HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

CONSEQUENCES OF ARMED CONFLICTS ON THE LANDSCAPE, SUMAPAZ PÁRAMO REGION CASE STUDY

DOI: 10.54598/004890

FERNANDO ARTURO MÉNDEZ GARZÓN

Budapest

2024

The PhD School

Name: **Hungarian University of Agriculture and Life Sciences**
Doctoral School of Landscape Architecture and Landscape Ecology

Discipline: Agro-technical science

Head: **Dr. László Bozó**
Professor, DSc, MHAS
MATE University
Institute of Horticultural Science,
Department of Soil Science and Water Management

Supervisor: **Dr. István Valánszki**
Associate professor, PhD
MATE University
Institute of Landscape Architecture, Urban Planning and Garden Art
Department of Landscape Protection and Reclamation

....

Approval of the Head of Doctoral School Approval of the Supervisor

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

- **Areas:** (FPTZ) Forest-Páramo Transition Zone, (PA) Protected Area, (SNP) Sumapaz National Park, and (SPR) *Sumapaz Páramo Region*.
- **Belligerents:** (Army) The National Army of the Republic of Colombia, (AUC) Autodefensas Unidas de Colombia – The United Self-Defense Forces of Colombia, (ELN) Ejército de Liberación Nacional – The National Liberation Army, (FARC) Fuerzas Armadas Revolucionarias de Colombia – The Revolutionary Armed Forces of Colombia.
- **Biome:** (AD) Arid Desert, (AT) Alpine Tundra, (DS) Dry Steppe, (GS) Grass Savanna, (MF) Monsoon Forest / Dry Forest, (MnF) Montane Forest, (MV) Mediterranean Vegetation, (SD) Semiarid Desert, (SDF) Subtropical Dry Forest, (STR) Subtropical Rainforest, (TBF) Temperate Broadleaf Forest, (TR) Tropical Rainforest, (TS) Tree Savanna, (XS) Xeric Shrubland.
- **Cause:** (Ag) Agriculture, (Bo) Bombing, (CR) Cattle Ranching, (Fi) Fires, (FM) Forced Migration, (IC) Illegal Crops, (LM) Landmines, (Lo) Logging, (MC) Military Confrontation / Conflict Intensity, (MI) Military Infrastructure, (Mn) Mining, (NFM) Non-Forced Migration.
- **Consequence:** (AAL) Abandonment of Agricultural Lands, (Cr) Craters, (Df) Deforestation, (Ds) Desertification / Land Degradation, (Fo) Forestation, (LULCC) Land Use – Land Cover Changes, (MI) Military Infrastructure, (Wa) Water Pollution.
- **Departments (Administrative sub-division)**: (AMA) Amazonas, (ANT) Antioquia, (ARA) Arauca, (ATL) Atlántico, (BOG) Bogotá, (BOL) Bolívar, (BOY) Boyacá, (CAL) Caldas, (CAQ) Caquetá, (CAS) Casanare, (CAU) Cauca, (CES) Cesar, (CHO) Chocó, (COR) Córdoba, (CUN) Cundinamarca, (GUA) Guainía, (GUV) Guaviare, (HUI) Huila, (LAG) La Guajira, (MAG) Magdalena, (MET) Meta, (NAR) Nariño, (NSA) Norte de Santander, (PUT) Putumayo, (QUI) Quindío, (RIS) Risaralda, (SAP) San Andrés y Providencia, (SAN) Santander, (SUC) Sucre, (TOL) Tolima, (VAC) Valle del Cauca, (VAU) Vaupés, (VID) Vichada.
- **Ecoregion:** (AV) Apure-Villavicencio, (ChDM) Chocó-Darién Moist, (CM) Caquetá Moist, (CO) Cordillera Oriental, (CVM) Cauca Valley Montane, (GX) Guajira Xeric, (Ll) Llanos, (MUM) Mag-Urabá Moist, (MVD) Magdalena Valley Dry, (NA) Northern Andean, (NP) Northern Paramo, (NWA) Northwestern Andean, (SVD) Sinú Valley Dry.
- **Geographical Scale:** (ha) Hectares, (La) Landscape, (Lo) Local, (m) Meters, (m.a.s.l) Meters Above Sea Level, (Na) National, (NP) National Park, (PA) Protected Areas, (Re) Regional, (m2) Square Meters.
- **Multivariate:** (MSa) Multi-satellite, (MSc) Multi-scale, (MSp) Multispectral, (MSt) Multi-spatial, (MT) Multi-temporal, (MV) Multivariate.
- **Period:** (AC) Armed Conflict, (ACP) Armed Conflict Processes, (Con) Conflict Period, (Neg) Negotiation Period or Truce, (Pre) Pre-conflict Period, (Post) Post-conflict Period.
- **Regions:** (Am) Amazonas, (An) Andes, (Ca) Caribbean, (Or) Orinoquia, (Pa) Pacific.
- **Remote Sensing:** (ATCOR) Atmospheric & Topographic Correction, (EVI) Enhanced Vegetation Index, (IDOS) Improved Dark Object Subtraction, (LULC) Land-Cover Land-Use classification, (MSAVI) Modified Soil-Adjusted Vegetation Index, (NDVI) Normalized Difference Vegetation Index, (TOA) Top of Atmosphere, (TOC) Top of Canopy.
- **Satellite Imagery Sensor:** (ALOS) Advanced Land Observation Satellite, (ALS) Lidar - Airborne Laser Scanning, (AP) Aerial Photo, (ASTER) Advanced Spaceborne Thermal Emission and Reflection Radiometer, (AVHRR) Advanced Very-High-Resolution Radiometer, (CBERS) China–Brazil Earth Resources Satellite, (GE) GeoEye, (GE-VHR) Google Earth Very High Resolution, (IKONOS), (IRS) IRS-1C LISS-III Indian Remote-Sensing Satellite, (KVR-1000) Kometa, (LS1-3) Landsat 1-3 MSS, (LS4-5) Landsat 4-5 TM, (LS7) Landsat 7 ETM+, (LS8) Landsat 8 OLI, (MODIS) Moderate Resolution Imaging Spectroradiometer, (Pl) Pleiades-1A, (QB) Quick Bird II, (RE) Rapid Eye, (Se) Sentinel 2,

(SPOT-5) Satellite Pour l'Observation de la Terre, (VIIRS) Visible Infrared Imaging Radiometer Suite, (WV2) WorldView-2.

- **Variables:** (AA) Airport Activity, (Ac) Accessibility / Ruggedness, (AeS) Aerial Spraying, (AF) Armed Forces Presence, (Ag) Agriculture Crops, (AS) Asylum Seekers, (Bi) Biome, (CC) Cloud Cover, (CE) Manual Coca Eradication, (Cl) Climate, (Co) Conflict Intensity / Fatalities, (CR) Cattle Ranching, (DEM) Digital Elevation Model, (Df) Deforestation / Fragmentation, (Dr) Drought, (EC) Energy Consumption, (EcR) Ecoregion, (Ed) Education, (Ex) Exportations, (Fa) Fauna, (FD) Field Data, (Fi) Fires, (Fl) Flickr Photos, (Go) Governance, (IC) Illegal Crops, (IDP), Internally Displaced Person Rate, (Mn) Mining / Oil, (NL) Night Lights, (PA) Protected Area Boundaries, (PC) Population Change, (PD) Population Density, (Po) Population Size, (Pr) Precipitation, (Ps) Pastures, (Pv) Poverty, (RiD) River Density, (RoD) Road Density, (SH) Shell Hole, (TA) Terrorist Attacks, (Top) Topography, (Tou) Tourist Arrivals, (Ve) Vegetation, (WS) Water Surfaces.
- (N.D) No Data, (N.A.) Not Applicable.

PREFACE: THE LANDSCAPE AS A WITNESS AND MEMORY OF THE WARFARE

Mountains, forests, valleys, plains, lakes, rivers, and nature speak to us. They are not silent witnesses of what we do. In contrast, they are evidence and traces of our passage through the planet. How does landscape tell us about war? The Landscape resembles a canvas, constantly changing, as if repeatedly painted in an eternal artistic session. Landscape as a concept differs based on the definition of human perception; it absorbs, reflects, and mutates not only with the dynamics of nature, but is constantly altered by human activities. What does Landscape Show us about Armed Conflicts? How is the concept of landscape related to human activities such as war? What role does landscape play in the war? Is it only a scenario in which conflicts occur? Is it an active victim of war? Is it a war spoil? Is it even an indirect beneficiary of war activities? These questions motivated this study.

Landscapes are guardians of the memory of armed conflict and tell us the story of what we did, what we do, and even what we can do. This research seeks to put the landscape at the center of the discussion and define its relationship with one of the longest-lived, recurring, and dramatic human activities: warfare. Based on the literature review, analysis, and evaluation, I seek to understand what has happened in Colombian landscapes and, from there, build a memory of the relationship between nature and society.

Jorge Bela, ***Sumapaz: El Paraíso Empieza en Bogotá, El chivo Benedito, con Sumapaz al fondo*** 2012. (Source: http://www.quepenaconusted.com/2012/11/sumapaz-el-paraiso-empieza-en-bogota.html)

Unlike other related research, where the focus has been placed on human beings, this dissertation has a scientific approach to the environment, precisely to the consequences on the landscape. I approached it from fields of knowledge such as landscape ecology and landscape architecture. I address a theoretical debate around landscape, armed conflict, causes, consequences, and triggers. I seek to find traces of war in the environment, showing reflections that allow us to improve our understanding of the landscape as a holistic concept that is constantly changing and sensitive to our actions and perceptions.

I approached the Landscape of *Sumapaz Páramo* in Colombia as a study area from two perspectives to conduct a comprehensive and integral investigation. First, I carried out an objective remote sensing analysis based on satellite imagery. Second, I developed a subjective approach based on fieldwork in local communities. The sum of the two approaches allowed me to generate a comprehensive and conclusive diagnosis of the relationship between the landscape and armed conflict. It is relevant to clarify that landscapes are based on human perceptions. Landscapes therefore constitute a sensitive experience. Therefore, I sought to provide living testimony from surveys, cartographies, and stories of the local population.

I hope the research helps to understand the role of the landscape and the environment as victims of armed conflict. This research seeks to show the landscape more than just the stage where armed conflicts occur. The Landscape includes interaction, dynamism, conflict, and relationships. Through the explicit narration, it helps us understand the causes and events of the armed conflict and, through its restoration, helps to repair the victims, where the environment undoubtedly has a differential and transcendental role in post-conflict processes.

1

1. INTRODUCTION

1.1. Research background

1.1.1. Armed conflict and environment

The complex relationship between warfare and the environment has been studied relatively little; one exception is the Report on Protection of the Natural Environment in Armed Conflict made by the International Law and Policy Institute ILPI (2014). This report shows that war may significantly damage the environment and populations dependent on natural resources. Attacks directly and indirectly harm animals, vegetation, soil, and water systems, consequently affecting local, regional, and even national ecosystems. Combatants also utilize vast defoliation campaigns to achieve strategic dominance. Meanwhile, severe contamination may incidentally result from attacks on industrial sites, oil wells, or other infrastructure (Le Billon, 2001; Hanson *et al.*, 2009; Gorsevski *et al.*, 2012; Potapov *et al.*, 2012; ILPI, 2014; Jha, 2014; Butsic *et al.*, 2015; Murad and Pearse, 2018). Secondary consequences, such as forced displacement, may, in turn, take a higher toll on the natural environment (Sanchez-Cuervo and Aide, 2013; Leiterer *et al.*, 2018). In some cases, the environmental impacts of warfare extend over large regions and continue for years or perhaps decades after the conflict finishes (*Figure 1.1*).

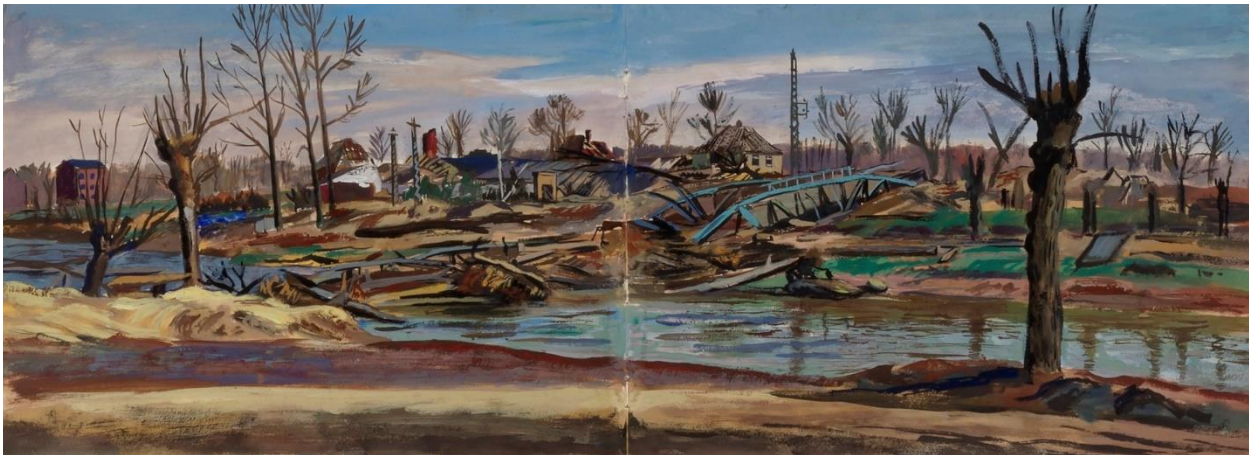


Figure 1.1: Harry Dix, ***War Landscape***, ca. 1940-1949, gouache and pencil on paper. (Source: Smithsonian American Art Museum, Bequest of Olin Dows, 1983.90.33)

Empirical investigations, such as the ILPI (2014), suggest a complex and sometimes even paradoxical link between warfare and forest conservation (Draulans and Van Krunkelsven, 2002; Armenteras *et al.*, 2006; Rustad *et al.*, 2008; Gorsevski *et al.*, 2012). Armed conflict has historically been a minorly studied driver of deforestation (Machlis and Hanson, 2011; Butsic *et al.*, 2015). However, this trend has changed over the last two decades, and this type of study has increased significantly, mostly in tropical forests worldwide (Geist and Lambin, 2002; Hecht and Saatchi, 2007; Gorsevski *et al.*, 2012).

The appraisal of the implications of warfare on the environment is incredibly challenging because of the endogenous nature of vegetation cover loss and land-use changes. Warfare is also the outcome and/or the reason behind deforestation, implying a close, unique, and particular relation. Neglecting this particularity in deforestation models can produce biased coefficients and standard errors, thus constraining our ability to determine the causal structure between warfare and deforestation within a statistical framework (Blackman, 2013; Butsic *et al.*, 2015).

According to Ordway (2015), during periods of war and post-conflict, the landscape can be altered, and deforestation increases. In addition, conflicts can directly influence land-use and land-cover activities. Land-use changes have promoted the devastating deterioration in biodiversity through habitat dissolution, modification and destruction, resulting in the decline of ecosystems and environmental services (Kwarteng, 1998; Qamer *et al.*, 2012; Jha, 2014; Nackoney *et al.*, 2014; Ordway, 2015). Some assessments have shown that conflict and warfare not only can stimulate deforestation but on the contrary as well promote vegetation cover recovery (Biswas and H. Cecilia Tortajada-Quiroz, 1996; Lodhi, Echavarria and Keithley, 1998; Dávalos, 2001; McNeely, 2003; Álvarez, 2003; Hecht and Saatchi, 2007).

1.1.2. Colombian armed conflict and environment

The internal armed conflict between the guerrilla, paramilitary groups, and government has determined Colombian recent history and has been extending for over 60 years. Since the 80s, the conflict has been reinforced and funded by the emergence of illicit activities such as drug trafficking, illegal mining, and extensive logging, making the conflict even more harmful to socioeconomic and political stability and environmental conservation.

The armed conflict has generated profound changes in society, economic production systems and land use, which in addition have modified rural and urban landscapes in a significant way (Rettberg, Leiteritz and Nasi, 2014; Arias, Ibáñez and Zambrano, 2019; Garcia Corrales, Avila and Gutierrez, 2019; Negret *et al.*, 2019). (*Figure 1.2*).

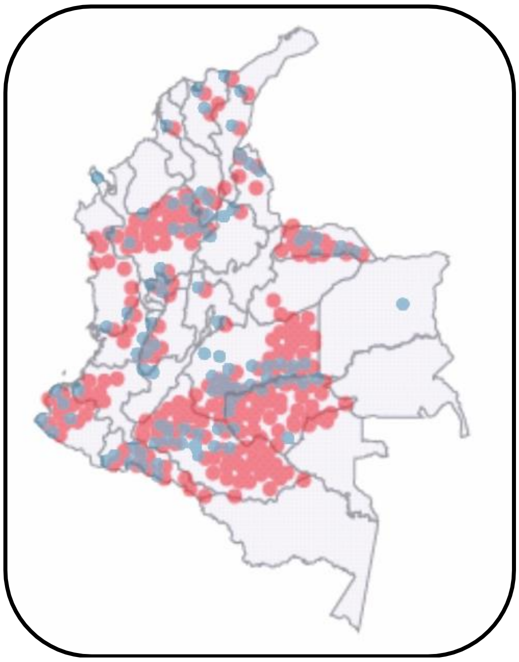


Figure 1.2: Influence of the conflict and deforestation spots.
Red dots; Areas under high influence of the Conflict. *Blue dots;* Deforestation spots.
Source: (Calderón Díaz *et al.*, 2016)

These consequences have sometimes been paradoxical. During periods of high military activity, the conflict has inadvertently encouraged preserved areas due to land mines or intense disputes over strategic territories, mainly in Orinoquia and the Amazon foothills (Clerici *et al.*, 2020; Murillo-Sandoval *et al.*, 2020, 2023) (*Figure 1.2*). Contrarily, in several regions, post-agreement activities have increased the pressure on ecosystems, driving deforestation and land cover changes, mostly in fragile ecosystems such as the Amazon Rainforest, where the presence of the government has been scarce or non-existent and where the guerrilla had a strong influence (Dávalos, 2001; Armenteras, Gast and Villareal, 2003; Armenteras *et al.*, 2006, 2011; Rincón Ruiz *et al.*, 2013; Landholm, Pradhan and Kropp, 2019).

Armed conflict has had varied consequences for Colombian ecosystems. The effects on tropical forests of the Amazon have not been the same in intensity or type as in the paramos, desert, or Andes Mountains. Throughout the development of armed conflict, few ecosystems have not been directly or indirectly affected (Calderón Díaz *et al.,* 2016).

1.2. Research relevance

Currently, the world is experiencing strong geopolitical changes. Therefore, warfare and conflicts have been at their highest levels in number and intensity since World War II. Warfare has played an increasingly relevant part in altering the main social and environmental systems at multiple spatial and temporal scales. Increasing resource flow and environmental changes have led to intercrossing with increasingly violent conflicts in considerably yet poorly understood ways.
Warfare has long occurred in conservation priority areas with significant environmental repercussions. Within the last few decades, 80% of armed conflicts have occurred in biodiversity hotspots, many of which are rainforest areas (Hanson *et al.*, 2009).

In the Colombian case, several types of research have been dedicated to understanding the ethical, socio-economic, and political consequences of armed conflict; however, environmental impacts have received less attention. The end of the conflict has brought several opportunities to analyze the environment from a scientific approach, place the landscape at the center of the discussion, and define it as a live memory and silent victim of the conflict. Given the importance of paramo as an ecosystem service provider, it is necessary to understand the correlation between armed conflict and the landscape in the Sumapaz region. There are no specific studies on the repercussions of armed conflict in the landscape within the *Sumapaz Páramo* limits, which generates a gap in the knowledge field and an opportunity for the academy to approach the topic (Armenteras *et al.*, 2013; Moreno-Rodríguez and Díaz-Melo, 2018; Prem, Saavedra and Vargas, 2020). Additionally, the discussion of the challenges in the post-agreement era from the landscaping point of view has gained high relevance in contributing to the peace and environmental restoration processes led by local communities and local authorities (Moreno-Rodríguez and Díaz-Melo, 2018; Jurisdicción Especial Para la Paz, 2022).

1.3. Research aims and objectives

First Stage. Worldwide case studies.

Aim 1. Review and assess how the relationship between armed conflicts/warfare and the landscape has been analyzed and studied worldwide.

Ob1.1. To review how, where, and when the link between armed conflict/warfare and landscape has been approached scientifically.

Ob1.2. To identify and link the assessment approaches and methods used to analyze the relationship between armed conflict and the landscape.

Ob1.3. To identify and link armed conflict causes with consequences in the landscape.

Second Stage. Colombian case studies.

Aim 2. Review and assess historically how has been analyzed and studied the consequences of the Colombian armed conflict in the landscape to understand, describe, and relate the links between the methods and results.

Ob2.1. To identify when, where, and how (department and ecoregion) the environmental and landscape changes caused by Colombian armed conflict have occurred.

Ob2.2. To identify and link Colombian armed conflict-derived causes with landscape changes (consequences) and the methods used.

Third Stage. Sumapaz Páramo Region case study; Vegetation disturbance and landscape changes.

Aim 3. Identify and relate forest disturbances with armed conflict causes in the *Sumapaz Páramo Region* during armed conflict periods.

Ob3.1. To identify, analyze, compare, and assess forest disturbances during armed conflict periods in the *Sumapaz Páramo Region* (study area) and the *Forest-Páramo Transition Zone* (buffer area).

Ob3.2. To Identify, analyze, compare, and assess the impact levels among various spatial units within the protected and non-protected areas of the *Sumapaz Páramo Region* and Sumapaz National Park based on vegetation disturbances during armed conflict periods.

Ob3.3. To determine the landscape impact levels among armed conflict intensity units (causes) and their relationship with vegetation disturbances (consequences) during armed conflict periods in the *Sumapaz Páramo Region*.

Ob3.4. To identify landscape impact levels in terms of vegetation disturbances (consequences) concerning the proximity to the military road network and military infrastructure (causes) during armed conflict periods in the *Sumapaz Páramo Region*.

Fourth Stage. Sumapaz Páramo Region case study; Local communities' armed conflict-landscape perception.

Aim 4. Collect, identify, and assess the perception of local communities about the landscape in the *Sumapaz Páramo Region* and the influence of armed conflict processes on it.

Ob4.1. To identify and analyze the local community's perceptions of the paramo's landscape values, conservation status, and their relationship to the armed conflict processes in the *Sumapaz Páramo*.

Ob4.2. To identify and analyze the local communities' perceptions of the relationship between landscape changes and belligerent forces and the causes derived from the armed conflict processes in the *Sumapaz Páramo Region*.

1.4. Research questions and hypotheses

First Stage. Worldwide case studies.

General Research Question 1. ***How has the relationship between armed conflict processes and landscape changes been approached and assessed worldwide?***

RQ1.1. What is the relationship between armed conflict/warfare features and the consequences on the landscape with geographical location and type of biome worldwide?

Hp1.1. Armed conflicts occur more frequently in tropical areas that are rich in biodiversity, especially in equatorial-near zones than in torrid zones. Over time, warfare can cause damage to and degradation of the environment, including forest cover, land cover, water surfaces, and biodiversity. However, it is also possible that armed conflict may inadvertently lead to conservation efforts, at least in the short-term.

RQ1.2. What are the primary landscape changes generated by warfare and how have they been assessed worldwide in terms of direct and indirect?

Hp1.2. The main causes of armed conflict in the landscape are direct drivers, such as bombing and landmines, and indirect drivers, such as forced migration and agriculture. The principal consequences of these conflicts are land use changes and deforestation. Satellite imagery analysis is the most effective method for addressing armed conflict landscapes, utilizing color bands, such as NDVI and NDWI, which provide accurate and suitable results. However, other remote sensing approaches such as SAR, LiDAR, nighttime light satellite imagery, and aerial photos (drones) are less commonly employed.

Second Stage. Colombian case studies.

General Research Question 2. ***How has the relationship between Colombian armed conflict processes and landscape changes been approached and assessed?***

RQ2.1. What are the primary landscape changes generated by the Colombian armed conflict and how have they been assessed concerning direct and indirect causes?

Hp2.1. The primary drivers of landscape changes caused by armed conflict in Colombia are indirect causes, such as the cultivation of coca crops, illegal mining, and forced migration. Direct drivers, such as bombings and military confrontations, have been less studied. Remote sensing methods have been used to assess the impact of armed conflict on the landscape in Colombia, with satellite imagery analysis being the most common approach. Landsat 7 ETM+ and Sentinel 2 datasets are the most frequently used satellite imagery in Colombia. However, in situ assessments, radar detection, and drone plot imagery have not been frequently employed.

Third Stage. Sumapaz Páramo Region case study; Vegetation disturbance and landscape changes.

General Research Question 3. *What has been the relationship between forest disturbances (consequences) and armed conflict processes (causes) during the high-intensity conflict period, negotiation, and post-agreement periods in the Sumapaz Páramo Region?*

RQ3.1 What has been the forest disturbance that occurred from 2001 to 2020 during armed conflict periods in the *Sumapaz Páramo Region* and the *Forest-Páramo Transition Zone*, and how has its geospatial distribution?

Hp3.1 The rates of deforestation and forest disturbance have decreased since the 2016 peace agreement, in part because of reduced conflict intensity and a larger state presence in the area. The region experiences a higher proportion of vegetation disturbance in lower altitude ecosystems (FPTZ >2900 m.a.s.l 5 km buffer) compared to the paramo ecosystem (SPR) due to denser vegetation cover and higher population density at its borders.

RQ3.2. What are the differences in impact levels among various spatial units of the *Sumapaz Páramo Region* and Sumapaz National Park based on vegetation disturbances during armed conflict periods?

Hp3.2. The effectiveness of Sumapaz National Park in preserving the landscape was found to be moderate compared with the area adjacent to Paramo, which did not cover the protected area. The latter area experienced more significant alterations due to ongoing warlike actions, which persisted during periods of war, negotiation, and after the agreement, irrespective of the park's boundaries. Although the total disturbed areas showed slight to moderate changes, the quality of the landscape was significantly impacted and varied over time owing to the fragility and vulnerability of the Paramo ecosystem.

RQ3.3. What are the differences in landscape impact levels among armed conflict intensity units (causes) and their relationship with vegetation disturbances (consequences) during armed conflict periods in the *Sumapaz Páramo Region*?

Hp3.3. The area is particularly susceptible to fluctuations in conflict levels and there is a clear correlation between the number of cases, victims, and disrupted land. During the periods of heightened conflict from 2001-2003 and 2006-2010, there was a marked increase in forest disturbance. However, since the 2016 Peace Agreement, the deforestation and forest disruption rates have declined. This can be partly attributed to more stringent environmental controls and the cessation of new military infrastructure development. Furthermore, a reduction in conflict triggers such as bombing and landmines has also contributed to this decrease.

RQ3.4. What are the landscape impact levels in terms of vegetation disturbances (consequences) concerning the proximity to the military road network and military infrastructure (causes) during armed conflict periods in the *Sumapaz Páramo Region*?

Hp3.4. During the development of the high-intensity conflict period (2000-2012), landscape changes (vegetation disturbance) were significant in the study area in proximity to the roads and military infrastructure built by the belligerent forces (Army or FARC). For instance, vegetation cover (Espeletia sp.) has been transformed into built areas and military infrastructure. After the peace agreement (2016-2020), consequences caused by direct drivers, such as military infrastructure and military road networks, have decreased disturbances and modifications in land use and land cover.

Fourth Stage. Sumapaz Páramo Region case study; Local communities' armed conflict-landscape perception.

General Research Question 4. ***What has been the perception of local communities about the relationship between armed conflict and the landscape of the Sumapaz Páramo Region?***

RQ4.1. What are the local community's perceptions of the paramo's landscape values, conservation status, and their relationship to the armed conflict processes in the *Sumapaz Páramo*?

Hp4.1. Local communities held a positive view of the current conservation status of the landscape after the war. However, they also experienced negative impacts during the conflict. They believe that external factors, such as large landowners and uncontrolled tourism, can potentially harm the ecosystem services provided by the paramo to local communities. Nevertheless, there has been an improvement in their perception of the landscape and the services it provides since the peace agreement and the FARC guerrilla retirement. Local communities have a strong aversion to military presence, as they perceive it to influence directly landscape preservation. The lingering effects of past conflict continue to influence conservation strategies.

1.5. Research approaches and stages

This study examined the relationship between landscape and armed conflict using three scales. (I) Worldwide (global case studies): The impact of armed conflicts on the environment from 1994 to the present. (II) National (Colombian case studies): Analysis of Colombian armed conflict and its environmental consequences. (III) Local-regional (*Sumapaz Páramo Region* case study): examination of forest disturbances in the *Sumapaz Páramo Region* and their connection to Colombian armed conflict over the past 20 years. (*Figure 1.3*).

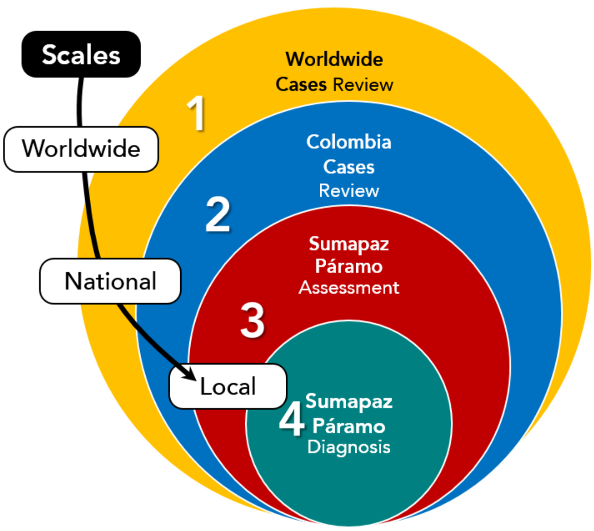


Figure 1.3: Dissertation's approaches. (Source: Own figure)

1.6. Dissertation structure

The dissertation is compounded into six chapters (*Figure 1.4*).

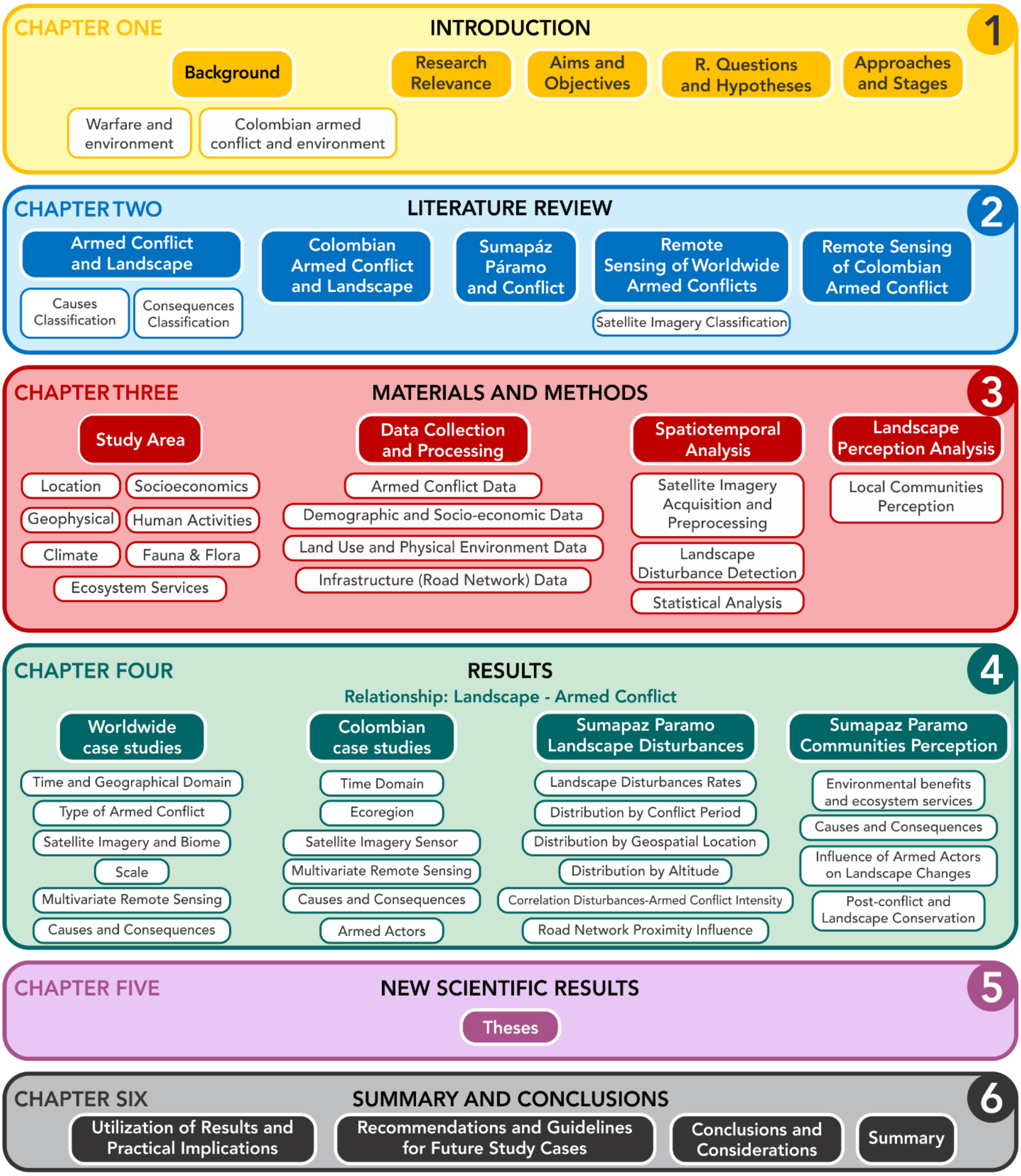


Figure 1.4: Dissertation structure. (Source: Own figure)

2

2. LITERATURE REVIEW

2.1. Armed conflicts in the last 50 years

Armed conflicts have been constant throughout the history of humanity; however, since the Second World War, the international community has made great efforts to prevent large-scale armed conflicts. Despite these efforts, armed conflicts persist, and nowadays, they are still present on four of the five continents. The proof of this is the armed conflict after the Russian invasion of Ukraine, which has emerged as the biggest threat to continental and even global stability since the end of the Cold War.

According to the Stockholm International Peace Research Institute and Uppsala Conflict Data Program, contemporary armed conflicts often involve regular armies, mercenaries, militias, and civilians. Large-scale state conflicts occasionally occur on defined battlefields, but most fighting is sporadic with varying intensities and intermittent truces. Conflict durations differ widely, from weeks (e.g., the Azerbaijan-Armenia Conflict of 2022) to decades (e.g., the Colombian armed conflict). The Stockholm International Peace Research Institute (2019) reported 68.5 million forcibly displaced people globally at the start of 2018, including over 25 million refugees. This number has significantly increased owing to ongoing or newly started conflicts in Ukraine, Afghanistan, Gaza, Yemen, and Syria (*Figure 2.1*). The characteristics of the studied armed conflicts are presented in detailed in *Appendix 9*.

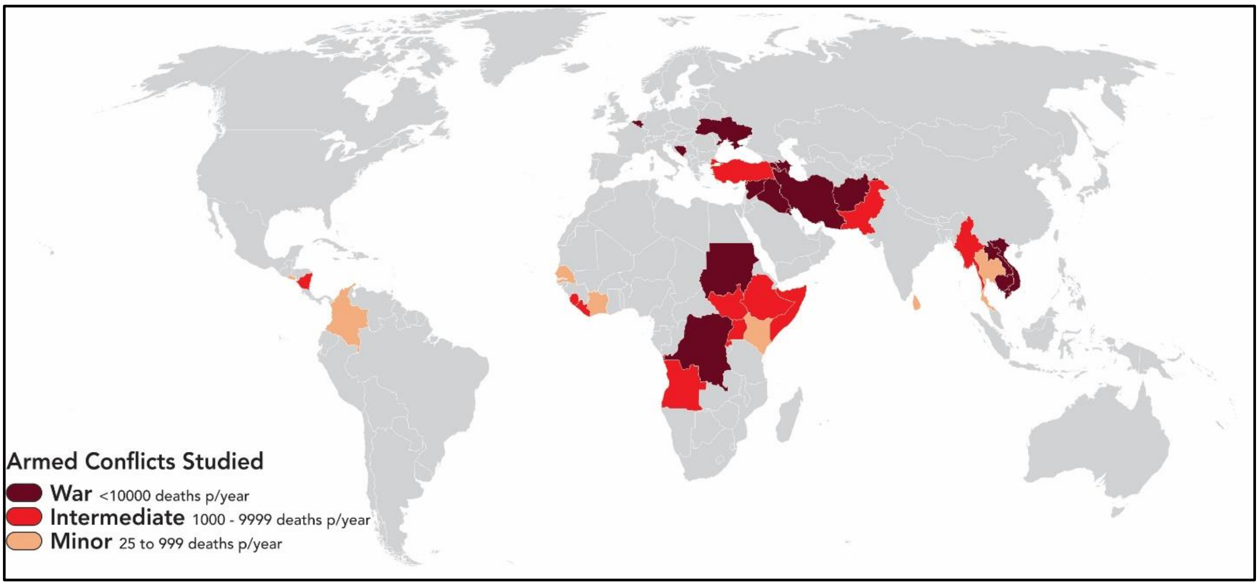


Figure 2.1: Location of studied Armed Conflicts. (Source: Own figure)

Americas

Some of the countries with the highest rates of violence in the world are found in the Americas, such as Honduras, El Salvador, and Mexico, mainly due to clashes between gangs and disputes between drug cartels; however, the Colombian armed conflict is the only one active in the region. Despite the peace process signed with the main guerrilla group, the FARC, in 2016, insecurity and instability persisted on a lesser scale in the country due to the presence of other guerrilla groups such as the ELN, FARC dissidents, and other organized criminals. In Nicaragua, political unrest and violence left over from the Sandinista Revolution of the 1970s and the 1980s are notorious. Other countries, such as Ecuador, Peru, and Brazil, present political violence with riots and confrontations that could destabilize democracy in the region. Finally, although the indices show a reduction in violence in Venezuela, the humanitarian crisis persists, including a large outflow of refugees.

Asia (Far East and Middle East)

In the latter half of the 20th century and the early 21st century, Asia experienced numerous armed conflicts, especially in Afghanistan, India, Indonesia, Myanmar, Pakistan, Sri Lanka, Vietnam, Cambodia, the Philippines, Thailand, and the Middle East. The Indochinese Peninsula was particularly violent in the 1960s and the 1970s due to Cambodia, Laos, and Vietnam's independence wars, prompting direct intervention by France and the United States. Afghanistan remains the most violent area, with persistent conflicts and brief periods of peace. The war in Afghanistan was the deadliest conflict globally in 2018, intensifying with the Taliban's rise in 2021 and the withdrawal of US forces.

The Middle East has been significantly affected by conflicts such as the Iran-Iraq War, the Persian Gulf War, and the recent Iraq War. Additionally, the region has seen conflicts between Israel and its neighbors, the Syrian civil war, the Turkish-Kurdish conflict, and confrontations with ISIS, making it one of the most troubled areas in terms of conflict diversity, intensity, and frequency over the past 50 years. Medium-intensity conflicts, such as those in Syria and Yemen, have persisted for years, contributing to regional instability, high refugee rates, and displacement. Although the intensity of the Syrian Civil War has decreased, it remains one of the world's most devastating conflicts. The armed conflict between Israel, Hamas, and other Palestinian groups has fluctuated in intensity, with no resolution in sight, and escalated hugely since October 2023. Its unprecedented intensity and potential for the involvement of other countries, such as Lebanon and Iran, pose the greatest threat to the region's stability.

A significant trend in the region is the rise of violence linked to identity politics, based on ethnic or religious polarization, as seen in Myanmar and Xinjiang, China. The truce over Kashmir between nuclear powers, India and Pakistan, is notable. Meanwhile, recent years have seen growing threats and provocations from North Korea toward South Korea and Japan and between China and Taiwan.

