benefiting the entire community. Addressing gender disparities in resource

management is vital for fostering sustainable development and ensuring that the benefits of conservation are shared equitably (Wordofa *et al*, 2020)

**Marital status**

Table 4.1 shows that, majority of the respondents were married as Ebo (72.9%) and Hawelti (67.3%) indicate the presence of stable family units that emphasize agricultural productivity as a means of economic security. This stability is conducive to collective action in conservation efforts, encouraging families to invest in soil and water conservation structures, such as check dams and contour farming practices (BassaandMarisennayya, 2022). However, the higher proportion of single individuals in Hawelti (25.1%) compared to Ebo (13.5%) (Table 4.1) suggests a potential openness to experimentation with new agricultural practices. Single individuals may face fewer traditional constraints, which can empower them to adopt more progressive land management techniques, thereby fostering innovative approaches to conservation.

In both Ebo and Hawelti, marriage emerges with the majority of the population being married. The disparity in single individuals could reflect variations in age distribution, cultural practices, or economic conditions that influence marriage patterns. Notably, divorce and widowhood are relatively uncommon, with slightly higher rates in Ebo than in Hawelti (Table 4.1).

Table 4.1 Sex, marital status and educational level, and age of the respondents

Gender	Ebo		Hawelti	
	Frequency	Percentage	Frequency	Percentage
Male	71	74%	113	66.1%
Female	25	26%	58	33.9%
<b>Marital Status</b>				
Married	70	72.9%	115	67.3
Single	13	13.5%	43	25.1%
Divorced	7	7.3%	10	5.8%
Widowed	6	6.3%	3	1.8%
<b>Education Level</b>				
Illiterate	60	62.5%	120	70.2%
Primary school	15	15.6%	24	14%
Secondary school	10	10.4%	20	11.7%
Vocational training	9	9.4%	5	2.9%
Bachelor’s degree	2	2.1%	2	1.2%
<b>Age</b>				
18-25	16	16.7%	20	11.7%
26-35	28	29.2%	45	26.3%

36-45	22	22.9%	41	24%
46-55	18	18.8%	37	21.6%
56-65	10	10.4%	25	14.6%
66+	2	2.1%	3	1.8%
<b>Mean</b>		38.89		37.85
<b>Std. Deviation</b>		10.13		10.01

### **Educational attainment**

War has a devastating impact on education, often resulting in the destruction of schools, displacement of students and teachers, and the prioritization of survival over learning. In conflict zones, millions of children are denied access to education, which can perpetuate cycles of poverty and inequality. These disruptions hinder long-term development, both at the individual and national levels, as education is crucial for rebuilding societies and economies post-conflict (UNESCO, 2019).

The higher illiteracy in Ebo (62.5%) and Hawelti (70.2%) (Table 4.1) may affect the community's engagement with soil and water conservation initiatives. Education plays a crucial role in fostering an understanding of sustainable practices. Individuals with higher educational attainment are more likely to grasp the long-term benefits of techniques such as agro-forestry and organic farming, which are essential for sustainable agricultural practices. Low levels of education hinder the community's ability to implement and maintain effective conservation structures. For example, constructing terraces requires knowledge of engineering principles and an understanding of hydrological cycles. Without educational programs that teach these skills, communities may struggle to establish effective soil and water conservation measures (Huffman *et al.*, 2013).

In Ebo, a substantial portion of respondents are illiterate (62.5%), indicating limited access to or utilization of formal education. The educational breakdown shows that primary school graduates comprise 15.6%, followed by those with secondary education (10.4%), vocational training (9.4%), and bachelor's degrees (2.1%) (Table 4.1). Hawelti exhibits even higher illiteracy rates at 70.2%, with a smaller percentage of individuals achieving primary (14%), secondary (11.7%), vocational (2.9%), and bachelor's (1.2%) degrees (Table 4.1). This disparity highlights that illiteracy is a pressing issue in both areas, with Hawelti facing a greater challenge. The low levels of higher education attainment reflect barriers such as economic constraints, lack of infrastructure, and

prevailing societal priorities. Notably, the slightly higher vocational training numbers in Ebo may indicate a local emphasis on skills-based education to meet the demands of the labor market.

### **Age distribution**

The age distribution in both Ebo and Hawelti reveals a predominantly young population, particularly within the 26-35 age brackets, which constitutes 29.2% in Ebo and 26.3% in Hawelti (Table 4.1). This youthful demographic presents a significant opportunity for implementing innovative conservation practices, as younger individuals are often more receptive to adopting new techniques that can enhance soil and water conservation efforts. Engaging youth in hands on conservation initiatives, such as tree planting and soil health workshops, can cultivate a sense of responsibility and ownership over local resources.

Furthermore, younger people are typically more familiar with modern technology, enabling the use of data-driven approaches in conservation. For instance, they can utilize satellite imagery or mobile applications to monitor changes in vegetation cover, facilitating more effective environmental management strategies (Kassahun *et al.*, 2019; O'Connor and Shultz, 2020). However, the low representation of older age groups (66+) raises concerns regarding the potential loss of traditional ecological knowledge. Older individuals often hold valuable insights into local ecosystems and sustainable practices developed over generations, which can be crucial for effective conservation efforts (Berkes, 2017).

In Ebo, the largest age group is 26-35, representing 29.2% of the population, followed by those aged 36-45 (22.9%) and 46-55 (18.8%) (Table 4.1). The younger (18-25) and older (56-65 and 66+) demographics are less represented, with only 2.1% being 66 or older. Similarly, in Hawelti, the 26-35 age groups dominate at 26.3%, closely followed by 36-45 (24%) and 46-55 (21.6%). The representation of younger respondents (18-25) is only 11.7%, and the elderly (66+) comprises a mere 1.8% (Table 4.1).

### **Type of dwelling**

In both Ebo (56.3%) and Hawelti (60.2%) (Table 4.2), the majority of residents live in mud houses, reflecting traditional construction practices. These structures are cost-effective and made from locally sourced materials; however, they often lack durability and resilience to environmental challenges, such as extreme weather, indicating limited financial means to invest in more

permanent and weather-resistant housing solutions (FAO, 2020). Renting is the second most common form of residence, with 25% in Ebo and 29.2% in Hawelti, suggesting that housing insecurity may be an issue for a significant portion of the population (UN, 2019).

Table 4.2 Type of dwelling, primarily occupations and income source of the respondents

<b>Type of Dwelling</b>	<b>Ebo</b>		<b>Hawelti</b>	
	<b>Frequency</b>	<b>Percentage</b>	<b>Frequency</b>	<b>Percentage</b>
Mud house	54	56.3%	103	60.2%
Rent house	24	25.0%	50	29.2%
Tent/temporary shelter	9	9.4%	8	4.7%
Group living facility	5	5.2%	4	2.3%
Farm	3	3.1%	6	3.5%
No permanent dwelling	1	1.0%	0	0%
<b>Primarily Occupations</b>				
Farmer	48	50%	101	59.1%
Laborer	23	24%	18	10.5%
Government employee	7	7.3%	16	9.4%
Private sector employee	7	7.3%	9	5.3%
Business owner	6	6.3%	13	7.6%
Unemployed	4	4.2%	9	5.3%
Herding/pastoralist	1	1%	5	2.9%
<b>Source of Income</b>				
Agriculture	73	76%	128	74.9%
Business	9	9.4%	17	9.9%
Government	7	7.3%	17	9.9%
Private sector	7	7.3%	9	5.3%

### Temporary shelters

The presence of temporary shelters, accounting for 9.4% in Ebo and 4.7% in Hawelti (Table 4.2), points to instability in living conditions for some households. Families in such transient accommodations are less likely to invest in long-term agricultural improvements like soil and water conservation, as the impermanence of their residence discourages sustained environmental

investments (Schwerdtle *et al.*, 2018). This may lead to a prioritization of short-term agricultural yields over sustainability.

### **Primary occupations**

Agriculture dominates as the primary occupation, with 50% of respondents in Ebo and 59.1% in Hawelti (Table 4.2) working as farmers. This highlights a heavy dependence on farming for livelihoods, stressing the need for sustainable agricultural practices to ensure long-term productivity and food security (WB, 2021). Without such practices, communities may experience deteriorating land quality and reduced yields over time.

### **Labor and economic vulnerability**

Ebo has a relatively high percentage of laborers (24%), compared to 10.5% in Hawelti. Laborers, often engaged in informal work, face economic instability, which limits their ability to invest in improvements for agriculture or soil conservation (ILO, 2020). This economic vulnerability can lead to a focus on immediate survival rather than long-term investments in sustainable practices that could improve environmental and economic resilience.

### **Diversity of occupations**

Low representation of government employees (7.3% in Ebo, 9.4% in Hawelti) and private sector workers (7.3% in Ebo, 5.3% in Hawelti) (Table 4.2) suggests limited economic diversification. A lack of alternative employment opportunities intensifies the pressure on agricultural land, often leading to unsustainable farming practices such as over-cultivation, which can degrade soil health and affect water availability (FAO, 2019).

### **Sources of income**

Agriculture remains the dominant source of income for both communities, with 76% in Ebo and 74.9% in Hawelti (Table 4.2) relying on it. This dependence underscores the importance of promoting sustainable farming practices, such as crop rotation and agroforestry, to improve soil fertility and mitigate the effects of climate variability (IPCC, 2019). Without diversification into other income sources, these communities remain vulnerable to agricultural disruptions.

### **Limited income diversification**

The heavy reliance on agriculture as the primary source of income, coupled with the limited contribution from business and government employment, suggests economic fragility. Communities highly dependent on a single income source, such as agriculture, are more susceptible to economic shocks from poor harvests or market fluctuations. Promoting alternative income-generating activities, like agro-businesses or small-scale enterprises, can enhance economic resilience and support long-term soil and water conservation efforts. The challenges of relying heavily on agriculture and the need for sustainable agricultural practices are echoed in reports by the Food and Agriculture Organization (FAO). Communities with limited livelihood options often face economic vulnerabilities, which hinder the adoption of sustainable practices (FAO, 2019).

## 4.2 Impact of War on Physical Soil and Water Conservation (SWC) Structures

Ebo and Hawelti rely on physical soil and water conservation structures to combat soil erosion, conserve water, and enhance agricultural productivity. The destruction of these systems during conflict poses risks to both the environment and agricultural sustainability.

Table 4.3 Impact of war on physical soil and water conservation (SWC) structures

<b>Constructing of physical SWC structures before the war</b>	<b>Ebo</b>		<b>Hawelti</b>	
	<b>Frequency</b>	<b>Percentage</b>	<b>Frequency</b>	<b>Percentage</b>
Yes	91	94.8%	168	98.2%
No	5	5.2%	3	1.8%
<b>Types of physical soil and water conservation (SWC) structures were commonly constructed</b>				
Contour bund	18	18.8%	49	28.7%
Bench Terraces and Contour Bund	20	20.8%	36	21.1%
Bench Terraces	25	26%	32	18.7%
Soil bund	11	11.5%	23	13.5%
Small half-moon	5	5.2%	12	7.0%
Gabion check dam	6	6.3%	11	6.4%
Deep trench	5	5.2%	8	4.7%
None	5	5.2%	-	-
Eyebrow basin	1	1%	-	-
<b>Type of physical soil and water conservation structures were mostly affected by the war</b>				
Bench Terraces	37	38.5%	64	37.4%
Soil bund	21	21.9%	37	21.6%
Contour bund	15	15.6%	51	29.8%
Gabion check dam	6	6.3%	8	4.7%
None	5	5.2%	3	1.8%
Stone bund	5	5.2%	6	3.5%
Deep trench	3	3.1%	-	-

Eyebrow basin	3	3.1%	2	1.2%
Normal Trench	1	1%	-	-
<b>Extent of damage</b>				
Partially destroyed	45	46.9%	91	53.2%
Completely destroyed	31	32.3%	77	45%
Not destroyed	20	20.8%	3	1.8%
<b>The main cause of damage to physical soil and water conservation structures during war</b>				
Flooding due to damaged structures	31	32.3%	63	36.8%
Deliberate destruction by combatants	25	26%	55	32.2%
Neglect and lack of maintenance	18	18.8%	21	12.3%
Heavy machinery and vehicles	13	13.5%	26	15.2%
Not applicable	5	5.2%	3	1.8%
Explosions and military activities	4	4.2%	3	1.8%

### **Pre-war construction of physical SWC structures**

The vast majority of respondents in both Ebo (94.8%) and Hawelti (98.2%) (Table 4.3) reported having constructed SWC structures before the war. This suggests a widespread recognition of the importance of soil and water conservation practices to combat soil erosion and water runoff. The minor percentage of respondents who did not construct SWC structures before the war (5.2% in Ebo and 1.8% in Hawelti) (Table 4.3) may be indicative of either physical limitations (e.g., land conditions) or a lack of resources (such as labor and materials) to build these structures.

### **Types of SWC structures constructed**

In both kebele, the most common structures constructed on farmlands included Bench Terraces, Contour Bunds, and combinations of the two. In Ebo, Bench Terraces accounted for 26% of the total, while Contour Bunds were implemented by 18.8% of farmers. In Hawelti, Contour Bunds were the most frequently used structures (28.7%), followed by Bench Terraces (18.7%) (Table 4.3). These results show that farmers opted for the type of structures best suited to their specific environmental conditions through indigenous knowledge and Woreda experts. Bench Terraces are known for their effectiveness in steep terrains where soil erosion is a major threat, while Contour Bunds are often used in moderately sloped areas to slow down water flow and reduce erosion. Other structures like Soil Bunds, Small Half-Moons, and Gabion Check Dams were used less frequently but still reflect efforts to adapt to local conditions (Shiferaw and Holden, 2000).