Europe

Although Europe has not frequently been the site of armed conflicts in recent decades, it has witnessed some of the most violent, high profile, and intense wars globally. Notable conflicts include those in the Balkans during the 1990s following Yugoslavia's dissolution and the Russian invasion of Ukraine. At the turn of the century, the Serbian-Kosovar War resulted in significant violence and displacement. Other unresolved tensions in the post-Soviet regions persist, including the Moldova-Transnistria War, Chechnya-Russia, Russia-Georgia, and the Nagorno-Karabakh conflict between Armenia and Azerbaijan. The ongoing war in Ukraine, which began with the

Euromaidan protests in 2013 and escalated with the Russian invasion, is currently the only active conflict in Europe. Its unprecedented intensity and potential for prolongation pose the greatest threat to continental peace and stability.

sub-Saharan Africa

Africa has had the highest number of conflicts and displaced persons worldwide over the last five decades. More than 30 countries have suffered armed conflicts, and 11 countries currently have active conflicts in sub-Saharan Africa: Burkina Faso, Central African Republic, Cameroon, Democratic Republic of the Congo, Ethiopia, Mali, Niger, Nigeria, Somalia, South Sudan, and Sudan. The Sahel region, Darfur, and the Horn of Africa are the areas most affected by conflict. Many of these conflicts overlap between the states and regions. These conflicts are associated with poor governance, extreme poverty, irregular exploitation of natural resources, and weak economies. Also noteworthy are the numerous civil wars in Sierra Leone, Rwanda, Congo, Liberia, the Ivory Coast, Senegal, and Angola, among other conflicts that devastated the continent in the last three decades of the 20th century.

2.2. Understanding the impacts of armed conflicts

Our understanding of how warfare increases deforestation or harms the efficacy of conservation efforts remains to be determined. This scarcity of understanding is partly because of the competing consequences of armed conflict, which can increase or decrease deforestation. Furthermore, interactions between armed conflict and other direct drivers of deforestation, such as mining and illicit crops, are complex and challenging to untie despite their occurrence throughout the planet. Deforestation has a deep link with warfare; hence, there is a need for practical and assertive research techniques to recognize causal and binding relationships specifically adapted to each particular case study.

Armed conflicts significantly affect landscape configuration through land use and land cover changes, leading to habitat fragmentation and ecosystem degradation, thereby complicating the availability of ecosystem services (DeFries, Foley and Asner, 2004; Foley, 2005; Castro-Nunez *et al.*, 2017). Studies indicate that conflicts can drive both deforestation (Armenteras *et al.*, 2006; Chadid *et al.*, 2015; Prem, Saavedra and Vargas, 2020) and reforestation (Clerici *et al.*, 2020; Kranz, Sachs and Lang, 2015; Murillo-Sandoval *et al.*, 2020), often occurring simultaneously in the same region (Gorsevski *et al.*, 2012; Nackoney *et al.*, 2014; Butsic *et al.*, 2015). This paradox reveals that conflict intensity is context-specific and is influenced by geographical conditions and the capabilities of the involved groups. Intense military activities may indirectly promote conservation or reforestation by restricting forest access to non-combatants. Some areas might also remain isolated due to landmines and unexploded ordnances, temporarily protecting forests (Baird and Le Billon, 2012; Mendoza, 2020; Suthakar and Bui, 2008; Witmer, 2008; Zúñiga-Upegui *et al.*, 2019). Conflicts also lead to the abandonment of agricultural lands, as seen in DR Congo, South Sudan, Colombia, and Bosnia. Conversely, conflicts cause deforestation through large refugees and internally displaced migrations, either towards urban centers or borderlands, necessitating agricultural expansion (Hagenlocher, 2011; Sosnowski *et al.*, 2016; Pech and Lakes, 2017; Leiterer *et al.*, 2018) (*Figure 2.2*).

Figure 2.2: Deforestation in the Colombian Amazon.
(Source: MinAmbiente – Colombia, 2018)

Owing to the relevance of current global armed conflicts, studies assessing the complex relationship between warfare and the environment have increased over the past decade. The International Law and Policy Institute's Report on the Protection of the Natural Environment in Armed Conflict (ILPI, 2014) reveals that war damages the environment and populations reliant on natural resources. Attacks harm animals, vegetation, soil, and water systems, impacting ecosystems at the local, regional, and national levels. Combatants have used extensive defoliation campaigns for strategic gain. The consequences of armed conflict require comprehensive analysis, including remote sensing technologies and in situ analysis, to provide context during and after wars while acknowledging the limitations of tracking specific changes and the necessity for ground verification.

2.2.1. The landscape during armed conflict stages

Armed conflicts often disrupt local economies, fostering parallel and illegal economies such as illicit crop cultivation and uncontrolled exploitation of natural resources, including illegal mining, logging, land grabbing, and large-scale cattle ranching (*Figure 2.3*). Conflict dynamics can either increase or decrease environmental pressure, resulting in varied impacts (Aung, 2021; Bromley, 2010; Ingalls and Mansfield, 2017; Spröhnle *et al.*, 2016; Suthakar and Bui, 2008; Tian *et al.*, 2011). There is limited empirical evidence on whether conflict accelerates or mitigates environmental damage. Given the strong spatial and physical correlation between conflict and the environment, and the need for environmental protection, more thorough reviews and evaluations are essential to understand the conflict-environment interaction (Ordway, 2015).

Figure 2.3: Deforestation in the northwestern Colombian Amazon.
(Source: Foundation for Conservation and Sustainable Development, 2019)

Landscape changes may be more visible in truce or post-conflict scenarios with minimal confrontation (Cabrera *et al.*, 2020; Clerici *et al.*, 2020; Murillo-Sandoval *et al.*, 2020, 2021; González-González *et al.*, 2021). Open forest access enables displaced populations, landowners, miners, loggers, and other stakeholders to exploit previously inaccessible resources, leading to increased deforestation, land-use changes, and water contamination (Hagenlocher, 2011; Grima and Singh, 2019; Cabrera *et al.*, 2020; Prem, Saavedra and Vargas, 2020; Murillo-Sandoval *et al.*, 2023). The environmental impacts of warfare may span large regions and persist for years or decades post conflict. Severe contamination may arise from attacks on industrial sites, oil wells, or infrastructure (Le Billon, 2001; Potapov *et al.*, 2012; ILPI, 2014; Jha, 2014; Butsic *et al.*, 2015; Murad and Pearse, 2018).. Indirect causes such as forced displacement may be even more harmful to the natural environment (Sánchez-Cuervo *et al.*, 2012; Sánchez-Cuervo and Aide, 2013; Leiterer *et al.*, 2018).

2.2.2. Causes derived from the armed conflict and its consequences on the environment

Direct causes are all actions that are physically related to the direct activity of warfare, which usually occurs within the instant or short term (bombings, armed confrontations, and military infrastructure). On the other hand, indirect causes are those that are generally associated with several activities triggered by war but are not military and only appear in the medium- or long-term (Partow, 2008; Jha, 2014; Solomon *et al.*, 2018; Mendez and Valánszki, 2019b, 2019a). Indirect causes may include non-military events, such as forced migration, and illegal economic activities, such as mining, logging, illegal agriculture, and illegal crops, which could reduce vegetation cover and increase land use changes (Stevens *et al.*, 2011; Jha, 2014). It has been proven that these impacts persist in post-conflict periods (Nackoney *et al.*, 2014) (*Figure 2.4*).

The intentional loss of natural resources, environmental contamination from military activities, ground slides, and craters are some of the direct consequences of war such as bombing, military debris and landmines. Indirect impacts encompass the ecological footprint of refugees (Hagenlocher, Lang and Tiede, 2012; Solomon *et al.*, 2018), deforestation due to agricultural expansion and displaced population needs, increased illicit crops and irregular mining, challenges in implementing environmental conservation policies, data discontinuity, and a lack of financial support for environmental conservation (Jha, 2014; Solomon *et al.*, 2018; Mendez and Valánszki, 2019b).

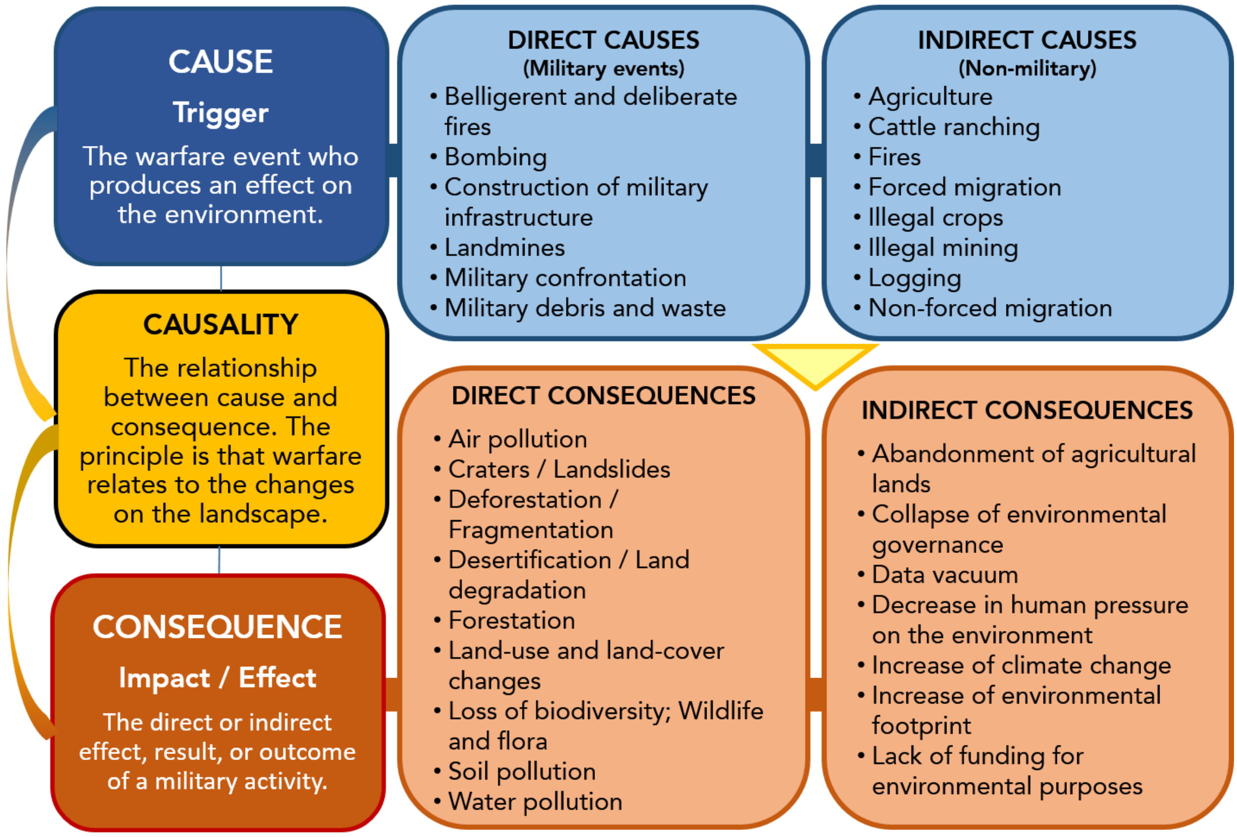


Figure 2.4: Causes derived from the armed conflict and its consequences on the environment. (Source: Own figure)

The indirect consequences of armed conflict from ammunition use on land, air, and water can have adverse long-term pervasive effects on people and the environment (Gorsevski *et al.*, 2012). Conflict successively affects biodiversity (Dudley *et al.*, 2002), 90% of the main armed conflicts between 1950 and 2000 occurred in countries with high biodiversity (Hanson *et al.*, 2009). Studies have confirmed that warfare is detrimental to flora and fauna owing to territorial destruction and fragmentation, direct wildlife decline from illegal hunting or land mines, over-extraction and deterioration of natural resources, and increased land and water contamination (Kanyamibwa, 1998; Loucks *et al.*, 2009; Nackoney *et al.*, 2014; Gleditsch, 2015) (*Figure 2.4*).

Experimental studies have suggested that warfare can affect wild forest conservation both negatively and positively (Rustad *et al.*, 2008; Rincón Ruiz *et al.*, 2013), even in localized areas (Gorsevski, Geores and Kasischke, 2013; Butsic *et al.*, 2015). The effectiveness of protected areas during conflict also varies across space and time (De Merode *et al.*, 2007). Gorsevski (2012) notes that conflicts can sometimes benefit biodiversity by creating "no-go areas" due to belligerent actions, reducing human pressure on the environment and fauna (Nietschmann, 1990; Kaimowitz and Fauné, 2003; McNeely, 2003; Witmer, 2008) (*Figure 2.4*).

Witmer (2015) affirms that impacts can be classified into four categories, arranged by the time required for each consequence to be visible. For instance, the physical harm generated by military events such as bombs or fire detonations is commonly an immediate effect (I), which appears in minutes or hours. Alternative impacts such as environmental damage (hours to days) (II), forced and unforced population displacement (days to months) (III), and changes in land cover/use (months to years) (IV) take longer to emerge. Even though there is some overlap between various impacts of warfare, direct and indirect (*Tables 2.1 & 2.2*).

Table 2.1: Types of conflict-derived causes. (Source: Own table, based on Witmer, 2015)

Type	Conflict-derived Cause	Temporal Lag
Direct	Belligerent and deliberate fires	Immediate
	Bombing	Immediate
	Military confrontation	Immediate
	Landmines	Short term to long term
	Military debris and waste	Short term to half term
	Construction of military infrastructure	Half term to long term
Indirect	Agriculture	Long term
	Cattle ranching	Long term
	Fires	Short term to long term
	Forced migration (Refugees camps)	Long term
	Illegal crops	Long term
	Illegal mining	Long term
	Logging	Half term to long term
	Non-forced migration (Colonization)	Long term

Table 2.2: Types of conflict-derived consequences. (Source: Own table)

Type	Affectation	Conflict-derived Consequence	Temporal Lag
Direct	Negative	Air pollution	Immediate to long term
		Deforestation / Fragmentation	Immediate to long term
		Desertification / Land degradation	Immediate to long term
		Water pollution	Immediate to long term
		Land-use and land-cover changes	Long term
		Loss of biodiversity; Wildlife and flora	Immediate to long term
		Craters / Land slides	Immediate
		Soil pollution	Immediate to long term
	Positive	Forestation	Long term
Indirect	Negative	Abandonment of agricultural lands	Half term to long term
		Collapse of environmental governance	Long Term
		Data vacuum	Half term to long term
		Increase of climate change	Long term
		Increase of environmental footprint	Long term
		Lack of funding for environmental purposes	Long term
	Positive	Decrease in human pressure on the environment	Short term to long term

2.3. Colombian armed conflict and landscape

Colombia, located in northwestern South America, acts as a transitional zone between the Andes, Amazon, Pacific, Orinoquía, and Caribbean ecoregions. This unique geographical position fosters diverse biological landscapes and a rich cultural heritage. However, the ongoing armed conflict has differentially affected Colombian ecosystems. Consequences in tropical forests of the Amazon have not been the same in intensity or type as effects in regions such as the paramos, deserts, and Andes Mountains. The prolonged internal armed conflict involving guerrillas, paramilitary groups, and the government has significantly shaped Colombian history for over six decades. Since the 1980s, this conflict has intensified and been funded by illicit activities, including drug trafficking, illegal mining, and extensive logging, contributing to increased socioeconomic and political instability and environmental degradation.

The conflict has modified rural and urban landscapes through changes in society, economic production modes, and land use (Rettberg, Leiteritz and Nasi, 2014; Arias, Ibáñez and Zambrano, 2019; Garcia Corrales, Avila and Gutierrez, 2019; Negret *et al.*, 2019). Most of the Colombian ecosystems have been directly or indirectly war-affected. The consequences have sometimes been paradoxical. During periods of military activity, warfare has promoted conservation areas because of landmines or the intense dispute over strategic territories, mainly in the Orinoquia and the Amazon foothills (Clerici *et al.*, 2020; Murillo-Sandoval *et al.*, 2020, 2021). Contrarily, post-agreement activities have increased the pressure on ecosystems, driving deforestation and land cover changes, mostly in fragile ecosystems such as the Amazon Rainforest, where the presence of the government has been scarce or non-existent and where the guerrilla had a strong influence (Dávalos, 2001; Armenteras, Gast and Villareal, 2003; Armenteras *et al.*, 2011; Rincón-Ruiz and Kallis, 2013; Rincón-Ruiz, Pascual and Flantua, 2013; Landholm, Pradhan and Kropp, 2019).

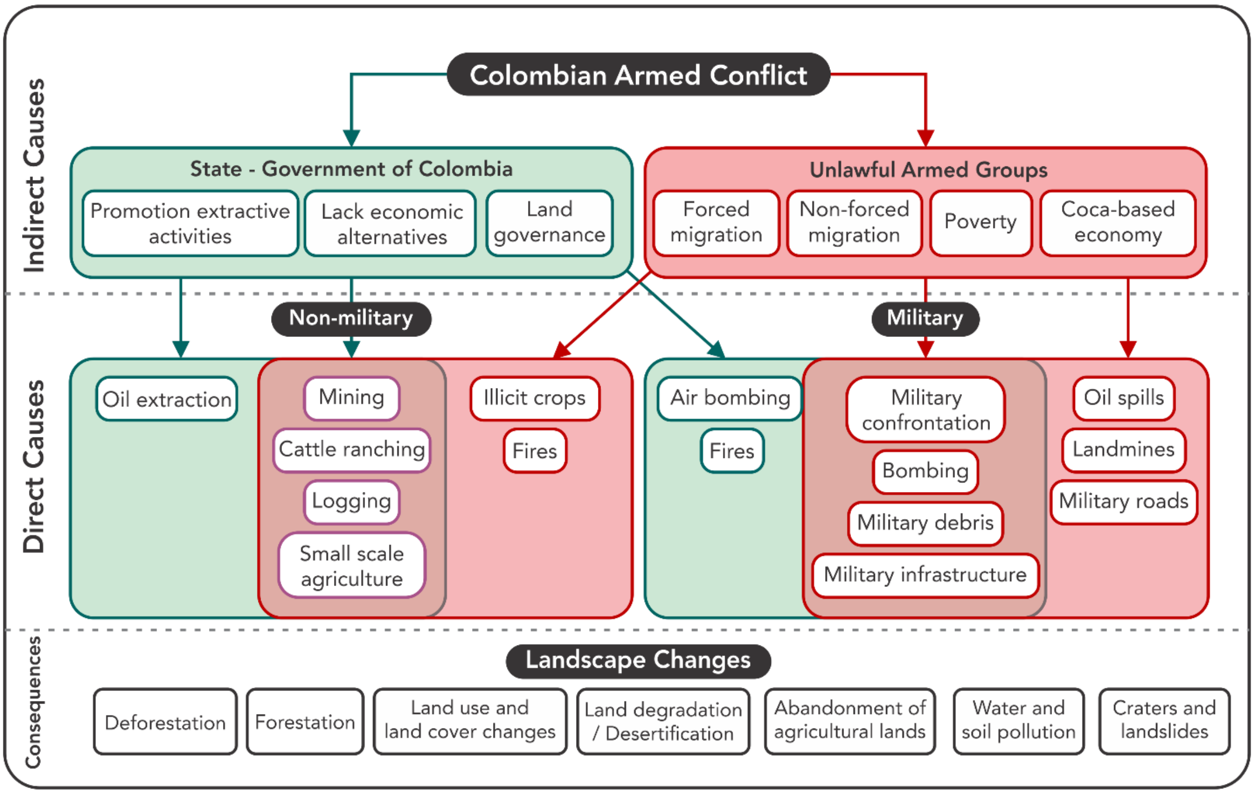


Figure 2.5: Colombian armed conflict direct and indirect conflict-derived causes.
(Source: Adapted from (Hoffmann, García Márquez and Krueger, 2018)

The armed conflict has altered rural landscapes through changes in community lifestyles, economic production methods, and land use (Rettberg, Leiteritz and Nasi, 2014; Arias, Ibáñez and Zambrano, 2019; Garcia Corrales, Avila and Gutierrez, 2019; Negret *et al.*, 2019). In Colombia, the armed conflict has directly or indirectly affected most ecosystems. The consequences have been paradoxical. During periods of armed conflict, military activity has unintentionally promoted conservation areas due to strict territorial control, land mines presence, or intense disputes over strategic territories foothills (Clerici *et al.*, 2020; Murillo-Sandoval *et al.*, 2020, 2021). Conversely, during the post-peace agreement period between the *Fuerzas Armadas Revolucionarias de Colombia* (FARC) and the Government of Colombia, new environmental regulations on how land is used and accessed generated rapid changes in land cover associated with the FARC's withdrawal (Landholm, Pradhan and Kropp, 2019; Zúñiga-Upegui *et al.*, 2019; Cabrera *et al.*, 2020; Murillo-Sandoval *et al.*, 2021; Rodríguez-de-Francisco *et al.*, 2021; Cantillo and Garza, 2022; Christiansen *et al.*, 2022). The conflict is linked to weak governance, which generates the proliferation of criminal organizations that take advantage of this governmental void to illegally tap natural resources through coca crops, mining, logging, and illegal cattle ranching expansion (*Figure 2.5*).

2.3.1. Brief history of Colombian armed conflict

Colombia's internal armed conflict, the longest in the Western Hemisphere since the late 1950s, has caused prolonged sociopolitical instability in the country (Kalmanovitz, 2003). Land inequality and restricted political participation fueled violence as a means of demanding social justice, agrarian reforms, and land ownership. This led to the formation of guerrilla groups such as the Fuerzas Armadas Revolucionarias de Colombia (FARC) and the National Liberation Army (ELN). Since the 1980s, as guerrillas gained power, new actors, such as paramilitary groups and private armies funded by large landholders, emerged, complicating and intensifying the conflict. Drug trafficking, terrorism, extortion, and kidnapping have become common in financing military campaigns and weapon supplies (Kalmanovitz, 2003) (*Figure 2.6 and 2.7*).

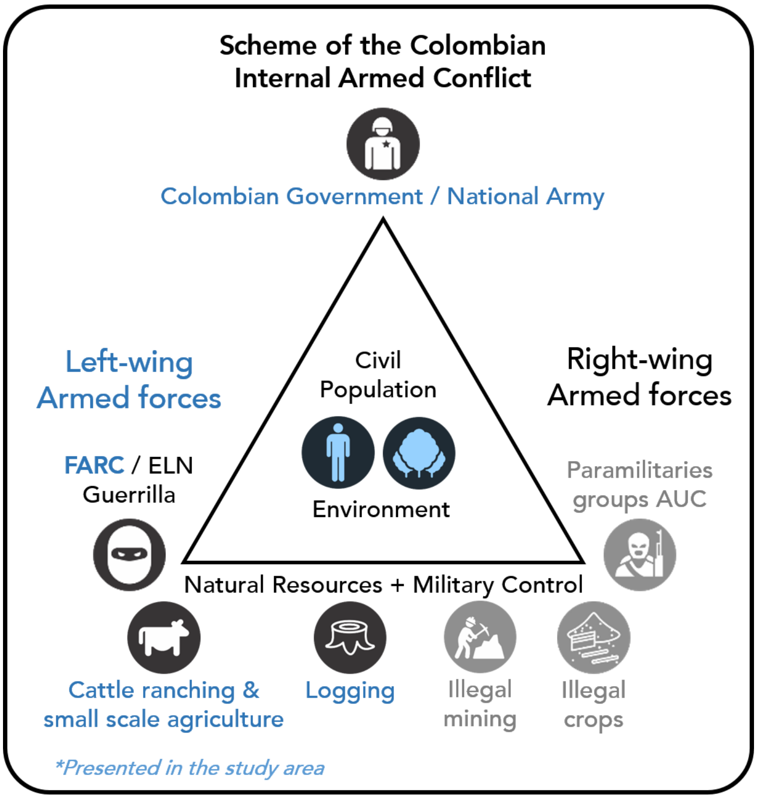


Figure 2.6: Scheme of the Colombian Armed Conflict. (Source: Own figure)

The economic, political, and social impacts of armed conflict have been widely discussed (Rincón Ruiz *et al.*, 2013, 2013; Sanchez-Cuervo and Aide, 2013; Reyes, 2014; Rodríguez-Garavito, 2017; Arias, Ibáñez and Zambrano, 2019). From 1958 to 2018, the casualties were 261,619, around 6 million refugees, and 8 million victims, including those killed, injured, displaced, and kidnapped (CNMH, 2021). Colombia has the largest internally displaced population after Syria (UNHCR, 2021).

2.3.2. The transition towards peace and abrupt landscape transformation

In 2002, a peace process was initiated with the paramilitary group *Auto Defensas Unidas de Colombia* (AUC) during President Álvaro Uribe Vélez's first term, concluding in 2006 (INDEPAZ, 2013). Concurrently, the Colombian government enacted the Justice and Peace Law to facilitate peace processes and the reintegration of members of illegal armed groups into civilian life (INDEPAZ, 2013, 2021). In 2012, after five decades of conflict, negotiations began between the Colombian government and FARC, leading to a peace agreement in November 2016. Over the past six years, Colombia has seen significant changes in internal conflict due to the weak implementation of the 2016 Peace Agreement (KROC, 2020). At least 1,270 social leaders and ex-combatants have been killed (INDEPAZ, 2021) (*Figure 2.7*).

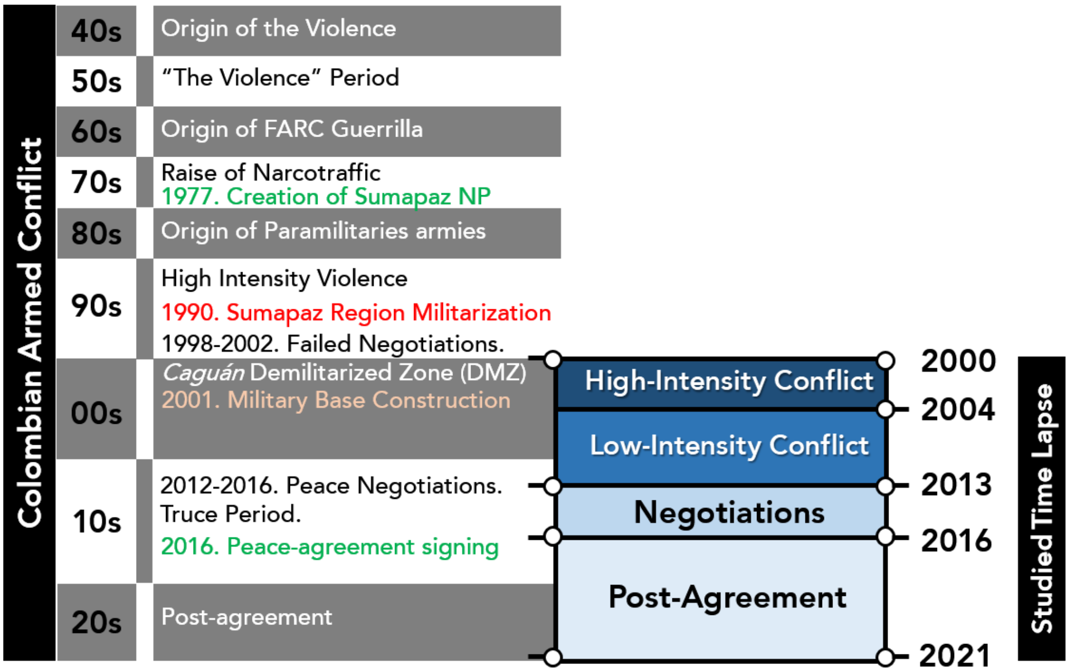


Figure 2.7: Time line of Colombian Armed Conflict in the Sumapaz Region.
(Source: Own figure)

The emergence of new illegal armed groups, including guerrilla dissidents, is notable and is financed by drug trafficking. These groups aim to occupy the void left by the FARC, undermining the hopeful post-peace agreement landscape and causing significant socioeconomic and environmental disruptions. Nonetheless, six years after the agreement, the post-conflict period facilitated numerous opportunities for scientific research. There has been a marked and consistent increase in studies evaluating the environmental impact of cessation of armed conflict.

2.3.3. Sumapaz Region during the armed conflict periods

The Sumapaz region's deep-rooted support for left-wing policies is tied to historical processes such as agrarian struggles and peasant unions, explaining its vulnerability as both a site and victim of conflict and the stigmatization of its inhabitants by some governmental institutions (Vicepresidencia de la República, 2002; Unidad de Victimas, 2024). This area has a long tradition of agrarian struggles, dating back to the 1920s. The armed conflict in Sumapaz was developed uniquely, as the FARC guerrilla did not conduct many sustained massive military actions, unlike other regions. The Army initiated the most significant military confrontations. Nonetheless, the area experienced the conflict violently and served as a crucial strategic corridor for FARC's movements, maneuvers, and camps (Morales Acosta, 2017) (*Figure 2.8*).

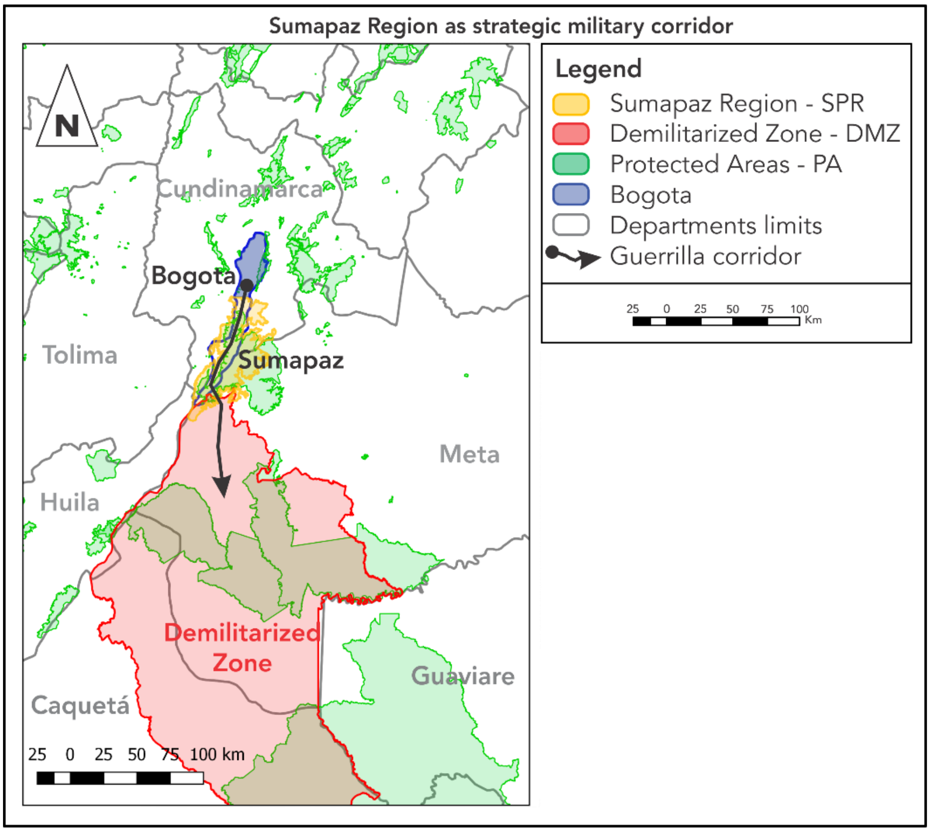


Figure 2.8: *Sumapaz Páramo* as strategic corridor. (Source: Own figure)

Between 1998 and 2002, unsuccessful peace negotiations occurred in El Caguán between FARC and President Andrés Pastrana's administration. To facilitate talks, the government established the El Caguán Demilitarized Zone (DMZ), a 42,000 square kilometer area under complete FARC control, free from state military presence. This zone includes some municipalities of the Department of Meta, and Department of Caquetá. The Sumapaz region gained significant strategic importance during these negotiations, enabling the FARC to link the country's center, including Bogotá, with the DMZ. Militarily, the páramo served as the FARC's main security corridor, featuring rudimentary roads that connected the DMZ to Bogotá's outskirts. The corridor allowed the circulation of combatants, hostages, weapons, and money to southeastern Colombia. The most significant evidence is the road called *Troncal Bolivariana*, built by the guerrillas to connect the *Sumapaz Páramo* with the Amazonian foothills through the *Duda* River canyon (Castaño Uribe, 2004; Galvis Hernández, 2014; Peñaranda-Currie, Otero-Bahamon and Uribe, 2021; Uribe, Otero-Bahamón and Peñaranda, 2021). Since 2001, the National Army has established three high-mountain military bases to restrict guerrilla movements *(Figure 2.8)*.

2.3.4. Approaching the armed conflict studying in the Sumapaz Region

The socioeconomic and political impacts of armed conflict in the Sumapaz Region have been extensively studied (Hofstede *et al.*, 2003; Morales Acosta, 2017), focusing on the origins of peasant movements and disputes over agrarian policies related to land use and distribution (Londoño Botero, 2011). Research has also included testimonies to reconstruct and analyze violent events (Vicepresidencia de la República, 2002; Moreno-Rodríguez and Díaz-Melo, 2018), with few studies evaluating human impacts on hydrological regimes at broad scales (Buytaert *et al.*, 2006). However, small-scale forest disturbances in Sumapaz have been less examined because of environmental conditions, limited secondary information such as satellite images, and lack of field validation of landscape changes. Sumapaz Region, like other conflict-affected regions, saw heavy use of forest resources during wartime, leading to long-term degradation (Rotherham, 2024; Vadas and Baráth, 2024). Short-term disturbances in the paramo during conflict may have future impacts on hydrological regimes, CO2 storage, landscape fragmentation, and forest recovery, which have been understudied in post-conflict periods (Martin, 2023).

2.4. The remote sensing of worldwide armed conflicts

Over the past 15 years, remote sensing analysis for studying violent conflicts has significantly increased and is expected to continue to grow (Witmer, 2015). This rise is partly due to ongoing conflicts in sub-Saharan Africa, the Middle East, and Latin America, as well as the recent Russian invasion of Ukraine, coupled with technological advancements and the greater availability of ultra-high-resolution satellite imagery (Potapov *et al.*, 2012; Rincón-Ruiz, Pascual and Flantua, 2013; Sanchez-Cuervo and Aide, 2013; Butsic *et al.*, 2015; Leiterer *et al.*, 2018; Murad and Pearse, 2018). Initially, remote sensing methods, including aerial photo analysis in conflict zones, were primarily used for military purposes because of the military's historical role in technological innovation and substantial financial resources (Corson and Palka, 2004). Advances in remote sensing technology and satellite imagery have enhanced the effectiveness and precision of military operations, as demonstrated in the Ukraine-Russia War, where these technologies have been crucial in shaping military strategies and troop movements (Witmer, 2015; Pereira *et al.*, 2022).

The impacts of armed conflicts on ecosystems vary and are difficult to assess because of the restricted access to war-affected areas, making satellite imagery useful for remotely studying these effects on landscapes (Hanson *et al.*, 2009; Hoffmann, García Márquez and Krueger, 2018; Murad and Pearse, 2018). Wartime access limitations and unclear conflict boundaries complicate timely and accurate impact assessment (Butsic *et al.*, 2015). Therefore, satellite remote sensing data offer insights into how conflicts directly affect physical environments and indirectly alter human populations and land use patterns.

2.4.1. Satellite imagery sensors

Most conflict-related research employs passive technology based on the solar radiation reflected or emitted from a satellite platform (Witmer, 2015). Free online imagery, such as Google Earth, is limited to the visible range and lacks multispectral data in the infrared range. While these images can validate conflict-related land abandonment and the effects of war, deeper analysis requires multispectral imagery such as Landsat and Sentinel, or commercial imagery such as Quickbird, GeoEye, and Rapid Eye. Resolution is crucial for remote sensing, with spatial, spectral, and temporal resolutions being the most pertinent, although radiometric resolution also influences the detection capabilities. *Appendix 1* lists the sensors commonly used to study violent conflict effects categorized by spatial resolution according to the SAGE Remote Sensing Manual (Warner, Nellis and Foody, 2009): very fine (≤1 m), fine (1-10 m), moderate (10-250 m), and coarse (>250 m) (*Appendix 2*).

The latest satellite sensors, combined with advanced computer capabilities, enable precise analysis of contemporary armed conflicts. Multivariate remote sensing analysis has become a crucial tool for managing vast and complex datasets. "Multivariate imaging" encompasses varied data media, including multisource observations, multiscale, color imaging, multimodal data, multitemporal, and multispectral images. The significance and application of compound data from multivariate imaging systems have garnered growing interest in remote sensing, particularly in the analysis of armed conflicts and their environmental impacts (Collet, Chanussot and Chehdi, 2010).

2.5. The remote sensing of Colombian armed conflict

The environmental impacts of armed conflict, although historically understudied, are now gaining attention, partly owing to the relevance of the ongoing conflicts and the vast availability of satellite imagery and data processing platforms, such as Google Earth Engine (Gorelick *et al.*, 2017). Studies in Colombia have rarely utilized remote sensing technologies to analyze direct impacts, such as military confrontations and bombings. Conversely, indirect impacts have been studied more frequently, including activities such as illicit crops, illegal mining, cattle ranching, logging, forced and non-forced migration, and small-scale agriculture. Over the past 15 years, research has focused on deforestation, reforestation, land use, and land cover changes. For instance, deforestation from illegal mining in the conflict-affected *Bajo Cauca* region has been identified using NDVI time series (Gómez-Rodríguez *et al.*, 2017).

Deforestation and reforestation have been monitored using MODIS time series and various vegetation indices (Sánchez-Cuervo and Aide, 2013). Forest disturbances and Land Use and Land Cover Changes (LULCC) in the Andes-Amazon region have been tracked during conflict and post-conflict periods using change detection algorithms, such as BFAST Spatial and Land Trendr (LT) (Murillo-Sandoval, Van Den Hoek and Hilker, 2017; Murillo-Sandoval, 2020; Murillo-Sandoval *et al.*, 2020, 2021; Murillo-Sandoval, Clerici and Correa-Ayram, 2022). Changes driven by coca crops, cattle ranching, and agriculture have been analyzed using the LULC classification system, Forest Cover Classification (FCC), and Maximum Likelihood Classifier (MLC)) (Sánchez-

Cuervo and Aide, 2013; Chadid *et al.*, 2015; Murad and Pearse, 2018; Mendoza, 2020; González-González *et al.*, 2021). The Hansen dataset (Hansen *et al.*, 2013) has been widely used to detect forest disturbances (Armenteras *et al.*, 2006; Murad and Pearse, 2018; Clerici *et al.*, 2020; Prem, Saavedra and Vargas, 2020). Few studies have utilized high-resolution imagery, such as QuickBird and Google Earth VHR (Sánchez-Cuervo *et al.*, 2012; Sánchez-Cuervo and Aide, 2013). Forest disturbances within Protected Areas (PA) have been examined by Armenteras et al. (2006), Murad and Pearse (2018), Prem et al. (2020), and Clerici et al. (2020). Murillo-Sandoval et al. (2020) detected and characterized landscape changes with BFAST in the post-agreement period in the Andes-Amazon transition region, covering five national parks. Moderate spatial resolution sensors, such as Landsat and MODIS, have primarily been used to detect landscape changes in Colombia. Other studies have also employed global datasets from Hansen et al. (2013) and MODIS.

3. MATERIALS AND METHODS

3.1. Methodology overview

The methodology chapter describes the steps carried out during the main stages of the dissertation in detail: review of literature, data collection and classification, preprocessing, processing and results generation. A flowchart of the study methodology is presented in *Figure 3.1*.