Similarly, in line with the quantitative findings, the qualitative FGD participants also recognized that before the war, the community had constructed various types of soil and water conservation structures such as soil bunds, normal trenches, dip trenches, stone bunds, bench terraces, Contour

bund, Gabion check dam and biological conservation measures. These initiatives were implemented in both kebeles through free mobilization efforts and support from NGOs like SLMP, PSNP4, CRGE, and other partners.

### **Types of SWC structures affected by the war**

Table 4.3 reveals that substantial SWC structures were damaged as a result of the war. In Ebo, Bench Terraces were the most affected, with 38.5% of these structures being impacted, while in Hawelti, 37.4% of Bench Terraces were damaged. Similarly, Soil Bunds and Contour Bunds were also heavily affected in both areas. The higher rate of damage to Contour Bunds in Hawelti (29.8%) (Table 4.3) suggests that these structures, which are often located on more open or easily accessible land, were particularly vulnerable to destruction (Liniger *et al.*, 2011). This damage likely resulted in increased soil erosion, reduced water retention, and a general decline in the productivity of agricultural lands, exacerbating the environmental and socio-economic impacts of the war. Furthermore, based on data from the Woreda RDAO, 105 hours in Ebo and 169 hours in Hawelti were allocated to constructing soil and water conservation structures in 2016 E.C. These structures, such as soil bunds, normal trenches, deep trenches, stone bunds, and others, were implemented in both watersheds following the ceasefire agreement in Pretoria post-war. Consequently, there has been a noticeable increase in the construction of structures in both kebelles compared to the wartime period.

Similarly, in line with the quantitative findings, the qualitative FGD participants also recognized that after the war, everything changed. There was a halt in the construction of new structures of soil and water conservation structures and biological plantations in both kebeles. The soil and water conservation structures, such as soil bunds mainly in the farmlands, normal trenches, dip trenches, stone bunds, bench terraces, Gabion check dams, and biological conservation measures in the watershed, were damaged.

Furthermore, military shields were constructed, particularly in Hawelti in both forested areas and farmlands, and partially in Ebo in the farmland and residences of the community. Even in forested areas and community farmlands, military shields were erected. Additionally, the existing physical soil and water conservation structures in both kebeles were damaged.

### **Extent of damage**

In terms of the extent of damage, 46.9% of structures in Ebo and 53.2% in Hawelti were partially destroyed, while a significant proportion 32.3% in Ebo and 45% in Hawelti (Table 4.3) were destroyed. The high levels of destruction, particularly in Hawelti, suggest that this area experienced more intense military activity or flooding, like military shields were constructed, free grazing and using improperly firewood. The near-total destruction of these systems in some cases will have major consequences for post-war recovery and rehabilitation efforts, as restoring these structures will be both time-consuming and resource-intensive (Keesstra *et al.*, 2016).

### **Main causes of damage**

The causes of damage to SWC structures vary, with flooding due to damaged structures (32.3% in Ebo, 36.8% in Hawelti) (Table 4.3) being the leading cause. This reflects the cascading effect that war-induced damage can have on the environment. When structures meant to prevent water runoff are damaged, the resulting floods can cause further destruction. Deliberate destruction by combatants (26% in Ebo, 32.2% in Hawelti) (Table 4.3) was also a significant cause of damage. This suggests that these structures were seen as strategic targets during the conflict. Destroying SWC structures could have been aimed at disrupting agricultural production and resource management, further debilitating the local economy (Liniger *et al.*, 2011).

Other causes, such as heavy machinery and vehicles (13.5% in Ebo, 15.2% in Hawelti) (Table 4.3) point to collateral damage during the war. Military vehicles and equipment likely traversed farmland, inadvertently damaging the structures. Finally, neglect and lack of maintenance during the conflict further contributed to the degradation of these essential conservation systems. The war severely damaged physical SWC structures in Ebo and Hawelti, leading to heightened soil erosion, water loss, and decreased agricultural productivity.

Deliberate destruction by combatants, along with flooding and neglect and lack of maintenance, underscores the fragility of SWC structures during conflicts. Rebuilding these systems is essential for restoring agricultural capacity and ensuring long-term land sustainability.

In line with the quantitative HH survey findings, the qualitative FGD participants reported that the main causes of damaged physical soil and water conservation structures and changes in vegetation cover in both kebeles are:-disrespect for community by-laws, government proclamations, and free

grazing of livestock, as a coping strategy, communities collect and use firewood, selling the wood for income and both kebeles serve as military stations and war zones.

As a result, the physical soil and water conservation structures are deteriorating due to soil erosion caused by the lack of respect for regulations, leading to decreased soil fertility and negatively impacting agricultural productivity. Consequently, this has led to food insecurity in the community.

### 4.3 Extent of War-Induced Damage to SWC Structures and Vegetation Cover

#### Damage to soil and water conservation (SWC) structures

In Ebo, 42.7% (Table 4.4) of respondents reported significant damage to SWC structures, while in Hawelti, 39.8% reported the same. The fact that such a large proportion of respondents from both sites experienced severe damage highlights the direct impact of war on land conservation efforts. SWC structures, essential for preventing soil erosion and maintaining water retention, often become casualties of conflict, leading to long-term land degradation (Lal, 2014; Schmidt *et al.*, 2009).

Table 4.2 Impact of war on soil and water conservation structures, grazing lands, and woodlots

	Ebo		Hawelti	
	Frequency	Percentage	Frequency	Percentage
<b>Damage of soil and water conservation structures due to war on communal lands</b>				
Yes, significant damage	41	42.7%	68	39.8%
Yes, moderate damage	32	33.3%	67	39.2%
Yes, minor damage	18	18.8%	33	19.3%
No, noticeable damage	5	5.2%	3	1.8%
<b>The impact of war on the grazing land, woodlot and SWC structures</b>				
Significantly affected	51	53.1%	95	55.6%
Somewhat affected	39	40.6%	73	42.7%
Not affected	6	6.3%	3	1.8%

Moderate damage was reported by 33.3% in Ebo and 39.2% in Hawelti (Table 4.4). This indicates that a substantial portion of the structures faced damage, which, while not catastrophic, still reduced the effectiveness of SWC systems. This damage likely resulted from a combination of direct conflict and the lack of maintenance during war (UNDP, 2013). Minor damage affected 18.8% in Ebo and 19.3% in Hawelti, reflecting areas where the infrastructure was only partially

impacted. However, even minor disruptions can lead to reduced efficiency in preventing soil degradation, especially if not quickly addressed (WB, 2006).

A small percentage (5.2% in Ebo and 1.8% in Hawelti) (Table 4.4) reported no noticeable damage, possibly reflecting regions spared from the most intense fighting or those where conservation systems were more resilient (Schmidt *et al.*, 2009).

### **Impact on grazing lands, woodlots, and SWC structures**

The impact of war on grazing lands, woodlots, and SWC structures was significantly felt by 53.1% in Ebo and 55.6% in Hawelti (Table 4.4). These findings highlight the widespread destruction of vital communal resources, which rural communities depend on for livestock grazing, firewood, and soil conservation. The loss of these resources not only affects the environment but also deepens the economic challenges for these communities (Tadros, 2012; Peters *et al.*, 2018).

Somewhat affected responses were provided by 40.6% in Ebo and 42.7% in Hawelti (Table 4.4). While these areas faced less severe impacts, the data shows that conflict still disrupted resource availability. In such regions, the land may still be usable but would require restoration efforts to return to full productivity (Buhaug and Lujala, 2005). Only a small percentage (6.3% in Ebo and 1.8% in Hawelti) (Table 4.4) reported that the land was not affected by the war. These figures likely reflect regions that were either geographically isolated from conflict or where proactive management had provided some level of protection against degradation (FAO, 2017).

The data reflects the profound impact of war on natural resource management systems in both kebele. SWC structures and communal lands are critical for maintaining ecological stability and supporting rural livelihoods. The widespread damage to these resources in Ebo and Hawelti underscores the need for post-conflict recovery efforts to prioritize the rehabilitation of conservation structures. Sustainable land management and the rebuilding of SWC systems are essential to prevent further degradation and restore the productivity of these communal lands (Lal, 2014; FAO, 2017).

Table 4.5 Total number of SWC structures constructed by free mobilization before war in 2012 and after war in 2016

S/N	Type of SWC structure contracted (km, and m <sup>3</sup> )	Unit	Before war (2012)			After war (2016)		
			Hawelti	Ebo	Total	Hawelti	Ebo	Total
1	Normal trench	km	51.87	0	51.87	62.45	3.7	66.15
2	Deep trench	km	50.81	35.238	86.048	20.88	46.22	67.1
3	Stone bund	km	30.03	3.728	33.758	37.24	0	37.24
4	Hillside terrace	km	43.488	15.452	58.94	13.01	2.25	15.26
5	Percolation channel	m <sup>3</sup>	614	0	614	756	0	756
6	Biological conservation	number	8880	28616	37496	173525	48550	222075
7	Soil bund	km	1.6	0	1.6	40.88	0	40.88

According to the data provided by the woreda natural resources and management processes SWC expert, before the war started, the community constructed various soil and water conservation structures at the community level through free mobilization every year. These activities were very helpful in conserving their soils, water, and biological resources in their watersheds, even fostering a sense of ownership within the community.

However, after the war began, the physical structures and forest areas were completely damaged due to the absence of forest guards, government structures collapsing, and the community not being mobilized for free work on constructing SWC structures and free grazing livestock in the watershed. For three years, no physical SWC structures were built in both kebeles due to the war. After the ceasefire agreement was signed by EFDRE and TPLF, the free mobilization for constructing SWC structures in both kebeles resumed. Some projects even initiated plans to support them by providing funds for area closure and constructing PSWC structures in the community.

#### **4.4 Socio-Economic Implications of War-Induced Damage**

##### **Impact of damaged SWC structures on farming and productivity**

The data indicates that damage to SWC structures significantly impacted farming and productivity in both Ebo and Hawelti kebele. In Ebo, 35.4% of respondents reported increased food insecurity, while 24% reported decreased agricultural productivity. Similarly, in Hawelti, 33.3% of respondents indicated reduced productivity, and 22.2% noted increased food insecurity (Table 4.6). The destruction of SWC structures led to widespread environmental degradation, including increased soil erosion (19.8% in Ebo and 18.1% in Hawelti) (Table 4.6), further exacerbating the challenges of maintaining agricultural output during and after the conflict.

Table 4.6 Impact of damaged soil and water conservation structures on farming productivity, and household food security

	Ebo		Hawelti	
	Frequency	Percentage	Frequency	Percentage
<b>damages to soil and water conservation structures affected your farming and productivity</b>				
Increased food insecurity	34	35.4%	38	22.2%
Decreased agricultural productivity	23	24%	57	33.3%
Increased soil erosion	19	19.8%	31	18.1%
Economic hardship	15	15.6%	42	24.6%
No change	5	5.2%	3	1.8
<b>The impact of loss of soil and water conservation structures on agricultural productivity</b>				
Significant decrease	58	60.4%	102	59.6%
Moderate decrease	33	34.4%	66	38.6%
No change	5	5.2%	3	1.8%
<b>The impact of war on household food security</b>				
Much worse	61	63.5%	109	63.7%
Somewhat worse	22	22.9%	52	30.4%
Not worse	8	8.3%	7	4.1%
No change	5	5.2%	3	1.8%

The economic consequences of these disruptions were also significant, with 15.6% of respondents in Ebo and 24.6% in Hawelti citing economic hardship due to damage to SWC structures (Table 4.6). These findings align with research highlighting that conflicts often result in the degradation of SWC structures, which in turn undermines local economies and increases poverty in war-affected regions (UNDP, 2013; Tadros, 2012).

### **Loss of SWC structures and agricultural productivity**

The loss of SWC structures had a profound effect on agricultural productivity. In both Ebo and Hawelti (Table 4.6), the majority of respondents reported a significant decrease in productivity (60.4% in Ebo and 59.6% in Hawelti) with a notable portion also indicating a moderate decrease (34.4% and 38.6%, respectively). SWC structures, such as terraces and bunds, play a vital role in protecting farmland from erosion, maintaining soil fertility, and ensuring consistent water retention. The destruction of these structures during the war would have left farmlands vulnerable to erosion and reduced water availability, leading to sharp declines in crop yields (Lal, 2014; FAO, 2017).

This finding is consistent with the broader literature on post-conflict recovery, which emphasizes that the restoration of agricultural infrastructure is essential to revitalizing war-torn economies and

reducing food insecurity (Schmidt *et al.*, 2009; Buhaug and Lujala, 2005). Without functioning SWC systems, farmers are unable to sustain high levels of productivity, resulting in long-term economic losses and heightened food insecurity.

According to the FGD participants, the primary socioeconomic impacts of physical soil and water conservation (SWC) structures and changes in vegetation cover in both kebeles are as follows:- Before the war began, both kebeles had supportive NGOs that assisted the community by:- paying fees for participation in constructing SWC structures., planting seedlings., guarding the forest, producing beehives in the forest, utilizing forest products for agricultural tools, establishing youth cooperatives for livestock fattening. However, after the war, all these sources of socioeconomic support ceased, negatively affecting the community's livelihoods. The long-term effects of the war on natural resources raise concerns, leading to environmental degradation and decreased agricultural productivity.