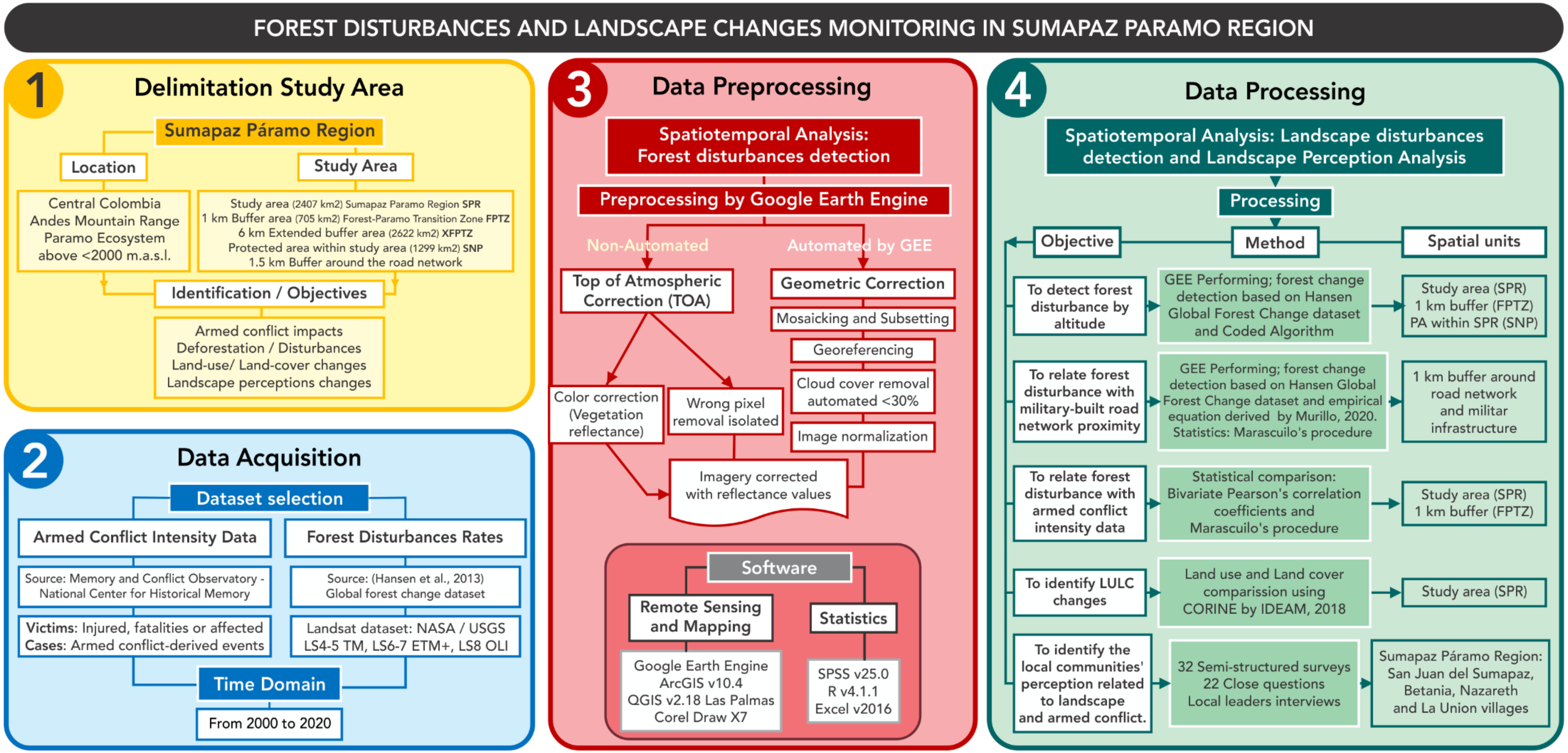
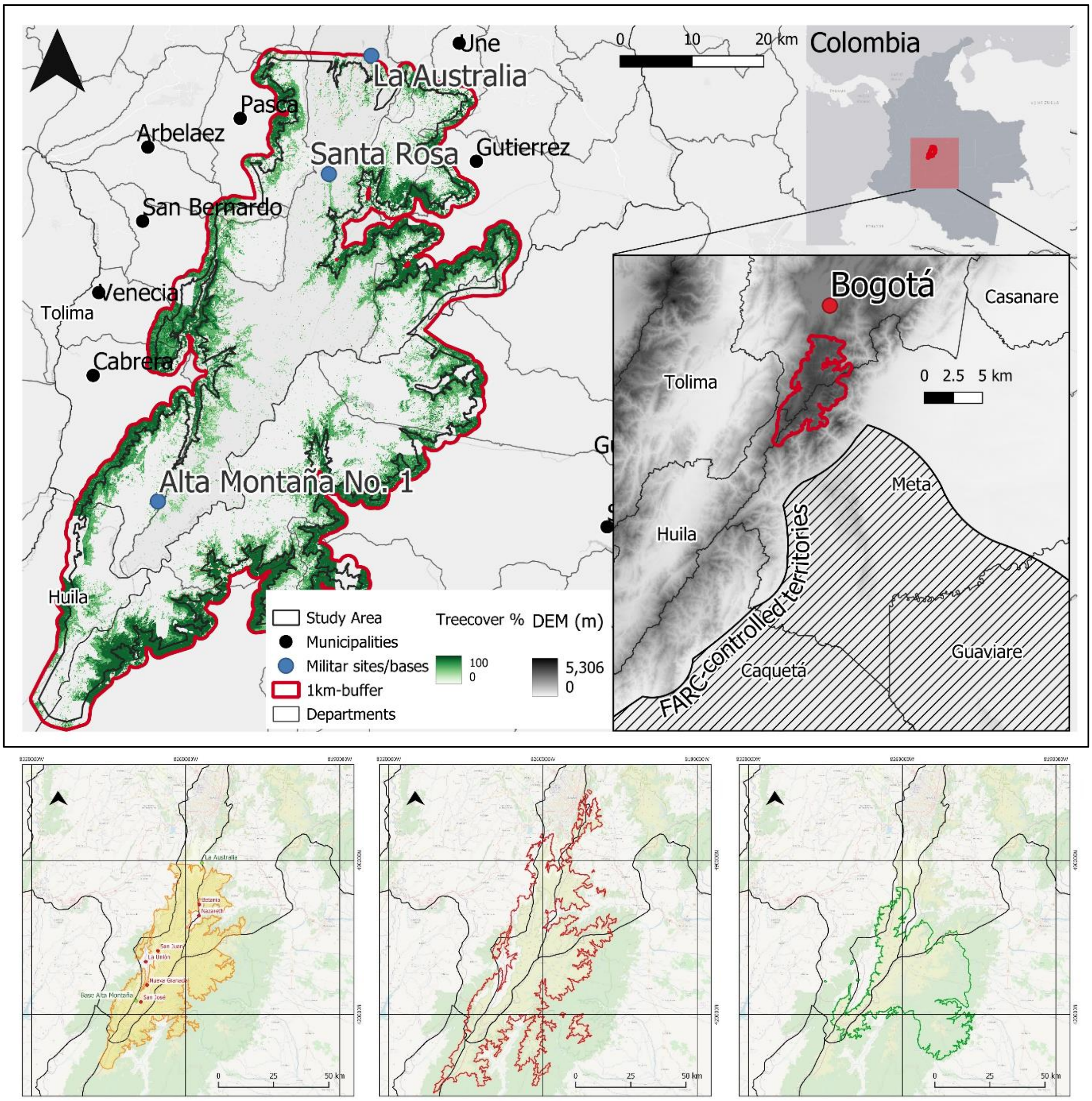


Figure 3.1: Flowchart of methodology overview. (Source: Own figure)

3.2. Study area: *Sumapaz Páramo Region* characterization

3.2.1. Geographical location and delimitation

The study area is in the central region of Colombia, situated in the eastern cordillera of the Andes. The study area encompasses the intersection between the protected area of Sumapaz National Park and the boundaries of the *Cruz Verde-Sumapaz Páramo*, as determined by the Alexander von Humboldt Institute (Morales-Rivas *et al.*, 2007; HUMBOLDT and CEERCCO, 2015). Its geographical coordinates are between LAT_GMS LONG_GMS: North: N 4° 23' 8.268" W 74° 15' 33.659" / East: N 4° 8' 56.364" W 73° 57' 28.799" / South: N 3° 32' 56.04" W 74° 31' 4.763" / West: N 3° 34' 38.64" W 74° 33' 9.323" (*Figure 3.2*).



Study Area Sumapaz SPR **Cruz Verde-Sumapaz Paramo Ecosystem limits** **Sumapaz National Park SNP**

Figure 3.2: Geographical location. (Source: Own figure)

The study area calculated by ellipsoidal measurement has an extent of 240 700 ha. It includes rural areas of the following municipalities; *Arbeláez, Cabrera*, *Gutiérrez*, *Pasca*, *San Bernardo, Une and Venecia* in the department of Cundinamarca; *Guamal* and *San Luis de Cubarral* in the Department of Meta and a large part of the 20th Sumapaz District, belonging to the capital city; Bogotá D.C. We created a 1 km buffer around the study area, which spans 70 584 hectares. The buffer allows us to document whether forest disturbances are at altitudes around 2500 meters (*Figure 3.2*).

Delimitation of the *Sumapaz Páramo Region* and the *Forest-Páramo Transition Zone*

The connectivity between the paramo and high Andean forests is crucial for ecosystem integrity, functionality, and provision of ecosystem services. Paramos are highly variable across mountain ranges and slopes, necessitating specific identification for delimitation, as in *Sumapaz Páramo*. Studies have recognized that paramos and high Andean forests are interconnected through hydrology, biodiversity, and various ecological, cultural, and economic processes that rely on both ecosystems and their interactions (Morales-Rivas *et al.*, 2007; Sarmiento Pinzón *et al.*, 2013; HUMBOLDT and CEERCCO, 2015; HUMBOLDT and UDFJC, 2015). According to HUMBOLDT and CEERCCO (2015), the lower limit of paramo is identified at the juncture between the high Andean forest and the subparamo, marked by semi-open plant formations, interdigitating shrub and tree elements, and significant variability in floristic composition, cover, and physiognomy, resulting in high heterogeneity, richness, and species diversity (Morales-Rivas *et al.*, 2007).

To delimitate the areas of the *Sumapaz Páramo Region* (SPR) and the *Forest-Páramo Transition Zone* (FPTZ), I used the distribution models of HUMBOLDT and UDFJC (2015). The model defines the FPTZ and paramo zones based on the potential distributions of forests, shrublands, and grasslands. The sampling involved satellite images, yielding 2,311 presence points (1,075 herbaceous, 570 shrubby, and 666 arboreal) from image sampling, satellite, and field data. Elevation and slope were significant variables in the model development. The FPTZ ranges from 2500 m in some areas to 3380 m at its highest, whereas the SPR spans from approximately 3200 to 4300 m in altitude (*Figure 3.3*).

Figure 3.4: *Sumapaz Páramo* ecosystem.
(Source: Photo by National Natural Parks

3.2.2. Geophysical factors and landscapes configurations

The *Sumapaz Páramo* is a high mountain ecosystem that includes natural habitats between the montane tree line ((approximately 2800-3200m) and the permanent snowline ((approximately 4200m). It is considered the most phyto-diverse tropical-alpine ecosystem on Earth, with about

5000 plant species, 60% of which are endemic (Sklenář, Dušková and Balslev, 2011; Peyre, 2015; Anthelme and Peyre, 2020) (*Figure 3.4*).

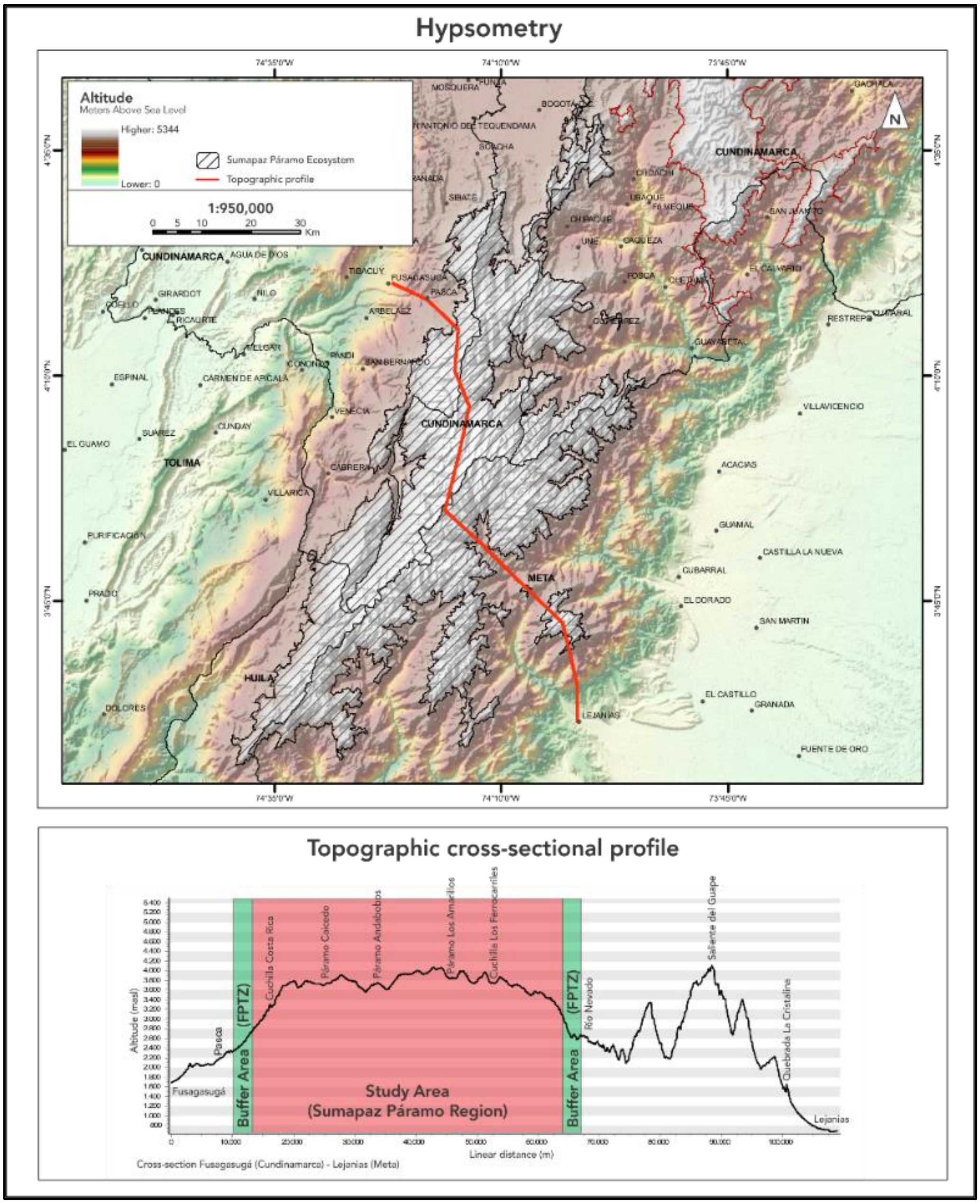


Figure 3.3: Hypsometry and topographic cross-sectional profile.
(Source: Modified and Based on *Instituto Alexander von Humboldt*, 2017)

The Andean paramos feature varied glacier-formed valleys and plains with numerous lakes, peat bogs, and wet grasslands interspersed with shrublands and small forest patches. These ecosystems span the northern Andes, between approximately 11°N and 8°S latitude. The paramo terrain includes diverse topographical forms such as valleys, plains, plateaus, mountains, and foothills. Ecosystem boundaries are not strictly defined and vary by region. Altitudinal differences influence the soil and vegetation (Zorro *et al.*, 2005) (*Figure 3.4 and 3.5*).

• High Andean Montane Forest (2500m-3200m): dense forests with high species diversity, transitioning from foggy forests to subparamo.

• *Subparamo* (2800m-3400m): dominated by shrubby vegetation and low trees.

• *Paramo* (3200m-4000m): Grass cover including frailejones (*Espeletia sp*.), pajonales (*Calamagrostis sp*.), and chuscales (*Chusquea sp*.).
• *Super-paramo* (>4000m): Extends to the lower limit of perpetual snow; plant cover and diversity significantly decrease, with isolated plants and a predominance of rocky substrates.

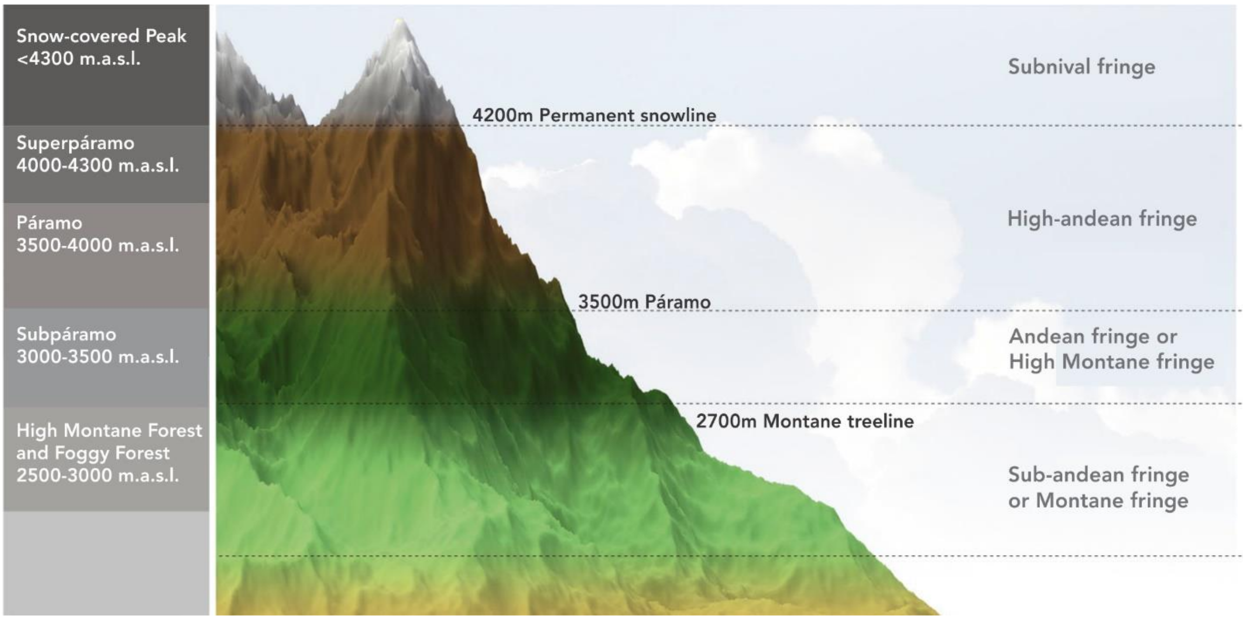


Figure 3.5: Paramo's ecosystem variations by altitude.
(Source: Adapted from (Díaz Merlano, Silva Alvarez and Montes Arango, 2018)

3.2.3. Flora

The Paramo is an isolated tropical highland ecosystem, recognized as a biodiversity hotspot with over 3,400 vascular plant species and high endemism, making it one of the world's hyper-diverse mini-hotspots (Myers *et al.*, 2000).

Paramos are separated into zones based on elevation and vegetation, and these zones contain various types of vegetation (Valencia *et al.*, 2021). The highest zone, known as the Superparamo, is characterized by intense solar radiation and night frost, which requires vegetation to be highly resilient to extreme weather conditions. The temperatures in this zone fluctuate significantly, and it is located in high mountains. This area is minimally disturbed by humans and is home to many endemic species. The flora in the Superparamo includes *Azorella pedunculata* (Apiaceae) and species from *Asteraceae*, *Fabaceae*, and *Ericaceae* (Renvoize *et al.*, 2000; HUMBOLDT and UDFJC, 2015; Peyre, 2015).

In the Paramo ecosystem, vegetation is continuous, displaying a "yellowish to olive-brown" color from a mix of dead and living grasses, primarily tussock grass. The dominant species are *Calamagrostis intermedia sp* and *Festuca sp*. This region supports various plants including shrubs, stunted trees, cushion plants, herbs, rosette plants and mostly *Espeletia sp* (*Figure 3.6*). Despite grass dominance, the zone features diverse communities of tall and short grasses as well as herbaceous and woody vegetation. Human activities, such as burning and grazing, significantly impact this zone owing to its accessibility and abundant grasses (Renvoize *et al.*, 2000; Morales-Rivas *et al.*, 2007; Sklenář, Dušková and Balslev, 2011; HUMBOLDT and UDFJC, 2015).

Subparamo, the most diverse and lowest paramo-ecosystem, is characterized by shrubs and features of both paramo and high-andean and foggy forests. This area also contains scattered small trees that transition into grass and herbs in the paramo grass. Dominated by thickets of shrubby or woody vegetation, including genera like *Ilex*, *Ageratina,* and *Baccharis*, this zone may also have fragmented forests due to microclimatic or soil conditions. However, abrupt changes typically result from human activities such as cutting, burning, and grazing. Lichens are common across all types of paramos, with specific environmental conditions favoring different forms of growth (Renvoize *et al.*, 2000; Morales-Rivas *et al.*, 2007; HUMBOLDT and UDFJC, 2015; Peyre, 2015).

Figure 3.6: ***Frailejones*** **vegetation (*Espeletia sp*).**
(Source: Maria Luisa Moreno-Cesar Romero CNMH, 2018)

3.2.4. Ecosystem services

The paramo provides essential ecosystem services to millions of people, including major cities such as Quito and Bogotá, smaller towns, and numerous Andean indigenous communities (Buytaert *et al.*, 2006; Célleri and Feyen, 2009). The primary provisioning and regulating service of paramo is water supply because of its exceptional water retention and regulation capacity (Buytaert *et al.*, 2006; Vuille *et al.*, 2008). Many Andean cities rely heavily on paramo water, especially because other potential sources such as Andean forests have dwindled. For example, Bogotá, with a population of approximately 8 million and a freshwater demand of 27 m^3/s, almost exclusively uses water from paramo. The city sources its water from the Chingaza and La Regadera reservoirs, which are fed by the *Chingaza* and *Sumapaz Páramo* (UAESPNN, 2000) (*Figure 3.7*).

Other provisioning services include food, timber, and fiber supplies, which are beneficial to local communities. An important regulating service provided by the paramo is carbon storage, facilitated by volcanic soil components that enhance the ability of the soil to capture and retain atmospheric carbon dioxide (Podwojewski *et al.*, 2006) . The paramo also offers natural supporting services, such as soil formation, nutrient cycling, and photosynthesis. Moreover, the spiritual significance for Andean communities and the landscape's appeal for tourism are key cultural services provided by the paramo (Anderson *et al.*, 2011). The paramo region is ecologically fragile, and its homeostasis is critically threatened by local anthropogenic activities and global climate change (Hofstede *et al.*, 2003).

Figure 3.7: *La Regadera* water reservoir. (Source: Own photo)

3.2.5. Human activities

Human activity in the high northern Andes dates back to the pre-Columbian era. Since the arrival of the Spanish and particularly post-1960s, traditional land use has increasingly shifted to modern agricultural and pastoral practices, such as burning and grazing, significantly affecting natural ecosystems (Vásconez and Hofstede 2006). In the paramo, agriculture mainly involves cultivating hardy tuber crops like potatoes, oca, and mashua, as well as legumes like quinoa and cereals at lower elevations (Mena-Vásconez & Estrella 2000; Mena-Vásconez & Medina 2001) (*Figure 3.8*). These methods have considerable consequences for the ecosystem, as vegetation removal exposes soil to erosion and agrochemicals, thereby reducing nutrient content and water retention (Molinillo & Monasterio 2002). The upper agricultural limit in paramo is continuously rising to meet local community needs, approaching the ecotone between paramo and super- paramo, where harsh climates and infertile soils pose significant challenges (*Figure 3.10*).

Figure 3.8: Small-scale agriculture (Potato crops). (Source: Own photo)

Burning significantly affects biodiversity loss, soil quality degradation, and vegetation succession, shifting from shrublands to grasslands and eventually to meadows (Ramsay & Oxley, 1996; Suárez

& Medina, 2001). Although burning can homogenize large landscapes, it also introduces spatial and temporal variations. Moreover, grazing by cows or sheep leads to soil pollution and selective plant growth (Hofstede et al., 2003) (*Figure 3.9*). Additionally, human activities such as deforestation of *Polylepis* forests are now reduced to 10% of their original extent (Kessler, 2006), and widespread reforestation of paramo grasslands with *Pinus*, causing soil drying and acidification (Farley et al., 2004), exacerbates these effects.

Human activities such as mining have led to the rapid removal of ecosystems and contamination in some paramo areas (Vélasquez, 2012). In contrast, regulated tourism has a lower impact on these ecosystems; however, it is highly restricted (Rangel-Churio & Pinto-Zárate, 2012). Human pressure on paramo ecosystems has increased over time with the diversification and acceleration of activities through technological advances and agrarian reforms, especially in the latter half of the 20th century (Hofstede et al., 2003). Each innovation in human practices has intensified and expanded geographically, gradually replacing native specialized species with opportunistic ones and allowing alien species to invade alpine belts. Consequently, landscapes have become homogenized over large areas and fragmented in others.

Climate change will profoundly affect paramo's ecosystem services, leading to glacier melt and increased insolation, potentially causing gradual desertification and diminishing water retention and regulation (Vuille et al., 2008). Human activities have already modified these services, likely accelerating degradation through practices such as high-altitude farming and artificial water regulation methods (Anderson et al., 2011).

Figure 3.9: Cattle ranching.
(Source: Own photo)

Figure 3.10: Agricultural frontier in the paramo.
(Source: Photo by Jose Armando Plaza, n.d.)

3.3. Case studies: Data collection and processing

To ensure a comprehensive analysis, data acquisition, selection, classification, and categorization were performed across the three scales of the study. At global and national scales, case studies of armed conflicts and their impact on the environment were collected from the available literature. Additionally, specific information about the relationship between Colombian armed conflict and the environment was gathered at the national scale. Finally, at the regional scale, detailed searches were conducted to identify the independent variables of the *Sumapaz Páramo Region*.

3.3.1. Worldwide case studies. Data acquisition, selection and classification

First, I compiled a database containing information on RS systems and 37 armed conflict events. I synthesized the findings regarding the study methods, geographical conditions, land use/cover changes, their immediate drivers, and underlying causes. I compiled the independent variables used to link these relationships. Based on the available literature, I classified the studies and conducted a meta-analysis to identify the trends, divergences, and convergences in the application of remote sensing to environmental impacts.

I conducted an exhaustive search of indexed databases, including Scopus, Science Direct, Taylor and Francis Online, Springer Link, and MDPI, focusing on publications from 1998 to 2021 (1406 studies). The initial search criteria included keywords such as "Deforestation + Armed Conflict," "Remote sensing + Armed conflict," "Multivariate + Armed conflict," "Multitemporal + Armed conflict," "Multispectral + Armed conflict," and "Biomes + Armed conflict." Additional keywords included multivariate analysis, satellite sensor, consequence, deforestation, drivers of deforestation, forestation, land-use, causes of deforestation, biome, imagery preprocessing, and forest loss. In the Scopus database, searches were conducted on article titles, keywords, and abstracts, including articles in Spanish. From this eligibility analysis, 306 studies were chosen by title and narrowed down to 207 after reading the abstracts. After eliminating duplicates and filtering, 165 case studies that initially complied with the selection criteria were selected. The final review yielded 77 case studies worldwide that fully met the evaluation criteria based on the data categories sought (*Figure 3.11*).

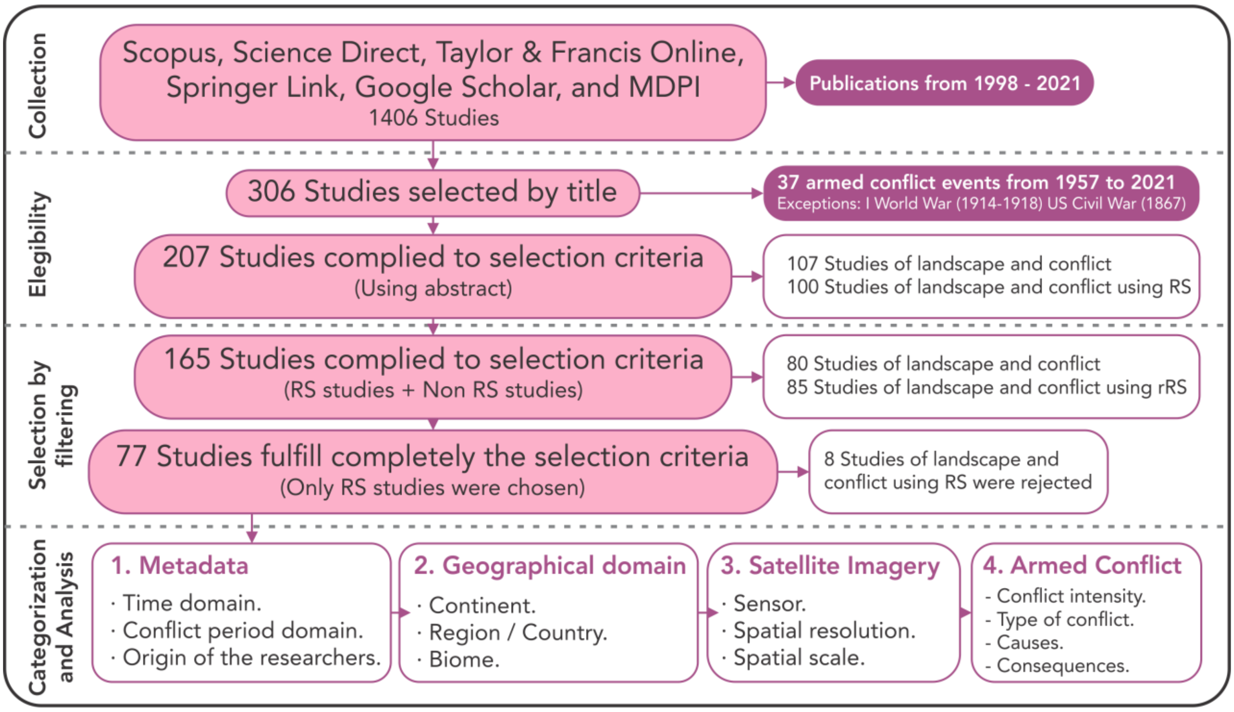


Figure 3.11: Worldwide case studies data acquisition, selection and classification.
(Source: Own figure)

Global case study results were categorized into four groups. The first group includes metadata, such as the time domain and conflict periods: pre-conflict (before violence), conflict (during military actions), and post-conflict (after peace agreements and cessation of military actions). The second group is organized by geographical region, encompassing the continent, region, country, and biome. Regions are large areas with distinct groups of countries, whereas biomes are geographical units that are based on the physical environment and regional climate. Whittaker's (1962) classification of natural communities, consisting of 18 biomes ranging from alpine tundra and arid desert (lowest forest cover) to tropical rainforests (highest forest cover), was used. The third group focuses on remote sensing features such as satellite imagery sensors, resolution, and spatial scales.

I categorized the study findings based on armed conflict data, such as conflict intensity, into three levels based on annual fatalities: Minor Armed Conflict (at least 25 but fewer than 1,000 battle-related deaths annually), intermediate (at least 25 annual deaths with a total of at least 1,000 but fewer than 1,000 deaths in any year), and war (at least 1,000 deaths per year). This classification accounts for the direct and indirect causes, consequences, and belligerent forces. Conflict types, as defined by Gleditsch et al. (2002) and the Uppsala Conflict Data Program (2021), include interstate conflicts (between states), extra-state conflicts (between a state and non-state group outside its territory), internationalized internal conflict (between a state government and internal opposition with foreign states' intervention), and internal conflict (between a state government and internal opposition without foreign intervention) (*Figure 3.11*). Further details regarding the classification of the characteristics of worldwide case studies are presented in *Appendix 3*.

Quantitative and statistical analyses of the parameters identified in these studies contribute to the understanding of key drivers and their impacts. I performed a meta-analysis to identify the output's trends, divergences, and convergences. I then performed correspondence analysis to establish the relationships between belligerent forcesaffo, causes, and consequences. The documents were read, evaluated, synthesized, and tabulated for processing; the results are presented in *Appendix 4*.

3.3.2. Colombian case studies. Data acquisition, selection and classification

I collected scholarly studies and reports from indexed databases, such as Scopus, Science Direct, Taylor & Francis Online, Springer Link, Google Scholar, and MDPI, covering 1994 to 2021 (916 case studies). Studies meeting these criteria appeared only from 2006. Initial keyword searches were "Remote Sensing + Colombian Conflict," "Multivariate + Colombian Conflict," "Deforestation + Colombian Armed Conflict," "Illicit Crops + Armed Conflict," and "Land Use Changes + Armed Conflict." From these, 108 studies were chosen by title and narrowed down to 87 after reading the abstracts. Further filtering used keywords such as multivariate analysis, satellite sensors, sequence deforestation, deforestation drivers, forestation, land-use change, proximate causes, deforestation causes, and forest cover change. Spanish articles using English keywords or abstracts were included in this study. After removing duplicates, 65 studies linked the Colombian Armed Conflict to environmental effects. The final review yielded 19 case studies that explicitly used RS methodologies to assess the topic and fulfilled all of the aforementioned parameters based on the data categories sought (*Figure 3.12*).

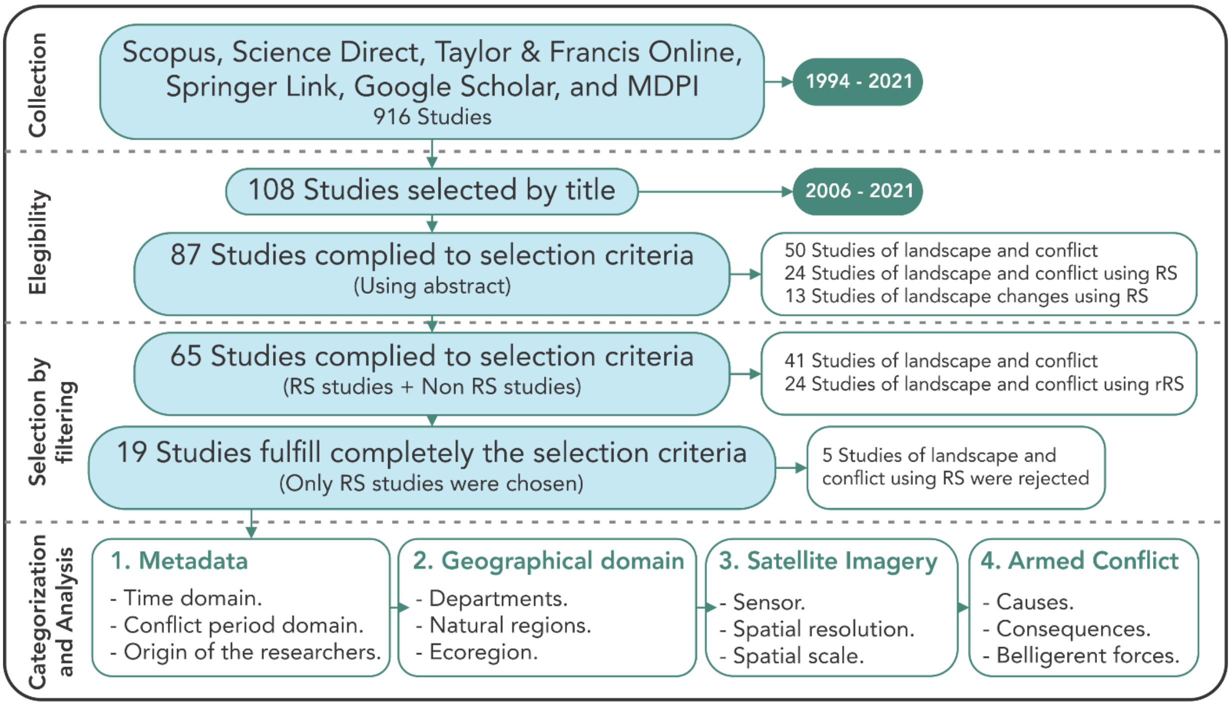


Figure 3.12: Colombian case studies data acquisition, selection and classification.
(Source: Own figure)

I classified the Colombian case studies into four categories. First, the studies were divided by time domain into three periods of armed conflict: (I) Conflict (2000-2011), characterized by high-intensity military actions; (II) Negotiations (2012-2016), marked by peace talks and reduced military actions due to ceasefires or truces; and (III) Post-conflict (2016-2021), following a peace agreement with the cessation of military actions. Second, the studies were categorized into three geographical domains: (I) By Departments, the thirty-two geopolitical administrative divisions, and a capital district, which are level-2 subdivisions with autonomy; (II) By Ecoregions, large geographical units with distinct natural communities and species, classified by forest cover density using the World Wildlife Fund ecoregion classification adapted for Colombia (Olson et al., 2001), ranging from the lowest (Guajira Xeric and Northern Páramo) to densest (Mag-Urabá Moist, Caquetá Moist, and Chocó-Darién Moist); and (III) by Natural Regions, large non-official territorial divisions based on terrain, climate, vegetation, and soil classes, differentiating six regions: Amazon, Andes, Caribbean, Insular, Orinoquia, and Pacific. Third, I sorted them based on satellite imagery features, such as sensor resolution and scale. Finally, I synthesized the findings of these studies according to direct and indirect causes, consequences, and belligerent forces (*Figure 3.12*). Further details regarding the classification of the characteristics of Colombian case studies are presented in *Appendix 5*.

Quantitative and statistical analyses of the parameters identified in these studies contribute to the understanding of key drivers and their impacts. I performed a meta-analysis to identify the output's trends, divergences, and convergences. I then performed correspondence analysis to establish the relationships between Colombian armed forces, conflict-derived causes, and conflict-derived consequences. The documents were read, evaluated, synthesized, and tabulated for processing; the results are presented in *Appendix 6*.

3.3.3. Regional case study - Sumapaz Páramo Region. Data acquisition, selection and categorization of independent variables

The spatiotemporal database included conflict events, changes in forest cover (forest disturbance), population, and other variables over the entire period from 2001 to 2020. Given that other drivers can also influence land cover change, other important drivers, such as environmental and social variables, were associated with each of these buffers. Data were collected for 34 variables in the study area. These variables were grouped into seven categories to evaluate their possible effects on landscape changes.

1. **Armed conflict:** Acts of War, Conflict Intensity-Fatalities, Terrorist Attacks, Enforced Disappearance, Homicides, Landmines, Kidnapping, Abandonment of Land, Slaughter, Torture, Threats.
2. **Demographic:** Population, Population Projection, Internally Displaced Person, Reinserted Guerrilleros, Agricultural Productive Unit, Population Age, Population Gender, Births, and Deaths.
3. **Socio-economic:** Unsatisfied Basic Needs, Poverty, Population by Socio-economic Level.
4. **Land Use:** Protected Area Boundaries.
5. **Infrastructure:** Paved Roads, Unpaved Roads, Dirt Roads.
6. **Physical environment:** Climate, Cloud Cover, Fires, Precipitations.
7. **Biodiversity:** Fauna, Flora, Biome.

The units of the independent variables, spatial resolution, descriptions, and sources are explained in detail in *Appendix 7*.

Armed conflict data acquisition

Data on armed conflict were sourced from the Memory and Conflict Observatory (OMC) database of the National Center for Historical Memory (CNMH, 2021), which integrates 592 sources and 10,236 databases and documents, forming the most extensive archive of Colombian internal armed conflict. The search parameters spanned from 2001 to 2020, focusing on rural areas of nine municipalities in the study area, including Sumapaz, the 20th District of Bogotá D.C. Conflict intensity was measured using two rates: the total number of victims, which includes the number of fatalities, missing persons, deaths due to landmines, and kidnapped individuals. The second variable is the number of armed conflict events. A conflict event includes attacks on civilian and military locations, the number of massacres, the number of infrastructure destruction, the number of kidnapping events, and forced disappearances. Additionally, the analysis detailed guerrilla attacks and deaths from military confrontations from 2001 to 2021, with most guerrilla activities occurring between 2001 and 2011. The focus was on the Fuerzas Armadas Revolucionarias de Colombia (FARC) because of their historical presence in Sumapaz.

Demographic and socio-economic data acquisition

I compiled demographic and socioeconomic information on the *Sumapaz Páramo Region*, including data on unsatisfied basic needs, poverty rates, population age, population gender, and the number of inhabitants. These data were obtained from the 2005, 2015, and 2020 population censuses (Departamento Administrativo Nacional de Estadística, DANE) and the projection rates from 2021 to 2035. The RUV, 2016; SIPOD, 2020; UARIV, 2020, and UNHCR 2020 statistics reference databases have provided an index of Internally Displaced People (IDP).

Land use and physical environment data acquisition

Climatic variables, such as monthly precipitation and temperature, were derived from IDEAM 2020 and averaged for the study area. These variables were derived from the climatic database of meteorological stations. For fires data, I used the fire report dataset from 1998 to 2021, carried out by IDIGER, 2020 dataset. Digital maps (1:500,000) of the national protected areas (WDPA-IUCN, 2020), municipalities, road networks, and human settlements were obtained from the Geographical Information System for Planning and National Territorial Ordering in the Geoportal of the Agustin Codazzi Geographical Institute (SIGOT-IGAC, 2018). SIGOT-IGAC also provided a digital elevation model based on the Shuttle Radar Topography Mission (SRTM-NASA, 90 m resolution), from which a slope map (in degrees) was derived and I used to classy the disturbance by elevation in three altitude classes: high mountain forest, sub-paramo, and paramo. Sumapaz-Cruz Verde Páramo Ecosystem boundaries were obtained from the Geoportal of Alexander von Humboldt Biological Resources (HUMBOLDT 2019).

Infrastructure (road network) data acquisition

The SIGOT-IGAC data portal provides a dataset of roads and tracks within the study area. However, because of its lack of accuracy and completeness for Remote Sensing road proximity analysis, the dataset was manually supplemented and refined using QGIS 2.18 Las Palmas software based on visual interpretation of Landsat 4-5 TM and Landsat 7 ETM+ satellite imagery. This was further supported by interviews with the local residents. Linear infrastructure was categorized into paved roads, unpaved roads, and dirt roads, with sub-classifications for roads built by the FARC-Guerrilla or the National Army, and those constructed by the state or community. The variables were defined as the total length per road type within the total area of each region. In addition to official road network data, interviews with local community leaders who mapped the roads they helped build and those constructed by the FARC were conducted. These leaders identified where the bulldozer operated and provided the georeferenced data. These georeferenced tracks and sketches were overlaid on satellite imagery. The map does not fully represent the rural feeder road network in the *Sumapaz Páramo Region* or the road system constructed between the FARC in Cundinamarca and neighboring departments. All interviews took place between October 2021 and January 2022, and interviewees' anonymity was preserved through pseudonyms.

3.4. Spatiotemporal analysis methodology

The methodology of the study area was divided into four segments. The first segment involved detecting forest disturbances by creating annual vegetation cover maps from 2001 to 2020 using Google Earth Engine (GEE) and Landsat time-series imagery. I then analyzed the forest disturbance differences in impact levels among various spatial units of the *Sumapaz Páramo*

Region (SPR; FPTZ, SNP, XSPR, XSPR and SNP). The second segment examined the relationship between forest disturbance changes and stages of armed conflict based on conflict intensity rates. A statistical model was used to test the impact of armed conflict events on the vegetation cover. The third segment correlates disturbances with military road network proximity using a statistical model. The fourth segment assessed local communities' perceptions of the relationship between armed conflict and the landscape through interviews and structured surveys.

3.4.1. Satellite imagery acquisition and pre-processing

I imported the Global Forest Change dataset (Hansen *et al.*, 2013) into Google Earth Engine (GEE) to detect forest changes at a 30 m resolution. Dry season imagery (December to February) is preferable for land-cover mapping because of the low cloud cover compared to the rainy or winter seasons. Therefore, I utilized Landsat 4-5 TM, 7 ETM+, and 8 OLI satellite images from the U.S. Geological Service, covering 2001-2020 with less than 30% cloud cover. I employed a collection of level-1 terrain-corrected Landsat surface reflectance imagery across 10 WRS-2 tiles for the 2001–2020 time series. Preprocessing included the following automated steps: (I) image resampling, (II) conversion of raw digital values (DN) to top-of-atmosphere (TOA) reflectance, (III) cloud/shadow/water screening and quality assessment (QA), and (IV) image normalization. (*Figure 3.13*).

The unique conditions of the paramo, such as high altitude, cloudiness, high ultraviolet radiation, intense daily temperature fluctuations, marked seasonality due to rainfall, extreme photosynthetic activity, and insolation followed by significant cloudiness with low radiation, daily soil freezing and thawing, underdeveloped acidic oligotrophic soils deficient in plant nutrition, and hypoxia due to low atmospheric pressure, resulted in vegetation under 5m in height with low chlorophyll (greenish leaves) and high anthocyanin (reddish-brown leaves). This, combined with rocky ground cover blending with bare ground, complicates the performance of the standard vegetation cover disturbance algorithms. These conditions forced the modification and adaptation of disturbance detection parameters in the landscape to levels distinct from those in tropical forests. I conducted a visual analysis by combining three information bands from each satellite image to create false and true color images using red-green-blue (RGB) channels. A sequence of filters and data purification steps was implemented. Pixel correction using proximity and similarity was applied to the original imagery to remove misclassified pixels (*Figure 3.13*).

I corrected the apparent errors in the dataset, notably those associated with SCL-off from Landsat 7 ETM+. High-resolution imagery from Google Earth and Bing Maps was used to verify issues in the change detection disturbances. I meticulously examined small, isolated disturbed patches to identify anomalous pixels, particularly in the upper paramo with minimal tree cover. Spatial filters, such as majority filters, were not used to preserve small changes related to subsistence agriculture. These measures are crucial to minimize significant false disturbance detections caused by topographic effects, cloud shadows, and mixed land-use areas prevalent in our study region.

3.4.2. Forest disturbance detection

The analysis utilized the GEE platform with the aforementioned Landsat imagery dataset. Here, "tree cover" refers to all vegetation over 5 m in height, including natural forests or plantations with varying canopy densities. Forest disturbances identified by the dataset were associated with complete forest conversion to other land uses or degradation, marked by gradual vegetation decline or temporary changes. The automated GEE process integrates all Landsat spectral bands for consistent disturbance detection. Disturbed forest areas were calculated annually and reported for three periods: conflict period (2001-2012), negotiation period (2013-2016), and post-peace agreement period (2016-2020). Disturbances were compiled for both the study area and a 1 km external buffer zone for each conflict stage. Disturbances were classified by elevation using the SRTM-NASA digital elevation model as high mountain forests, sub-paramos, and paramos (Farr *et al.*, 2007). Disturbance areas and patch numbers were aggregated at a 10 km grid size to identify the most affected locations spatially. The algorithm outputs involve a magnitude of change, date, and location (*Figure 3.13*). The magnitude of the change threshold was calculated to remove spurious breakpoints unrelated to forest disturbance. Post-GEE analysis, images were processed in ArcGIS10.1 and QGIS 2.18 Las Palmas.

The analysis covered the following spatial units of the Study Area: *Sumapaz Páramo Region* (SPR, 2407 km²), Buffer Area: Forest-Páramo Transition Zone (FPTZ, 705 km²), Extended Study Area (SPR+FPTZ, 3112 km²), Protected Area within SPR: Sumapaz National Park (SNP, 1298 km²), and SPR excluding SNP (1108 km²). Additionally, road proximity disturbance was detected at distances of 500 m, 1000 m, and 1500 m, categorized into civil and military purpose-built roads.

3.5. Statistical model

3.5.1. Relationship between forest disturbance rates and conflict intensity rates

In this study, I assessed the relationship between conflict-intensity rates and forest disturbance rates in the study area (*Sumapaz Páramo Region*-SPR) and the 1 km buffer area (*Forest-Páramo Transition Zone* -FPTZ). Conflict events were considered to be as spatially and temporally implicit influences on land cover, but not as the primary cause of landscape changes. Roads built by the FARC guerrilla and the National Army were included as indirect conflict-derived causes, acting as explicit influences on land cover and triggers for landscape changes. Access to information on specific violent events in the Sumapaz region is limited and restricted, leading to ignorance of their exact locations and dates. These events, related to the Colombian armed conflict, such as the location of bombings, military confrontations, and antipersonnel mines, are likely to affect the landscape. Hence, in this study, an explicit correlation analysis did not include these variables because of the lack of geospatial and temporal references.

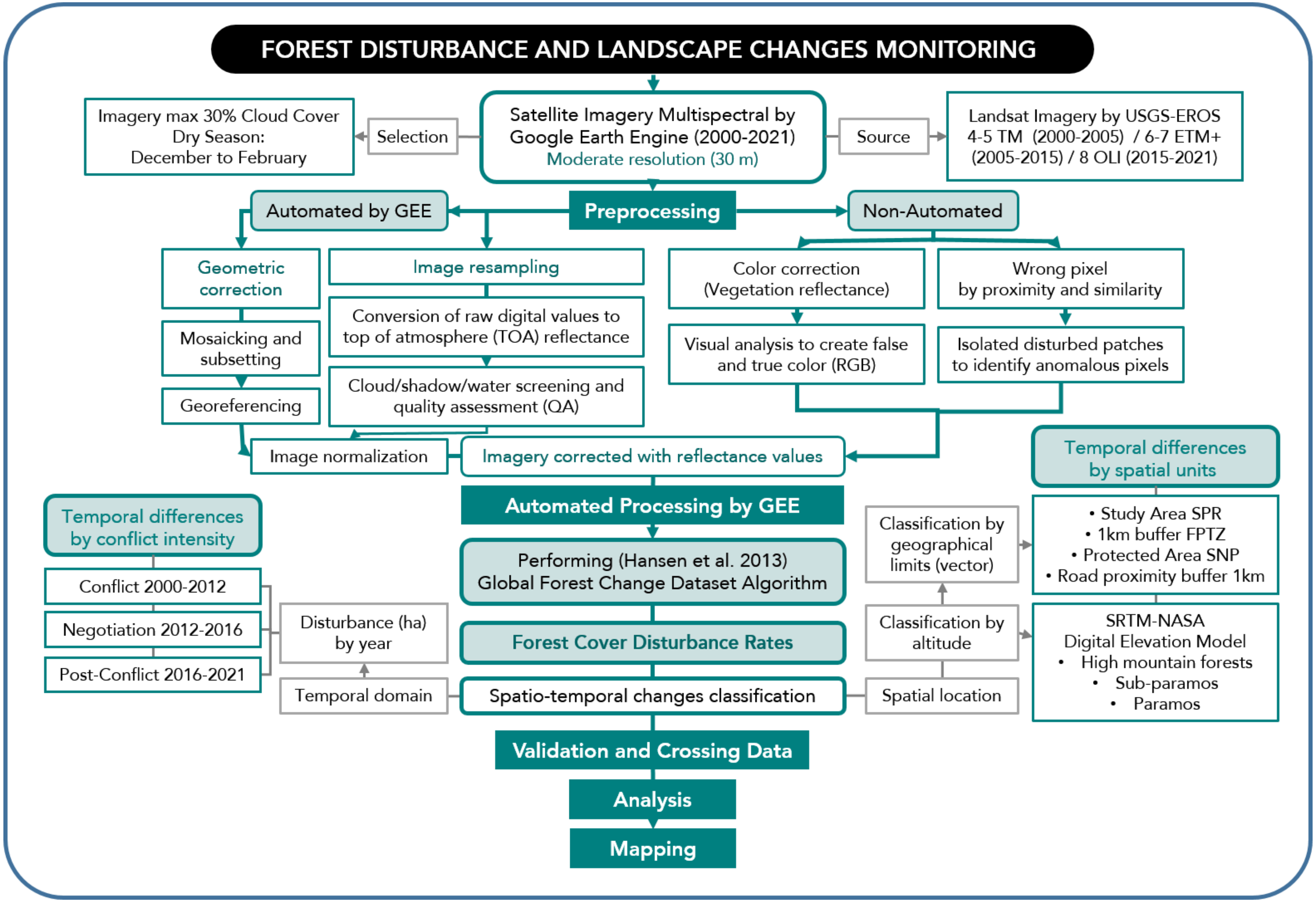


Figure 3.13: Scheme of forest disturbance detection by remote sensing. (Source: Own figure)

The assumption is that, in the specific case of the *Sumapaz Páramo Region* in periods with high-intensity conflict rates, the areas follow a significantly higher forest disturbance trend compared to the same areas that experience a decrease in forest disturbance rates during the low-intensity conflict rates or post-conflict periods (*Figure 3.14*).

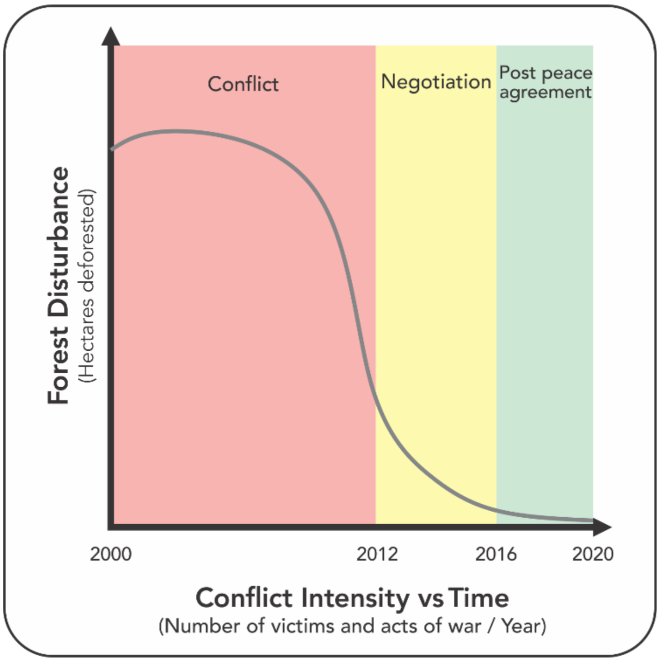


Figure 3.14: Forest disturbance vs Conflict intensity rates assumption.
(Source: Own figure)

I applied Bivariate Pearson's correlation coefficients and Marascuilo's procedure to examine and compare the varying relationships between conflict intensity rates on a regional scale and geospatial characteristics, such as road proximity and forest disturbance area. I tracked forest disturbance was tracked by hectares in the study area (study area SPR and FPTZ 1 km buffer). I then explored the direct (military roads) and indirect (conflict intensity rates) effects of conflict-related events on forest disturbance. A general linear model (GLM) was used to explore the relationships between ha-disturbed and conflict-related variables (conflict intensity rates), and physical environment variables (road proximity distance). Statistical analyses were performed using SPSS v27.0, Excel v2013, and R v4.1.1 software.

I set out the following from the raw dataset with disturbance frequency records on:

$$r = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}}$$

r = [Equation]

Σ = Number of pairs of sources

Σxy = Sum of the products "Disturbance *ha*" * "Act of War / Fatalities + Injuries"

Σx = Sum of "Disturbance *ha*"

Σy = Sum of "Act of War / Fatalities + Injuries"

Σx^2 = Sum of squared "Disturbance *ha*"

Σy^2 = Sum of squared "Act of War / Fatalities + Injuries"

Bivariate Pearson's correlation coefficients were calculated for the raw variables. Next, the cumulative disturbance values over the investigated interval were computed to identify trends. The record of disturbed areas for a year can overlap with that of the previous years. I reasoned this step because, in this case, the disturbance problem has an accumulated effect weighted by extended time. For the cumulated data, I calculated Pearson's correlation of the study area and disturbance variables during the 'conflict,' 'negotiation,' and 'post-agreement' periods. Additionally, I determined the slopes and correlation coefficients of the linear trends in the time series, including the corresponding p-values. Given the unique features of the study area, disturbances in land cover have accumulated and persisted for months or years. Thus, for a more accurate analysis, I conducted geospatial comparisons using five-year intervals to better capture the conflict and post-conflict dynamics in the landscape. Consequently, I calculated the slopes of the cumulative values running a linear trend with a 5-year window.

3.5.2. Forest disturbances comparison between the study area and the buffer area

I assumed that in the lower altitude ecosystem 1 km buffer area, defined as the Forest-Páramo Transition Zone (FPTZ; Foggy Andean Forest) located between 2500-3000 m above sea level, presents higher rates of vegetation disturbance proportionally in hectares than in higher altitude ecosystems such as the *Sumapaz Páramo Region* (SPR) (Between 3000-4300 m above sea level) (*Figure 3.15*). This assumption is based on the following premises.

- Lower altitude ecosystems such as the foggy Andean forest (FPTZ) contain denser, taller, and woody vegetation cover, which tends to prompt deforestation.
- Vegetation in lower altitude ecosystems (FPTZ) contains greener vegetation cover owing to the higher quantity of chlorophyll, which makes it easier to identify disturbances using remote sensing technologies.
- In lower altitude ecosystems (FPTZ), there is a greater population living within its borders due to better conditions for living and cropping, which prompts an increase in deforestation and degradation rates.
- In the lower altitude ecosystems (FPTZ), there were more severe conflict-related events in intensity and quantity than in the high-altitude ecosystems (SPR), such as in paramo, making identifying disturbance patches related to the conflict more visible.

I ran Z-tests of proportion comparisons for all studied years. 2001-–2020. The evaluated proportions were calculated annually as follows: The disturbance in the Study Area SPR 0 km buffer/total area, and the disturbance only in the FPTZ 1 km buffer/total area of 1 km buffer.

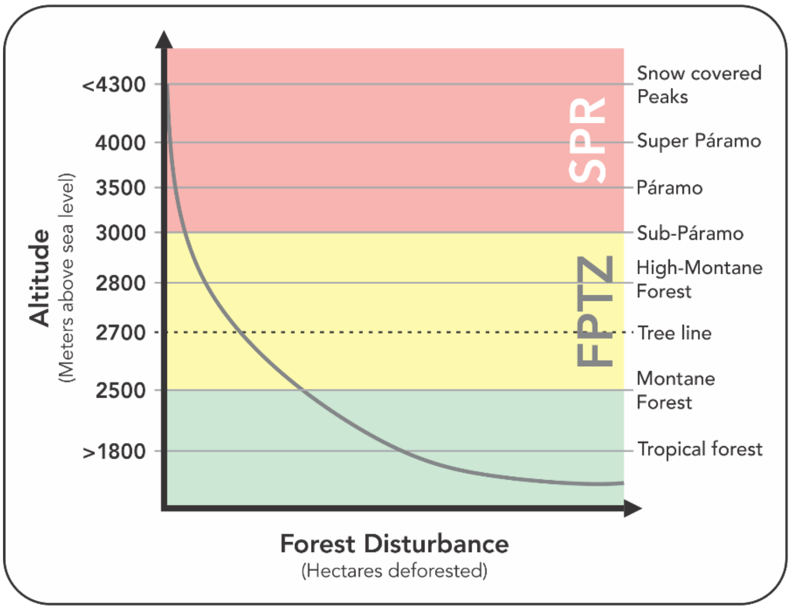


Figure 3.15: Forest disturbance vs Altitude assumption. (Source: Own figure)

3.5.3. The influence of the military road network on landscape changes

Indirect causes derived from Colombian armed conflict, such as military infrastructure, significantly disturb vegetation in the *Sumapaz Páramo Region*. Specifically, the unpaved road network constructed by the FARC guerrilla and the National Army is a major factor. It is assumed that vegetation disturbance patches increase in proximity to these roads, and the influence of roads on landscape changes diminishes with distance. This trend would be observed significantly from 2001 to 2012 (*Figure 3.16*). Using Marascuilo's procedure, I compared the proximity disturbance ratios at distances of 500m, 1000m, and 1500m from the road.

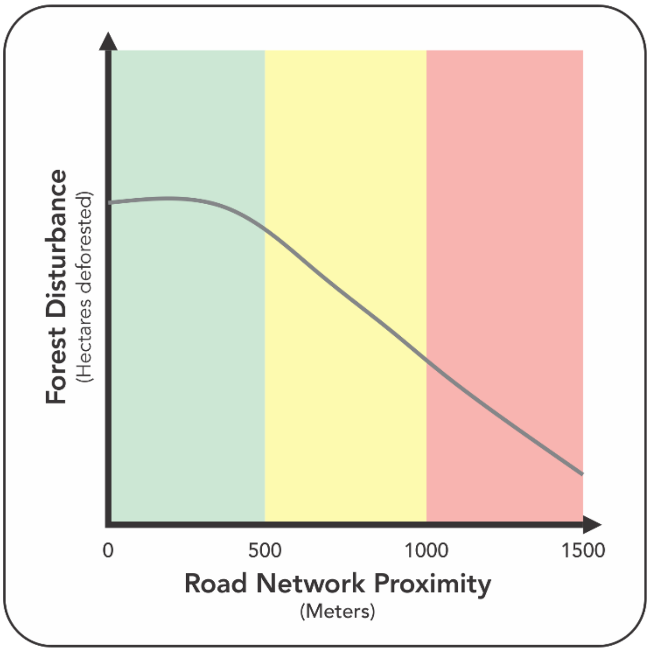


Figure 3.16: Forest disturbance vs Road network proximity assumption.
(Source: Own figure)

3.6. Landscape changes perceptions. Data collection and processing

I collected local communities' landscape changes perceptions in *Sumapaz Páramo Region* villages. Semi-structured surveys (*Appendix 8*) and interviews were conducted over six months to study the perceptions of landscape and armed conflict interactions (Van Dexter and Visseren-Hamakers, 2020) (*Figure 3.17 and 3.18*). Ethnographic data were gathered during four site visits, incorporating participant observation with rural farmers, local leaders, and public officers, with the support of Dr. Maira Judith Contreras Santos from the *Universidad al Páramo* Program, Faculty of Geography, National University of Colombia. The interviewees were selected voluntarily through purposive sampling due to their involvement in social activities, agriculture, education, administration, and local projects that affect land use. Semi-structured interviews were conducted with farmers and community leaders, focusing on ecosystem services, drivers of change, consequences, conservation, triggers of change, and the relationship between armed conflict and environment during and after the conflict. Government officials and park rangers citing privacy policies and impartiality declined to participate. The National Army was contacted for conflict data, but did not provide satisfactory responses for interviews and surveys with soldiers. Owing to the lengthy and demanding permission process, the study proceeded without the National Army's official input.

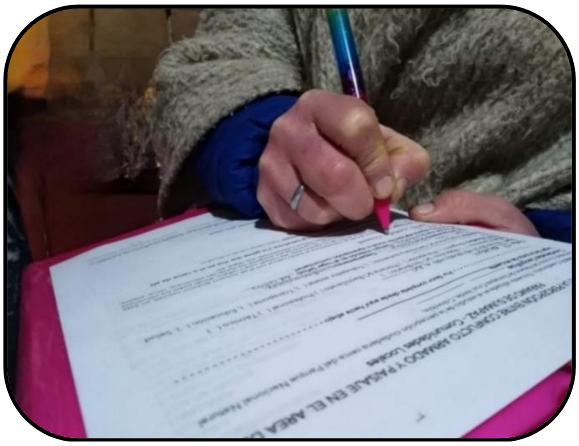


Figure 3.17: Local responder. (Source: Own photo)

I employed a semi-structured, in-person survey, and a Google Forms online semi-structured survey (*Appendix 8*, available online at https://forms.gle/PzHKokEkCyA7a4hu6), each comprising 8 personal data questions and 14 conflict-landscape perception questions. The survey was developed using literature reviews (Marta-Pedroso, Freitas and Domingos, 2007; Andrade C. *et al.*, 2017; De Pourcq *et al.*, 2019; Pedraza *et al.*, 2020) and consultations with Sumapaz National Park officials and local community leaders. Five leaders and researchers piloted the survey and feedback was used to refine the questions to minimize fatigue and improve comprehension. Surveys were administered in various villages, public schools, plazas, and settlements in collaboration with local students and the *Sindicato Campesino del Sumapaz* to ensure representativeness. The municipalities were visited between November 2021 and January 2022; however, online surveys were conducted until April 2022. Onsite samples were collected from rural villages in the 20th locality of Sumapaz – Bogotá, including Nazareth, San Juan de Sumapaz, and Betania. Surveys targeted residents or recent residents of the region. 32 respondents participated: 13 online digital and 19 onsite, paper-based and in person (*Figure 3.18*).

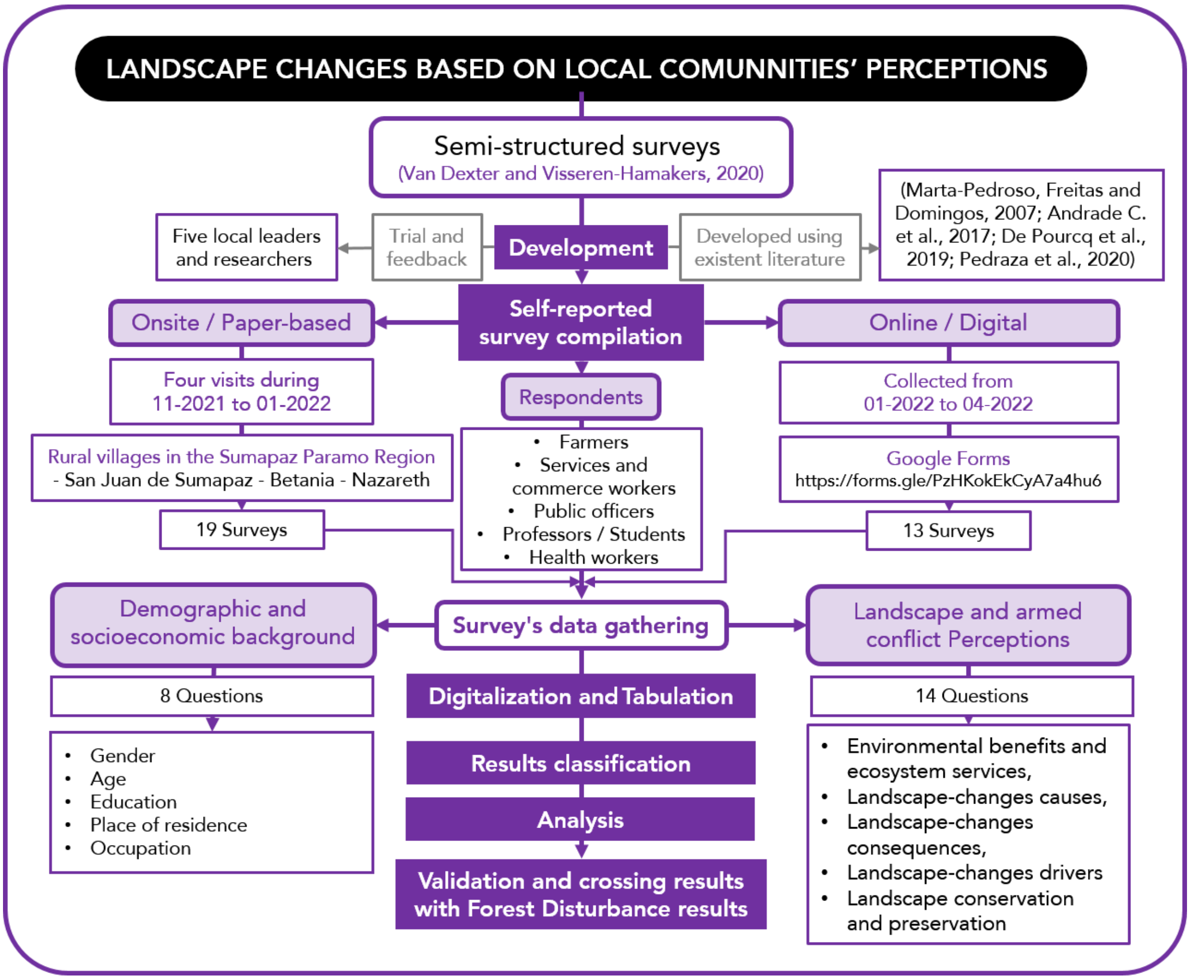


Figure 3.18: Scheme of landscape changes perceptions by locals (Source: Own figure)

Upon obtaining consent from the respondents, the in-person surveys commenced with an introduction to the project objectives and a description of the "Landscape" concept. The survey was conducted in two parts. The first part collected self-reported demographic and socioeconomic data (e.g., gender, age, education, residence, and occupation). The second part assessed perceptions of landscape-related issues and armed conflict (including causes, consequences, belligerent forces, and conservation status). I examined the relationship between deforestation data and conflict-related variables using survey responses on human-nature issues (i.e., 'ecosystem services'), anthropogenic problems, and conservation efforts. The survey responses were digitized, and groups of questions and answers were consolidated to create five perception indices. After classification, the perception variables were assigned a numerical scale into five categories: (I) environmental benefits and ecosystem services, (II) landscape change conflict-derived causes, (III) landscape change consequences, (IV) landscape change drivers, and V) landscape conservation and preservation (*Appendix 8*). I then analyzed the numerical results and synthesized them. Finally, the results were validated and compared with the forest disturbance results to identify similarities, differences, and patterns (*Figure 3.18*). Understanding the impact of armed conflict on deforestation and analyzing local perceptions are crucial for validating remote sensing results.

4. RESULTS

4.1. Landscape and armed conflict: Worldwide case studies

4.1.1. Time domain and type of armed conflict

A systematic search identified 77 studies that used remote sensing to examine the environmental and landscape impacts of armed conflicts, with publications dating from 1998 to 2021 (*Appendix 4*). These studies show a notable increase from 2008 to 2019, partly because of the reduction or cessation of major conflicts in regions such as Colombia and sub-Saharan Africa after 2014, which has led to more studies (Burgess, Miguel and Stanton, 2015; Butsic *et al.*, 2015; Chadid *et al.*, 2015; Sosnowski *et al.*, 2016; Murad and Pearse, 2018; Clerici *et al.*, 2020; Mendoza, 2020). The average publication rate rose from 0.8 articles per year (1998-2007) to 4.92 articles per year (2008-2021), indicating a nearly fivefold increase (*Figure 4.1*).

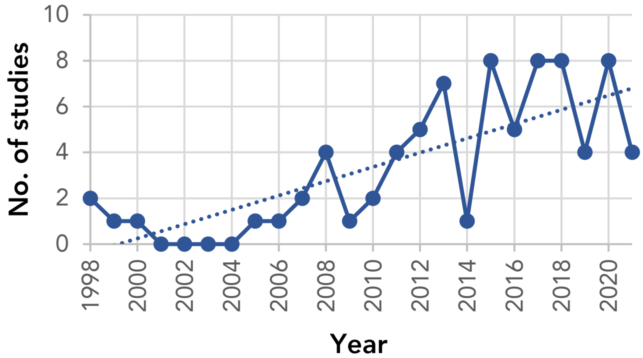
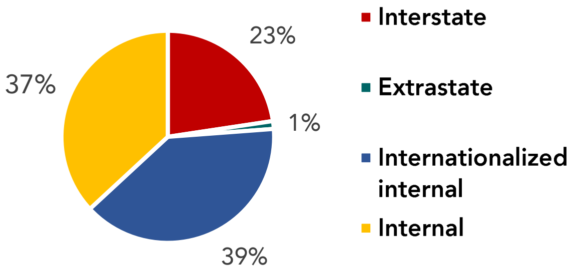


Figure 4.1: Publications per year. (Source: Own figure)

The database was organized according to the types of armed conflict defined by Gleditsch et al. (2002) and the Uppsala Conflict Data Program 2021. Of the publications, 39.3% examined *internationalized internal conflicts*, involving a state government and internal opposition groups with external state intervention (Loucks *et al.*, 2009; Bromley, 2010; Brown, 2010; Wilson and Wilson, 2013; Kranz, Sachs and Lang, 2015; Eklund *et al.*, 2017; Knoth and Pebesma, 2017; Wales, 2020). Additionally, 37% analyzed *internal conflicts* between a state government and internal opposition without external intervention (Armenteras *et al.*, 2006, 2011, 2013; Hecht and Saatchi, 2007; Ayana *et al.*, 2016; Cabral and Costa, 2017; Armenteras, Schneider and Dávalos, 2019; Cabrera *et al.*, 2020; Murillo-Sandoval, 2020; Murillo-Sandoval *et al.*, 2021). Furthermore, 22.6% focused on *interstate conflicts* between two or more states (Kwarteng, 1998; Abuelgasim *et al.*, 1999; Bjorgo, 2000; de Beurs and Henebry, 2008; Baumann *et al.*, 2015; Stichelbaut *et al.*, 2016; Ingalls and Mansfield, 2017; Kong *et al.*, 2019; Beygi Heidarlou *et al.*, 2020; Wales, 2020). Only 1.2% of the studies addressed *extra-state* conflicts involving a state and a non-state group outside its territory (van Etten *et al.*, 2008) (*Figure 4.2*). Further details regarding the characteristics of the studied Armed Conflicts are presented in *Appendix 9*.

The second categorization, based on the conflict intensity variable (Uppsala Conflict Data Program 2021), defines violence levels annually. Intensity is divided into three categories by annual fatalities: 33.7% of studies addressed *Minor Armed Conflict*, with at least 25 but fewer than 1,000 conflict-related deaths per year. Additionally, 30.1% analyzed *Intermediate Armed Conflict*, with at least 25 deaths annually and a total of 1,000 deaths, but fewer than 1,000 deaths in any single year. Finally, 36.2% focused on conflicts classified as *War*, with at least 1,000 conflict-related deaths per year. It is important to highlight that the same study could have analyzed a conflict in two periods of different intensities (*Figure 4.3 and Appendix 9*).



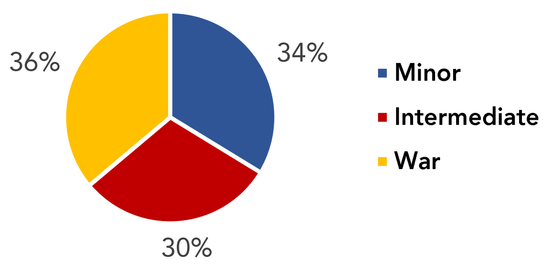


Figure 4.2: Type of armed conflict.
(Source: Own figure)

Figure 4.3: Armed conflict intensity.
(Source: Own figure)

I identified which conflict stages were analyzed and compared within the studies. Armed conflict has three main phases: *Pre-conflict*, the period before the conflict is used as a reference for comparative analysis in remote sensing studies; *Conflict*, the period of military action; and *Post-conflict*, following a peace agreement or ceasefire when military actions cease. The negotiation or truce period, which is part of the post-conflict period, was excluded from this study due to insufficient information. The research found that 35% of the studies analyzed pre-conflict satellite imagery, 87% analyzed conflict imagery, and 58.4% analyzed post-conflict imagery. Additionally, 44% of the publications focused on a single conflict stage without comparison, 28% compared two stages, and 28% analyzed all three stages.

4.1.2. Geographical domain and type of biome

Most studies utilizing remote sensing to examine environmental impacts in conflict zones have focused on equatorial regions, the planet's most biodiverse areas (*Appendix 4*). Africa accounted for 32% of these studies: 31% in Asia, 28% in the Americas, and 9% in Europe. Case studies predominantly occurred in equatorial countries, with Colombia, South Sudan, and Sudan comprising more than one-third (38.3%) of the studies. Another 31.4% of the studies were dispersed across tropical regions near the equator, including Southeast Asia, sub-Saharan Africa, and Central America, while 9.3% were in temperate European zones and 5.8% in temperate Asian regions. Fourteen percent of the studies were conducted in Middle Eastern countries with arid, semi-arid, or grassland cover (*Figure 4.4*). Some studies have employed remote sensing to study conflict-related ecological and wildlife impacts or to identify at-risk animal populations, but these topics are beyond the scope of this review and were not included. This analysis covers research up to 2020, prior to conflicts such as the 2022 Russian invasion of Ukraine, the 2022 Armenian-Azerbaijani border conflict, and the 2023 Israel-Hamas conflict in Gaza.

Unlike country borders, biome boundaries are rarely clear, and are completely defined. Several studies have examined the effects of warfare in multiple biomes. Among the 77 studies reviewed, 14 types of biomes were analyzed using RS in 170 cases. This indicates that each study might have employed multiple sensors to assess more than one biome based on the imagery dataset, complexity, and availability. Analysis of studies by biome revealed that high biodiversity areas near the equator, line such as tropical rainforests (41.5%), grass savannas (31.2%), monsoon/dry forests (27.3%), and tree savannas (22%), had the most studies. Substantial research has been conducted in subtropical regions, including montane forests (26%), semiarid deserts (23.4%), temperate broadleaf forests (9.1%), subtropical dry forests (7.8%), subtropical rainforests (5.2%), and alpine tundras (2.6%). Studies on temperate biomes included dry steppe (10.4%), Mediterranean vegetation (9.1%), xeric shrubland (4%), and arid desert (1.3%) (*Figures 4.5 and 4.6*).