### **Impact of war on household food security**

The war's impact on household food security was particularly severe, with 63.5% of respondents in Ebo and 63.7% in Hawelti (Table 4.6) reporting that their food security had become much worse since the conflict began. Another 22.9% in Ebo and 30.4% in Hawelti (Table 4.6) indicated that their food security had worsened to some degree. Only a very small percentage of respondents (8.3% in Ebo and 4.1% in Hawelti) reported no negative change.

These findings are consistent with other studies that document how conflicts lead to widespread disruptions in food supply chains, destruction of agricultural infrastructure, and displacement of farming communities (FAO, 2017; Peters *et al.*, 2018). The war not only affected the physical ability to produce food but also had a direct impact on the economic access to food, as households faced heightened insecurity and economic hardship.

Based on the FGD participants, the aftermath of the war resulted in the following impacts: - In both kebeles, there were direct and indirect impacts on agricultural productivity due to soil erosion and deforestation across farmlands and forest areas. Animals were even forced to seek food over long distances, such as at the border of the Afar region, known as Eurna and some community members' farmland experienced decreased agricultural productivity due to the construction of

military structures, which reduced the coverage of farmland. Generally, the war has affected the overall livelihoods of the community and resulted in their food insecurity.

## **4.5 The Impact of War on Vegetation Cover and Household Livelihoods**

### **4.5.1 Primary drivers of vegetation cover change during the war**

The data from Table 4.7 illustrates that deforestation for firewood and construction was the most prominent driver of vegetation cover change in both Ebo (55.2%) and Hawelti (40.9%). This can be attributed to the breakdown of traditional supply chains and the loss of access to regular resources, forcing communities to rely on local vegetation for firewood and materials for construction (FAO, 2017).

Overgrazing by livestock was another critical factor, reported by 22.9% of respondents in Ebo and 33.9% in Hawelti. The concentration of livestock in limited areas due to the war put significant pressure on already vulnerable lands, further reducing vegetation cover (Lal, 2014). Other factors, including logging for military purposes (7.3% in Ebo and 4.1% in Hawelti), the expansion of agricultural land (6.3% and 14.6%), and clearing for settlements (3.1% and 4.7%), reflect how war intensified demands on the environment (UNDP, 2013).

Table 4.7 Analysis of drivers of vegetation cover change and economic impacts during war

The main or primary driver of vegetation cover change during the war	Ebo		Hawelti	
	Frequency	Percentage	Frequency	Percentage
Deforestation for firewood and construction	53	55.2%	70	40.9%
Overgrazing by livestock	22	22.9%	58	33.9%
Logging for military purposes	7	7.3%	7	4.1%
Expansion of agricultural land	6	6.3%	25	14.6%
None	5	5.2%	3	1.8%
Clearing for settlements	3	3.1%	8	4.7%
<b>The impact of war on household's economic situation</b>				
Decreased income	91	94.8%	168	98.2%
No change	5	5.2%	3	1.8%
<b>The main or primary impacts of the loss of vegetation cover on your household's livelihood</b>				
Reduced access to fuel wood and construction materials	50	52.1%	73	42.7%
Decreased forage for livestock	25	26%	56	32.7%
Increased risk of natural disasters	16	16.7%	39	22.8%
No change	5	5.2%	3	1.8%

#### 4.5.2 Impact of war on household economic situations

Economic impacts were widespread, as 94.8% of respondents in Ebo and 98.2% in Hawelti (Table 4.7) reported decreased income due to the war. The destruction of infrastructure and the reduced agricultural productivity are key reasons behind these figures. As vegetation cover was lost, and agricultural land became unproductive, households faced increased economic vulnerability (Schmidt *et al.*, 2009). The reliance on local resources for daily needs such as firewood and construction materials further compounded economic difficulties, as deforestation and land degradation took away key survival resources (Peters *et al.*, 2018).

#### 4.5.3 Impact of vegetation loss on livelihoods

The loss of vegetation cover had significant impacts on household livelihoods. A majority of respondents, 52.1% in Ebo and 42.7% in Hawelti (Table 4.7), reported reduced access to fuel wood and construction materials, directly reflecting the deforestation highlighted earlier. Decreased forage for livestock was another major concern, affecting 26% of respondents in Ebo and 32.7%

in Hawelti (Table 4.7). The reduction of grazing lands due to vegetation loss placed a further strain on pastoral and agricultural livelihoods (Buhaug and Lujala, 2005).

Additionally, the respondents reported that, 16.7% of households in Ebo and 22.8% in Hawelti noted an increased risk of natural disasters such as floods and landslides, which is exacerbated by reduced vegetation cover. The loss of vegetation exacerbates soil erosion and reduces the land's ability to absorb water, increasing the frequency and intensity of natural disasters (WB, 2006).

#### **4.6 Community Perception of War's Impact on Natural Resources**

The data gathered on community perceptions of the war's impact on natural resources, mental health, and soil health in Ebo and Hawelti provides valuable insight into the socio-environmental effects of conflict on these localities. The findings reveal that the war has had widespread consequences on natural resources and the ability of the communities to maintain the health of their land, with considerable variations in the severity of the perceived impacts between the two areas.

##### **Perception of damage to SWC structures and natural resources**

Both Ebo and Hawelti reported high levels of damage to SWC structures and natural resources due to the war (Table 4.8). In Ebo, 53.1% of respondents indicated significant damage, while 40.6% reported being somewhat affected. Similarly, Hawelti exhibited comparable perceptions, with 55.6% of respondents reporting significant damage and 42.7% somewhat affected (Table 4.8). This data underscores the war's substantial disruption to natural resource management and infrastructure. The destruction of SWC structures is particularly concerning, as these are vital for protecting land from erosion, maintaining soil fertility, and regulating water resources, all of which are crucial for the sustainability of agricultural livelihoods in the region (FAO, 2020).

##### **Impact on mental health**

The war's toll on mental health is another critical dimension explored in this study. In Ebo, 50% of respondents felt somewhat affected by the war's psychological consequences, while 44.8% were significantly affected (Table 4.8). In Hawelti, the figures were similar, though with a slightly higher proportion (55.6%) reporting significant impacts on their mental well-being and 42.7% somewhat affected (Table 4.8). This suggests that the psychological burden of the conflict has

been profound in both areas, reflecting the broader, often underappreciated, consequences of war on community mental health (Betancourt *et al.*, 2017).

The widespread distress caused by displacement, loss of livelihoods, and destruction of homes likely contributes to these elevated rates of mental health issues. The intersection between ecological damage and psychological health is also notable, as the degradation of natural resources may exacerbate feelings of insecurity and hopelessness among community members.

### **Impact on the ability to maintain soil health**

The war has also hindered the ability of both Ebo and Hawelti communities to maintain soil health, which is essential for sustainable agriculture and food security. In Hawelti, the majority of respondents (67.8%) felt somewhat affected, and 30.4% reported being significantly affected in their ability to maintain soil health (Table 4.8). Ebo, while showing a slightly different distribution, still presented high levels of concern, with 54.2% of respondents somewhat affected and 40.6% significantly affected (Table 4.8).

The disruption of farming activities, displacement of populations, and damage to soil conservation infrastructure are likely contributors to this impact. The war's effect on soil health is particularly concerning, as degraded soil can lead to reduced agricultural productivity and increased vulnerability to food insecurity (Tadesse and Belay, 2021).

Table 4.8 Community perception of war's impact on natural resources

	<b>Ebo</b>		<b>Hawelti</b>	
	<b>Frequency</b>	<b>Percentage</b>	<b>Frequency</b>	<b>Percentage</b>
<b>Perception of damage to SWC structures and natural resources</b>				
Significantly affected	51	53.1%	95	55.6%
Somewhat affected	39	40.6%	73	42.7%
Not affected	6	6.3%	3	1.8%
<b>The impact of war on mental health</b>				
Somewhat affected	48	50%	73	42.7%
Significantly affected	43	44.8%	95	55.6%
Not affected	5	5.2%	3	1.8%
<b>The war affected your ability to maintain soil health</b>				
Somewhat affected	52	54.2%	116	67.8%
Significantly affected	39	40.6%	52	30.4%
Not affected	5	5.2%	3	1.8%

#### **4.7 Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) of study area**

The analysis of NDVI (Normalized Difference Vegetation Index) changes between 2000, 2020, and 2022 for Ebokebele and Haweltikebele illustrates shifts in vegetation health over this period. NDVI is a key indicator used to assess vegetation vigor and density, with values ranging from -1 to 1, where higher values correspond to healthier vegetation. In this regard, Ebokebele has experienced a significant improvement in vegetation health in 2000 and 2020 with a marked increase in areas of healthy vegetation and a decrease in non-vegetation and unhealthy vegetation. However, following poor effort during the war the vegetation health has diminished in postwar (2022) (Figure 1a-c). On the other hand, Haweltikebele has seen some positive changes before the war compared to former study period, such as a reduction in non-vegetation areas, but it also faces challenges, including decrease in unhealthy vegetation in the post war study period (2022). Although they showed similar trends in these two regions, but they underscore the varying dynamics of vegetation health and the need for targeted management strategies to address specific local conditions. Figure 1 a-c shows that the NDVI values of Ebo ranges from -0.3 to 0.33 in 2000 and this has slightly increased to 0.036 to 0.50 in 2020, and this has substantially decreased to 0.07 to 0.484 in 2022 compared to the second study period (Figure 3 a-c). This reduction may be due to war that communities engaged in forest cutting for different purpose. In the same token, the

average enhanced value indexes (EVI) are slightly increased from 3.87 to in 2000 to 0.432 in 2020, and this has trivially decreased to 0.412 in 2022 (Figure 2 a- c).

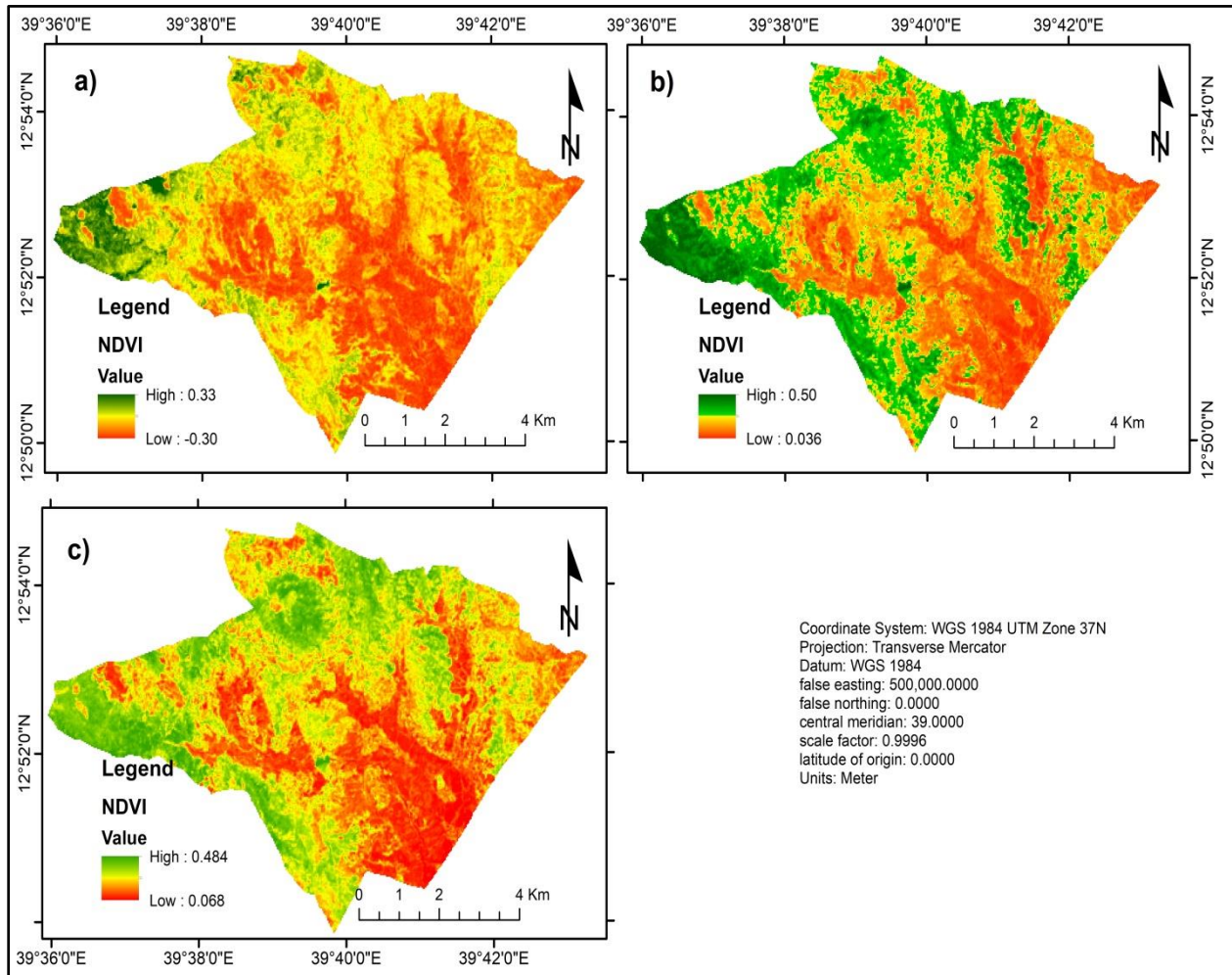


Figure 1 NDVI values of Ebo in 2000 a), 2020 b), and 2022 c)