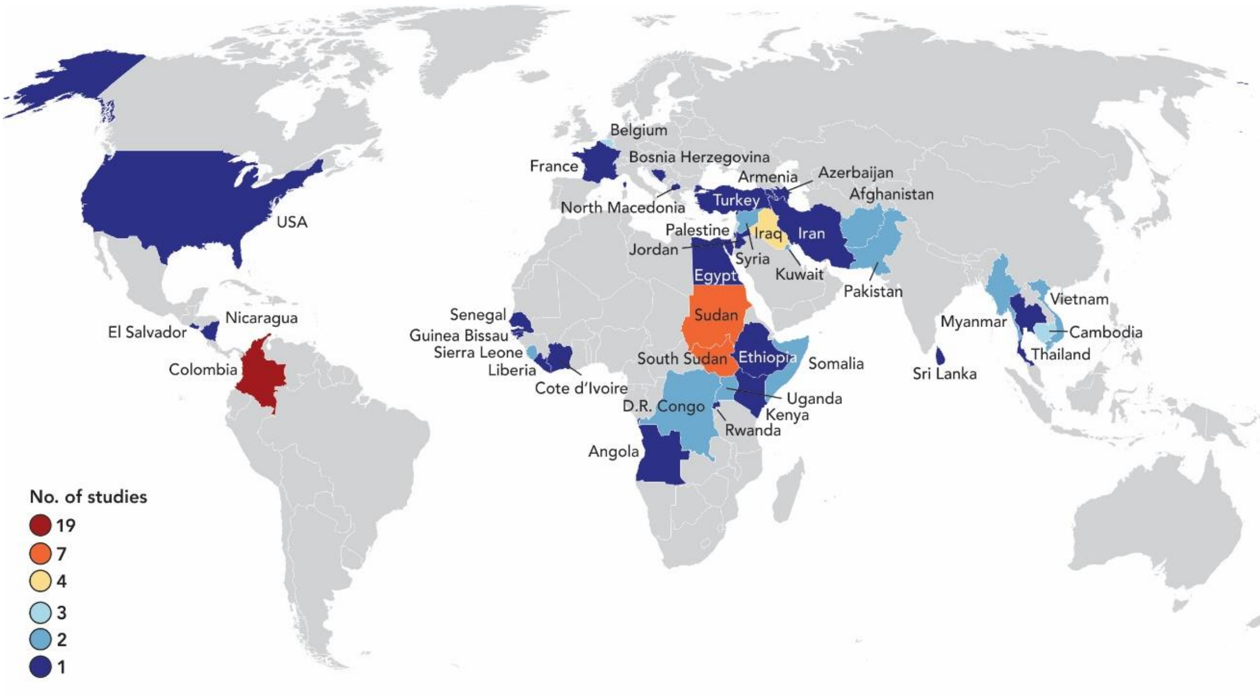


Figure 4.4: Geographical distribution of case studies by country of the conflict. (Source: Own figure)

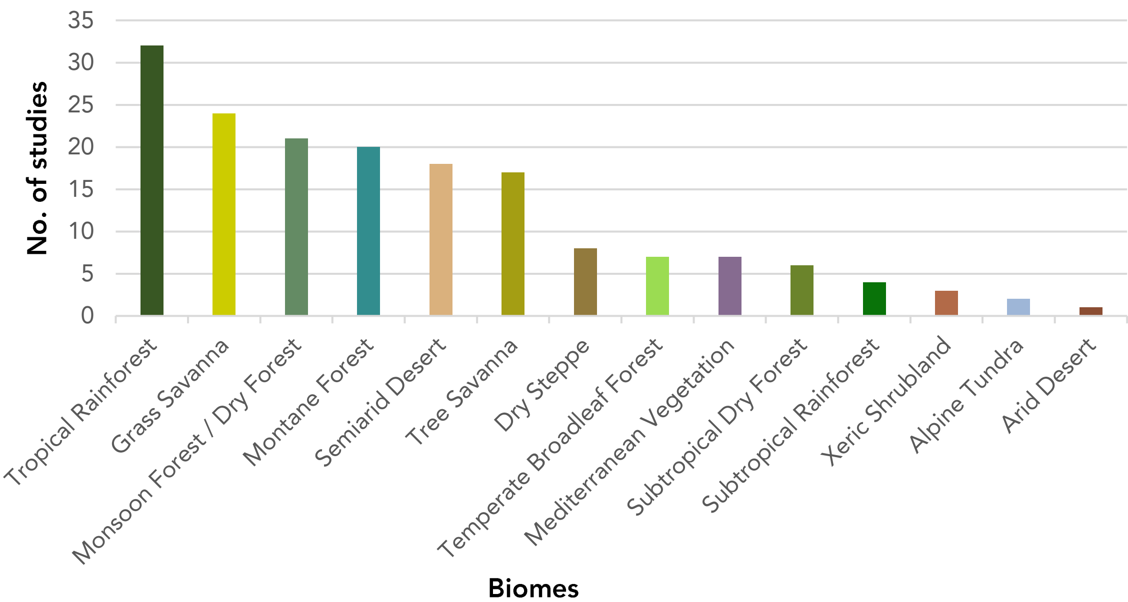
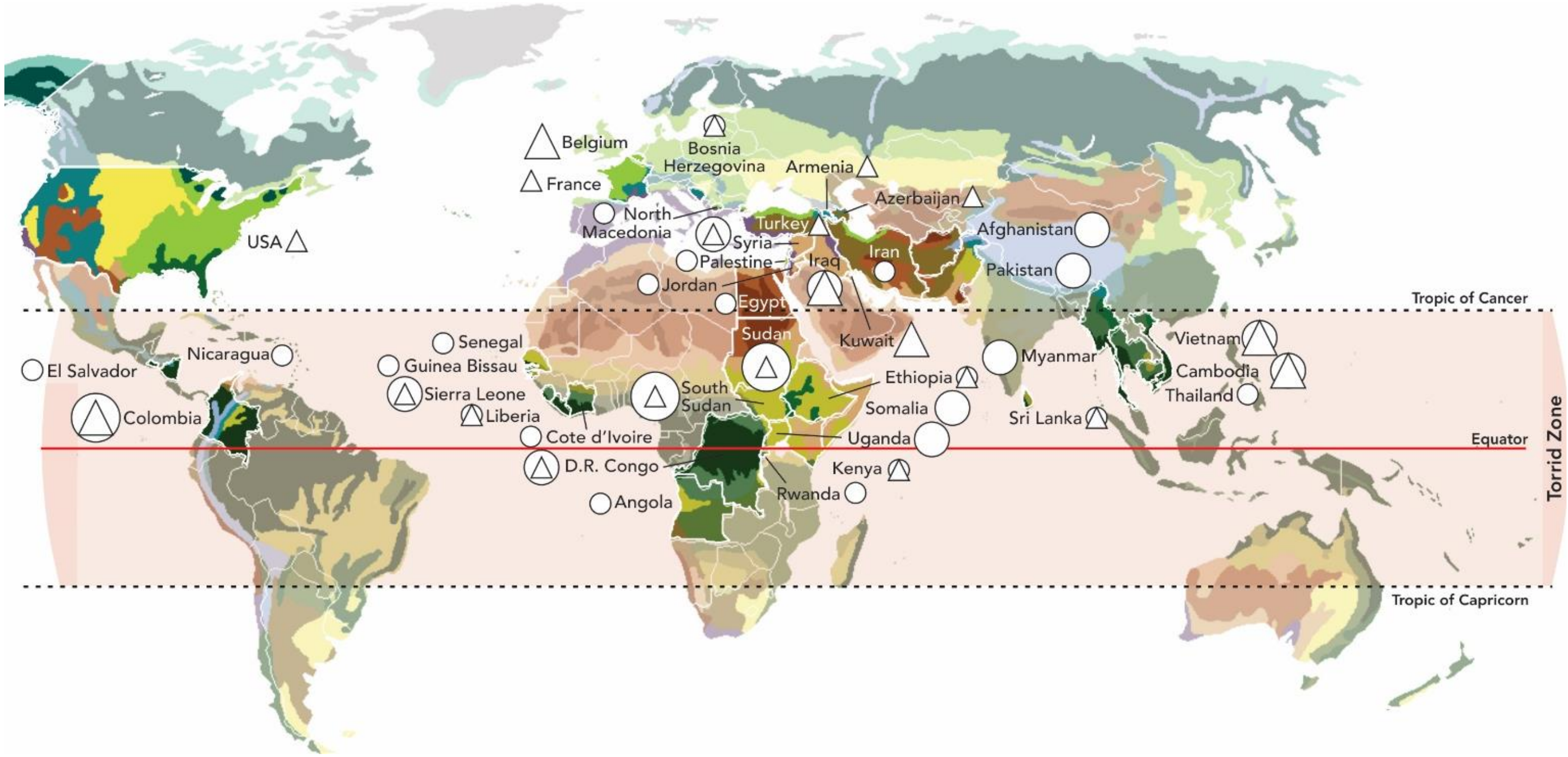


Figure 4.5: Number of studies by type of biome. (Source: Own figure)



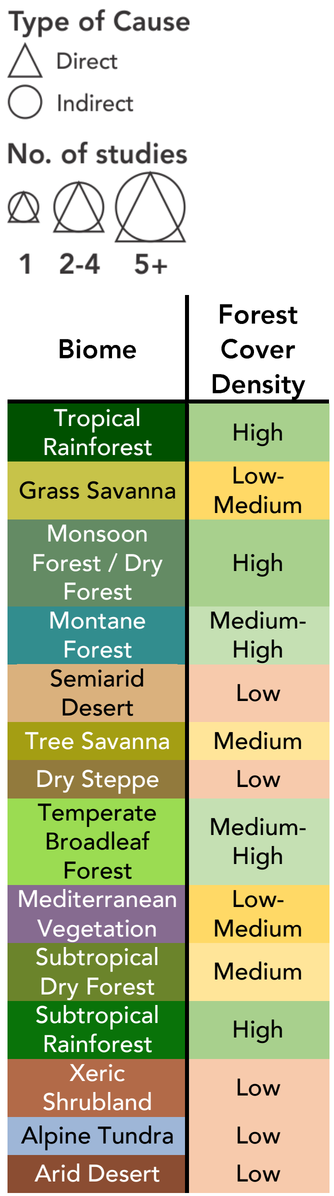


Figure 4.6: Geographical distribution of studies by biome. (Source: Own figure)

4.1.3. Satellite imagery sensor and biome

Table 4.1 is based on an extensive analysis of cross-referenced data on biome types and satellite imagery sensors for remote sensing (RS). The analysis indicated that Moderate-resolution sensors (10-120 m) were used in 66.2% of studies (Gorsevski *et al.*, 2012; Butsic *et al.*, 2015; Leiterer *et al.*, 2018; Murad and Pearse, 2018). The most frequently used sensors were Landsat 4-5 TM and Landsat 7 ETM+ for biomes such as tropical rainforests, monsoon/dry forests, montane forests, tree savannas, and grass savannas, with Landsat 8 OLI also relevant. Fine-resolution sensors (1-10 m) were used in 27.3% of the studies, with Google Earth VHR and SPOT-5 being the most common for studying tropical rainforests, monsoon/dry forests, montane forests, tree savannas, grass savannas, and semi-arid deserts (Petit, Scudder and Lambin, 2001; Qamer *et al.*, 2012).

Very Fine sensors (≤1 m) were used in 22% of studies. Quickbird II, IKONOS, and World View II are the most frequently used sensors in biomes with medium or low-level forest cover, such as tree savannas, grass savannas, and semiarid deserts. GeoEye sensors have been used once in non-common biomes such as xeric shrublands, dry steppes, and alpine tundra. Coarse-resolution sensors (>250 m) appeared in 20.8% of the studies, with MODIS being the most common for biomes such as grass savannas and tree savannas (Hecht and Saatchi, 2007; Gorsevski *et al.*, 2012; Sanchez-Cuervo and Aide, 2013; Sosnowski *et al.*, 2016). Uncategorized sensors were used in 11.7% of studies. Aerial photographs were mainly used in temperate broadleaf forests (Note *et al.*, 2018) (*Figure 4.7*). *Appendix 2* presents details of the characteristics of the most common sensors.

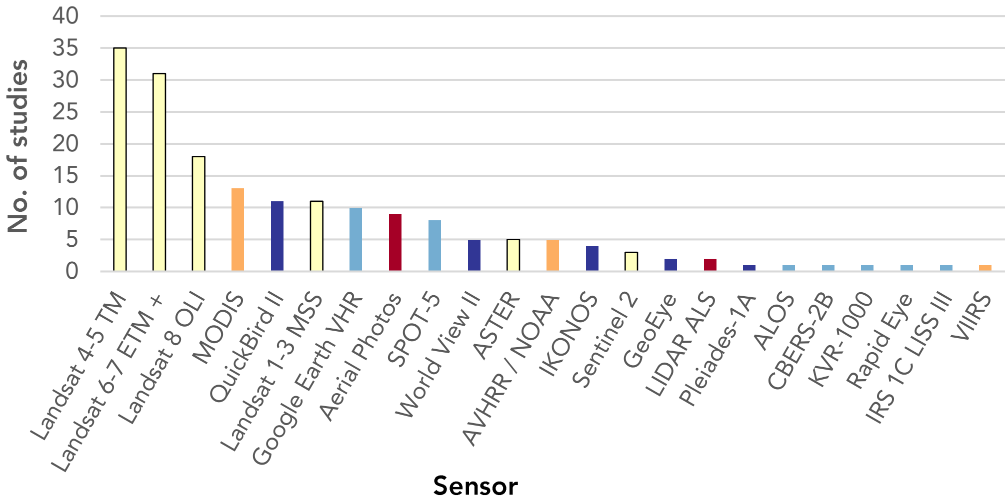


Figure 4.7: Studies by satellite imagery sensor. (Source: Own figure)

An analysis of various case studies revealed that 67.5% depended on multiple sensors for satellite imagery, which is often necessary for comprehensive analysis. The key reasons for this include temporal limitations, lack of high-resolution images, unavailability of cloud-free imagery, and the need for specialized satellite data for multivariate remote sensing in specific fields. These findings highlight the importance of multi-sensor approaches for accurate and reliable satellite imaging analyses.

Table 4.1: Satellite imagery sensor vs Biome. (Source: Own figure)

Satellite Imagery Sensor / Biome	Very Fine (≤1m)					Fine (>1–10m)							Moderate (>10–120m)						Coarse (>250 m)			No Class		
	GeoEye	WV II	Pleiades	QuickBird II	IKONOS	ALOS	SPOT-5	CBERS-2B	KVR-1000	Rapid Eye	Google E. VHR	IRS 1C	Sentinel-2	ASTER	LS 8 OLI	LS 6-7 ETM+	LS 4-5 TM	LS 1-3 MSS	MODIS	VIIRS	AVHRR/NOAA	LIDAR-ALS	Aerial Photos	**Total**
Temperate Broadleaf Forest				1	1		1										1	2				2	5	13
Subtropical Rainforest				1			1				1				1	1	1		3		1			10
Mediterranean Vegetation				1	1		1								3	3	3	1	1	1	1			16
Monsoon Forest / Dry Forest			1	3	1	1	2	1	1	1	4			3	5	13	13	3	4				2	58
Arid Desert																			1		1			2
Xeric Shrubland	1														1		1		1		1			5
Dry Steppe	1										1				1	2	6	2	1		1			15
Semiarid Desert		2		4	3		2				2		2		4	4	3		4	1	2		1	34
Grass Savanna	1	4		7	1		2				5		1		6	8	6		7		2			50
Tree Savanna		1		4	1		2				3	1			4	7	8	2	6		1		1	41
Subtropical Dry Forest				1							1				4	4	3		3				1	17
Tropical Rainforest		1	1	3	1	1	3		1	1	6	1	1	4	10	19	19	6	4		1		2	85
Alpine Tundra	1			1			1				1			1	1	1	2		1					10
Montane Forest				3			2	1			4		1	4	6	15	13	3	4		1		1	58
Total	4	8	2	29	9	2	17	2	2	2	28	2	5	12	46	77	79	19	40	2	12	2	13	414

4.1.4. Scale of the study area

Milcu et al. (2013) categorize study areas into four spatial scales: *Local* (0-999 km²), *Size-landscape* (1000-9999 km²), *Regional* (10,000-99,999 km²), and *National/Global* (≥100,000 km²). Local-scale studies constituted 18.2%, Size-landscape scale studies were the most frequent (36.3%), followed by regional-scale studies (24.7%), and national/global-scale studies (23.4%) (*Figure 4.8*).

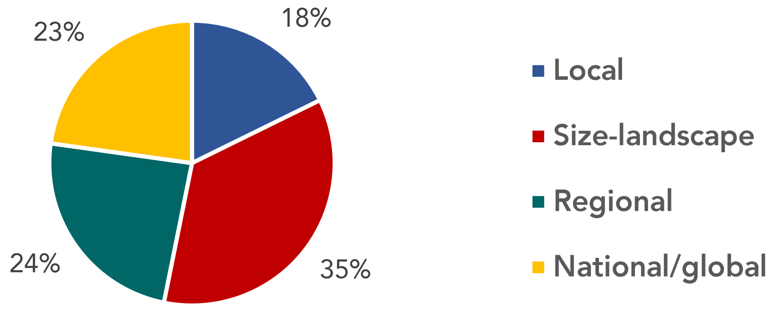


Figure 4.8: Percentage of studies by scale of the study area. (Source: Own figure)

Table 4.2 was created by cross-referencing satellite imagery data with the scale of the study area to identify trends and repetition patterns. The findings indicate that moderate-resolution sensors (10-120 m), such as Landsat 4-5 TM, Landsat 7 ETM+, and Landsat 8 OLI, were most frequently utilized across all spatial scales. These sensors are particularly common in medium- to large-scale studies at the size-landscape, regional, and national levels. For instance, Gorsevski et al. (2012) and Leiterer et al. (2013, 2018), Monroy and Armenteras (2017), and van Etten (2008) employed moderate-resolution sensors to examine the environmental impact of armed conflict. This preference was attributed to the high availability of high quality, recurrent and temporally accessible satellite images with low cloud cover. Moderate resolution is sufficient for analyzing vegetation cover in these biomes, and these sensors are easily accessible owing to their public domain status.

Fine (1-10m) and very fine resolution (≤1m) satellite sensors, such as Quick Bird II, Google Earth VHR, SPOT-5, World View II, and IKONOS, have predominantly been used to study small areas, such as local and size-landscape-scale regions (Jahjah *et al.*, 2007; Hagenlocher, 2011; Rembold *et al.*, 2013; Knoth and Pebesma, 2017; Liu *et al.*, 2018). Quick Bird and Google Earth VHR have also been used at larger scales (Al-Khudhairy, Caravaggi and Giada, 2005; Tian *et al.*, 2011; Sanchez-Cuervo and Aide, 2013; Sánchez-Cuervo and Aide, 2013). Coarse sensors (>250 m) are rarely used and MODIS is notable in Regional and National studies (de Beurs and Henebry, 2008; Bromley, 2010; Kranz, Sachs and Lang, 2015; Ayana *et al.*, 2016; Eklund *et al.*, 2017; González-González *et al.*, 2021). Aerial photos and ALS sensors have largely been applied in local and size-landscape scale research (Hupy and Koehler, 2012; Van *et al.*, 2015; Stichelbaut *et al.*, 2016; Monroy and Armenteras, 2017; Gheyle *et al.*, 2018; Liu *et al.*, 2018). Multiple sensors are often employed to compensate for the limitations of a single sensor, particularly when Landsat data lack sufficient cloud-free imagery or do not cover the required period.

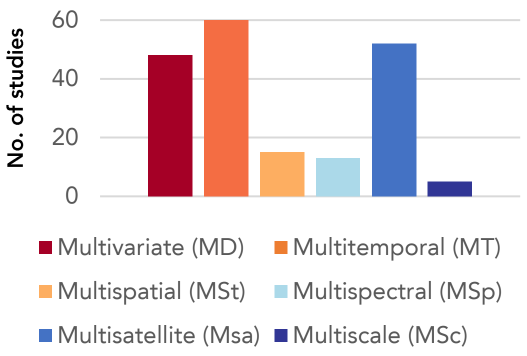
Table 4.2: Satellite imagery sensor vs Study area scale. (Source: Own figure)

	Sensor / Scale	Local	Size-landscape	Regional	National / Global	Total
Very Fine (≤1m)	GeoEye	1	1			2
	WV II	2	3			5
	Pleiades			1		1
	QuickBird II	5	2	1	3	11
	IKONOS	1	1	1	1	4
Fine (>1–10m)	ALOS				1	1
	SPOT-5	2	4		2	8
	CBERS-2B				1	1
	KVR-1000	1				1
	Rapid Eye				1	1
	Google E. VHR	1	4	2	3	10
	IRS 1C		1			1
Moderate (>10–120m)	Sentinel-2	2			1	3
	ASTER		2		3	5
	LS 8 OLI	1	5	6	6	18
	LS 6-7 ETM+	3	10	8	10	31
	LS 4-5 TM	1	15	10	9	35
	LS 1-3 MSS	4	5	2	1	12
Coarse (>250 m)	MODIS	1	3	5	6	15
	VIIRS				1	1
	AVHRR/NOAA			3	1	4
Radar Data	LIDAR-ALS		2			2
	Aerial Photos	5	5			10
	Total	30	63	39	50	182

4.1.5. Multivariate remote sensing and independent variables

Remote sensing multivariate analysis is essential for processing extensive and complex data, aiding information systems in assessing the environmental impacts of warfare. "Multivariate imaging" includes diverse data sources such as multisource observations, multiscale and color imaging, multimodal data, and multitemporal and multispectral images, as classified by Collet C. (2009). A review of 77 studies revealed that 67 studies (87%) utilized multivariate remote sensing analysis and 60 studies (78%) employed multi-temporal images for comparison maps and land use changes, including deforestation. Additionally, 48 studies (62%) incorporated multivariate data from at least one of the eight categories of independent variables. Furthermore, 52 publications (67.5%) used more than one satellite sensor for data collection from multiple imagery sources. In contrast, multispatial and multispectral analyses were used in fewer studies (19% and 17%, respectively), while only five studies (6%) employed multiscale analyses combining different scales (*Figure 4.9 and Appendix 4*).

Appendix 7 provides an overview of the categories and subcategories of the independent variable data used for the correlation with remote sensing data from conflict-affected areas. In 77 studies, 80.5% used multivariate data, with 62% correlating it with independent variables. Among the eight main categories, Land Use variables appeared in 54.5% of the studies (42), followed by demographic variables in 44% (34) and Physical Environment variables in 31% (24). Armed Conflict data were used in 27% of the studies (21), while socioeconomic variables and infrastructure data appeared in approximately 15% of the studies (12 and 11, respectively). Biodiversity-related variables were used in 9% (7) and unclassified variables were used in 18% (14) of the studies (*Figure 4.10*).



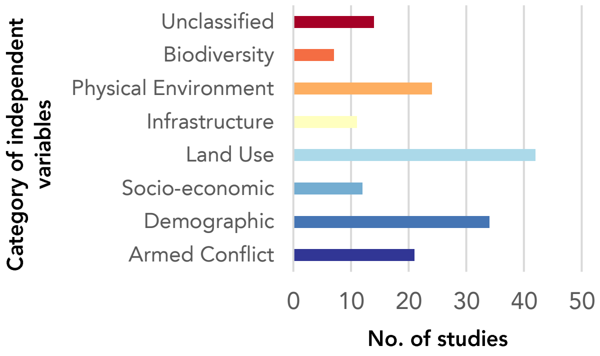


Figure 4.9: Studies by multivariate analysis. Figure 4.10: Categories of variables.

Examining the 43 subtypes of independent variables in remote sensing studies, internally displaced persons and population size were the most frequently used (21 and 20 studies, respectively), followed by deforestation, fragmentation, crop size, precipitation rates, and protected area boundaries (16 studies each). Illicit crop data, conflict intensity/fatalities, road density, and field-acquired data were used in approximately 11 studies (*Figure 4.11*).

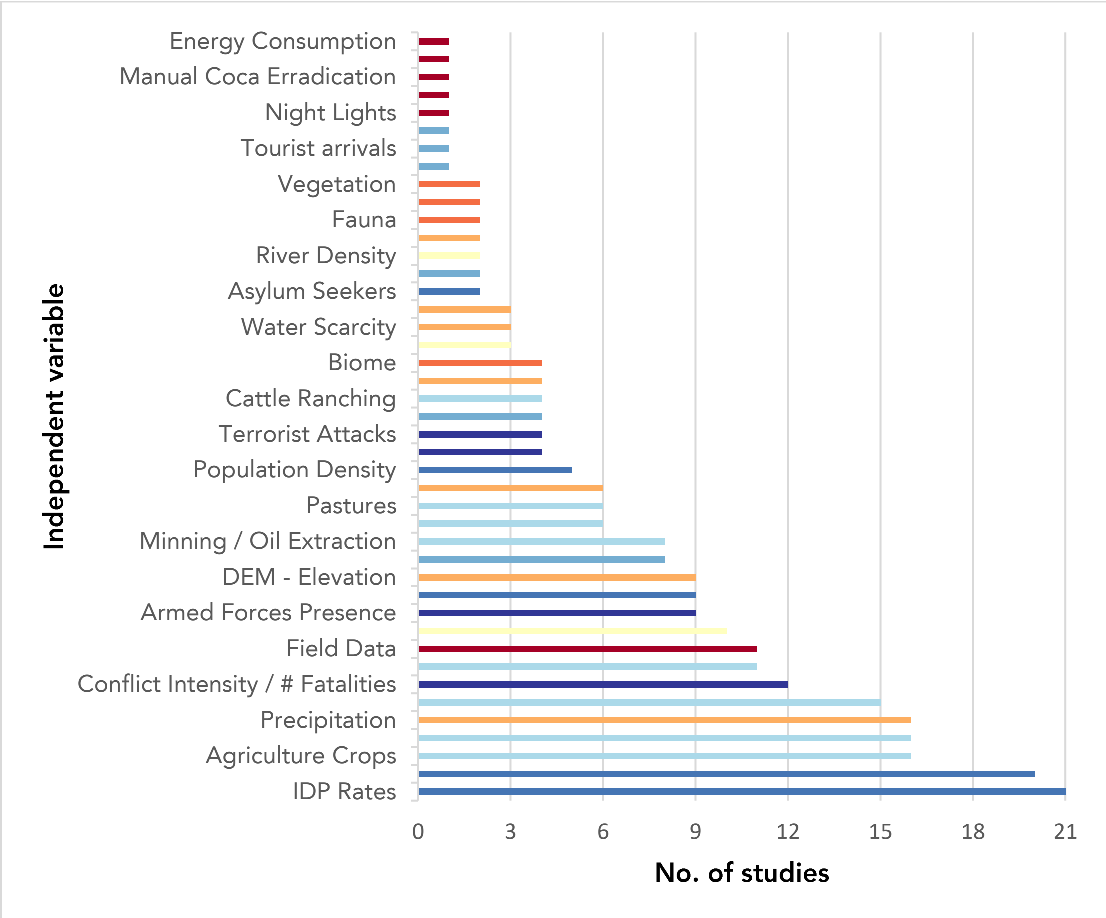


Figure 4.11: Independent variables. *For bar category color see fig 4.10* (Source: Own figure)

4.1.6. Relationship between causes and consequences

I cross-referenced data on conflict-derived causes and conflict-derived consequences to determine their relationship and recurrence. This link was fully established only after explicitly mentioning the cause-and-effect data. Direct causes of armed conflicts, such as military confrontations, showed a direct relationship with consequences such as changes in land use (18%) and deforestation (17%). Bombings directly affected land use changes (13%). Abandonment of agricultural land (8%) and forestation (6.5%) were also related to military confrontations, albeit to a lesser extent. Antipersonnel mines had a lower incidence of environmental consequences such as land-use changes (4%) and deforestation (3%). Evidence indicates that indirect causes significantly impact landscapes. Forced migration had the most substantial effect on land use changes and deforestation (26%), followed by irregular agriculture (19.5%). It also significantly influenced on forestation processes (6.5%). Forced migration also contributes to desertification and soil degradation (6.5%). This topic is well-documented, with forced migration being the primary focus of many studies. Non-forced migration (colonization) and illicit crops caused deforestation in 9.1% and 13% of the studies, respectively, and altered land use in 9.1% and 7.8% of the cases, respectively. Logging, livestock farming, and mining were identified as lesser but still significant causes of land use change and deforestation, with logging linked to deforestation in 12% of the studies. Finally, fires related to armed conflicts were the least associated with landscape changes (*Figure 4.12 and Table 4.3*).

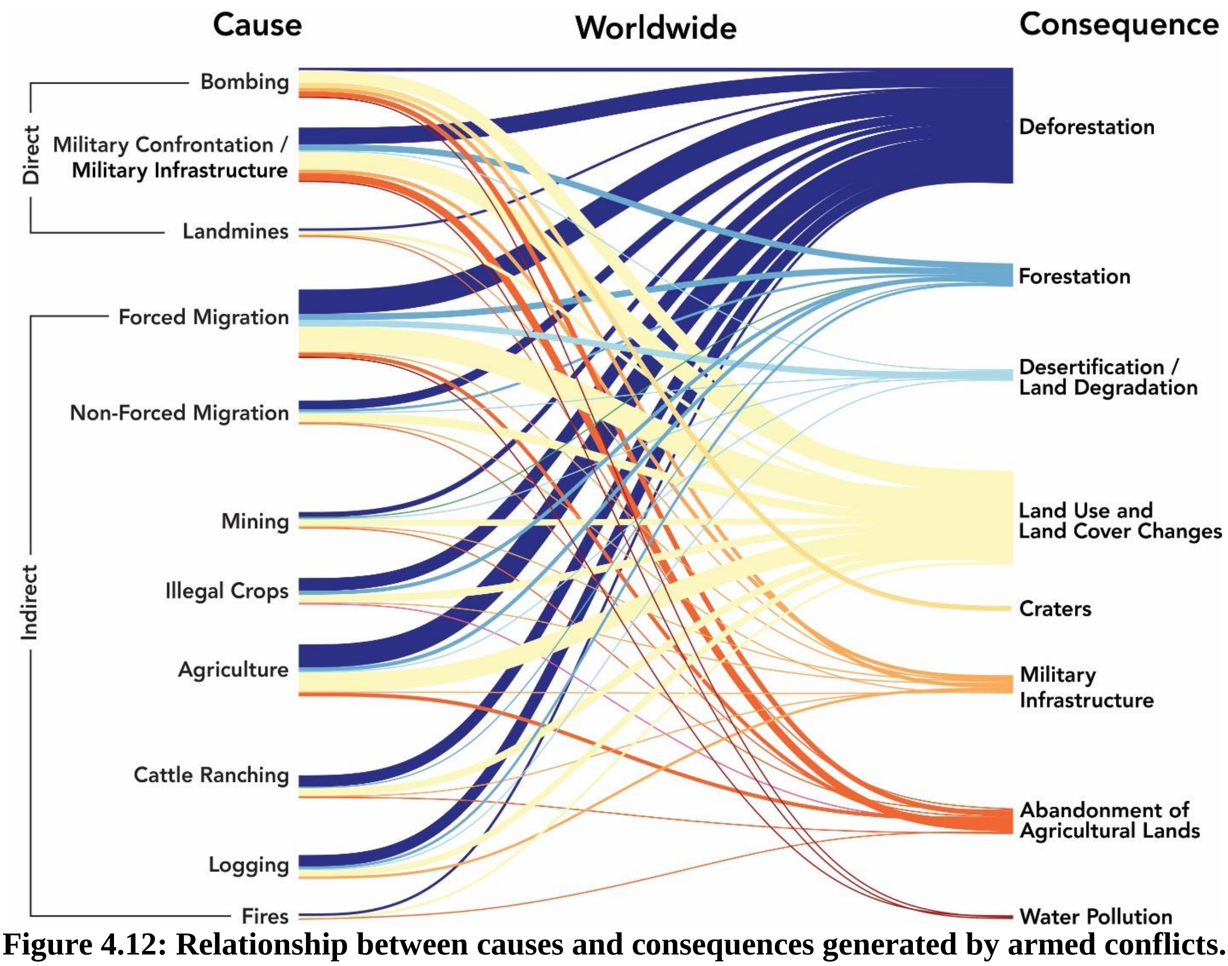


Figure 4.12: Relationship between causes and consequences generated by armed conflicts.
(Source: Own figure)

Table 4.3: Relationship between causes and consequences generated by armed conflicts. (Source: Own figure)

	Armed conflict-derived Cause / Consequence	Deforestation	Forestation	Desertification / Degradation	Land Use / Land Cover Changes	Craters	Military Infrastructure	Abandonment of Agricultural Lands	Water Pollution	Total
Direct	Bombing	3			10	4	3	4	1	25
	Military Confrontation / Military Infrastructure	13	5	1	14		3	6	1	43
	Landmines	2			3		1	1		7
Indirect	Forced Migration	19	5	5	20		1	3	1	54
	Non-Forced Migration	7	2	1	7		1	1		19
	Mining	4	1	1	5		1	1		13
	Illegal Crops	10	3		6		1	1		21
	Agriculture	18	3	1	15		1	3		41
	Cattle Ranching	9	1		6		1	1		18
	Logging	9	2	1	5		2			19
	Fires	2			2			1		5
	Total	96	22	10	93	4	15	22	3	265

4.1.7. Causes and consequences assessment by geographical domain and biome

Conflict-derived causes and consequences assessment by region

Studies indicating bombings as triggers of landscape changes (21%) are primarily situated in temperate zone countries, such as Belgium (3), Kuwait (2), and Iraq (2). Research on military confrontation and/or infrastructure causing environmental impacts (27.3%) is mainly concentrated in Colombia (7) and, to a lesser extent, in regions such as Syria (2). Regarding the remote sensing analysis of landmines' environmental impact (4%), only three documents exist, each from Colombia, Sri Lanka, and Bosnia-Herzegovina. The most studied indirect cause of armed conflict-derived landscape changes was forced migration (36.3%), primarily in African countries (15), Colombia (4), the Middle East (3), Southeast Asia (3), Pakistan (2), Central America (2) and Bosnia (1). Unforced migration (colonization) (14.3%) was examined in six studies in Africa, four in the Middle East, and three in Colombia. Mining (6.5%) has rarely been studied, with a few instances in Colombia (3), Congo (1), and Liberia (1). Illicit crops (13%) were notably researched in Colombia (8), and less so in Afghanistan and Myanmar (one each). Non-regulated agriculture (26%) was the second most studied indirect cause and has been extensively analyzed in Colombia (9). Cattle ranching (12%) was significant in Colombia (7) and was also studied in Pakistan and Afghanistan (one each). Logging (12%) was observed in Colombia (3) and Somalia (2). Fires (6.5%) have been studied only in Colombia (2), Iraq (2), and Pakistan (1) via remote sensing (*Table 4.4 and Appendix 10*).

Recent studies have focused on the environmental impact of armed conflict, with deforestation (61%) being a primary area of research, particularly in Colombia's Amazon Rainforest and sub-Saharan Africa, including South Sudan and Sudan. Other affected regions included Central America, Southeast Asia, and West Asia. Research on forestation (13%) is predominantly conducted in Colombia. Desertification and land degradation (6.5%) have been minimally studied, with research limited to South Sudan, Liberia, Iraq, and Uganda. Land-use and land-cover changes (64%) are the most extensively researched consequences, especially in Colombia. Studies on craters (5.2%) are rare and are primarily conducted in Belgium, Vietnam, and France. Abandonment of agricultural land (16%) has been examined chiefly in Africa, the Middle East, and Europe. Water pollution (2.6%) has received minimal attention, with single studies in South Sudan and Kuwait performing remote-sensing methods (*Table 4.5 and Appendix 11*).

Table 4.4: Distribution of causes by region. (Source: Own figure)

	Cause / Region	Americas	Southeast Asia	Middle East	sub-Saharan Africa	Europe	Total
Direct	Bombing	1	2	7	1	7	18
	Military Confrontation / Military Infrastructure	8	2	6	7	2	25
	Landmines	1	1			1	3
Indirect	Forced Migration	6	3	5	15	1	30
	Non-Forced Migration	3	2	2	6		13
	Mining	3			2		5
	Illegal Crops	8	1	1			10
	Agriculture	9	2	2	8		21
	Cattle Ranching	7		2			9
	Logging	3	1		6		10
	Fires	2	1		2		5
	Total	51	15	25	47	11	149

The RS analysis predominantly focused on tropical and monsoon forest areas near the equator. This does not imply that more conflicts occur there, as many conflicts have also occurred in temperate or desert regions, such as the Caucasus, Balkans, and Middle East, where RS utilization is lower. The reasons for this concentration of RS research in tropical and monsoon forest areas near the equator are unclear yet. However, this may be due to their ecological sensitivity and vulnerability to conflict or the availability of RS data in tropical regions. Researchers should recognize the environmental impacts of armed conflicts across various regions and adapt RS analyses according to specific geophysical conditions.

Table 4.5: Distribution of consequences by region. (Source: Own figure)

Consequence / Region	Americas	Southeast Asia	Middle East	sub-Saharan Africa	Europe	Total
Deforestation	21	6	4	19		50
Forestation	6			5		11
Desertification / Land Degradation				6		6
Land Use and Land Cover Changes	9	7	14	22	4	56
Craters		1			4	5
Abandonment of Agricultural Lands	1		3	9	3	16
Water Pollution			1	1		2
Total	38	14	22	62	11	153

Bombings have been examined in Middle Eastern and European conflicts, but there is limited research on the landscape damage from bombings in America, Southeast Asia, and Africa. This gap may result from the nature of the conflicts in these regions and the difficulty in accessing bombing records. Conflict intensity has been studied globally, with a particular emphasis on Colombia, due to 35 years of reliable data. Forced migration has been extensively studied in Sudan, South Sudan, Colombia, Congo, and Uganda, where high displacement rates have led to enduring refugee camps. By contrast, forced migration in Europe and the Middle East has not been strongly linked to landscape changes. Non-forced migration is most common in sub-Saharan Africa. In Colombia, conflict is associated with illicit crops, unregulated agriculture, and cattle ranching, which are the most extensively studied causes, while unregulated agriculture is also a significant factor in sub-Saharan Africa.

Conflict-derived causes and consequences assessment by biome

Table 4.6 reveals a notable difference in the use of Remote Sensing (RS) for examining indirect causes (73.2%) compared to direct causes (26.8%). Direct causes, such as bombing (21%) (Burgess et al., 2015; Kwarteng, 1998; Note et al., 2018; Witmer, 2008; van Etten et al., 2008), have been studied mostly in temperate broadleaf forests and semiarid desert biomes, with some research on Mediterranean vegetation, monsoon forests, dry forests, and tropical rainforests. Military confrontation and infrastructure (27.3%) (Kwarteng, 1998; Suthakar and Bui, 2008; van Etten et al., 2008) have been primarily examined in tropical rainforests, grass savannas, montane forests, monsoon forests, dry forests, dry steppes, and semi-arid deserts. Landmines (4%) are rarely studied, with limited research on tropical rainforests, montane forests, grass and tree savannas.

Table 4.6: Relationship between biomes and causes. (Source: Own figure)

Cause / Biome		Temperate Broadleaf Forest	Subtropical Rainforest	Mediterranean Vegetation	Monsoon Forest / Dry Forest	Xeric Shrubland	Dry steppe	Semiarid Desert	Grass Savanna	Tree Savanna	Subtropical Dry Forest	Tropical Rainforest	Alpine Tundra	Montane Forest	Total
Direct	Bombing	6		3	3		2	6				3		2	25
	Military Confrontations / Military Infrastructure	2	2	3	6		5	5	8	3	1	12	2	7	56
	Landmines			1			1		1	1		2		2	8
Indirect	Forced Migration		2	3	7	1	2	4	13	9	2	12	2	9	66
	Non-Forced Migration			1	4		1	1	2	4	2	7		3	25
	Mining				3						1	4		2	10
	Illegal Crops		1		6	1	2		3	2	2	8	2	8	35
	Agriculture		1		8	1	2		5	6	4	12	3	9	51
	Cattle Ranching				2	1	2		2	1	1	7	3	7	26
	Logging				2			3	3	3	1	6		3	21
	Fires				1			2	2	2		2		1	10
Total		8	6	11	42	4	17	21	39	31	14	75	12	53	333

In my analysis, forced migration was the most studied phenomenon among indirect armed conflict-derived causes, constituting 36.3% of all studies. This primarily affects biomes such as grass savannas, tropical rainforests, montane forests, tree savannas, and monsoon/dry forests. Notable studies include that by Enaruvbe et al. (2019), Hecht and Saatchi (2007) and Hagenlocher et al. (2012), Leiterer et al. (2018), Lodhi et al. (1998), and Suthakar and Bui (2008). Irregular agriculture accounted for 26% of the studies, focusing on tropical rainforests, montane forests, monsoon/dry forests, tree savannas, and grass savannas, with research by Armenteras et al. (2006), Murad and Pearse (2018), and Qamer et al. (2012). Non-forced migration, representing 14.3% of the studies, primarily involved tropical rainforests, monsoon forests, and tree savannas, with contributions from Armenteras et al. (2013). The analysis of illegal crops, constituting 13% of the total studies, focused on dense forest biomes, such as tropical rainforests, monsoon forests, and montane forests (Armenteras et al., 2013; Murad and Pearse, 2018; Rincón Ruiz et al., 2013). Studies on cattle ranching, logging, and mining, representing 12% of all studies, have primarily examined tropical rainforests and montane forests (Murad and Pearse, 2018; Monroy and Armenteras, 2017; Potapov et al., 2012). Fires, accounting for 6.5% of the studied area, predominantly affected tropical rainforests, followed by tree savannah, grass savannah, and semi-arid deserts (*Figure 4.13 and Table 4.6*).

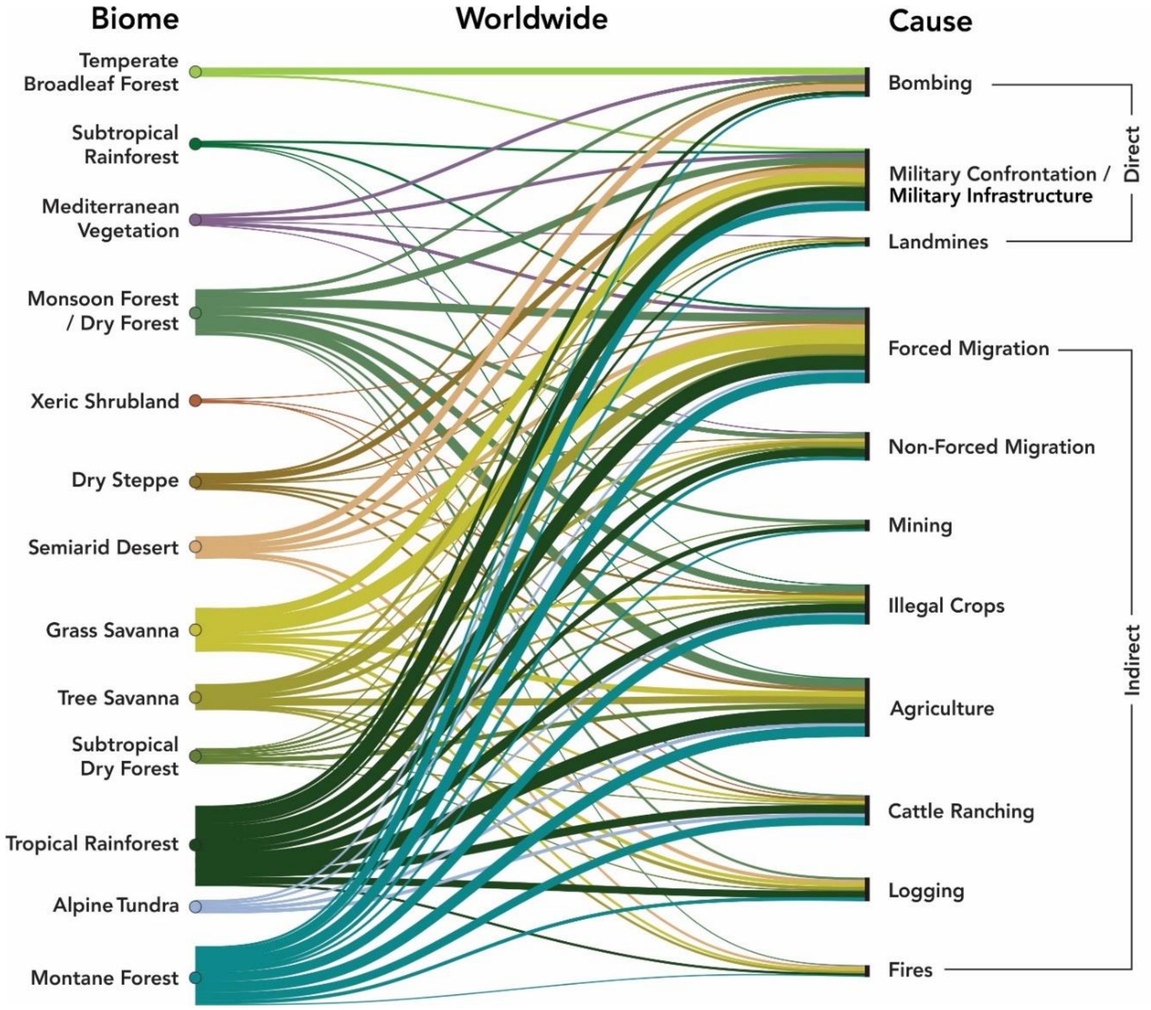


Figure 4.13: Relationship between biomes and causes generated by armed conflict.
(Source: Own figure)

A significant relationship exists between indirect and, to a lesser extent, direct armed conflict-derived causes and the application of remote sensing (RS) in various biomes, including tropical rainforests and monsoon forests. Indirect causes, such as forced migration, lead to the establishment of large refugee camps, whereas non-forced migration results in the colonization of previously untouched areas and occasionally the creation of protected lands through forestation. Mining, agriculture, logging, and livestock production have also been studied in tropical biomes using RS. Although military confrontations and infrastructure have affected tropical forests, they are not predominant. Illicit crops, forced migration, and agriculture have significantly affected mountain forests. Monsoon forests and dry forests have experienced the most significant impacts from military infrastructure, confrontations, and bombing. Forced migration is the primary cause of damage to trees and grass savannas in sub-Saharan Africa, resulting in large refugee camps and changes in land use (*Figure 4.13 and 4.14*).

In the Analysis of the environmental impact of armed conflict, remote sensing (RS) predominantly addresses deforestation (61%) and land use/cover changes (63.3%) (Armenteras et al., 2006; Hagenlocher et al., 2012; Nackoney et al., 2014; Potapov et al., 2012; Rincón Ruiz et al., 2013; Stevens et al., 2011). These studies primarily targeted tropical rainforests, monsoon/dry forests, montane forests, grass savannas, and tree savannas (e.g., Bjorgo, 1999; Enaruvbe, 2019; Murad and Pearse, 2018; Petit et al., 2001; Rincón Ruiz et al., 2013). Agricultural land abandonment (15.6%) is notable in grass savannas, montane forests, monsoon/dry forests, dry steppes, semi-arid deserts, and tree savannas (Gorsevski et al. 2012; Hagenlocher et al. 2012; Witmer 2008). Forestations (13%) have been primarily studied in high-density tropical forest biomes. Lesser-studied impacts include desertification and land degradation (6.5%) and craters (5.2%), with few studies on grass savannah temperate broadleaf forests. Water pollution (2.6%) was the least studied, with a single focus on grass and tree savannah biomes (*Table 4.7 and Figure 4.14*).

Table 4.7: Relationship between biomes and consequences. (Source: Own figure)

Consequence / Biome	Temperate Broadleaf Forest	Subtropical Rainforest	Mediterranean Vegetation	Monsoon Forest / Dry Forest	Arid Desert	Xeric Shrubland	Dry Steppe	Semiarid Desert	Grass Savanna	Tree Savanna	Subtropical Dry Forest	Tropical Rainforest	Alpine Tundra	Montane Forest	Total
Deforestation	1	3		18		1	5	4	16	14	3	28	4	18	115
Forestation		1		5			1	1	5	4	2	7	1	6	33
Desertification / Land Degradation				1				1	3	2		1		1	9
Land Use and Land Cover Changes	3	1	5	12	1	3	6	13	16	10	4	17	3	10	104
Craters	4											1			5
Military Infrastructure	1			2			1	1		1	1	3		2	12
Abandonment of Agricultural Lands	1	1	2	3		1	3	3	5	3	1	2	1	4	30
Water Pollution								1	1						2
Total	10	6	7	41	1	5	16	24	46	34	11	59	9	41	310

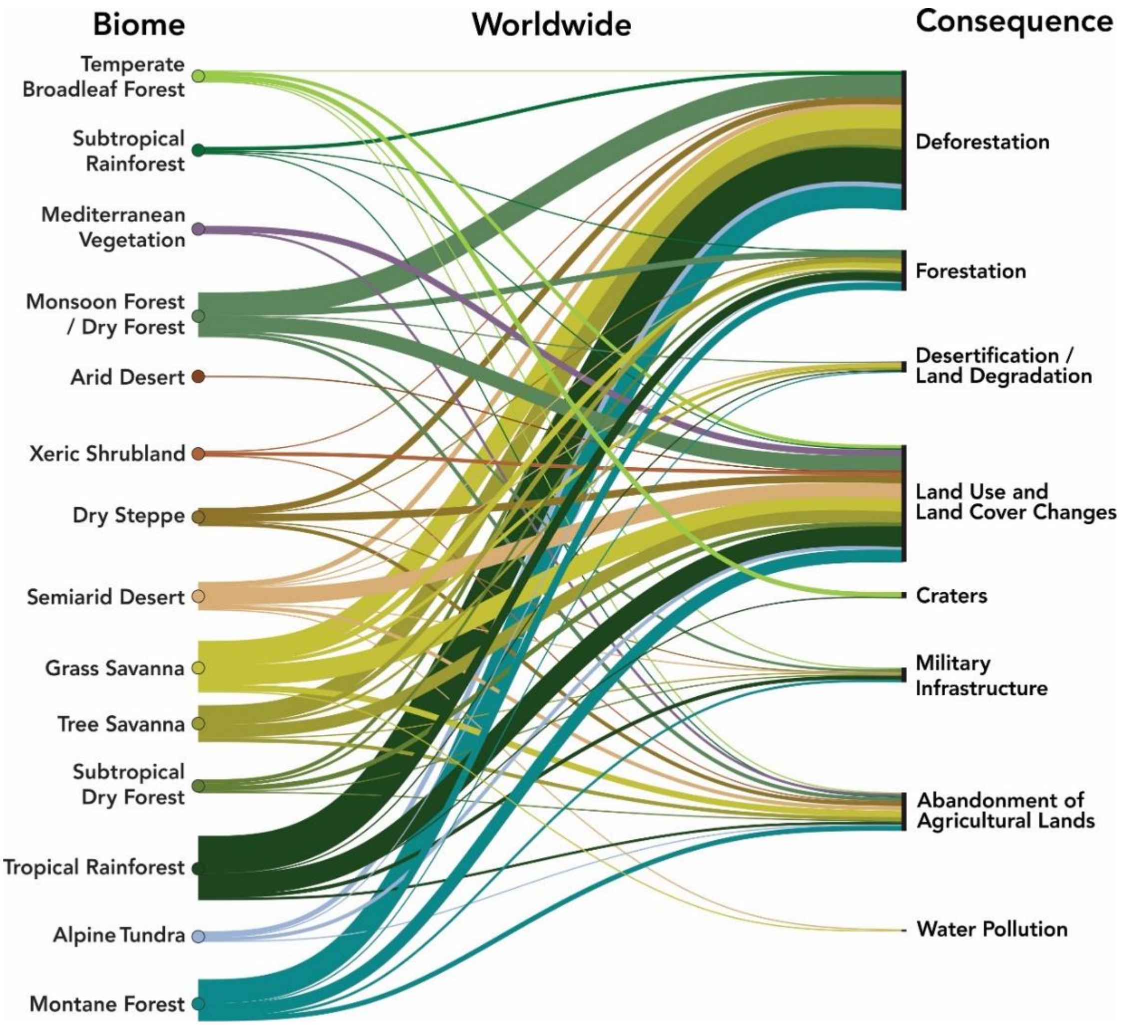


Figure 4.14: Relationship between biomes and consequences generated by armed conflict. (Source: Own figure)

The study encountered barriers; although numerous studies address conflict and the environment, few employ Remote Sensing (RS) methods. In RS studies, identifying specific biomes is difficult because they often emphasize country boundaries rather than biomes, which are harder to define because of biological transition zones. Thus, armed conflicts typically simultaneously affect multiple biomes. This is notably evident in Colombia, where six distinct biomes exist within a small area owing to unique geographical conditions.

Remote sensing methods are extensively used in equatorial zones compared to other biomes because of several reasons. Prolonged conflicts in these areas, often featuring guerrilla wars and internal strife with fewer bombings but higher displacements and fatalities, contribute significantly. Fragile tropical ecosystems are highly susceptible to land use changes and deforestation, making such changes more noticeable. In addition, tropical rainforests suffer from illicit crops, illegal logging, and mining, causing substantial environmental damage. These factors force local populations into refugee camps, increasing natural resource demand and further environmental degradation. In situ evaluations in these regions are challenging; therefore, remote sensing is frequently used. These findings highlight the need for further research on the environmental impacts of armed conflict, especially in under researched regions.

4.2. Landscape and armed conflict: Colombian case studies

4.2.1. The peace agreement's influence on the assessment of environmental impacts derived from armed conflict

The systematic search identified 65 studies on Colombian armed conflict processes and landscape changes, but only 19 used RS methods (*Appendix 6*). A notable increase in RS publications occurred post-2016 peace agreement. The positive trend from 2013 to 2021 peaked in 2020. The peace agreement heightened interest in the nexus between armed conflict and landscape changes. During the high-intensity conflict (2001-2012), the publication rate averaged 0.16 studies per year. During the 2013-2016 negotiations between the Government of Colombia and the FARC, this average surged to 1.6 per year. Post-agreement (2016-2021), the rate further increased to two studies per year (*Figure 4.15*).

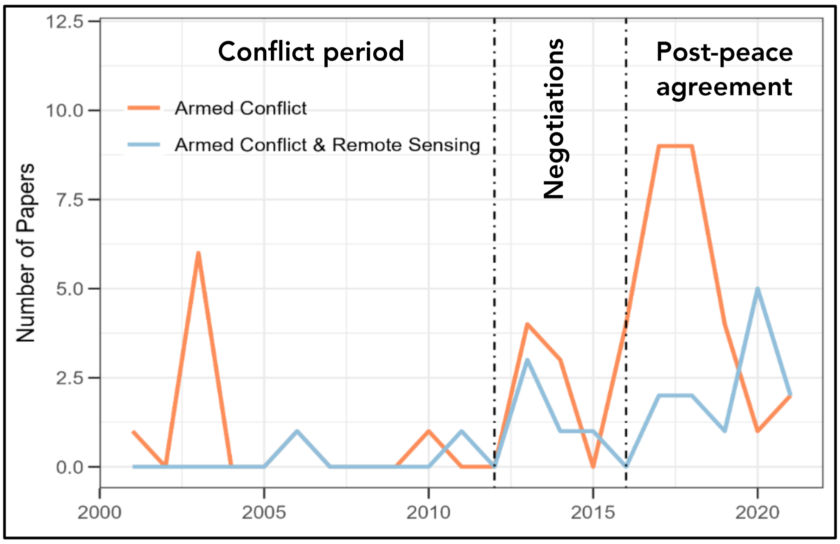
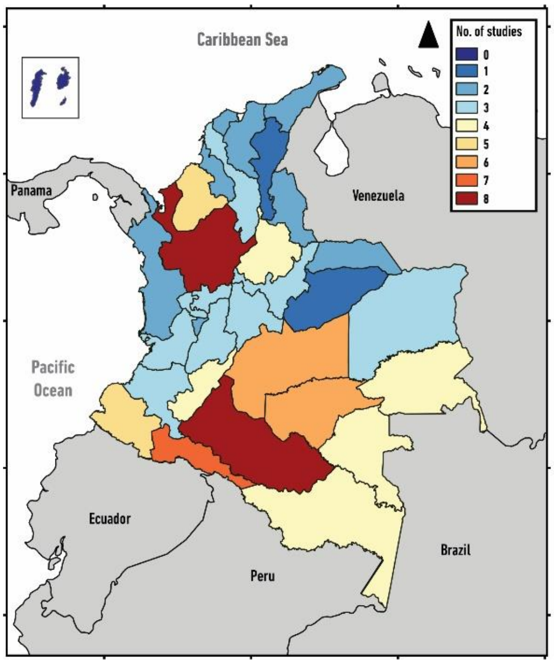


Figure 4.15: Number of studies during conflict, negotiations, and post-peace agreement periods. (Source: Own figure)

The conflict can be divided into three main periods: (I) the low- or medium-intensity conflict period before 1999 (CNMH, 2021), used in remote sensing studies as a comparative baseline; (II) the high-intensity conflict period (2000-2012) marked by significant military actions and casualties; and (III) the post-conflict period (2012-2021), beginning with the ceasefire in 2012 and the peace agreement in 2016. I found that 16% of the studies analyzed data before 1999 (Armenteras *et al.*, 2006, 2013; Murillo-Sandoval *et al.*, 2021), limited by the lack of high-quality satellite imagery from the 80s and 90s. Conversely, 84% of the studies analyzed the high-intensity conflict period (2000-2012) (Armenteras *et al.*, 2006, 2013; Fergusson, Romero and Vargas, 2014; Chadid *et al.*, 2015; Gómez-Rodríguez *et al.*, 2017; Murad and Pearse, 2018; Cabrera *et al.*, 2020; Clerici *et al.*, 2020; Murillo-Sandoval *et al.*, 2020, 2021; Prem, Saavedra and Vargas, 2020). A total of 47% of publications focused on the study of the post-2012 period, noting increased deforestation in some areas (Armenteras, Schneider and Dávalos, 2019; Cabrera *et al.*, 2020; Prem, Saavedra and Vargas, 2020; Schoenig, Dupras and Messier, 2020; González-González *et al.*, 2021; Murillo-Sandoval *et al.*, 2021). Finally, 58% of the studies examined only one conflict period without cross-period comparisons, 37% compared two periods, and 5.3% analyzed all three conflict stages (*Appendix 6*).

4.2.2. Geographical domain

Colombian case studies have predominantly focused on deforestation in the southeastern lowlands, especially the Amazon Basin, with limited research on montane forests and the Andean ecosystem (Etter and van Wyngaarden, 2000; Armenteras *et al.*, 2011; Chadid *et al.*, 2015; Gómez-Rodríguez *et al.*, 2017; Monroy and Armenteras, 2017). Studies in the humid tropical forests of the Pacific and Caribbean, Paramos, and Dry Forests are scarce (Armenteras *et al.*, 2013, 2017; Fergusson, Romero and Vargas, 2014; Monroy and Armenteras, 2017). I found that the most studied departments were not necessarily the largest or the most populated. Antioquia and Caquetá were studied in 42% of the cases, followed by Putumayo in 37%, and Guaviare and Meta in 31.5%. Cordoba and Nariño were covered in 26% of the publications, while Amazonas, Guainía, Huila, Santander, and Vaupes appeared in 21% of the studies. The remaining 20 departments were mentioned in at least one study, except for San Andres Island, which was not studied (*Figure 4.16 and Appendix 6*).



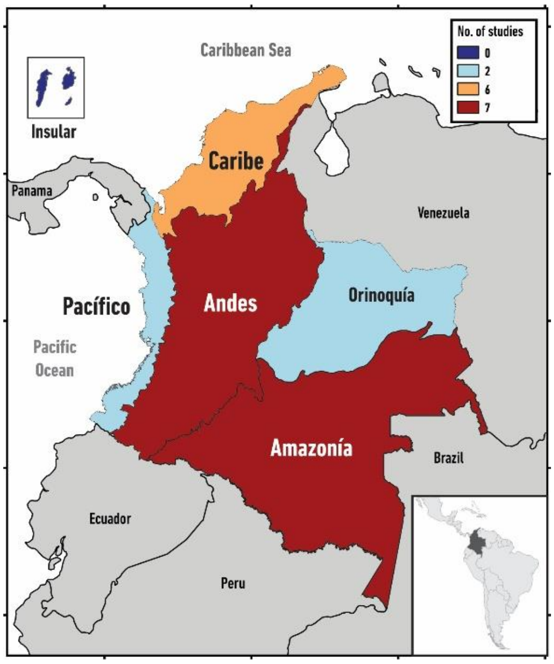


Figure 4.16: Distribution of case studies by departments and by natural regions.
(Source: Own figure)

Departmental boundaries do not align with natural region limits, thus allowing departments to encompass multiple regions. Hence, a study could encompass multiple regions or departments. Approximately 37% of the studies analyzed the entire country, covering all Colombian continental regions. The Amazon and Andes were mentioned in 37% of the studies, followed by the Caribbean (31%). The Orinoquia and Pacific regions were considered in approximately 10% of the studies. No studies have linked armed conflict processes and the landscape in the insular region (*Figure 4.19 and Appendix 2*). The most studied ecoregions were those with high and very high forest densities: Northern Andean, 47%; Mag-Urabá Moist, 42%; Cordillera Oriental, 42%; and Caquetá

Moist, 37%. These regions, known for their high biodiversity, serve as transition zones between the Andean mountain range, the Orinoquia plains, and the Amazon rainforest. Few studies have addressed ecoregions with lower forest cover density and low or moderate violence intensity rates, such as Northern Páramo, Sinú Valley Dry, and Guajira Xeric, each comprising 10% of the studies. (*Figure 4.17 and Appendix 6*).

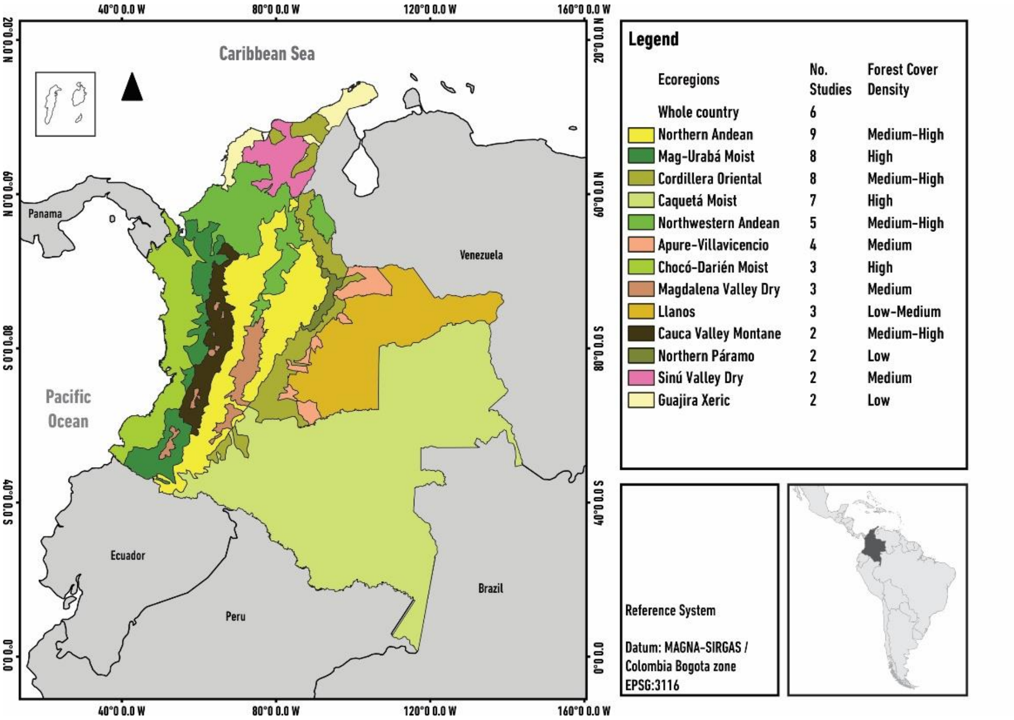


Figure 4.17: Ecoregions distribution. (Source: Own figure)

4.2.3. Multivariate remote sensing and independent variables

A review of 19 studies indicated that 90% of them conducted multivariate remote sensing analysis. Multi-temporal images (MT) were used in 84% of the cases to create comparison maps and detect land-uses and land-cover changes. Multivariate data (MD) from at least one of the eight defined categories (*Appendix 7*) were employed in 79% of the studies. Other types of multi-analyses were less common, such as multispectral analyses (MSp) in 26% of the studies and the use of multiple satellite sensors (MSa) in 16% to collect data from various sources. Multi-spatial (MSt) analyses were performed in 16% of cases. Only 11% of the studies used multiscale analyses (MSc), combining two types of scales within the study area (*Figure 4.18*).

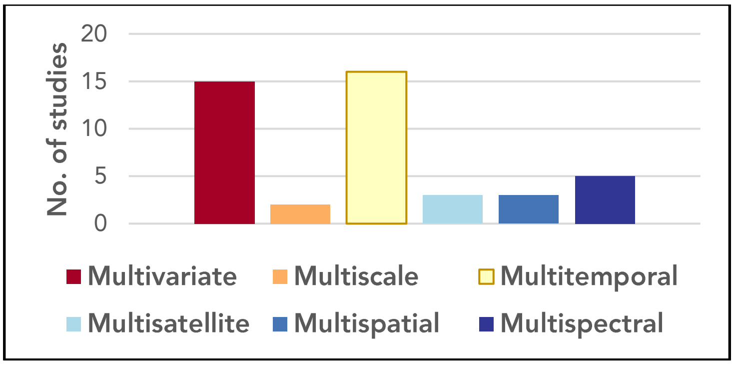


Figure 4.18: No. of studies that used multivariate remote sensing analysis.
(Source: Own figure)

Appendix 7 outlines the variables employed to correlate Colombian armed conflict with environmental factors via remote sensing studies. After analyzing 19 studies, I found that 79% (15) utilized multivariate data. The independent variables were classified into eight categories: land use variables were cited 43 times, demographic variables 20 times, physical environment variables 19 times, and armed conflict data variables only 14 times. Infrastructure (9), socioeconomic (8), and biodiversity (5) variables were infrequently used. Additionally, three instances of unclassified variables were noted (*Figure 4.19*).

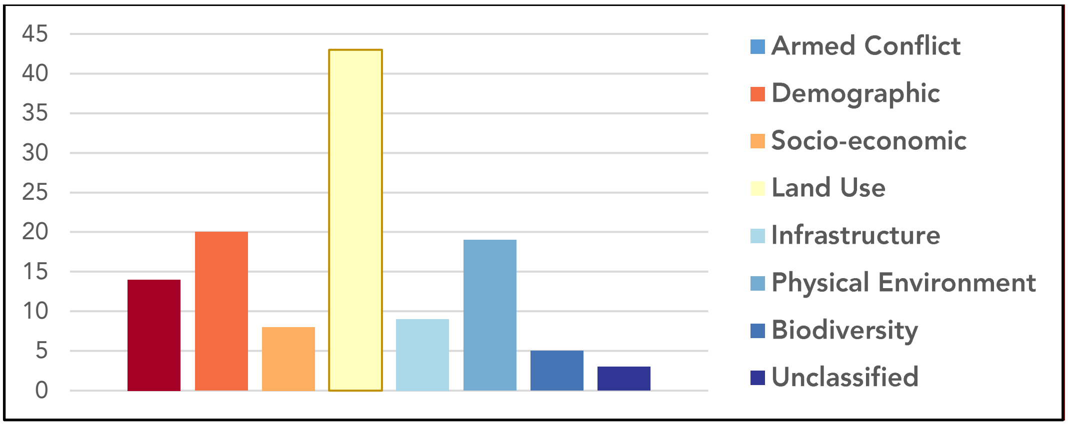


Figure 4.19. Number of independent variables used in remote sensing analysis.
(Source: Own figure)

Among the 32 subtypes of independent variables used in remote sensing studies, the most frequently used were population size (10) and illicit crop data (9). Conflict intensity/fatalities, deforestation data, crop rates, and protected area boundary variables were observed in seven studies each. The armed force presence, unsatisfied basic needs index, mining rates, road density, and DEM/elevation data were used in six and five studies, respectively.

4.2.4. Satellite imagery sensor

The resolution is crucial for RS analysis, with spatial, spectral, and time-series resolutions being the most significant. *Appendix 2* lists satellite imagery sensors used to detect armed conflict effects on landscapes, categorized by spatial resolution: Very Fine ≤1 m, Fine >1-10 m, moderate >10–120 m, and coarse >250 m. In each study, a single sensor was used. Moderate resolution sensors like Landsat 4-5 TM, Landsat 7 ETM+, and, to a lesser extent, Landsat 8 OLI, Landsat 1-3 MSS, and ASTER, were the most frequently used, cited 33 times across 19 studies. Fine resolution sensors were used five times: Google Earth VHR, Rapid Eye, CBERS-2B, and SPOT-5, followed by coarse resolution sensors, with MODIS used four times each. Very Fine resolution via QuickBird 2 was used twice, and aerial photographs appeared in one study. No global imagery studies were found (*Figure 4.20*). The study area was divided into four spatial scales: local (0-999 km2), size-landscape (1000-9,999 km2), regional (10,000-99,999 km2), and national (≥100,000 km2) (Milcu et al. 2013). Local-scale studies comprised 5%, size-landscape scale comprised 5%, regional 21%, and national 68% of all the studies (*Figure 4.21*).

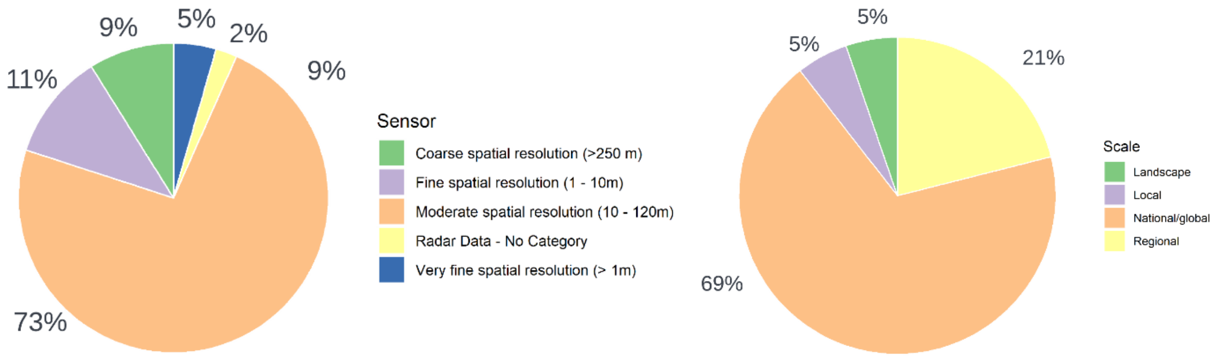


Figure 4.20: percentage of case studies by sensor resolution. Figure 4.21: percentage of case studies by scale. (Source: Own figure)

4.2.5. Causes, consequences and belligerent forces

Military confrontation (37%) emerged as the primary direct conflict-derived cause of environmental degradation. Studies (Sanchez-Cuervo and Aide, 2013; Sánchez-Cuervo and Aide, 2013; Fergusson, Romero and Vargas, 2014; Clerici *et al.*, 2020; Mendoza, 2020; Prem, Saavedra and Vargas, 2020; Murillo-Sandoval *et al.*, 2021) have utilized conflict intensity data to correlate armed conflict with environmental impacts. However, events directly associated with conflicts, such as bombings and landmine placements, have rarely been studied, likely because of the difficulty in accessing restricted military data necessary for geospatial and temporal analyses in RS studies. Mendoza (2020) is the only study linking landmine use to landscape changes. No research has addressed bombings, terrorist attacks, or oil spills as causes of landscape changes.

On the other hand, indirect conflict-derived causes have been the most studied triggers of environmental impacts. Non-regulated agriculture (47%) (Armenteras *et al.*, 2013; Sanchez-Cuervo and Aide, 2013; Sánchez-Cuervo and Aide, 2013; Murad and Pearse, 2018; Cabrera *et al.*, 2020; Prem, Saavedra and Vargas, 2020), coca crops (42%) (Armenteras *et al.*, 2011, 2013; Chadid *et al.*, 2015; Mendoza, 2020; Murillo-Sandoval *et al.*, 2020), illegal cattle ranching (37%) (Murad and Pearse, 2018; Cabrera *et al.*, 2020; Murillo-Sandoval *et al.*, 2020; Prem, Saavedra and Vargas, 2020), and forced migration (21%) (Armenteras *et al.*, 2011, 2017; Sánchez-Cuervo and Aide, 2013; Mendoza, 2020) have been extensively studied as landscape change generators. Non-forced migration (16%) (Armenteras *et al.*, 2011; Sanchez-Cuervo and Aide, 2013; Sánchez-Cuervo and Aide, 2013; Mendoza, 2020), illegal mining (16%) (Gómez-Rodríguez *et al.*, 2017; Monroy and Armenteras, 2017; Cabrera *et al.*, 2020), and illegal logging (16%) (Armenteras *et al.*, 2006, 2013; Murillo-Sandoval *et al.*, 2020) have been studied as indirect causes of deforestation, but to a lesser extent. Finally, fires (11%) generated directly or indirectly by armed conflicts were the cause least related to landscape changes (Armenteras *et al.*, 2013; Armenteras, Schneider and Dávalos, 2019) (*Figure 4.22 and 4.23*).

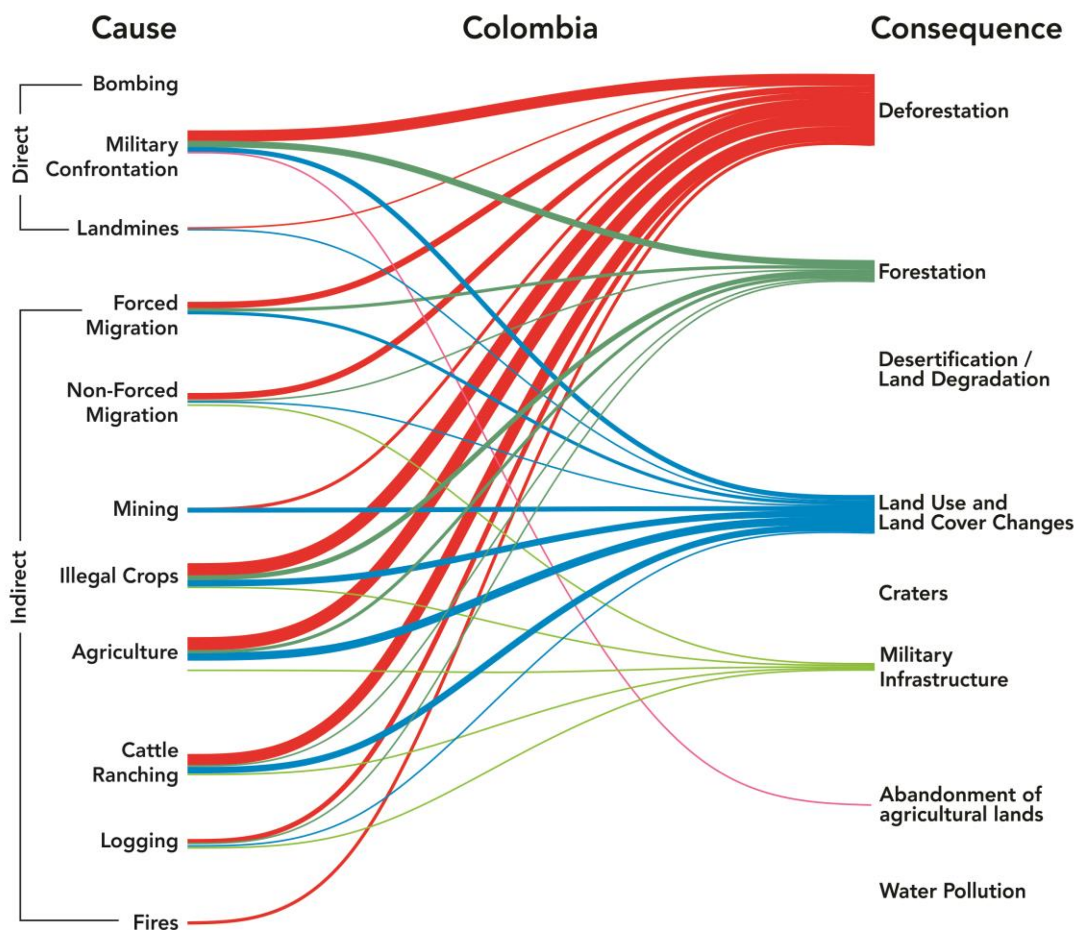


Figure 4.22: Relationship between Colombian armed conflict-derived causes and consequences. (Source: Own figure)

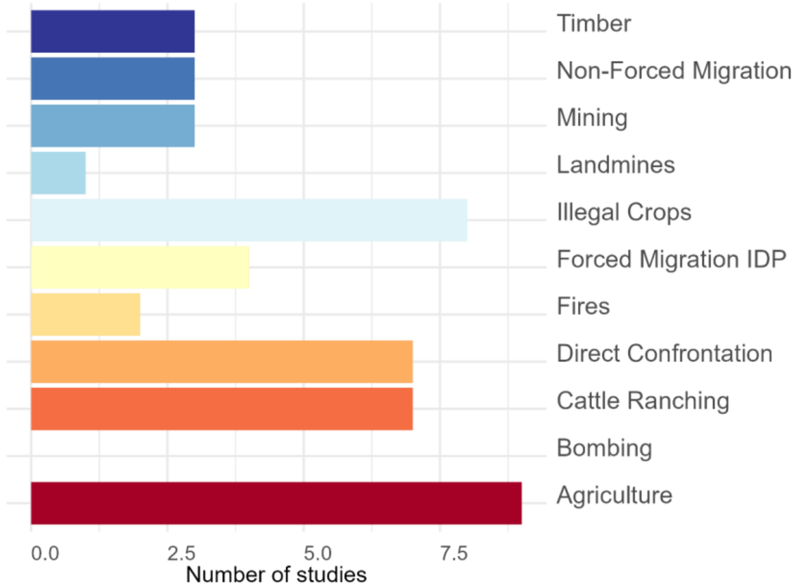


Figure 4.23: Number of publications that study the Colombian armed conflict-derived causes. (Source: Own figure)

Deforestation was identified as the most studied impact of armed conflict, cited in 95% of publications, followed by LULCC (42%). Paradoxically, 31% of studies reported forestation as a consequence. Only few studies has examined the abandonment of agricultural lands. (Sánchez-Cuervo and Aide, 2013; Murillo-Sandoval *et al.*, 2021). Regarding forest cover change, 42% of the publications reported a decrease in vegetation cover, 5% reported an increase, and 53% reported both deforestation and forestation from 2000 to 2021 (*Figure 4.24*).

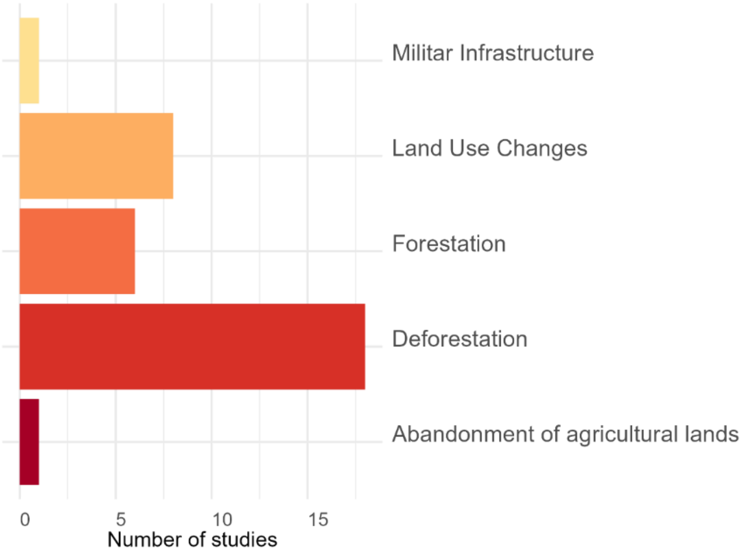


Figure 4.24: Number of case studies that study consequences on the environment. (Source: Own figure)

Colombian armed conflict involves several key groups. The government's armed forces include the national army, navy, air force, and police. The major guerrilla groups are the *FARC* and *ELN*, while prominent paramilitary groups include the *AUC* and *Águilas Negras*. In terms of environmental impact, 42% of studies attributed responsibility to the FARC, 31% to paramilitary groups such as the AUC, and 5% to the ELN. More than half of the case studies did not specify which group caused environmental changes, and none identified the National Army as a contributor (*Figure 4.25*).

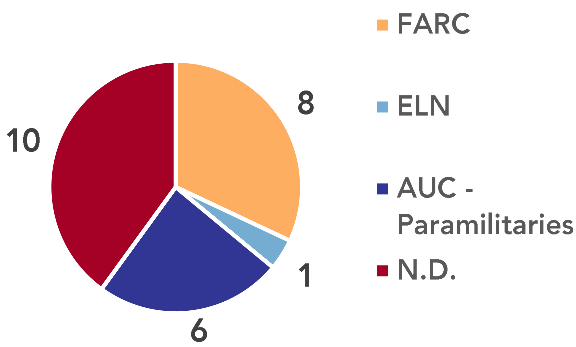


Figure 4.25: Belligerent forces responsible for landscape changes. (Source: Own figure)

4.3. Landscape and armed conflict: *Sumapaz Páramo Region* case study

4.3.1. Forest disturbances within the Sumapaz Páramo Region's spatial units

Forest disturbance in this study encompasses stand-replacement deforestation (e.g., full land-use conversion) and forest degradation (e.g., forest thinning). Forest disturbances can manifest either abruptly or gradually. Abrupt degradation produces short-term "breaks" in the time series, caused by events such as fuelwood harvesting, indiscriminate logging, wildfires, and conflict-related activities such as bombings or landmine explosions. Gradual degradation appears as "segments" with slopes in the time series, evident over the medium to long term. This results from continuous tree extraction for crops, pastures, or mining (often illegal logging) and in conflict-related activities, such as military infrastructure and road construction.

4.3.1.1. Sumapaz Páramo Region and Forest-Páramo Transition Zone spatial units

The lower limit of the paramo ecosystem is situated between the high Andean forest and the lower subparamo. This transition zone is marked by the tree line limit and semi-open plant formations with interdigitating shrubs and tree elements, and shows significant variability in floristic composition, cover, and physiognomy. Consequently, it exhibits high heterogeneity, species richness, and diversity (Sarmiento Pinzón and León Moya, 2015; Henao-Díaz *et al.*, 2019; Olaya Angarita, 2019). Generally, the forest density decreases with increasing altitude. Elevation and slope are the key variables for delimiting borders (*Figure 4.27*). *Forest-Páramo Transition Zone* (FPTZ) areas ranged from 2500 m.a.s.l. to 3200 m.a.s.l., whereas *Sumapaz Páramo Region* (SPR) areas ranged from approximately 3000 m.a.s.l. to 4300 m.a.s.l (*Figure 3.5*).

Chapter 3.2.1 describes the parameters used to delimit the SPR and the FPTZ. The measured spatial units included: (I) the study area (SPR) covering 240,700 ha, (II) the buffer area (FPTZ) covering 70,584 ha, adding up to a total extended study area (XSPR) of 311,284 ha, and (III) the extended buffer area (XFPTZ) around 6 km of the SPR, covering 262,209 ha (*Figure 4.26 and Table 4.8*).