Table 4.9 NDVI class values of the study area in 2000, 2020, 2022 (SqKm and percent)

		Classes	2000		2020		2022	
			Area					
Target areas	Ranges		Sq.km	%	Sq. km	%	Sq.km	%
Ebo Kebele	-1-0.00	Non vegetation	12.41	21.84	4.24	7.46	8.09	14.25
	0.01-0.30	Unhealthy vegetation	15.84	27.90	29.41	51.78	14.56	25.64
	0.31-0.60	Moderate healthy	21.03	37.04	16.51	29.07	18.37	32.35
	0.61-1.00	Healthy vegetation	7.51	13.23	6.63	11.68	15.77	27.76
	Total		56.79	100	56.79	100	56.779	100
Hawelti Kebele	-1-0.00	Non vegetation	96.89	79.12	54.30	44.34	86.97	71.02
	0.01-0.30	Unhealthy vegetation	18.59	15.18	43.54	35.55	27.07	22.10
	0.31-0.60	Moderate healthy	5.75	4.70	18.15	14.82	7.15	5.84
	0.61-1.00	Healthy vegetation	1.23	1.00	6.46	5.27	1.28	1.05
	Total		122.46	100	122.46	100	122.46	100

The spatial analysis, as depicted in Figures 3 a-c, which presents the average NDVI value of -0.088 in initial period, and 0.11 in 2020, and 0.13 in the final study period for Haweltikebele, suggest that this kebele exhibits lower vegetation health and density compared to Ebokebele although the average EVI value of the Hawelti increased twice from 0.282 in 2000 to 0.499 in 2022. The lower NDVI values indicate that Hawelti may have poorer vegetation cover, potentially due to factors such as war, land degradation, population pressure, limited vegetation recovery or environmental stressors like overgrazing, deforestation, or poor soil quality. This difference in vegetation indices between the two kebeles implies that Haweltikebele might require more focused land management and conservation efforts to enhance its vegetation health and ecosystem services. Addressing these issues is crucial for improving the ecological resilience and sustainability of the region.

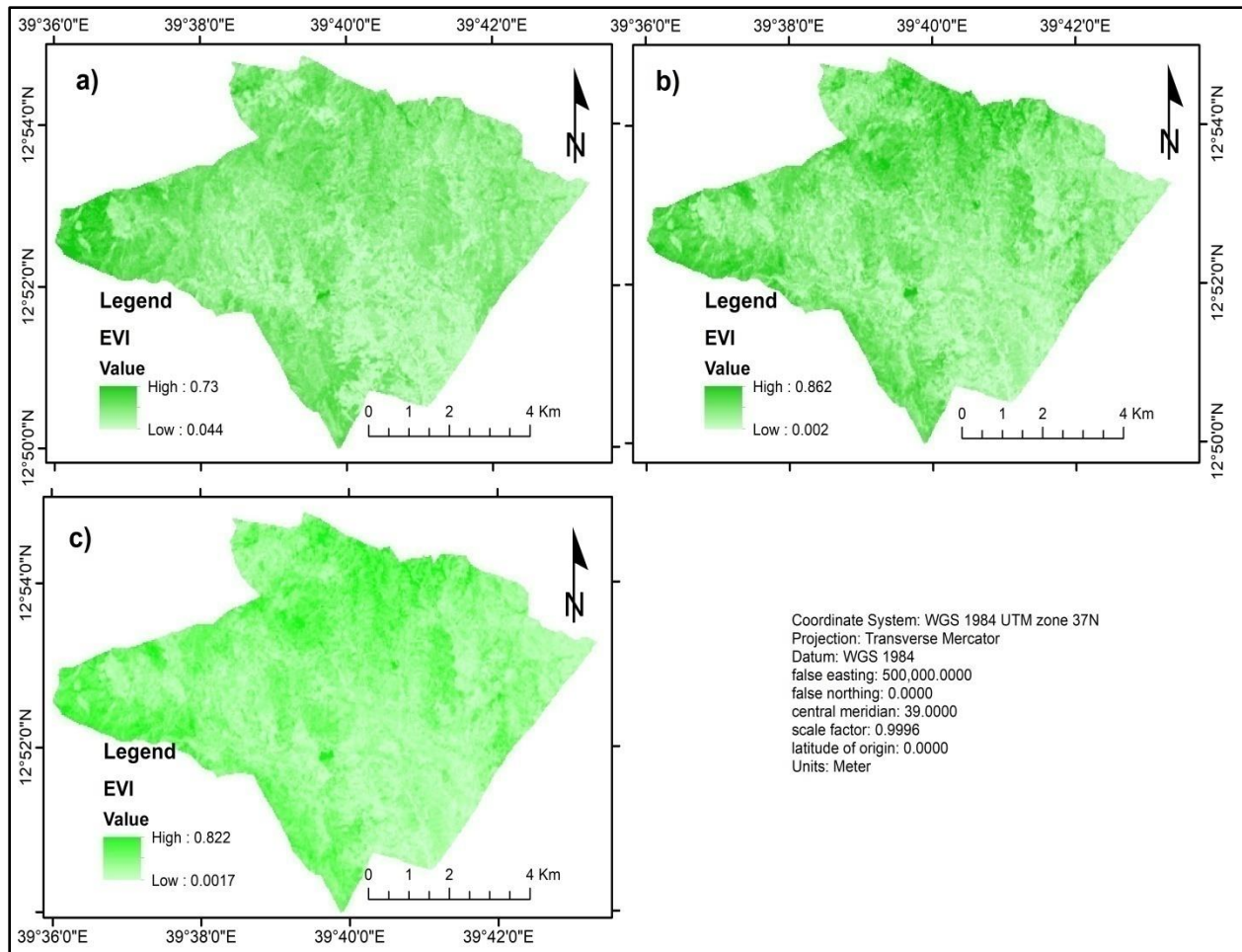


Figure 2. EVI values of Ebo in 2000 a), 2020 b), and 2022 c)

In terms of NDVI reclassification, Ebo Kebele has witnessed a significant positive transformation in vegetation health between 2000 and 2020, though a notable setback occurred in 2022 due to the impact of the war (Figure 5 a-c; Table 4.9). During the initial two decades, the area classified as non-vegetation (with NDVI values ranging from -1 to 0) shrank from 12.41 SqKm (21.84%) in 2000 to 4.24 SqKm (7.46%) by 2020. This represents an improvement of approximately 8.17 SqKm (14.38%) that transitioned from barren or sparsely vegetated land to vegetated areas. The key drivers behind this positive change likely included concerted rehabilitation and afforestation efforts that were ramped up in the period before the outbreak of conflict in the Tigray region. However, these efforts were disrupted after the war, leading to a resurgence of non-vegetated areas, which expanded to 8.09 SqKm (14.25%) by 2022. This regression indicates that some of the previously rehabilitated land was once again subject to degradation, resulting in a significant increase in areas lacking vegetation (Figure 5 a-c; Table 4.9). This finding is consistent with a

study conducted in the vicinity of Mekele city, which also recorded a 2% increase in vegetation from 2000 to 2020, followed by a decline of 5% post-conflict (Hisheet *al.*, 2024).

The category of unhealthy vegetation (NDVI values between 0.01 and 0.30) also demonstrated some changes over this period. In 2000, unhealthy vegetation covered 15.84 SqKm (27.90%) of Ebokebele, but by 2022, this had slightly reduced to 14.56 SqKm (25.64%) (Table 4.9). This reduction in unhealthy vegetation suggests that some areas have transitioned toward healthier vegetation classes over time, reflecting an overall improvement in the ecosystem's condition.

On the other hand, the area classified as moderately healthy vegetation (NDVI range 0.31 to 0.60) experienced a decline from 21.03 SqKm (37.04%) in 2000 to 18.37 SqKm (32.35%) in 2022 (Figure 5a-c; Table 4.9). This shift may be attributed to a portion of the moderately healthy areas evolving into the category of healthy vegetation, as efforts to restore and rehabilitate these landscapes were initially successful before the setback caused by the war. The most remarkable change occurred in the healthy vegetation class (NDVI values from 0.61 to 1.00), which nearly doubled over the study period. In 2000, only 7.51 SqKm (13.23%) of Ebokebele was classified as healthy vegetation. However, by 2022, this figure had surged to 15.77 SqKm (27.76%), particularly in the western and north-central regions of the kebele. This significant increase in the proportion of healthy vegetation reflects notable improvements in vegetation density and overall land health, indicating the success of reforestation and land management practices in the pre-war period. However, the challenges brought on by the conflict in the region underline the need for renewed efforts to sustain and further build upon the gains made in vegetation restoration. The results highlight the delicate balance between human-induced recovery efforts and the vulnerability of ecosystems to political and environmental disruptions.

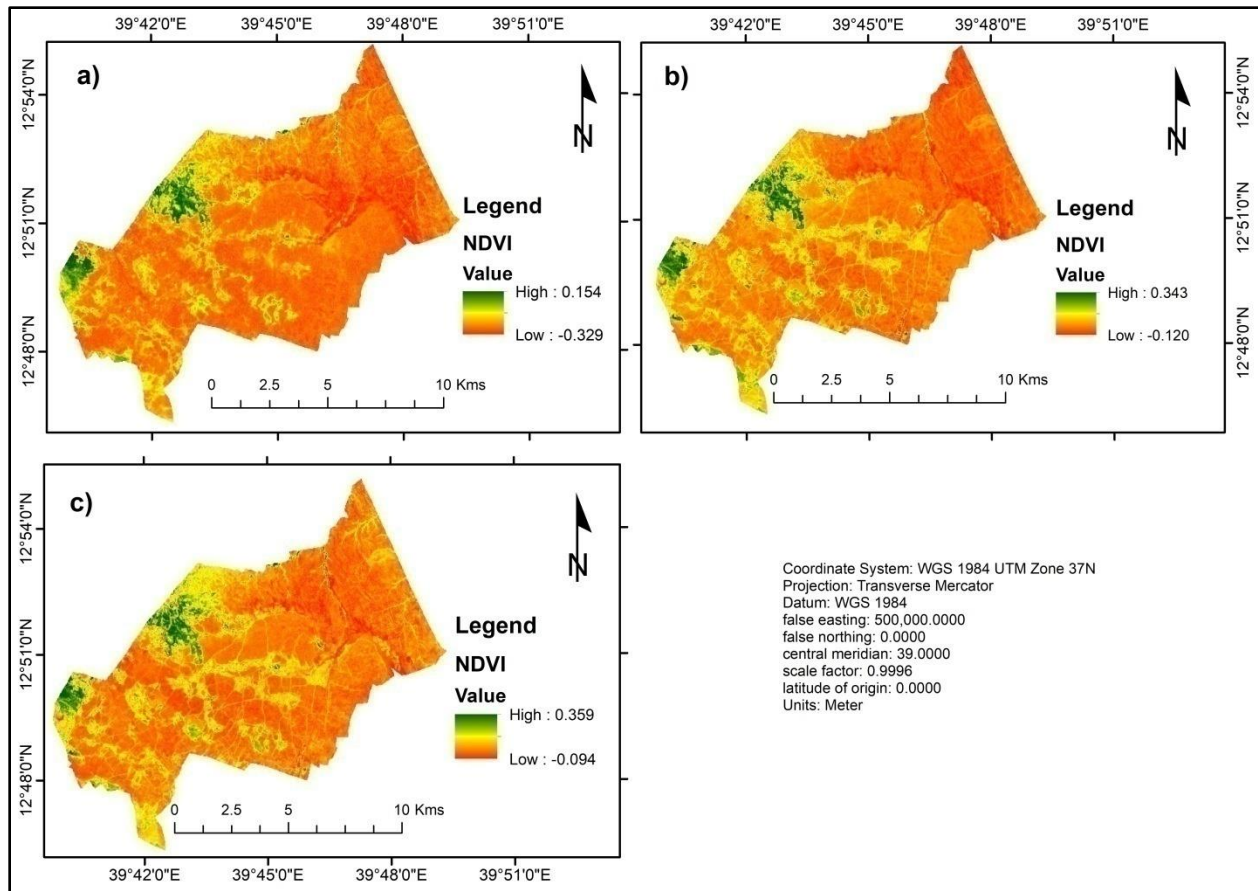


Figure 3 NDVI values of Hawelti in 2000 a), 2020 b), and 2022 c)

In contrast to Ebokebele, Haweltikebele demonstrates a more complex pattern of NDVI class changes between 2000, 2020, and 2022 (Figure 3 a-c; Figures 6 a-c and Table 4.9). The non-vegetation category (NDVI range -1 to 0), representing areas devoid of significant vegetation, covered a vast majority of the land in 2000, with 96.89 SqKm (79.12%) (Table 4.9). By 2020, this decreased significantly to 54.30 SqKm (44.34%), suggesting a substantial recovery in vegetation during this period, likely driven by efforts to rehabilitate degraded lands or favorable climatic conditions. However, by 2022, the non-vegetated area rebounded to 86.97 SqKm (71.02%), reflecting a sharp decline in vegetative cover after the war in the region, which may have disrupted conservation efforts and exacerbated land degradation (Figure 6 a-c; Table 4.9).