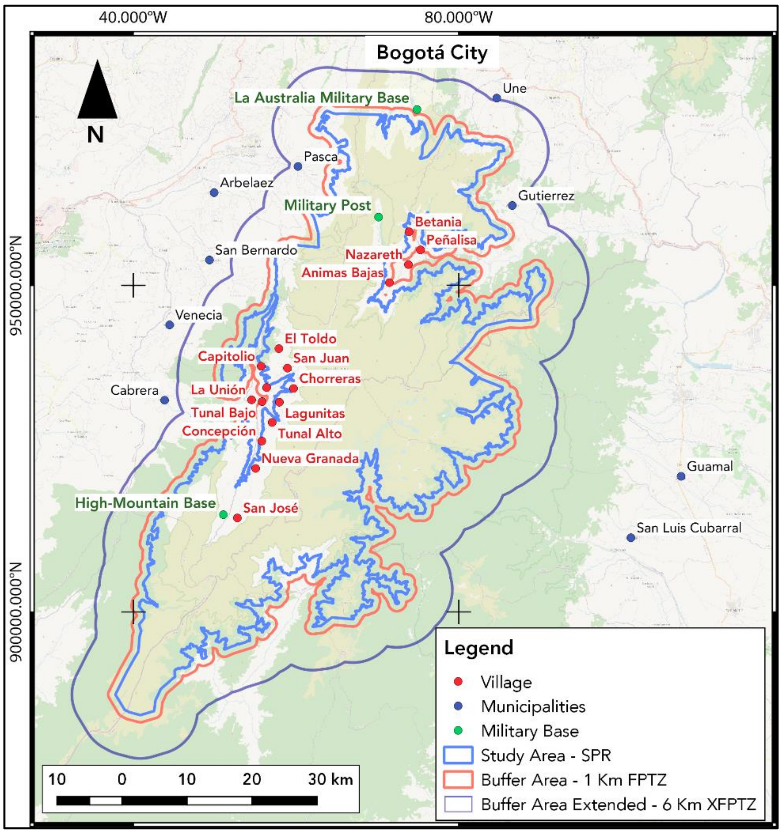


Figure 4.26: Study areas. *Blue line:* Study Area (SPR). *Red line:* 1 km Buffer Area *(*FPTZ). *Dark Purple line:* 6 km Extended Buffer Area (XFPTZ). *Red dot:* Village. *Blue dot:* Municipality. *Green dot:* Military Base. (Source: Own figure)

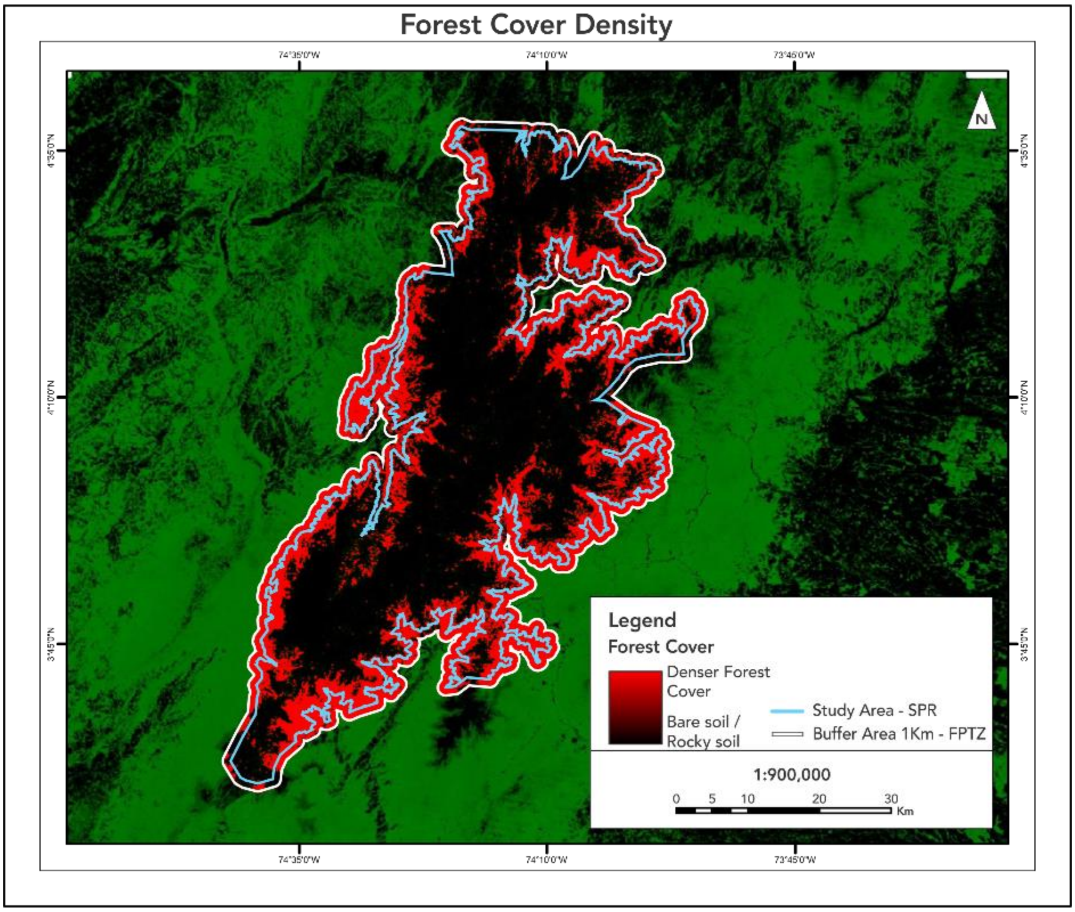


Figure 4.27: Forest cover density. *Red pixels:* Forested Areas. *Blue line:* Study Area (SPR). *White line:* 1 km Buffer Area *(*FPTZ). (Source: Own figure)

Table 4.8: Study areas; SPR, FPTZ, XSPR and XFPTZ spatial units. (Source: Own table)

Spatial units	ha	km2
ha 0 **Study area (SPR)**	240,700	2407
ha 1 **1 km Buffer (FPTZ)**	70,584	705
ha **Study area + buffer (SPR+FPTZ = XSPR)**	311,284	3112
6 km buffer (XFPTZ)	262,209	2622

4.3.1.2. Forest disturbances distribution by armed conflict periods

Landsat cumulative of forest disturbance data identified 705.7 ha of disturbed area within SPR from 2001 to 2012 (conflict period) and 60.16 ha from 2013 to 2020 (negotiation and post-agreement), totaling 765.83 ha or 0.32% of SPR area. In the 1 km buffer area (FPTZ), 507.51 ha were disturbed from 2001 to 2012 and 105.81 ha from 2013 to 2020, totaling 613.32 ha or 0.87% of the buffer zone. Overall, the extended study area (XSPR= SPR + FPTZ) showed 1213.18 ha disturbed from 2001 to 2012 and 165.97 ha from 2013 to 2020, totaling 1379.15 ha or 0.44% of the extended study area (*Table 4.9 and Figure 4.28*). While the percentages for total areas are small, if we calculate the percentage of forest disturbances using only the available tree cover >30%, these values are higher. For the study area, disturbance reached 6.5%, and for the external 1 km buffer, it reached 1%.

Table 4.9: Total of forest disturbance rates in the SPR and FPTZ areas.
(Source: Own table)

Period / Area (Spatial unit)	Study Area *ha* 0 (SPR)	Buffer Area *ha* 1 (FPTZ)	Extended Study Area *ha* (XSPR)	Protected Area *ha* 2 (SNP)
ha	**240,700**	**70,584**	**311,284**	**129,876**
Stable area	239,934	69,970	309,904	129,694
Percentage of stable area	99.68%	99.13%	99.55%	99.86%
Disturbance conflict period (2001-2012)	705.7	507.51	1213.18	178.98
Disturbance negotiation + post-peace agreement period (2013-2020)	60.16	105.81	165.97	3.07
Disturbance total (2001-2020)	765.86	613.32	1379.15	182,05
Percentage of the total studied area	0.32%	0.87%	0.44%	0.14%
Total disturbance ha / Total ha	0,00318	0,00869	0,00443	0,00140
Disturbance ha / Year	38,29	30,67	68,96	9,58

The study revealed that the forest disturbance during the peak conflict years (2001-2012) was significantly higher in the study area (SPR) and percentage-wise greater in the buffer area (FPTZ) than in the low-intensity conflict period (2012-2020), with notable differences between 2006 (*ha 0*: 0.66%, *ha 1*: 0.34%) and 2014 (*ha 0*: 0.67%, *ha 1*: 0.33%). A sharp decline (break) in the degradation was observed between 2012 and 2013. During the negotiation and post-agreement periods, a break occurred between 2013 and 2020. However, since 2015, disturbances have been higher in ha 1 (FPTZ) than in *ha 0* (SPR), both percentage-wise and in total hectares, with significant percentages in 2016 (*ha 0*: 0.27%, *ha 1*: 0.73%) and 2020 (*ha 0*: 0.25%, *ha 1*: 0.75%) (*Figure 4.28 and 4.29*).

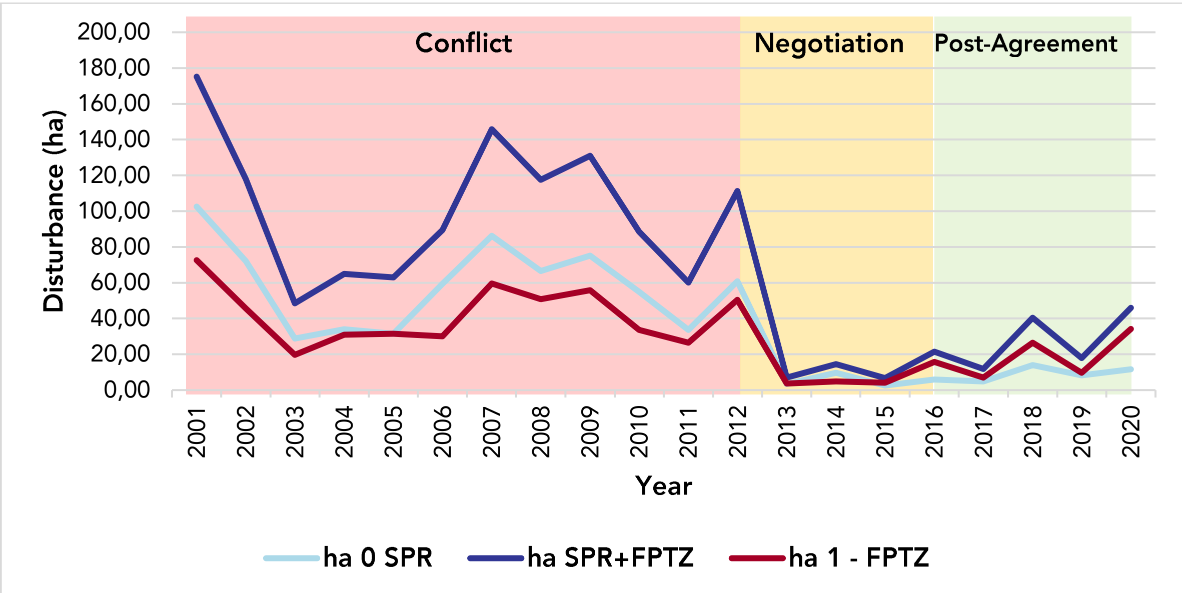


Figure 4.28: Forest disturbance rates yearly distribution.
Purple line: Extended Study Area (XSPR= SPR+FPTZ). *Blue line:* Study Area (SPR). *Orange line:* 1 km Buffer Area (FPTZ). (Source: Own figure)

Between 2001 and 2020, the total forest disturbance area within the SPR was 765.83 ha, which is 0.15 times higher in absolute disturbance rates compared to the adjacent 1 km-wide buffer areas

(FPTZ). However, in percentage terms, disturbances in the buffer area were more than double (0.87%) those in SPR (0.32%). 2001, 2007, 2008, 2009, and 2012 saw the most significant forest disturbances in the FPTZ, whereas 2001, 2007, and 2009 showed the highest changes within the SPR. Since 2013, there has been a notable decline in disturbances (Breaks), although small-scale increases have been concentrated in the buffer zone. Periods of high- and medium-intensity conflicts were marked by sudden increases in disturbance rates in contrast to the negotiation and post-agreement periods, where vegetation changes were gradual, minor, and moderate (Segments). A reduction in vegetation disturbance post-negotiations and the peace agreement is more evident in the study area than in the 1 km outer buffer (*Figure 4.28 and 4.29*). Disturbance analysis primarily utilized satellite imagery from December or January owing to reduced cloud cover during the dry season, which is conducive to logging and forest felling by fire.

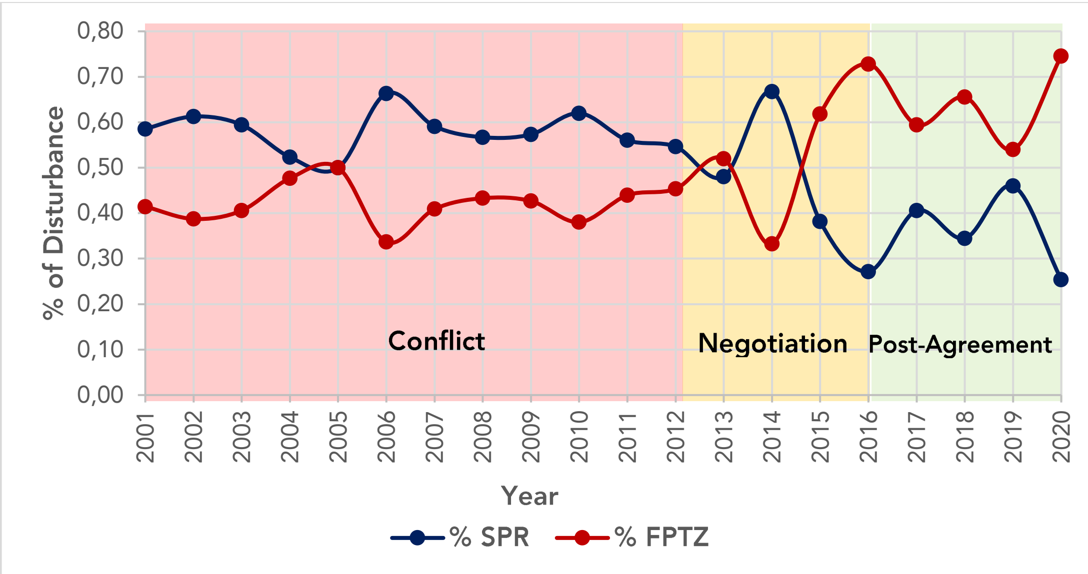


Figure 4.29: Ratio of disturbance distribution.

Blue dots: Study Area (SPR). *Orange dots:* 1 km Buffer Area (FPTZ). (Source: Own figure)

Disturbance rates were significantly higher during periods of intense conflict in both the SPR and FPTZ compared to the lower disruption rates during and after the peace agreement. This can be explained by several factors: (I) High-intensity conflict periods saw reduced government presence and environmental control, facilitating deforestation and land use change, including within the national park, paramo, and cloud forest, and an increase in livestock areas. (II) Belligerent forces directly influenced deforestation through road construction for military use by both the Army and FARC-Guerrilla, along with other military infrastructure such as bases, trenches, outposts, camps, and the use of vegetation such as frailejones for construction or fuel. (III) The incidence of arson and natural fires was higher owing to weak control and government presence, including the absence of firefighters. (IV) Some National Army bombings caused fires and landslides, particularly in the southern region. Since 2012, when peace negotiations commenced, disturbance rates have significantly declined. This can be attributed to several factors: (I) National and local governments have enhanced their presence and environmental control, managing land use and deforestation more effectively. (II) The National Parks Board and local communities have increased environmental oversight, ecological stewardship, and forestation efforts. (III) The cessation of armed conflict halted the construction of military infrastructure, bombings, and the use of anti-personnel mines, aiding landscape conservation. (IV) During peacetime, the National Army can focus on demining, waste control, reforestation, and establishing frailejones nurseries, which support regional reforestation.

4.3.1.3. Forest disturbances distribution by geospatial location

To determine the forest disturbance locations, we employed two approaches. First, disturbances were normalized by the number of years in each conflict period based on elevation. Disturbances were found within military bases and near roads, primarily between the high mountain forest and sub-paramo categories during the armed conflict period (*Figure 4.30*). An elevation shift between conflict periods was observed: disturbances reached the paramo thermal floor (~4000 m.a.s.l.) during the conflict, but no disturbances were recorded above 3500 m.a.s.l. in the negotiation and post-peace periods, indicating a -500 m elevation shift. At lower elevations corresponding to high mountain forests, the disturbance patterns were similar (*Figure 4.30*).

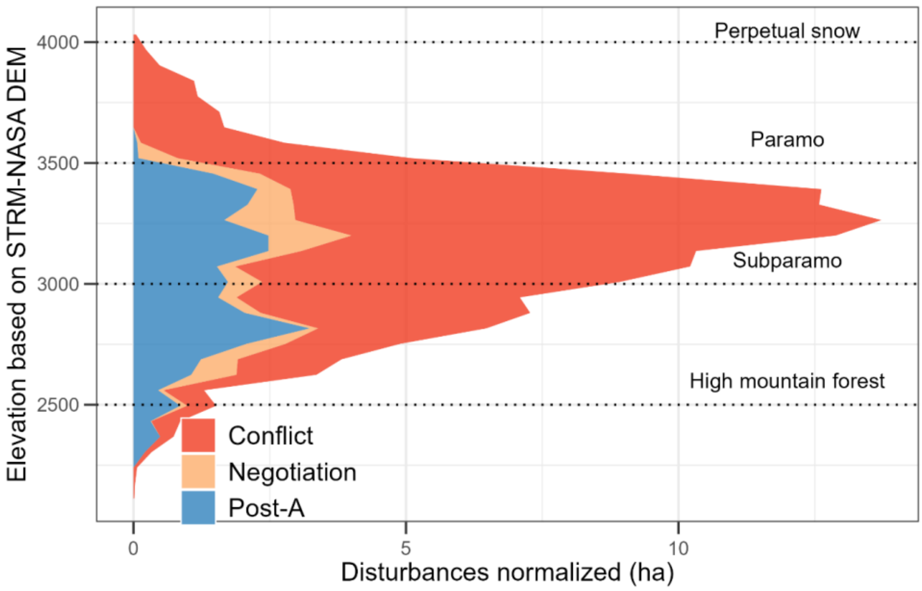


Figure 4.30; Forest disturbances in the 1 km buffer area. Normalized by years of conflict in each period and the elevations are classified by thermal floors. (Source: Own figure)

The second method used a 10 km grid to aggregate disturbances, revealing that areas north and south of the *Sumapaz Páramo* had the most disturbed patches, often near high-density roads and walls. More disturbance changes were linked to agricultural activity near military sites such as *La Australia* and *Santa Rosa*. Around *Batallón de Alta Montaña No1*, there were fewer changes with less tree canopy cover (*Figure 4.31*).

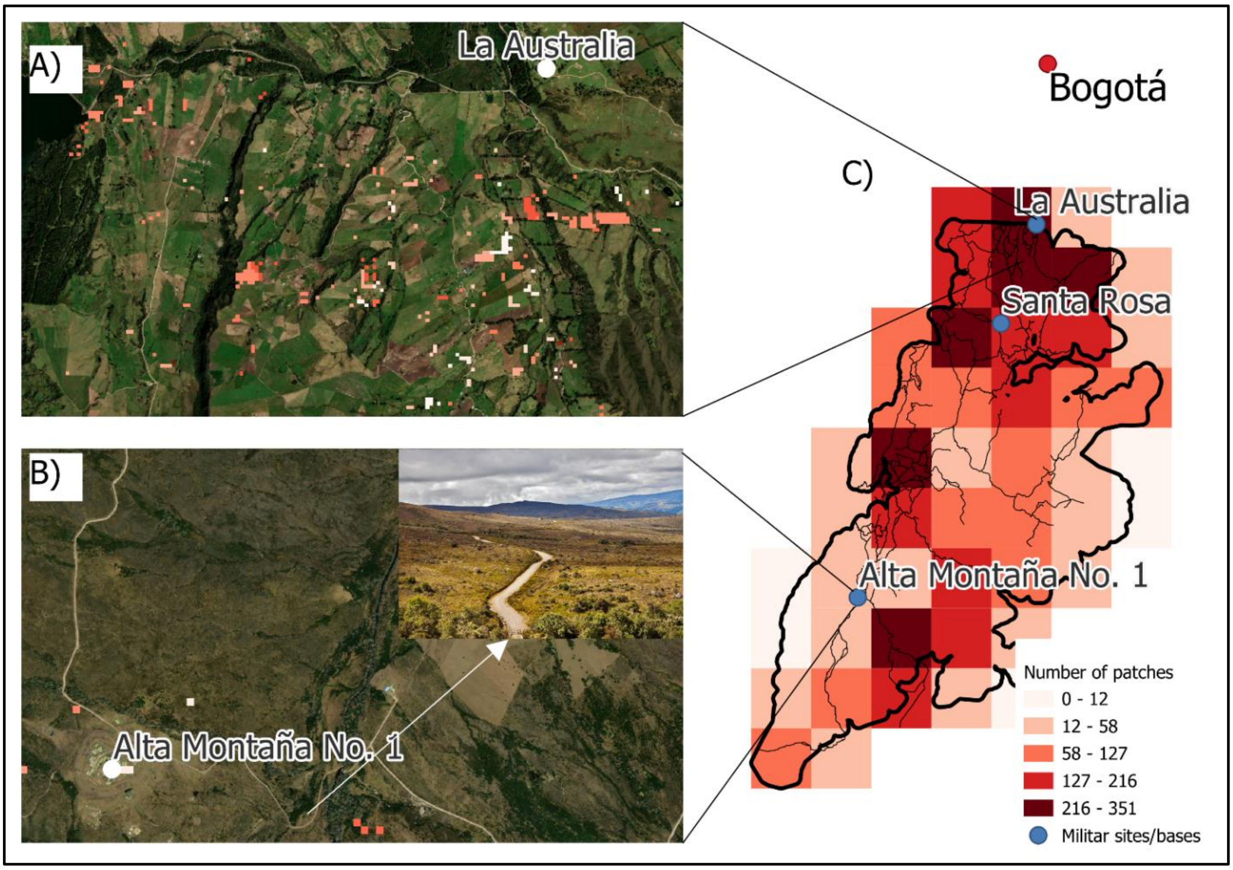


Figure 4.31; Forest disturbances in the Sumapaz study area. A) Smaller disturbances detected by the Hansen dataset linked to agriculture expansion. B) The military base *Batallon de Alta Montaña No1* and *Troncal Bolivariana* road construction. C) Number of disturbed patches across the study area. (Source: Own figure)

The mean patch sizes ranged from 0.19 to 0.72 ha. The average size of Landsat-derived disturbed patches per pixel is 0.25 ha across all years. Within the SPR, disturbed patches are significantly smaller than the 1.9 ha patches observed in other tropical forest regions of Colombia (Murillo, 2020). Forest disturbances are primarily located on the paramo periphery (montane forest, subparamo, and paramo ecosystems), particularly in lower altitude areas bordering the high-Andean, low-Andean, and montane forests at altitudes between 2100 and 3100 m.a.s.l. Disturbed areas are dispersed in the northeast of *Frutica* village in Une municipality, north of *La Regadera* village in Sumapaz near *La Regadera* and *Chisacá* reservoirs, and northwest of *El Contadero* village in *Pasca* municipality (A) (*Figure 4.33*). On the eastern slope, disturbances are concentrated in the valleys of *Río Blanco*, *Río Gallo*, and *Río Chiquito*, especially in *Las Margaritas* village. On the western slope, disturbed areas are scattered along the valleys of the *San Juan* and *Pilar* rivers near the villages of *Plan de San Antonio*, *Santo Domingo*, *Concepción*, *La Unión, and San Juan in Sumapaz*, *Bogotá* (B) (*Figures 4.32 and 4.33*). In the south, disturbances were concentrated in the *Duda* River valley and its tributaries *in La Esperanza* village, *Cubarral* municipality, and Meta Department (C) (*Figure 4.33*). In this area, the *Troncal Bolivariana* road was built by the FARC. There are some significant disturbances in the limits of the department of Meta and Huila.

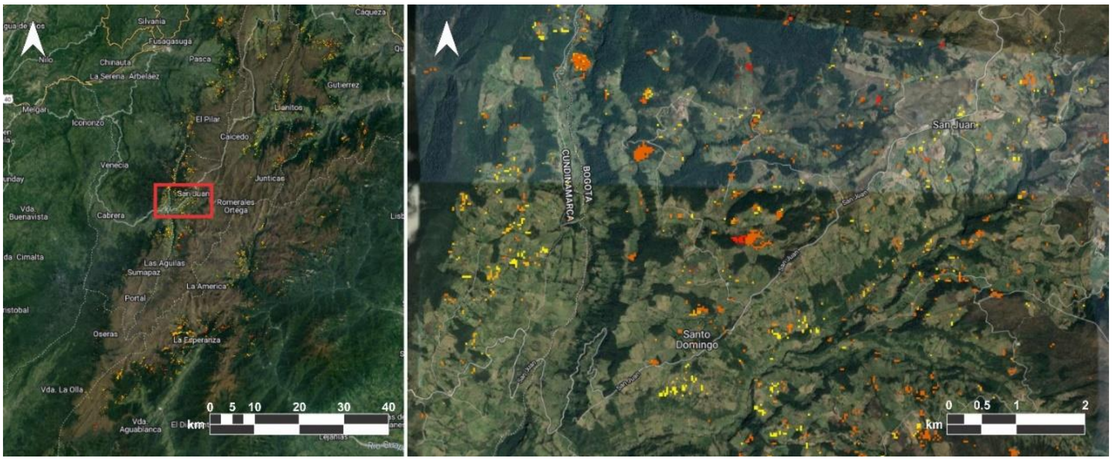


Figure 4.32: Vegetation disturbance in San Juan de Sumapaz village hotspot.
Left: Study area. *Right:* Zoom in San Juan area. (Source: Own figure)

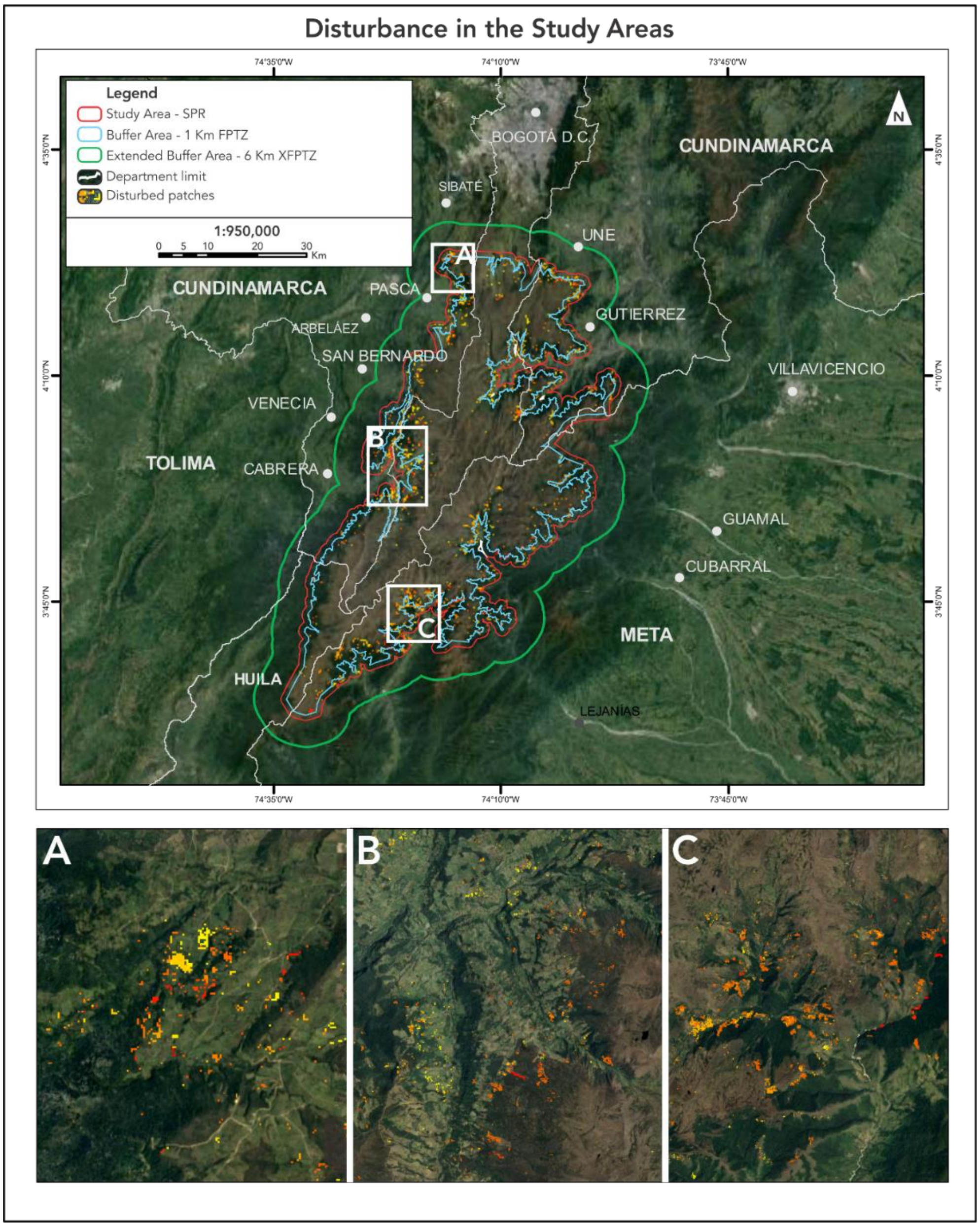


Figure 4.33: Disturbance distribution patches within SPR and FPTZ.
Blue line: Study Area (SPR). *Red line:* 1 km Buffer Area (FPTZ). *Green line:* 6 km Extended Buffer Area (XFPTZ). *Yellow-Red pixels:* Disturbed Area Patches. (Source: Own figure)

4.3.1.4. Statistical comparison of spatial units based on forest disturbances

Despite their fragility, the high-altitude ecosystems are less affected. In the high-altitude paramo ecosystem (>3200 m.a.s.l.) SPR), vegetation disturbance was significantly lower than that in the buffer area FPTZ (<3200 m.a.s.l.). To statistically determine if the means of the two disturbance areas differed regarding variances, a Z test was conducted in the Study Area-SPR 0 km buffer disturbed areas/total area and in the 1 km buffer FPTZ disturbed areas/Total of 1 km buffer area. Highly significant differences (p<0.001) are highlighted in red and slightly significant differences (p<0.05) are highlighted in yellow. Higher ratios (p1 of the 0 km buffer; p2 of the 1 km buffer) are in bold (*Table 4.10*).

Variables:
Years; *2001 to 2020*
Disturbance area: ha 0 *(Disturbance ha in the SPR/year);* ***ha 1*** *(Disturbance ha in FPTZ /year).*
Study area: tot ha 0 *(Total area SPR);* ***tot ha 1*** *(Total area FPTZ).*
p1 *= (ha 0/tot ha 0)* ***p2*** *= (ha 1/tot ha 2)*
Pooled P = *(ha 0+ha 1/tot ha 0+tot ha 1)*
Standard error = *√ (P (1-P) ((1/tot ha 0) + (1/tot ha 1)))*
Z = *diff/√ (P (1-P) ((1/tot ha 0) + (1/ha 1)))*

Table 4.10: Disturbance comparisons of ratios. (Source: Own figure)

Year / Total Area *ha*	*ha* 0 (SPR) 240,700	*ha* 1 (FPTZ) 70,584	*ha* 0 (SP) p1	*ha* 1 (FPTZ) p2	Sig=p	adjusted Z	adjusted Sig=adjusted p	Significance level	
2001	102.5505	72.6119	**0.000426051**	0,00102873	2,9E-09	5,91	3,5155E-09	strongly sig	**
2002	72.1721	45.6341	**0.000299842**	0,000646522	3,12636E-05	4,13	3,6997E-05	strongly sig	**
2003	28.8390	19.6928	0.000119813	0,000278998	0,00289548	2,92	0,00351708	strongly sig	**
2004	34.0290	30.9992	0.000141375	0,000439181	1,4783E-06	4,76	1,91479E-06	strongly sig	**
2005	31.4350	31.4721	0.000130598	0,000445882	2,19673E-07	5,13	2,91178E-07	strongly sig	**
2006	59.3717	30.1330	**0.000246663**	0,00042691	0,013002461	2,44	0,014710227	ns	ns
2007	86.1461	59.6217	**0.000357898**	0,000844692	1,46724E-07	5,22	1,77064E-07	strongly sig	**
2008	66.6346	50.8755	0.000276837	0,00072078	9,34454E-08	5,30	1,15553E-07	strongly sig	**
2009	75.0992	55.8897	0.000312003	0,000791818	4,61301E-08	5,43	5,66636E-08	slightly sig	*
2010	54.8726	33.6523	**0.000227971**	0,00047677	0,000566391	3,40	0,000667217	strongly sig	**
2011	33.6969	26.4246	0.000139995	0,000374371	8,13726E-05	3,89	0,000101778	strongly sig	**
2012	60.8208	50.5045	0.000252683	0,000715524	1,07293E-08	5,68	1,35417E-08	strongly sig	**
2013	3.3882	3.6630	1.40766E-05	5,1895E-05	0,063398826	1,70	0,0893771	ns	ns
2014	9.7015	4.8379	4.03054E-05	6,85415E-05	0,33442896	0,86	0,392321962	ns	ns
2015	2.5614	4.1465	1.06417E-05	5,87452E-05	0,015481668	2,26	0,023868764	ns	ns
2016	5.8476	15.6687	2.42943E-05	0,000221987	2,77045E-08	5,47	4,62692E-08	strongly sig	**
2017	4.8290	7.0711	2.00622E-05	0,00010018	0,002467641	2,91	0,003662036	strongly sig	**
2018	13.9422	26.5169	5.79235E-05	0,000375679	7,42304E-11	6,45	1,14828E-10	strongly sig	**
2019	8.2116	9.6408	3.41153E-05	0,000136586	0,001571106	3,06	0,002197808	strongly sig	**
2020	11.6786	34.2663	4.85195E-05	**0,000485469**	0	8,34	7,35176E-17	strongly sig	**

ns = Not significant p>0.05 * = slightly significant p<0.05 ** = strongly significant p<0.001

Although the study area (SPR) was 3.4 times larger than the buffer area (FPTZ), the Z test findings corroborate the hypothesis, indicating a significantly higher distribution of disturbances in the buffer area during the conflict period (2001–2005, 2007, 2008, and 2010–2012) compared to the SPR, except in 2006 (no significant difference) and 2009 (slightly significant difference). During the post-agreement period (2017–2020), disturbances were also significantly higher in the buffer area. However, the hypothesis was not proved during the negotiation period (2013–2015), when the difference in disturbance distribution between the areas was not significant. This can be attributed to the peace agreement negotiation period being a transition phase marked by a sharp decline in the disturbance and deforestation rates. In 2016, disturbances were predominantly concentrated in the buffer area, whereas the rates in the higher altitude region of *Sumapaz Páramo* approached zero.

4.3.2. Forest disturbances in the Sumapaz National Park

The Sumapaz Region contains 15 protected areas within the National System of Protected Areas (SINAP), with the Sumapaz National Natural Park (SNP) being the most significant. The SNP spans 224,719 ha, encompassing thirteen municipalities: five in *Cundinamarca* (*Pasca*, *Arbeláez, San Bernardo, Gutiérrez,* and *Cabrera*), six in *Meta* (*Cubarral, Acacías, Guamal, Lejanías, El Castillo,* and *La Uribe*), one in *Huila* (*Colombia*), and one in the Capital District (District 20th - Sumapaz). The SNP covers 45% of the *Cruz Verde-Sumapaz Páramo* complex, totaling 141,282 ha, of which 63% is the paramo ecosystem. This area is under strict conservation policies, with no permissible subtractions. Within the study area (SPR), 129,876 ha of the SNP were included, representing 54% of the study area (*Figure 4.34*).

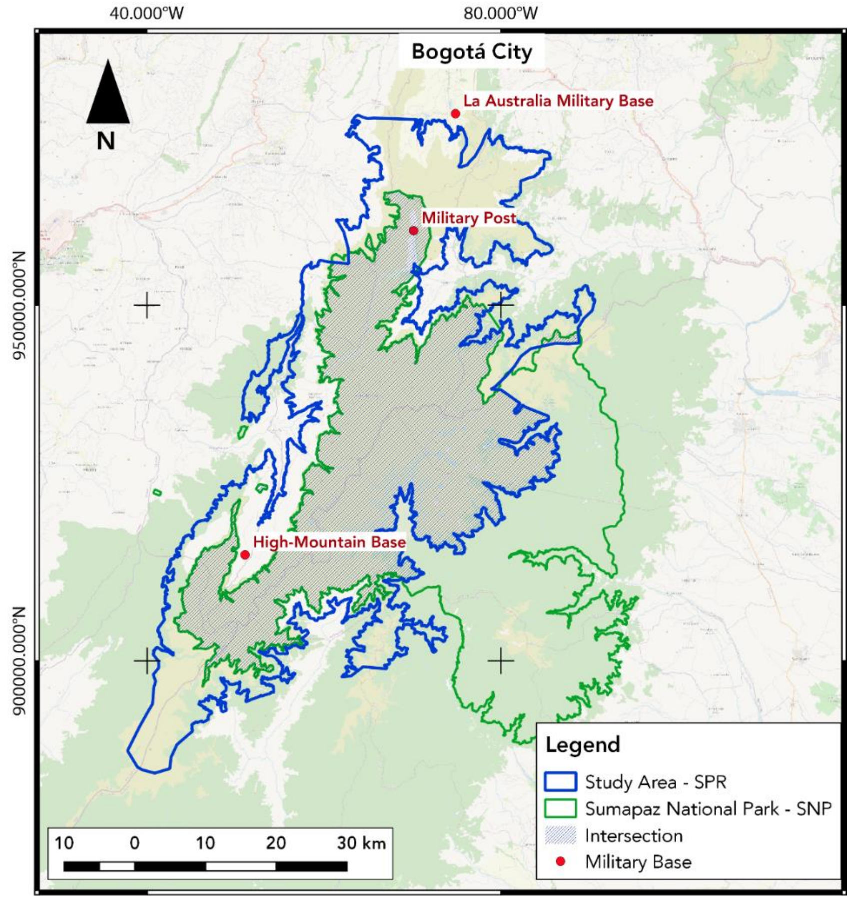


Figure 4.34: Study areas. *Blue line:* Study Area (SPR). *Green line:* Sumapaz National Park (SNP). *Gray shading:* Intersection SNP-SPR. (Source: Own figure)

I compared two spatial units: the *Sumapaz Páramo Region* (SPR), encompassing 240,700 ha, and the intersected area of the Sumapaz National Park (SNP), which is within the SPR, covering 129,876 ha (*Figure 4.34*). Using Landsat cumulative forest disturbance data, I measured 705.7 ha of disturbed area in the SPR (including SNP) from 2001 to 2012 (conflict period) and 60.16 ha from 2013 to 2020 (negotiation and post-agreement period), totaling 765.83 ha or 0.32% of the SPR. Within the SNP, 178.98 ha were disturbed from 2001 to 2012, and 3.07 ha from 2013 to 2020, totaling 182.05 ha or 0.14% of the SNP. Outside the SNP but within the SPR, 526.68 ha were disturbed from 2001 to 2012, and 57.09 ha from 2013 to 2020, totaling 583.77 ha or 0.53% of the SPR-SNP area (*Figure 4.35 and Table 4.11*).