The increase in unhealthy vegetation (NDVI range 0.01 to 0.30) is another notable trend in Hawelti Kebele over this period (Figure 3 a-c; Table 4.9). In 2000, this category covered 18.59 SqKm (15.18%) of the kebele, expanding to 43.54 SqKm (35.55%) in 2020—a nearly threefold increase

over two decades. This growth suggests deterioration in vegetation health during this period, possibly due to intensified human activities, land-use changes, or environmental stressors such as soil degradation or water scarcity. By 2022, unhealthy vegetation slightly declined to 27.07 SqKm (22.10%), but it remained significantly higher than in 2000, indicating that vegetation stress persists, even after the slight recovery in 2020. Despite the average value of EVI in the later period, the EVI values have also confirmed that the stress, particularly the moderate healthy vegetation has returned during the postwar in 2022 (Figure 4 a-c).

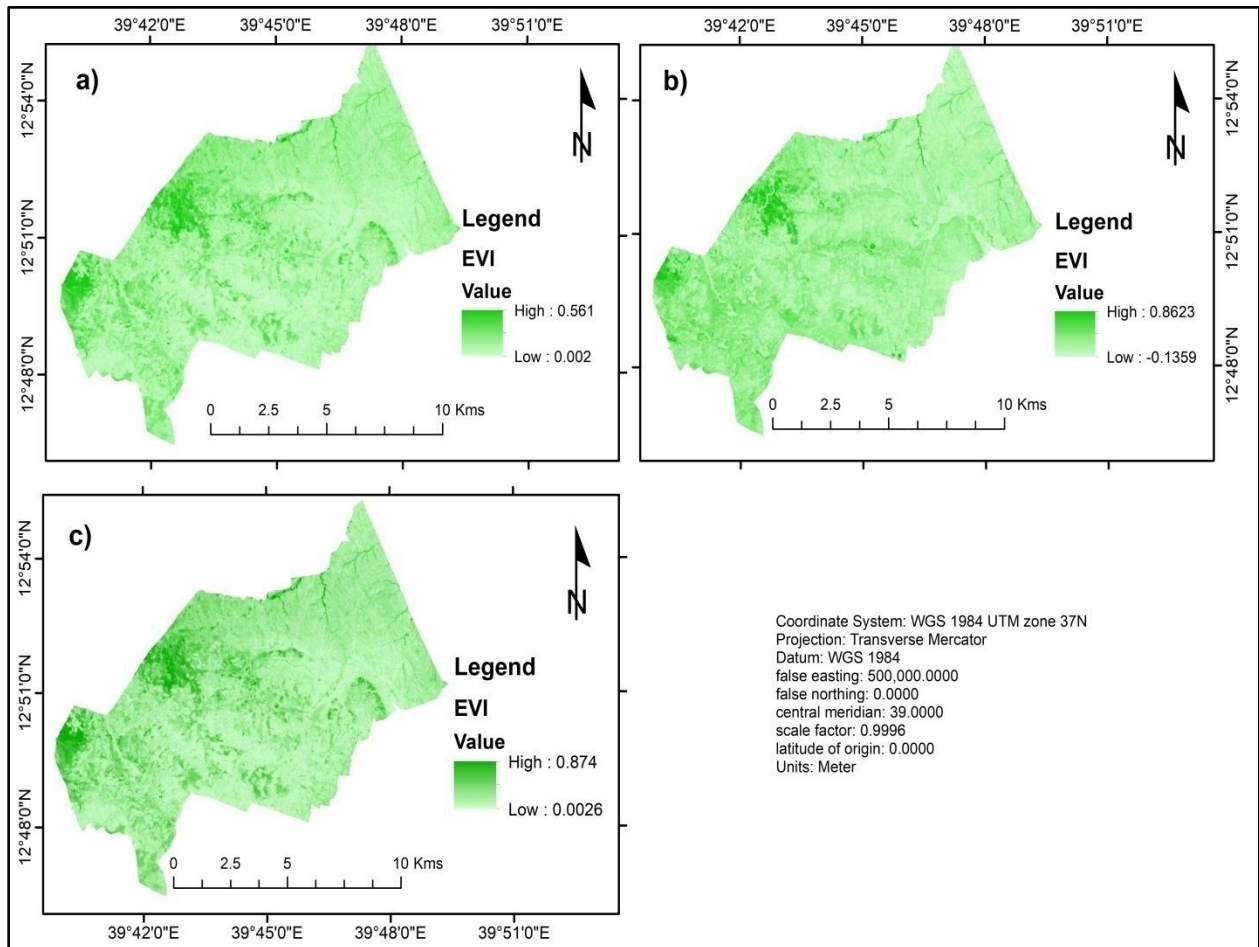


Figure 4 EVI values of Hawelti in 2000 a), 2020 b), and 2022 c)

Moderately healthy vegetation (NDVI range 0.31 to 0.60) experienced a more optimistic trend. In 2000, it occupied only 5.75 SqKm (4.70%) of the land, but by 2020, this figure increased dramatically to 18.15 SqKm (14.82%) (Figure 3 a-c; Table 4.9). This suggests that during this period, some areas of Hawelti saw improvement in vegetation health, likely driven by targeted

reforestation or natural regeneration processes. However, by 2022, this area decreased to 7.15 SqKm (5.84%), signaling a reversal of progress and a shift towards poorer vegetation conditions. The drop between 2020 and 2022 could be attributed to the disruption of ecological rehabilitation efforts due to the war, along with other environmental pressures.

The category of healthy vegetation (NDVI range 0.61 to 1.00), which reflects the areas with the most robust and thriving ecosystems, exhibited significant fluctuations over the study period. In 2000, healthy vegetation covered only 1.23 SqKm (1.00%) of Hawelti (Figure 3 a-c; Table 4.9). By 2020, this increased substantially to 6.46 SqKm (5.27%), showing marked improvement in the health and density of vegetation across parts of the kebele. This growth may have resulted from effective restoration initiatives or favorable environmental conditions during that time. However, by 2022, healthy vegetation sharply declined back to 1.28 SqKm (1.05%), reflecting the devastating impacts of the war and other stressors on the kebele's ability to maintain healthy vegetation.

The data for Haweltikebele highlights a period of significant vegetation recovery by 2020, with marked improvements in the extent of moderately healthy and healthy vegetation and a substantial reduction in non-vegetated areas (Figure 3 a-c; Table 4.9). However, the post-war period saw these gains largely reversed. The dramatic rebound of non-vegetation and the steep decline in healthy vegetation between 2020 and 2022 indicate the destructive effects of the war, which likely disrupted conservation efforts and led to widespread degradation.

The increase in unhealthy vegetation from 2000 to 2020, followed by a slight decline in 2022, signals persistent challenges in maintaining vegetation health despite the overall positive trends seen in 2020 (Figure 3 a-c; Table 4.9). Although some recovery occurred by 2022, much of the vegetative growth seems to have been degraded, likely due to human activities, conflict, and environmental degradation. The fluctuation in moderately healthy and healthy vegetation underscores the fragility of Hawelti's ecosystems. The significant improvement between 2000 and 2020, followed by a steep decline by 2022, reflects how vulnerable these systems are to external shocks, such as political instability, natural disasters, or unsustainable land practices.

The continued presence of unhealthy vegetation highlights ongoing stress on the land, possibly due to factors such as unsustainable agriculture, overgrazing, and deforestation. To reverse this trend and build on the gains made prior to 2020, targeted interventions focused on post-conflict

restoration, sustainable land management, and community-based conservation programs will be essential. The findings suggest that while environmental management and reforestation efforts were effective prior to 2020, the conflict likely disrupted these efforts and led to widespread degradation.

In conclusion, the NDVI analysis for Haweltikebele shows that while significant improvements in vegetation health were achieved by 2020, these gains were largely undone by 2022 due to the impacts of war and other environmental stressors (Figure 3 a-c; Table 4.9). The patterns suggest that the kebele's ecosystems are highly vulnerable to both human-induced and natural disturbances. To prevent further degradation and restore the landscape, it is necessary to implement a coordinated approach that focuses on post-conflict recovery, sustainable land-use practices, and long-term ecological restoration. The findings underscore the importance of maintaining environmental conservation efforts even in times of conflict to protect fragile ecosystems and support community resilience.

#### **4.8 Normalized Difference Vegetation Index (NDVI) transition dynamics between 2000, 2020, and 2022**

The NDVI transition analysis for these two kebeles reveals contrasting trajectories in vegetation health (Figures 5 a-c; Figure 6 a-c; Table 4.10a-c). Ebo kebele shows a clear trend towards improvement, with substantial gains in healthy vegetation and a reduction in non-vegetation and unhealthy vegetation areas. This positive development suggests that ecological restoration efforts or natural vegetation recovery processes have been effective, leading to an overall enhancement in land quality and vegetation health.

##### **4.8.1 NDVI transition dynamics between 2000 and 2020 in Ebo**

The transition period from 2000 to 2020 in Ebo reflects a positive trend in vegetation restoration, largely attributed to effective soil and water conservation strategies (Figure 6 a; Table 4.10a). During this time, the area classified as non-vegetation (Nv) significantly decreased from 12.41 SqKm (21.84%) to 4.24 SqKm (7.46%), with a loss of 8.17 SqKm (Figure 6 a; Table 4.10a). This shift signifies successful conversion of barren land into vegetated areas, driven by concerted rehabilitation efforts that focused on soil water management and land restoration practices. These

efforts are crucial in enhancing soil moisture retention and promoting vegetative growth, leading to an overall improvement in land cover.

The increase in unhealthy vegetation (Uv) from 15.84 SqKm (27.90%) to 29.41 SqKm (51.78%), representing a gain of 13.57 SqKm, indicates a dual trend (Figure 6 a; Table 2a). While the restoration initiatives bolstered some vegetative growth, the rise in Uv suggests that not all areas benefited equally. The increase in unhealthy vegetation may be a consequence of inadequate management in specific regions, where pressures such as overgrazing and unsustainable agricultural practices diminished the health of previously restored areas. Moreover, the transition from moderately healthy vegetation (Mhv) to unhealthy vegetation further emphasizes these challenges, with 10.60 SqKm moving into the lower health category. However, in terms of moderately healthy vegetation, the decrease from 21.03 SqKm (37.04%) to 16.51 SqKm (29.07%) reflects a net loss of 4.52 SqKm, indicating that while some areas improved, others deteriorated. This decline likely corresponds to land management practices that did not align with sustainable conservation methods. The movement of 7.87 SqKm from Mhv to Uv points to an emerging pattern of degradation, raising concerns about the long-term sustainability of vegetation health.

Healthy vegetation (Hv) saw a modest decrease from 7.51 SqKm (13.23%) to 6.63 SqKm (11.68%), a loss of 0.88 SqKm (Figure 6 a; Table 2a). Although the initial efforts resulted in some recovery, the shifting of 3.13 SqKm to moderately healthy vegetation signifies that even areas once classified as healthy experienced stress. As a result, this study period witnessed total gains of 26.83 SqKm balanced by losses of 26.83 SqKm, leading to a net change of 0.00 SqKm. This dynamic suggests that while restoration efforts were evident, significant challenges remained in maintaining healthy ecosystems.

Table 4.10 NDVI transition matrices of Ebo for the study periods (SqKm)

Where Nv is non-vegetation; Uv is unhealthy vegetation; Mhv is moderate health vegetation; Hv is healthy vegetation.

Target areas	Nv	Uv	Mhv	Hv	Total	Losses	Net Change	
<b>2000/2020</b>								
	<b>Nv</b>	<b>3.69</b>	8.56	0.09	0.07	12.41	8.72	-8.17
	<b>Uv</b>	0.50	<b>12.22</b>	2.86	0.25	15.84	3.62	+13.57
	<b>Mhv</b>	0.04	7.87	<b>10.43</b>	2.69	21.03	10.60	-4.52
	<b>Hv</b>	0.00	0.76	3.13	<b>3.62</b>	7.51	3.89	-0.88
	<b>Total</b>	4.24	29.41	16.51	6.63	56.79	26.83	0.00
<b>A</b>	<b>Gains</b>	0.55	17.19	6.08	3.01	26.83		
<b>2020/2022</b>								
	<b>Nv</b>	<b>3.39</b>	0.83	0.01	0.01	4.24	0.85	+3.84
	<b>Uv</b>	4.67	<b>12.92</b>	10.59	1.23	29.41	16.49	-14.84
	<b>Mhv</b>	0.03	0.76	<b>7.16</b>	8.56	16.51	9.35	+1.86
	<b>Hv</b>	0.00	0.05	0.61	<b>5.97</b>	6.63	0.66	+9.14
	<b>Total</b>	8.09	14.56	18.37	15.77	56.79	27.35	0.00
<b>B</b>	<b>Gains</b>	4.70	1.64	11.21	9.80	27.35		
<b>2000/2022</b>								
	<b>Nv</b>	<b>6.76</b>	5.17	0.47	0.0	12.41	5.64	-0.31
	<b>Uv</b>	1.11	<b>7.27</b>	6.67	0.79	15.84	8.57	-1.28
	<b>Mhv</b>	0.20	1.89	<b>9.84</b>	9.10	21.03	11.19	-2.66
	<b>Hv</b>	0.02	0.23	1.39	<b>5.87</b>	7.51	1.64	+8.25
	<b>Total</b>	8.09	14.56	18.37	15.77	56.79	27.04	0.00
<b>C</b>	<b>Gains</b>	1.33	7.29	8.53	9.89	27.04		

### NDVI transition dynamics between 2020 and 2022 in Ebo

The subsequent period from 2020 to 2022 paints a starkly different picture for Ebo's vegetation dynamics, primarily influenced by the ramifications of war and intensified overgrazing (Figure 6b; Table 4.10b). The non-vegetation area (Nv) saw a slight reduction from 8.09 SqKm (14.25%) to 4.24 SqKm (7.46%), reflecting a gain of 3.84 SqKm. Although there were improvements in land cover, this period's overall context is marked by the destructive impacts of conflict, which disrupted previous conservation efforts.

The alarming rise in unhealthy vegetation (Uv), from 14.56 SqKm (25.64%) to 29.41 SqKm (51.78%) again of 14.84 SqKm is indicative of significant environmental degradation (Figure 6b; Table 4.10b). This increase can be attributed to overgrazing exacerbated by the war, leading to the deterioration of vegetation health. The loss of control over land management practices during this tumultuous period likely accelerated the shift from previously healthier states, as evidenced by the 10.59 SqKm transition from moderately healthy vegetation (Mhv) to unhealthy vegetation. The

stresses placed on the land from both conflict and grazing pressures illustrate the fragility of restored areas when faced with such adversities.

Moderately healthy vegetation (Mhv) displayed slight resilience, with a marginal increase from 18.37 SqKm (32.35%) to 16.51 SqKm (29.07%), reflecting a gain of 1.86 SqKm (Figure 6b; Table 4.10b). However, this modest growth should be interpreted cautiously. The fact that 0.76 SqKm transitioned to healthy vegetation suggests localized successes, but these were overshadowed by the overarching trends of decline. Nevertheless, areas close to MahbereBokru (antique monastery in southern Tigray) have started managing the monastery during the postwar that lead increment of healthy vegetation during this period. Therefore, healthy vegetation (Hv) experienced a notable increase from 6.63 SqKm (11.68%) to 15.77 SqKm (27.76%), with a gain of 9.14 SqKm. This growth indicates that, despite the turmoil, some areas managed to recover, likely due to resilient ecological strategies or targeted restoration efforts after the war. The transition of 5.97 SqKm from unhealthy to healthy vegetation demonstrates that recovery is possible when conservation initiatives are prioritized.

During this period, total gains reached 27.35 SqKm, while losses equaled 27.35 SqKm (Figure 6b; Table 4.10b). This balance illustrates that while some areas regained health, the simultaneous rise in unhealthy vegetation emphasizes the ongoing challenges and vulnerabilities facing the ecosystem.

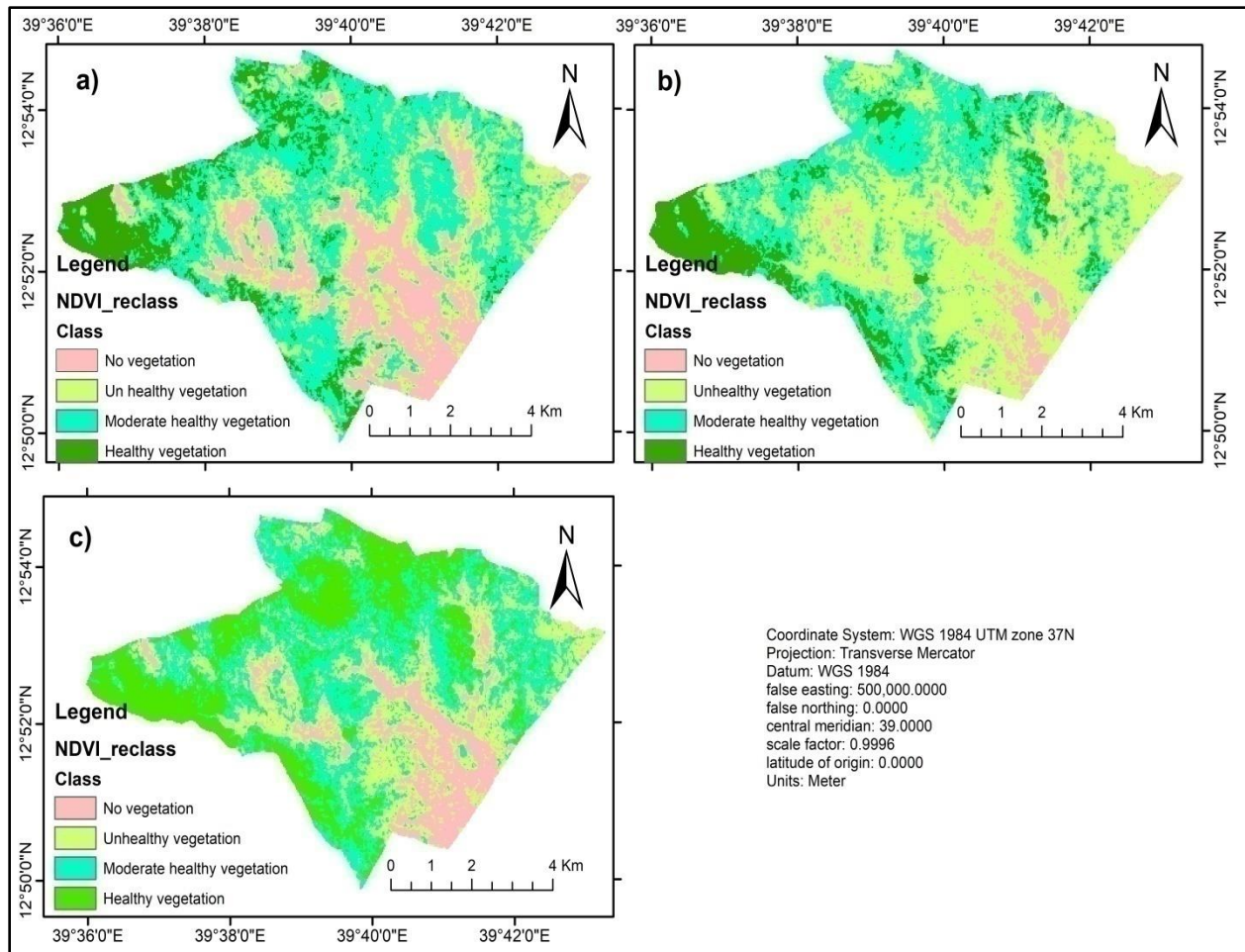


Figure 5 NDVI spatial trends of Ebo in 2000 a), 2020 b), and 2022 c)

### NDVI transition dynamics over the past 22 years (2000 to 2022) in Ebo

The overarching transition dynamics from 2000 to 2022 encapsulate the complex interplay of restoration efforts and the effects of external pressures on Ebo’s ecological health (Figure 6c; Table 4.10c). The reduction in non-vegetation (Nv) from 12.41 SqKm (21.84%) to 6.76 SqKm (11.89%), with a loss of 5.64 SqKm, underscores the effectiveness of earlier soil and water conservation strategies. The transitions from Nv to both unhealthy vegetation and moderately healthy vegetation reveal a mixed success in recovery efforts, highlighting areas where the impacts of conservation were significant.

Conversely, the increase in unhealthy vegetation (Uv) from 15.84 SqKm (27.90%) to 29.41 SqKm (51.78%), a gain of 8.57 SqKm, accentuates the detrimental impacts of conflict and mismanagement (Figure 6c; Table 2c). The transition dynamics from moderately healthy

vegetation to unhealthy vegetation totaling 9.84 SqKm point to areas severely affected by overgrazing and loss of agricultural practices that had previously promoted vegetation health. On the other hand, moderately healthy vegetation (Mhv) exhibited a net loss of 2.66 SqKm, decreasing from 21.03 SqKm (37.04%) to 18.37 SqKm (32.35%). This decline is indicative of the vulnerabilities present in areas that initially thrived under conservation efforts, suggesting that such strategies must be sustained and adapted to local conditions to prevent reversion.

Healthy vegetation (Hv) revealed a significant increase from 7.51 SqKm (13.23%) to 15.77 SqKm (27.76%), with a net gain of 8.25 SqKm (Figure 6c; Table 2c). This positive change, despite the adverse circumstances, highlights the potential for ecological recovery when adequate management practices are implemented. The successful transition of 5.87 SqKm from unhealthy to healthy vegetation illustrates the resilience of ecosystems when supported by effective restoration initiatives.

In conclusion, the NDVI transition dynamics in Ebo from 2000 to 2022 underscore the dual narrative of restoration success amidst environmental challenges (Figure 6c; Table 4.10c). While soil water conservation efforts in the earlier period significantly contributed to vegetation recovery, the subsequent effects of war and overgrazing posed considerable threats to these gains. This highlights the importance of sustainable land management and adaptive strategies to maintain and enhance vegetation health in the face of socio-environmental pressures.

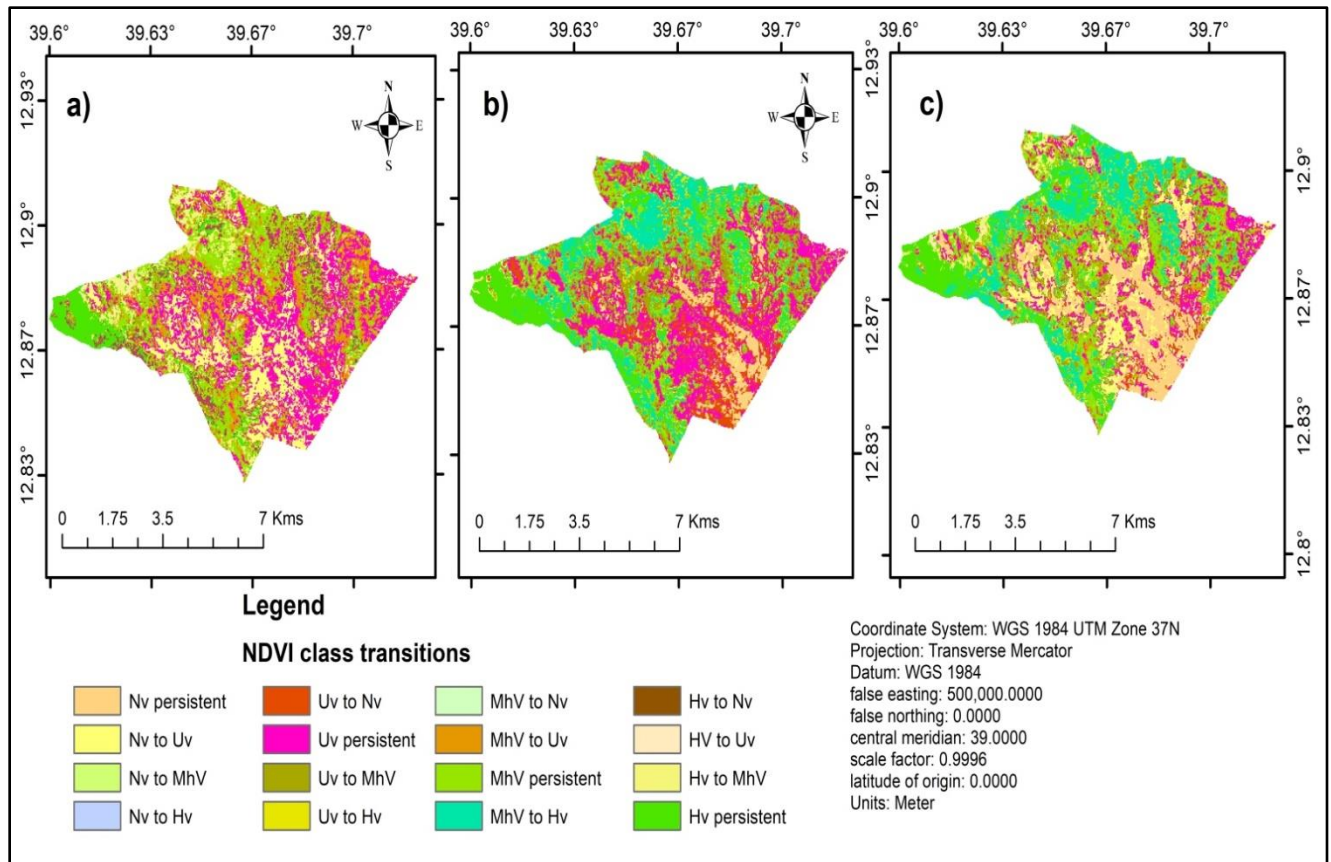


Figure 6 NDVI class transitional dynamics in Ebo between 2000 - 2020 a), 2020 - 2022 b), and 2000 - 2022 c)

### Normalized Difference Vegetation Index (NDVI) Transition Dynamics of HaweltiKebele between 2000, 2020, and 2022

On the other hand, Haweltikebele presents more concerning scenario over the past 22 (post war)(Figures 7 a-c; Figures 8a-c; Table 4.11a-c). Although there has been some reduction in non-vegetation, the corresponding increase in unhealthy vegetation points to ongoing difficulties in achieving sustainable vegetation health. The modest gains in moderately healthy vegetation and the stagnation in healthy vegetation further highlight the challenges faced in this region. These findings suggest that Hawelti Kebele may require targeted interventions, such as improved land management practices, reforestation efforts, or soil restoration, to address the underlying factors contributing to its less favorable vegetation dynamics.

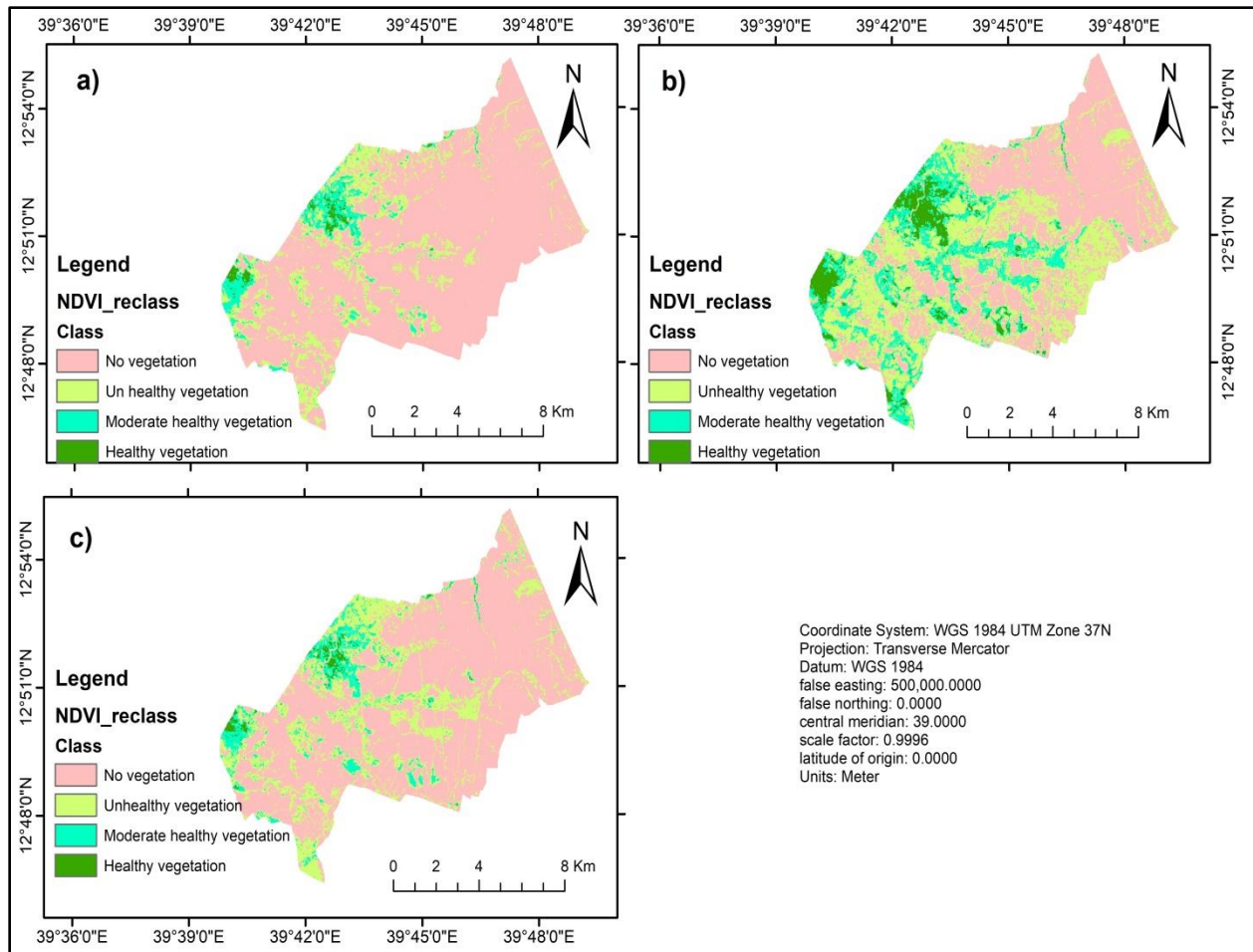


Figure 7 NDVI spatial trends of Hawelti in 2000 a), 2020 b), and 2022 c)

### NDVI Transition Dynamics of Hawelti Kebele between 2000 and 2020

The period from 2000 to 2020 in Haweltikebele illustrates a stark transformation in vegetation dynamics, suggesting various anthropogenic factors and environmental stressors (Figures 7a, b ; Figure 8a; Table 4.11a). The non-vegetation area (Nv) lessened significantly, shrinking from 96.86 SqKm (79.12%) to 54.30 SqKm (44.23%) to equating to a significant loss of 44.62SqKm with the net change of (-42.59 SqKm). This alarming de-escalation in non-vegetated areas highlights the implementation of the efforts of soil and water conservation that many studies in the Tigray highlighted in their findings. Such a shift suggests that forest improvement through excellent land management strategies, have led to widespread vegetation restoration and rehabilitation activities in Hawelti.

In contrast, unhealthy vegetation (Uv) experienced a notable increase from 18.59 SqKm (15.18%) to 43.54 SqKm (35.51%), marking a gain of 24.95 SqKm (Figure 8a; Table 4.11a). This shift reflects increases in vegetation cover although vegetation health across substantial portions of the kebele, is exacerbated by local climate change, overgrazing, soil erosion, and the depletion of soil nutrients. The transition of previously healthy or moderately healthy areas into the Uv category signifies a critical shift in ecosystem stability, emphasizing that the efforts made towards conservation and restoration were insufficient to counterbalance the extensive environmental degradation taking place. Conversely, moderately healthy vegetation (Mhv) displayed an encouraging increase from 5.75 SqKm (4.70%) to 18.15 SqKm (14.81%), with a gain of 12.40 SqKm (Figure 7a; Table 4.11a). This improvement can be attributed to localized soil and water conservation initiatives that aimed to rehabilitate degraded lands during the period of 2000 to 2020. However, while this growth offers a glimmer of hope, it remains overshadowed by the pervasive decline of other vegetation categories following the war in Tigray region.

The category of healthy vegetation (Hv) also saw a modest increase from 1.23 SqKm (1.00%) to 6.46 SqKm (5.27%), resulting in a gain of 5.23 SqKm (Figure 8a; Table 4.11a). This rise indicates that some targeted restoration efforts were successful, likely aided by community engagement and awareness about the importance of preserving healthy ecosystems. Nonetheless, the overall balance of gains and losses during this period was striking; total gains reached 61.42 SqKm, while losses matched this figure. This equilibrium underscores the paradox of localized successes amidst widespread degradation, emphasizing the need for more effective, large-scale interventions.

Table 4.11 NDVI transition matrices of Hawelti for the study periods (SqKm)

Target areas	Nv	Uv	Mhv	Hv	Total	Losses	Net Change	
<b>2000/2020</b>								
	<b>Nv</b>	52.27	37.12	7.27	0.23	96.86	44.62	-42.59
	<b>Uv</b>	1.99	<b>5.86</b>	8.90	1.84	18.59	12.73	+24.95
	<b>Mhv</b>	0.03	0.51	<b>1.85</b>	3.35	5.75	3.90	+12.40
	<b>Hv</b>	0.01	0.05	0.13	<b>1.04</b>	1.23	0.19	+5.23
	<b>Total</b>	54.30	43.54	18.15	6.46	122.46	61.42	-0.01
A	<b>Gains</b>	2.03	37.68	16.30	5.42	61.42		
<b>2020/2022</b>								
	<b>Nv</b>	<b>51.66</b>	2.60	0.05	0.00	54.30	2.64	+32.67
	<b>Uv</b>	32.47	<b>10.67</b>	0.40	0.01	43.54	32.88	-16.48
	<b>Mhv</b>	2.76	12.60	<b>2.72</b>	0.06	18.15	15.42	-11.00
	<b>Hv</b>	0.08	1.20	3.98	<b>1.21</b>	6.46	5.26	-5.19
	<b>Total</b>	86.97	27.07	7.15	1.28	122.46	56.21	0.00
B	<b>Gains</b>	35.31	16.40	4.43	0.07	56.21		
<b>2000/2022</b>								
	<b>Nv</b>	<b>83.6</b>	13.00	0.28	0.01	96.89	13.29	-912
	<b>Uv</b>	3.13	<b>12.56</b>	2.85	0.05	18.59	6.03	+8.48
	<b>Mhv</b>	0.35	1.41	<b>3.46</b>	0.53	5.75	2.29	+1.25
	<b>Hv</b>	0.08	0.1	0.41	<b>0.64</b>	1.23	0.59	-0.02
	<b>Total</b>	86.97	27.07	7.15	1.28	122.46	22.20	0.00
C	<b>Gains</b>	3.56	14.51	3.54	0.59	22.20		

Where Nv is non-vegetation; Uv is unhealthy vegetation; Mhv is moderate health vegetation; Hv is healthy vegetation

## NDVI Transition Dynamics of Hawelti Kebele between 2020 and 2022

The subsequent period from 2020 to 2022 reveals an unsettling continuation of the trends established earlier (Figures 7b, c; Figure8b; Table 4.11b). The non-vegetation area (Nv) experienced a marginal decrease, transitioning from 96.86 SqKm (79.12%) to 54.30 SqKm (44.23%), representing a gain of 32.67 SqKm. However, this seemingly positive trend must be scrutinized in the context of ongoing conflicts and environmental stressors that have disrupted the region's ecological balance. While some areas may have regained vegetative cover, the persistent pressures from overgrazing, land misuse, and the consequences of war continue to impede recovery.

Conversely, unhealthy vegetation (Uv) decreased significantly from 43.54 SqKm (35.51%) to 27.07 SqKm (22.08%), and revealing a gross loss of 32.88SqKm (Figure 8b; Table 3b). This sharp

decrease signifies the persistent stress on the ecosystem, with conflicts leading to the deterioration of previously healthy or moderately healthy landscapes during the war. The notable transition of 12.60SqKm from Mhv to Uv emphasizes the alarming decline in ecosystem health, necessitating urgent interventions to halt this trend and restore ecological balance. Nevertheless, the category of moderately healthy vegetation (Mhv) experienced a worrying decline, shrinking from 18.15 SqKm (14.81%) to 7.15 SqKm (5.83%) particularly to unhealthy vegetation (12.6 SqKm), resulting in net change of -11.00 SqKm (Figure 7b; Table 3b). This decrease further highlights the vulnerability of ecosystems under stress, illustrating that the benefits of past conservation efforts are rapidly eroding in the face of ongoing environmental challenges.

Healthy vegetation (Hv) faced a significant reduced, decreasing from 6.46 SqKm (5.27%) to 1.28 SqKm (1.04%), and reflecting a net loss of 5.19 SqKm, of which 3.98 SqKm to moderately health vegetation (Figure 8b; Table 3b). This drop indicates that even areas previously categorized as healthy are now under threat, necessitating immediate action to protect and enhance these vital ecosystems. This showed how the war had a massive impact on the vegetation cover of the area. Generally, during this period, gains reached 56.21 SqKm, while losses totaled 56.21 SqKm (Figure 8b; Table 3b). This balance indicates that while localized recovery is occurring, the broader context remains precarious due to persistent environmental and societal pressures.

### **NDVI Transition Dynamics of Hawelti Kebele between 2000 and 2022**

Overall the study period, examining the long-term trends from 2000 to 2022 reveals a complex narrative of restoration efforts and ongoing degradation although such efforts decreased after the war (Figure 8c; Table 4.11c). The non-vegetation area (Nv) decreased from 96.89SqKm (79.12%) to 86.97SqKm (71.02%), indicating a net loss of -9.12SqKm. This decrease underscores the conservation and management efforts primarily before the war posed by sustainable land management practices, which resulted good local ecosystems.

Meanwhile, unhealthy vegetation (Uv) exhibited a moderate increase from 18.59 SqKm (15.18%) to 27.07 SqKm (22.08%), with a net gain of +8.48SqKm. This category surged 13 SqKm to non-vegetation category, indicating efforts of afforestation and reforestation campaign such as wide spread of Safety-net program (Figure 8c; Table 4.11c). In other side, however, expansion of unhealthy vegetation highlights the ongoing pressures on the ecosystem, as previously healthy or moderately healthy areas succumb to stressors like overgrazing, land misuse, and the effects of

conflict. The health of the ecosystem continues to deteriorate, necessitating urgent attention and intervention to prevent further decline.

Moderately healthy vegetation (Mhv) remained relatively stable, changing from 5.75 SqKm (4.70%) to 7.15 SqKm (5.83%), representing a slight net gain of +1.25 SqKm (Figure 8c; Table 3c). While some areas displayed resilience, the overall implications suggest a pressing need for consistent conservation efforts to sustain these regions. The persistence of Mhv indicates that localized conservation strategies, when implemented effectively, can yield positive outcomes, but these efforts must be amplified to create broader impact. Yet, healthy vegetation (Hv) experienced negligible fluctuations, with minor changes that indicate the need for enhanced protective measures to preserve these critical areas. The changes in this category from 1.23 SqKm (1.00%) to 1.28 SqKm (1.04%) illustrate that while there are small signs of improvement, the overall health of these ecosystems remains fragile.

Over the past 22 years (2000 to 2022), the NDVI transition dynamics in Haweltikebele reveal a continuous struggle between restoration efforts and persistent degradation following the war (Figure 8c; Table 4.11c). While localized gains were noted, they were overshadowed by broader losses due to conflict, unsustainable land use, and environmental degradation. These findings highlight the urgent need for integrated and sustainable land management strategies that can enhance vegetation health, restore degraded ecosystems, and build resilience against ongoing

pressures.

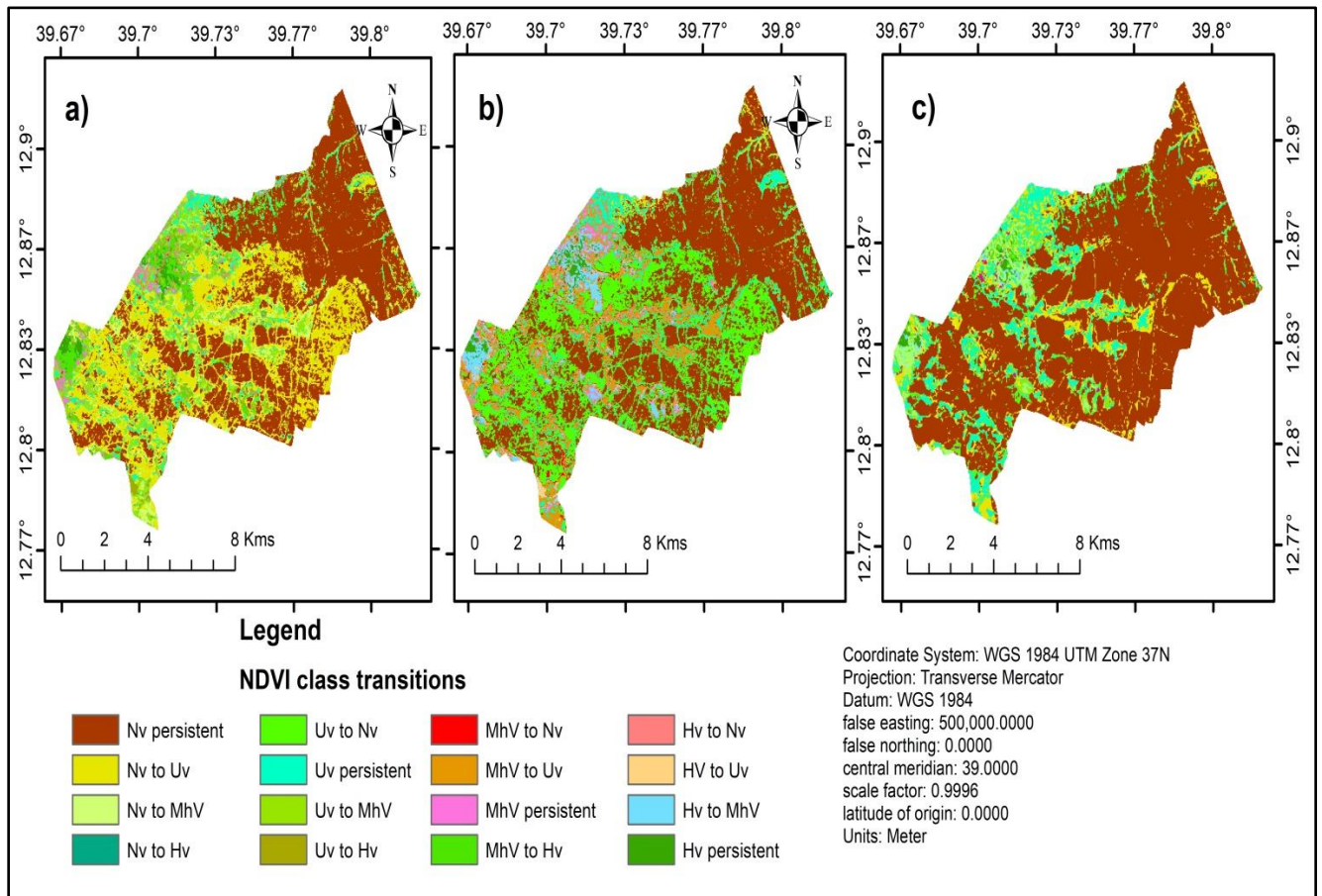


Figure 8 NDVI class transitional dynamics in Hawelti between 2000 - 2020 a), 2020 - 2022 b), and 2000 - 2022 c)

#### 4.9 Accuracy Assessment

The study identified four primary NDVI classes: non-vegetation, unhealthy vegetation, moderate vegetation, and healthy vegetation. For classification validation, historical Google Earth imagery from 2000 and 2020 was utilized alongside GPS points and various satellite images for the 2022 classification (Tables 12, 14). Approximately 800 reference points were collected, of which 30% were allocated for ground truth verification. To evaluate the accuracy of the classified NDVI maps, each year was assessed against reference data, with a contingency table, also known as a confusion matrix, used for reliability assessment.

The resulting confusion matrix (Tables 12, 14) shows overall accuracies of 90.42%, 94.58%, and 97.92% for the NDVI classifications of 2000, 2020, and 2022, respectively, with corresponding Kappa Coefficients (Khat) of 0.87 (87%), 0.93 (93%), and 0.972 (97.2%). This analysis followed

the Kappa method developed by Landis and Koch (1977) and Congalton and Green (2009), where a Kappa value above 0.8 (80%) indicates strong agreement, while values between 0.60 (60%) and 0.80 (80%) indicate substantial agreement between ground truth and classified land cover classes. Thus, the error matrix demonstrates that the classified maps meet the accuracy standards for further NDVI change detection analysis, confirming a positive correlation between classified data and reference data (Anderson *et al.*, 1976).

Table 4.12 Contingency table for the 2000 classification map

		Reference data 2000				Row Total	UA (%)	Comm (%)
		Nv	Uv	Mhv	Hv			
Classified data	Nv	53	3	1	1	58	91.38	8.62
	Uv	1	56	1	2	60	93.33	6.67
	Mhv	0	3	54	2	59	91.53	8.47
	Hv	1	2	6	54	63	85.71	14.29
	Column Total	55	64	62	59	240		
	PA (%)	96.36	87.50	87.10	91.53			
					8.47	<b>K= 0.87</b>		
Omn (%)	3.64	12.5	12.9			<b>OA=90.42%</b>		

NB: For the year of 2000, about 240 sample reference points were collected from the historical Google earth images of 2000 for reference data. OAC = Overall Accuracy, K = Kappa coefficient/index, PA = Producer Accuracy, UA = User Accuracy, Omn = Omission, Comm = Commission.

In the 2000 study period, classification results indicated that the unhealthy vegetation class was relatively well-predicted with 56 points, followed closely by moderate and healthy vegetation classes, each with 54 points out of 60 (Table 4.12). The user's accuracy ranged from 85.71% in the healthy vegetation class to 93.33% in the unhealthy vegetation class, showing that healthy vegetation had the highest commission error. Meanwhile, the moderate vegetation class displayed the greatest omission error. The highest producer accuracy was achieved in the non-vegetation class, whereas the lowest was recorded in the moderate vegetation class, indicating significant omission errors in this category.

By 2020, classification accuracy improved, with healthy vegetation pixels correctly classified in 59 cases, followed by moderate vegetation with 58 pixels. User's accuracy ranged from a low of 91.53% in the non-vegetation class to close to 97% in unhealthy and healthy vegetation classes (Table 4.13). Similarly, producer accuracy in 2020 showed that non-vegetation pixels were

accurately classified, while moderate vegetation had the lowest producer accuracy at 91.8%. Moderate vegetation also recorded the highest commission error at 6.67%, with healthy vegetation showing minimal commission errors at 3.28%. The non-vegetation class had the lowest omission error (3.57%), while moderate vegetation had the highest omission error (8.2%).

Table 4.13 Contingency table for the 2020 classification map

		Reference data 2020						
		Nv	Uv	Mhv	Hv	Row Total	UA (%)	Conn (%)
Classified data	Nv	54	2	2	1	59	91.53	8.47
	Uv	1	58	1	0	60	96.67	3.33
	Mhv	1	1	56	2	60	93.33	6.67
	Hv	0	0	2	59	61	96.72	3.28
	Column Total	56	61	61	62	240		
	PA (%)	96.43	95.08	91.80	95.16			
	Omn (%)	3.57	4.92	8.2	4.84	<b>K= 0.93</b>	<b>OA=94.58%</b>	

NB: For the year of 2020, about 240 sample reference points were used from the historical Google earth images of 2020 for reference data. OAC = Overall Accuracy, K = Kappa coefficient/index, PA = Producer Accuracy, UA = User Accuracy, Omn = Omission, Conn = Commission.

In the most recent study period (2022), both moderate and healthy vegetation pixels were classified with 100% accuracy (Table 4.14). Producer accuracy ranged from a minimum of 96.77% for moderate vegetation to a maximum of 98.36% for healthy vegetation. User accuracy varied, with moderate vegetation having a commission error of 0% and unhealthy vegetation showing a slight error at 5%.

Regarding commission errors, the unhealthy vegetation class recorded the highest addition error (5%), while the moderate vegetation class had no commission errors (0.00%). For omission errors, moderate vegetation had the highest omission error at 1.82%, and healthy vegetation had the lowest omission error at 1.64%. Thus, commission errors ranged from zero in the moderate vegetation class to a maximum in the unhealthy vegetation class, indicating high classification precision for the 2022 period.

Table 4.14 Contingency table for the 2022 classification map

		Reference data 2022						
		<b>Nv</b>	<b>Uv</b>	<b>Mhv</b>	<b>Hv</b>	<b>Row Total</b>	<b>UA (%)</b>	<b>Comn (%)</b>
Classified data	<b>Nv</b>	<b>58</b>	1	0	0	59	98.31	1.69
	<b>Uv</b>	1	<b>57</b>	1	1	60	95.00	5.0
	<b>Mhv</b>	0	0	<b>60</b>	0	60	100.00	0.00
	<b>Hv</b>	0	0	1	<b>60</b>	61	98.36	1.64
	<b>Column Total</b>	59	58	62	61	<b>240</b>		
	<b>PA (%)</b>	98.31	98.28	96.77	98.36			
<b>Omn (%)</b>	1.69	1.82	3.23	1.64	<b>K=0.972</b>	<b>OA= 97.92%</b>		

NB: For the year of 2022, about 240 sample reference points were used from the historical Google earth images of 2022 for reference data. OAC = Overall Accuracy, K = Kappa coefficient/index, PA = Producer Accuracy, UA = User Accuracy, Omn = Omission, Comn = Commission.

## 5. CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

The study identified damage to critical soil and water conservation (SWC) structures, including terraces, bunds, and other infrastructure, caused by war. This damage led to increased soil erosion, reduced water retention, and decreased agricultural productivity, posing significant challenges to soil and water management. The destruction of vegetation, primarily from deforestation for firewood, construction, overgrazing, and military logging, contributed to decreased vegetation cover, reduced access to resources, and heightened vulnerability to natural hazards such as floods, erosion, and decreased soil fertility, which, in turn, severely affected local food security and agricultural livelihoods.

Vegetation loss, primarily from deforestation for firewood and construction, overgrazing, and military logging, has further weakened ecosystem resilience. This decline in vegetation has reduced local communities' access to essential resources, such as fuel wood, construction materials, and livestock forage. Therefore, the socio-economic implications of the damage to SWC structures and vegetation included decreased household incomes, exacerbating economic strain and resource scarcity in the study area.

The war has also taken as many community members experienced stress and trauma related to displacement, economic instability, and the loss of livelihoods. The interplay between psychological distress and environmental challenges has further hampered recovery efforts, limiting individuals' ability to contribute to rebuilding efforts and sustainably manage resources.

The degradation of SWC structures, loss of vegetation, and compromised mental health collectively threaten long-term agricultural productivity, food security, and economic stability. These findings underscore the urgent need for focused interventions on environmental restoration, sustainable agriculture, and in post-war recovery for these communities.

The analysis of the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) for Ebo and Hawelti kebele between 2000, 2020, and 2022 reveals significant shifts in vegetation health over time. Ebo kebele exhibited notable improvements in vegetation health from 2000 to 2020, with healthier vegetation cover and a decline in non-vegetated areas. However, post-war (2022) saw a decline in vegetation health due to decreased efforts.

Conversely, Hawelti kebele showed positive changes pre-war, including decreased non-vegetated areas, but faced challenges post-war with a decrease in unhealthy vegetation. These findings emphasize the dynamic nature of vegetation health, urging tailored management strategies to address local conditions. NDVI values in Ebo ranged from -0.3 to 0.33 in 2000, increased to 0.036 to 0.50 in 2020, and significantly dropped to 0.07 to 0.484 in 2022. This reduction may be attributed to wartime activities like forest cutting. Similarly, the average EVI slightly rose from 0.387 in 2000 to 0.432 in 2020 and decreased marginally to 0.412 in 2022.

## 5.2 Recommendation

Based on the findings of this study, the following recommendations are proposed to address the socio-environmental and economic challenges faced by the communities in Ebo and Hawelti:

1. **Restoration of Soil and Water Conservation (SWC) Structures:** Priority should be given to rebuilding terraces, bunds, and other SWC infrastructure to mitigate soil erosion, improve water retention, and support agricultural productivity. This can be achieved through government and NGO partnerships, local community involvement, and training on SWC practices to ensure long-term maintenance and resilience.
2. **Reforestation and Vegetation Recovery Programs:** To counteract vegetation loss, targeted reforestation initiatives should be implemented; emphasizing native species that support soil health and provide fuel wood, construction materials, and livestock forage. Community-led tree-planting programs could be developed, incorporating sustainable land management practices to prevent overgrazing and uncontrolled logging.
3. **Sustainable Agriculture and Soil Health Management:** Implementing sustainable agricultural practices, such as crop rotation, agro-forestry, and composting, can help maintain soil fertility and improve food security. Community training and resources on sustainable land use and regenerative farming practices will empower residents to restore soil health and improve productivity.
4. **Disaster Risk Reduction (DRR) Initiatives:** Increased vulnerability to floods due to vegetation loss highlights the need for disaster risk reduction efforts. Building flood defenses, restoring wetlands, and promoting water absorption infrastructure can help mitigate disaster risks. Community-based training in disaster preparedness would further strengthen resilience.

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