Table 4.11: Forest disturbance rates in the SPR and SNP areas. (Source: Own table)

	Study Area excluding SNP	Study Area within SNP (Intersection)	Study Area (SPR)
Period / Area	***ha*** **3 (SPR-SNP)**	***ha*** **2 (SNP)**	***ha 0*** **(SPR)**
ha	**110,824**	**129,876**	**240,700**
Stable area	110,240	129,694	239,934
Percentage of stable area	99.47%	99.86%	99.68%
Disturbance conflict period (2001-2012)	526.68	178.98	705.7
Disturbance negotiation + post agreement period (2013-2020)	57.09	3.07	60.16
Disturbance total (2001-2020)	583.77	182.05	765.82
Percentage of the total area	0.53%	0.14%	0.32%

I divided the study area (ha 0 SPR) into two zones: within the National Park (ha 2 SNP) and outside its limits (ha 3). Although both zones covered similar areas, vegetation disturbance rates were unevenly distributed. The area outside SNP experienced significantly higher disturbance rates across the three periods. During the peak conflict years (2001-2012), the average ratio was 4:1, peaking in 2006 and 2009 and dipping in 2011. A notable decrease in disturbance rates occurred between 2012-2013, but the distribution trend remained unchanged. The disparity increased during the negotiation and post-agreement years (2012-2020), peaking in 2015, 2017, 2018, and 2019, with no disturbances detected within SNP in those years. This pattern indicates significantly lower disturbance rates within the protected area than outside; both in percentage and total hectares, demonstrating the effectiveness of PA in preserving the SNP landscape (*Figure 4.35 and 4.36*).

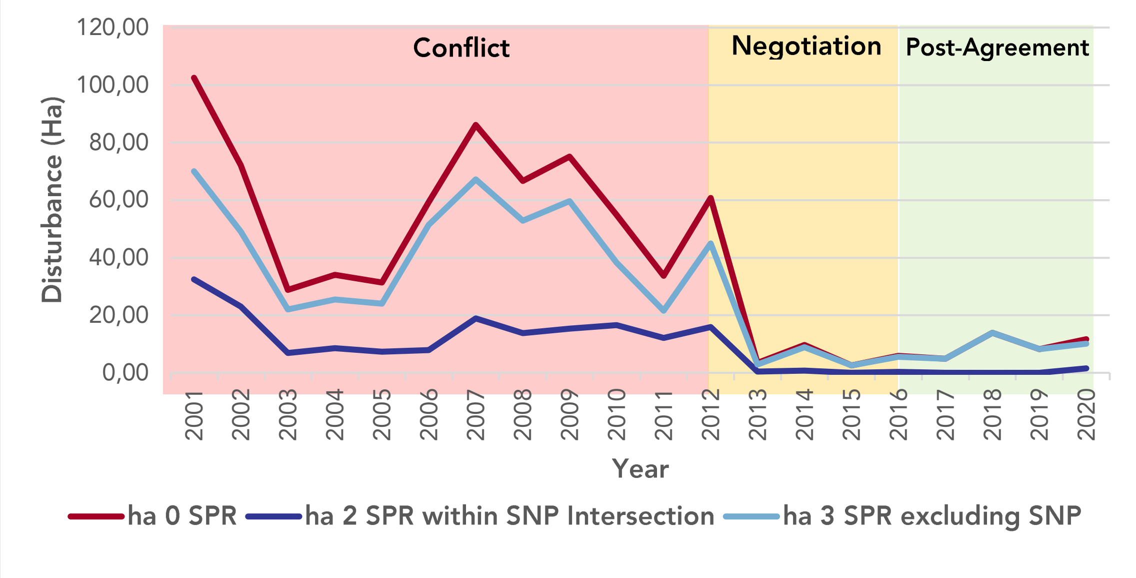


Figure 4.35: Disturbance distribution in Hectares.
Blue line: ha 0 = ha2+ha3, Study Area (SPR) *Red line:* ha 3 SPR excluding the SNP. *Green line:* ha 2 Intersection area of SNP and SPR. (Source: Own figure)

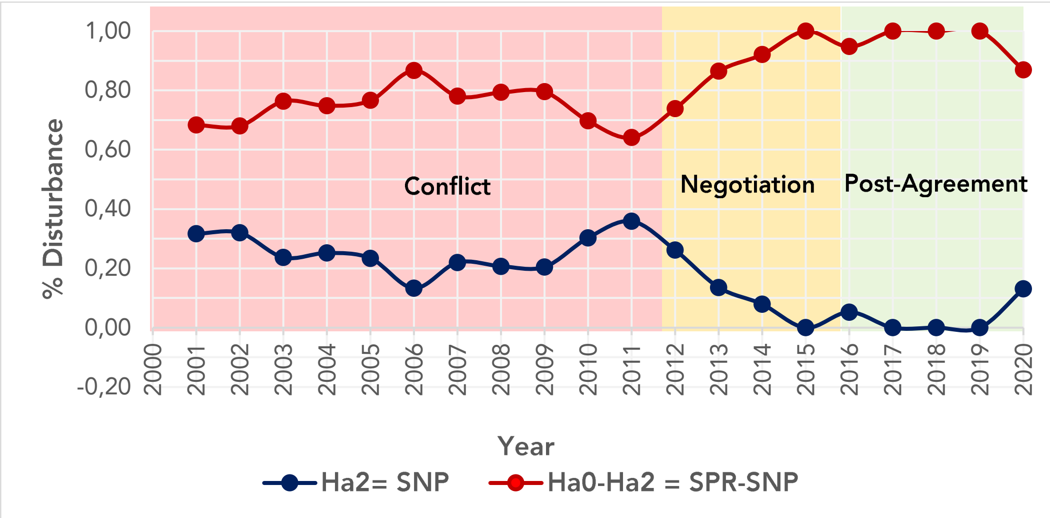


Figure 4.36: Ratio of disturbance distribution SPR and SNP. *Blue dots:* SPR excluding SNP (SPR). *Red dots:* Intersection area of SNP and SPR. (Source: Own figure)

Landsat forest disturbances in the National Park predominantly occur in the northern and eastern periphery and in some inner valleys, mainly in lower altitude areas of the paramo bordering the transition zones with high-Andean, low-Andean, and montane forests, situated between 2200 and 3100 m.a.s.l. Northern forest disturbances were evident in the villages of *Las Margaritas* and *La Preciosa* along the *Gallo* River Valley of Sumapaz District (A). In the south-central region, disturbances are found in the valleys of *Guape* and *Bogotacito* Rivers and *La Totuma*, *Los Laureles*, and *Faltriquera* creeks (B). The east-central area includes disturbances in the *Culebras* River Valley (C). Hotspots are scattered along east-range valleys, particularly along rivers flowing to the eastern flatlands, which are fertile but difficult to access owing to poor road infrastructure and high isolation. No significant disturbances were found near the SNP road network, with only a few patches near *Chisacá* Lake in the northern part of PA (*Figure 4.37*).

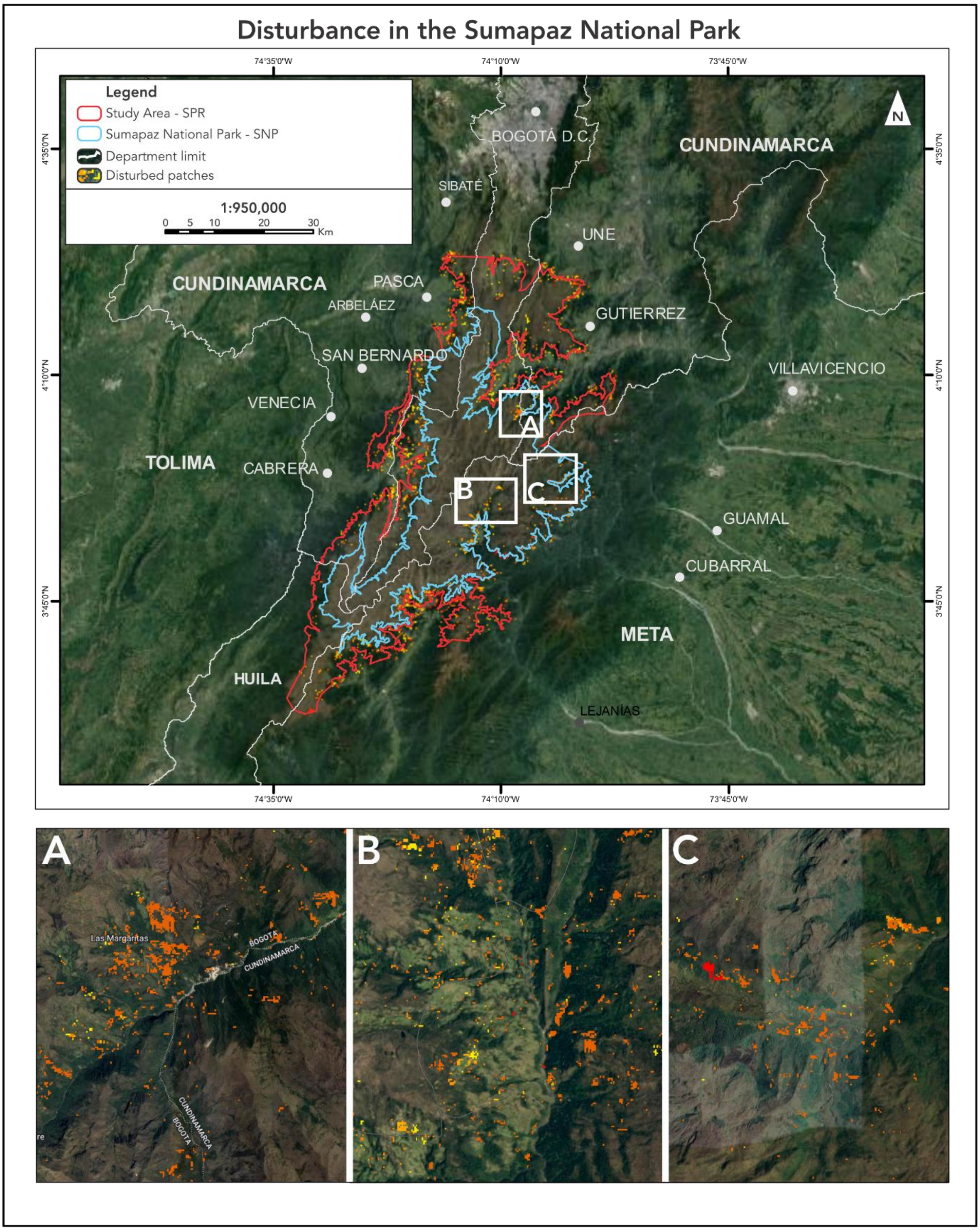


Figure 4.37. Forest disturbance distribution patches within SPR and SNP.
Blue line: Páramo ecosystem within Sumapaz National Park. *Red line:* Sumapaz Páramo Region. *Yellow-Orange-Red pixels:* Disturbed area. (Source: Own figure)

I seek to prove that protected areas have experienced less disturbance from Colombian armed conflict than have unprotected areas within the *Sumapaz Páramo Region*. It is hypothesized that vegetation disturbance is significantly lower in National Park areas at high altitudes (<3100 m.a.s.l.) than in similar unprotected areas (<3100 m.a.s.l.). A Z test was conducted to statistically compare the disturbance means between study areas outside the National Park and within the National Park. High significant differences in disturbance ratios are highlighted in red ($p<0.001$)

and in yellow (p<0.05) for slightly significant findings. Higher disturbance ratios (p1 of SPR; p2 of SNP) are in bold (*Table 4.12*).

Variables:
Years: *2001 to 2020*
Disturbance area: ha 2 *(Disturbance ha in the SNP/year);* ***ha 3*** *(Disturbance ha in SPR-SNP/ year).*
Study area: tot ha 2 *(Total area SNP);* ***tot ha 3*** *(Total area SPR-SNP).*
p1 *= (ha 2/tot ha 2)* ***p2*** *= (ha 1/tot ha 2)*
Pooled P = *(ha 2+ ha 3/tot ha 2+tot ha 3)*
Standard error = √ *(P (1-P) ((1/tot ha 2) + (1/tot ha 3)))*
Z = *diff/√ (P (1-P) ((1/tot ha 2) + (1/ ha 3)))*

Table 4.12: Disturbance comparisons of ratios within Sumapaz National Park. (Source: Own table)

Year / Total Area *ha*	*ha* 2 (SNP) 129,876	*ha* 3 (SPR – SNP) 110,824	*ha* 2 (SNP) p1	*ha* 3 (SPR - SNP) p2	Sig=p	adjusted Z	adjusted Sig=adjusted p	Significance level	
2001	32.48	70.07	0.000250092	0.00063226	5.9389E-06	4.48	7.48802E-06	strongly sig	**
2002	23.08	49.09	0.000177731	0.000442946	0.00017972	3.69	0.000226681	strongly sig	**
2003	6.83	22.01	5.25995E-05	0.000198581	0.00110829	3.17	0.001531396	strongly sig	**
2004	8.57	25.46	6.60156E-05	0.00022969	0.0007615	3.28	0.001034492	strongly sig	**
2005	7.36	24.08	5.66407E-05	0.00021727	0.00058736	3.35	0.000812562	strongly sig	**
2006	7.91	51.46	6.09099E-05	0.000464349	3.3347E-10	6.22	5.04607E-10	strongly sig	**
2007	18.93	67.22	0.000145729	0.000606542	2.5607E-09	5.90	3.55174E-09	strongly sig	**
2008	13.81	52.83	0.000106325	0.000476662	5.2202E-08	5.38	7.34277E-08	strongly sig	**
2009	15.39	59.71	0.00011852	0.000538749	5.9348E-09	5.76	8.35877E-09	strongly sig	**
2010	16.63	38.25	0.00012802	0.000345104	0.00043766	3.45	0.000562726	strongly sig	**
2011	12.09	21.61	9.31002E-05	0.000194952	0.03527673	2.02	0.043456293	slightly sig	*
2012	15.90	44.92	0.000122429	0.000405329	1.3456E-05	4.29	1.79779E-05	strongly sig	**
2013	0.46	2.93	3.54611E-06	2.64174E-05	0,13604204	1.22	0.22249892	ns	ns
2014	0.77	8.93	5.91037E-06	8.06134E-05	0.00400898	2.72	0.006579166	strongly sig	**
2015	0.00	2.56	0	2.31128E-05	0.08317083	1.42	0.155274868	ns	ns
2016	0.31	5.54	2.36375E-06	4.9995E-05	0.01812108	2.16	0.031004516	ns	ns
2017	0.00	4.83	0	4.35734E-05	0.01736353	2.15	0.031389649	ns	ns
2018	0.00	13.94	3.24393E-08	0.000125767	5.345E-05	3.91	9.36364E-05	strongly sig	**
2019	0.00	8.21	0	7.40814E-05	0.00192289	2.93	0.003412222	strongly sig	**
2020	1.53	10.15	1.178E-05	9.15748E-05	0.00508861	2.66	0.00791873	strongly sig	**

ns = Not significant p>0.05 / * = slightly significant p<0.05 / ** = strongly significant p<0.001

The results confirm the hypothesis, showing that the distribution of forest disturbances was significantly higher in the study area (excluding the SNP) during the conflict period (2001-2010, 2012) than within the SNP, except in 2011, when the difference was slightly significant. Similarly, disturbances were significantly higher outside the National Park during the post-peace period (2018-2020). However, the hypothesis was not supported during the negotiation period (2013, 2015-2017), when differences were not significant between the two areas (*Table 4.12*).

Differences in impact levels between protected and non-protected areas can be attributed to several factors: (I) altitude and forest density: higher altitudes within the protected area (3200-4300 m.a.s.l.) have lower forest density and exposed rocky soil, reducing disturbances, compared to lower, more forested non-protected areas; (II) Military refuge: remote, steep, and inaccessible areas of the national park led guerrillas to prefer lower altitude areas with greater forest cover for hiding, resulting in most confrontations and bombings occurring outside the protected area; (III) accessibility and civilian population: many disturbances occurred near roads, which are scarce in the high paramo within the park, and the population within the park is much lower than outside; (IV) despite limited state presence, management by national park rangers and peasant associations has kept disturbances within the paramo low compared to non-protected areas with less environmental control and greater influence of belligerent forces.

4.3.3. Conflict intensity rates in the Sumapaz Páramo Region

To assess the armed conflict intensity in the region yearly, I categorized the data into two main groups: the number of victims (514 in total, including injured, fatalities, and affected individuals) and the number of armed conflict-related cases (520 in total). Victim totals included military action victims, selective assassinations, massacres, forced disappearances, antipersonnel mines, and combat fatalities (80 total). High victim rates were observed during the initial conflict years (2001-2003), averaging 116 victims annually. From 2004 to 2012, there was a significant decrease, with an average of 18 victims per year, mostly because of sporadic military actions. During the negotiation period (2013-2016), victim rates further declined to an average of one per year. After the peace agreement (2017-2021), victims were nearly nonexistent, except for one mine-related victim in 2021 (*Figure 4.38 and 4.39*).

Figure 4.38: Soldiers of the High Mountain Battalion in the *Sumapaz Páramo*.
(Source: Cristian Garavito / El Espectador, 2017)

The total number of violent cases was calculated by summing up war acts, selective assassinations, attacks on towns, terrorist attacks, damage to civil property, forced disappearances, massacres, mines, and kidnappings. A large number of military actions were observed in 2001, 2002, and 2003, averaging 115 actions annually. From 2004 to 2012, the conflict intensity significantly decreased to an average of 18 actions per year. Between 2013 and 2016, the average decreased to just above two actions per year. From 2016 to 2021, violent actions further declined to one case per year during the post-agreement period (*Figure 4.39*).

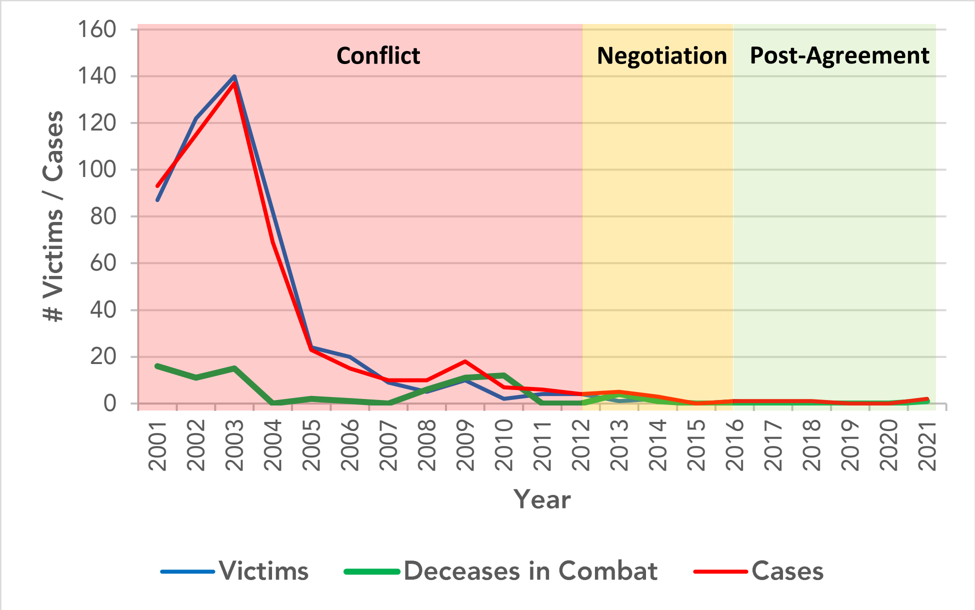


Figure 4.39: Victims, deceased in combat and conflict-related cases.
Blue line: Total victims (Injured, fatalities or affected). *Green line*: Fatalities due to combats. *Red line:* Total cases of conflict-related events. (Source: OMC and CNMH, 2021)

4.3.4. Relationship between conflict intensity rates and forest disturbances

The *Sumapaz Páramo* is an area with highly vulnerable ecosystems due to its unique topography, geography, climate, and social aspects, making it highly sensitive to natural and man-made changes. A less-studied factor influencing landscape changes is the Colombian armed conflict, which directly and indirectly affects land use and cover. Over the past 25 years, belligerent forces, primarily the FARC guerrilla and the National Army, have significantly impacted the region by constructing military infrastructure and roads, bombings, placing antipersonnel mines, and generating waste. Such activities have directly caused deforestation, water contamination, craters, and landslides. In addition, armed conflict has indirectly caused landscape changes through forced displacement, uncontrolled agriculture, illegal logging, and weakened institutions. The following statistical analysis demonstrates the relationship between conflict intensity and forest disturbance across the three main periods: conflict, negotiation, and post-agreement.

First, a visual comparison was conducted to link armed conflict intensity data with landscape change data, thereby revealing the relationship between disturbances and conflict rates (victims and cases). During the high-intensity conflict period (2001-2003), deforestation rates rapidly decreased from high to medium in the SPR and FPTZ, while the conflict intensity increased. The years 2001 and 2002 saw high vegetation disturbances and violence, with 2003 being the most violent, coinciding with a significant drop in disturbance rates. In 2004 and 2005, forest disturbance remained low and steady, whereas conflict intensity decreased significantly. Since 2005, conflict cases and victims have declined substantially, yet deforestation rates have risen significantly since 2007. During the low-medium-intensity conflict period (2007–2012), disturbance rates remained high and steady, peaking in 2007, 2009, and 2012. The year 2013 marked a turning point; during the negotiation period (2013-2016), both conflict intensity and disturbance rates were very low (nearly zero). However, since the 2016 peace agreement, violence rates have remained low, while disturbance rates have gradually increased (*Figure 4.40*).

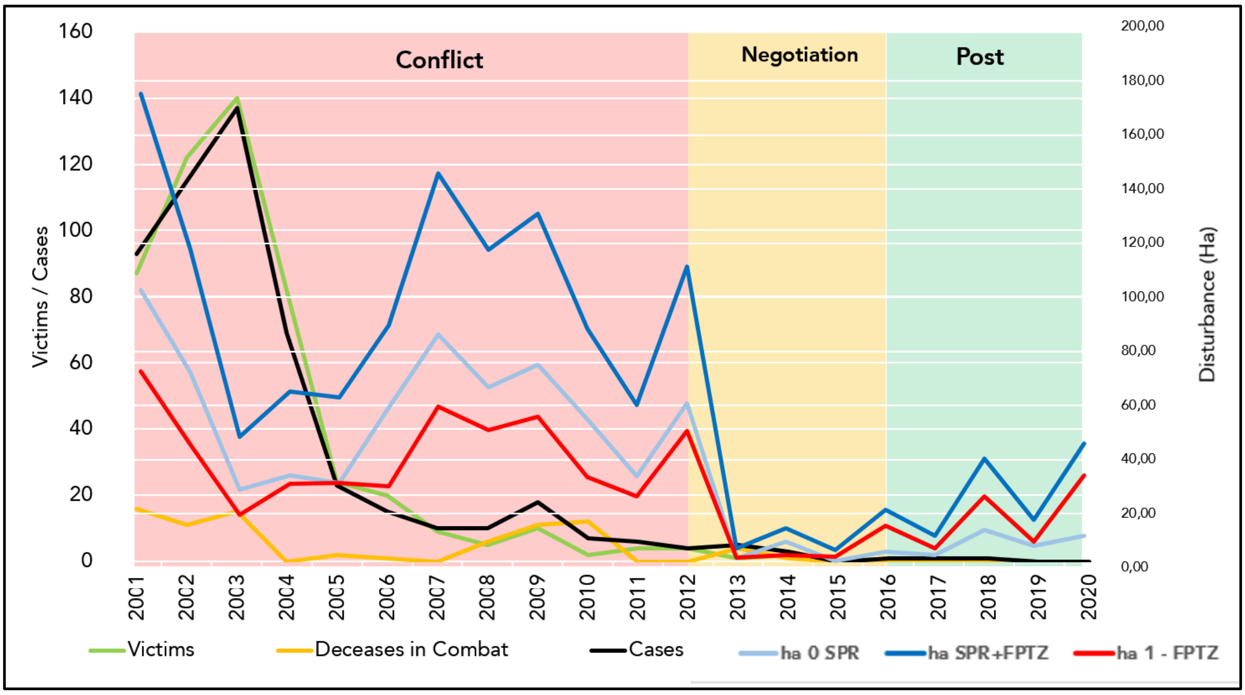


Figure 4.40: Conflict intensity rates and forest disturbance rates.
Dark blue line: Total disturbance in the extended study area (XSPR), *Light blue line:* Disturbance in the study area (SPR), *Red line:* Disturbance in the 1 km buffer area (FPTZ), *Green line:* Conflict-related victims, *Yellow line:* Fatalities due to combats. *Black line:* Conflict-related cases. (Source: OMC and CNMH, 2021)

The highest forest disturbances in paramo occurred in 2001-2002 and 2007-2010 (*Figure 4.40*). In 2001, the Colombian government deployed 4000 soldiers and aerial support to regain control of Sumapaz, establishing *Batallón de Alta Montaña* No.1 (Gómez, 2022). Military infrastructure construction and daily tree felling significantly affected paramos. Widespread agricultural activities have occurred because of a lack of environmental controls. "*Operation Fuerte*" in 2009 weakened the FARC, initiating their retreat and reducing disturbances (Osorio 2010). However, since 2018, disturbances have increased slightly in the study area and the 1 km buffer zone, with forest disturbance doubling in the buffer zone (*Figure 4.40*).

4.3.4.1. Statistical correlation between armed conflict intensity rates and forest disturbances

Pearson's correlation coefficient (*r*) was employed to assess the strength of the relationship between conflict intensity (Cases and Victims) and forest disturbance rates in the four study areas (SPR, FPTZ, XSPR, and SNP). The coefficient r measures the proximity of data points to the line of best fit, indicating the degree of linear relationship between the variables, but does not imply causation. An essential thing to understand about the correlation is that it only shows how closely related the two variables are. The association between changes in forest disturbance and conflict intensity does not necessarily imply that one causes the other, although they may move together.

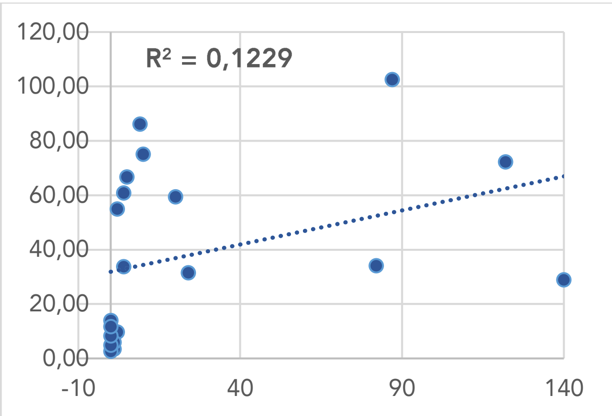
Throughout the study period (2001-2020), the Pearson's correlation coefficient consistently showed a positive relationship between vegetation disturbance rates and conflict intensity rates.

The coefficients, ranging from *-1* (negative correlation) to *1* (positive correlation), indicate a positive and moderate correlation between the number of hectares disturbed and the number of violent cases and victims per year. Specifically, the correlation coefficients varied from 0.270 (FPTZ-Victims) to 0.477 (SNP-Cases) (*Table 4.13; Figures 4.41 and 4.42 respectively*).

Table 4.13: Pearson's correlation matrix of forest disturbance rates and conflict-related events. (Source: Own figure)

r	SPR	FPTZ	XSPR	SNP	Victims	Cases
SPR	1	0,929	0,989	0,942	**0,351**	**0,387**
FPTZ	0,929	1	0,974	0,874	**0,270**	**0,305**
XSPR	0,989	0,974	1	0,932	**0,324**	**0,361**
SNP	0,942	0,874	0,932	1	**0,436**	**0,477**
Victims	**0,351**	**0,270**	**0,324**	**0,436**	1	0,995
Cases	**0,387**	**0,305**	**0,361**	**0,477**	0,995	1

The correlation matrix indicates a positive correlation between the variables in all areas. However, the SNP area shows a slightly stronger correlation, likely because the disturbance in SNP is, on average, only one-third of that in the rest of SPR and even smaller (one-eighth) than that in FPTZ. In the protected paramo area (SNP), changes were smoother and more stable concerning conflict intensity data. In contrast, the rest of the SPR and FPTZ exhibited more abrupt disturbances, which did not always correlate positively with the conflict intensity (*Table 4.13*).



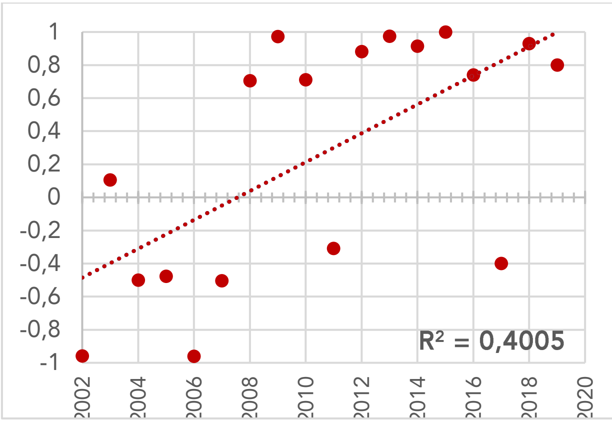


Figure 4.41: Scatterplot SPR-Victims rates. Figure 4.42: Correlation SPR-Victims rates. (Source: own figures)

The relationship between forest disturbance and violence rates gradually declined over time. The first two years, 2001 and 2002, experienced intense conflict and large forest disturbances. Around 2009, there was an increase in violence, accompanied by an increase in forest disturbances. I found a unidirectional relationship between the number of victims and forest disturbance in the study area (R2 = 0.61; $p < 0.001$). Regarding the number of armed conflict-derived events and forest disturbances, I found that R2 = 0.54, $p < 0.001$. *Figure 4.43* compares the forest-disturbed areas and the (loge) of the victims and armed conflict-derived events. I proved that both variables move together (sensitivity of the area to what happens with armed conflict). Thus, I defined it as a general statement that the study area is highly correlated with what happens independently of time (armed conflict stage).

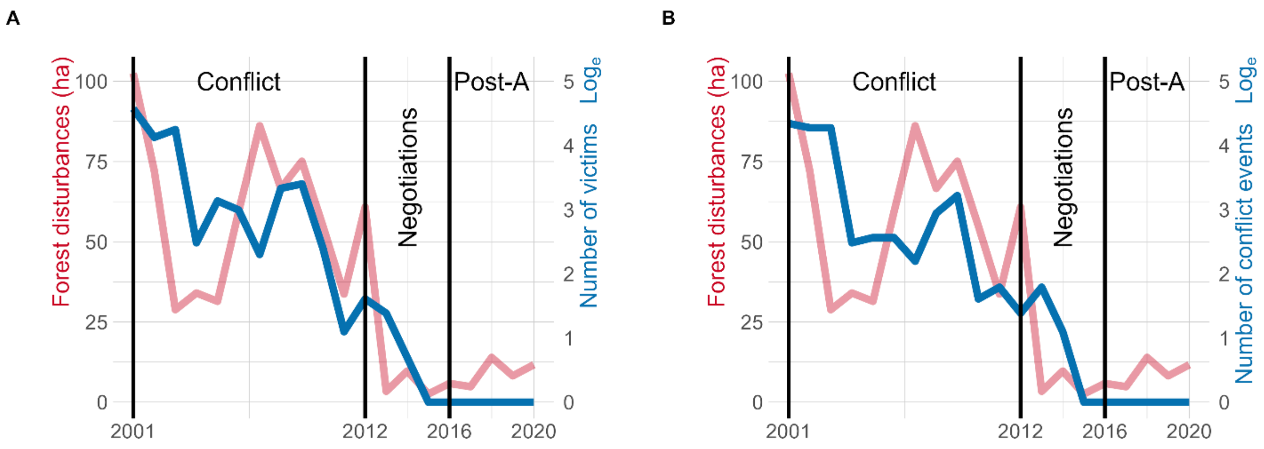


Figure 4.43: Armed conflict intensity and forest disturbance pathways. A) Shows a positive relationship between forest disturbances and ($\log_e$) number of victims and B) presents forest disturbances and ($\log_e$) conflict events with a positive relationship.

Table 4.14 presents the slopes of linear trends of cumulated variables were calculated for the three eras of war, negotiations, and 'post-agreement.' The highlighted p-values in red are significant at $p<0.001$, yellow at $p<0.01$, and green at $p<0.05$. The correlation was visible during the war and post-agreement periods; however, it was not significant during the negotiation period.

Table 4.14: Slope of disturbance within the study area, buffer zone and protected area related with conflict events during the conflict stages. (Source: Own figure)

	TREND	*ha* SNP	*ha* SPR+FPTZ	*ha* SPR	Victims	Cases
Conflict	slope	12,49	95,73	55,89	7,95	5,96
	R	0,99	0,99	0,99	0,94	0,85
	sig	2,61E-09	1,55E-09	2,45E-09	0,000	8,99E-04
					p<0.001	
Negotiation	slope	0,38	12,09	5,53	1,10	1,50
	R	0,95	0,98	0,98	0,80	0,78
	sig	0,01	0,00	0,00	0,10	0,12
					p>0.05 ns	
Post-Agreement	slope	0,46	33,06	10,97	0,00	0,00
	R	0,78	0,99	1,00	0,000	0,00
	sig	0,22	0,01	0,00	1,00	1,00
			p>0.05 ns		p>0.05 ns	

In the *Sumapaz Páramo Region*, substantial forest disturbances were observed during years with the highest levels of violence. There is a one-way relationship between conflict intensity, calculated by the number of victims, armed conflict incidents, and forest disturbances. This conclusion runs counter to other Colombian regions with higher forest densities, such as the Andean and Amazonian regions, where intense armed conflict has inadvertently resulted in landscape preservation (Murillo-Sandoval, Clerici and Correa-Ayram, 2022).

4.3.5. The influence of the military road network on the landscape changes

4.3.5.1. Southern Sumapaz road network and the origins of Troncal Bolivariana *construction*

Páramo lacks major roads, with existing roads largely resulting from the armed conflict. The southern routes were primarily constructed by the FARC (El Tiempo.com, 2001, October 1) under Henry Castellanos, alias "*Romaña*," who aimed to build a 100-kilometre highway, *La Troncal Bolivariana*, to connect the *Duda* River Canyon, *Sumapaz Páramo*, and Bogotá's Usme area, despite significant environmental damage to the fragile paramo ecosystem (*Figure 4.44*). During their presence in Sumapaz, the FARC developed access roads in the southern area, establishing trails and roads descending the mountain range into the *Duda* River Canyon, a guerrilla stronghold, facilitating movement to *La Uribe*, *La Macarena*, *Caquetá*, and the Distention Zone (Demilitarized Zone-DMZ). Historically, transportation within the region has relied on trails via foot, horseback, or muleback, with soldiers carrying heavy loads due to extreme temperatures. As altitude increases, vegetation decreases; therefore, free movement in the paramo becomes more challenging. Despite Bogota's relative proximity in kilometers, access remains difficult with a basic road network, making connections to the southern paramo region even more challenging, sometimes taking days to reach certain areas.

Figure 4.44: Dirty road built by FARC in the southern SPR.
(Source: Cesar Romero - CNMH, 2018)

By 2000, amidst tensions from the new peace process initiated in *Caguán* without halting hostilities and bolstering Military Forces through Plan Colombia funds, the government launched Operation Annihilator II to retake Sumapaz. After the operation, *Alto de las Águilas*, a strategic plain in the mountains of Cabrera previously controlled by the FARC, became the Military Forces Operations Hub in Sumapaz. In 2001, the *High-Mountain Battalion* was established, reinforcing control over the region and marking a controversial new military presence (*Figure 4.45*). A few years before, the FARC began constructing the *Troncal Bolivariana* in this area, linking the paramo with the *Orinoquía* lowlands of *Meta* (*La Macarena*) and *Caquetá* (*Caguán*) (*Figure 4.44*).

Figure 4.45: National Army, High Mountain Military Battalion No.1.
(Source: Cesar Romero - CNMH, 2018)

4.3.5.2. Relationship between forest disturbances and military-derived road network proximity

In this study, the road network of the Sumapaz region was categorized into two main groups (*Figure 4.46*).

(I) The road network constructed by the national government, local authorities, and/or local communities primarily connects the region to Bogotá in the north and *Cabrera* in the west. This network, although mostly unpaved, is the most extensively used and well-maintained. The central Sumapaz highway originates from Usme on Bogotá's outskirts, heading south into paramo, and links major towns, such as *San Juan de Sumapaz, Betania, La Unión,* and *Nazareth*.

(II) The road network built by the FARC guerrilla during the 1990s and the early 2000s for military purposes started from La Unión and extended south to connect paramo with the *Duda* River Canyon and further to the old demilitarized zone in Meta and Caquetá in the Amazon foothills. When the national army arrived in 2000, they not only utilized this road network but also enhanced and expanded it for strategic military purposes, including the construction of roads around military bases.

The forest disturbance detection rates indicate that in the *Sumapaz Páramo Region*, proximity to the road network and administrative centers consistently attracts deforestation. The proximity to roads primarily acts as a deforestation attractor. However, other drivers may have complex and opposing effects; for example, armed conflict may attract deforestation in some areas, while repelling it in others. The years with the highest conflict intensity (2001-2004) and 2007, which also saw a peak in conflict, had the highest disturbance rates near the highways. At least 50% of the total disturbance occurred within the first 500 m of the road, 20% occurred between 500 m and 1000 m, and the remaining 30% occurred between 1000 and 1500 m.

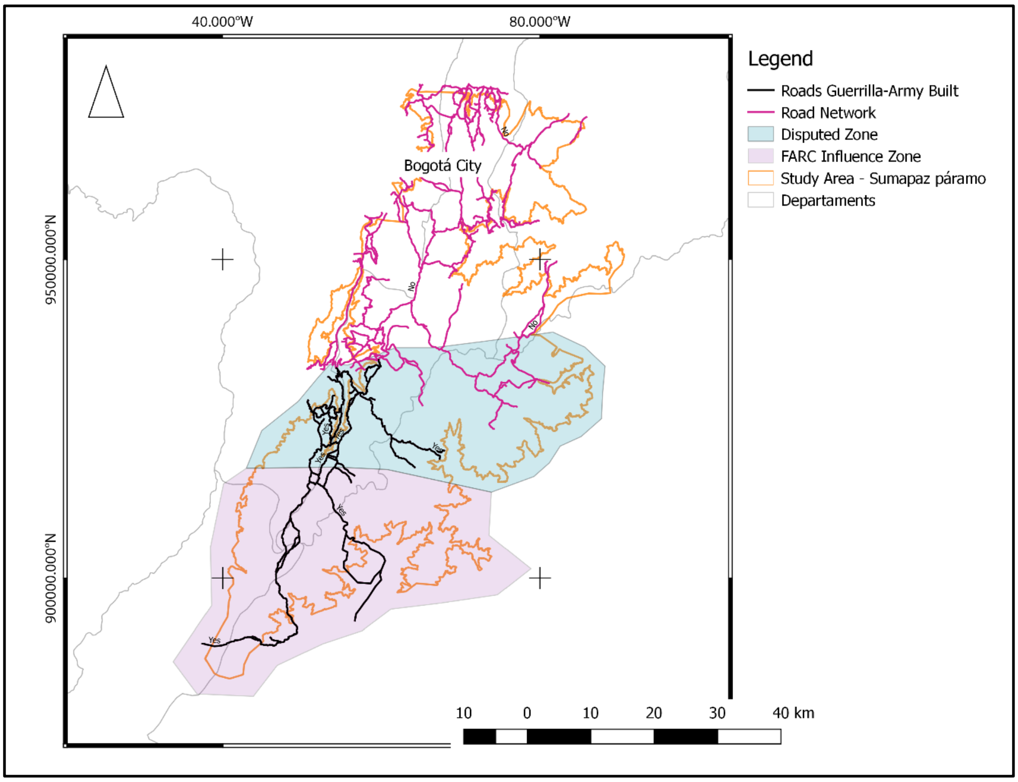


Figure 4.46: Dirty road built by FARC southern SPR.
Green Area: Military Disputed Zone. *Purple Area:* FARC Influenced Zone. *Orange line:* Study Area - Sumapaz Páramo Region. *Purple line:* Civil Roads Network. *Black lines:* Roads built by the FARC and the National Army. (Source: Own figure)

Although the disturbance near guerrilla-built roads was less overall than that near civilian-built roads, it was proportionally significant given that the civilian road network was four times more extensive. In the Andean region, proximity to previously deforested areas increased deforestation, mostly within 1 km, with the effect diminishing beyond 1.5 km (*Figure 4.47 and Table 4.15*). This suggests that land use exerts immediate pressure on forests. Proximity to road infrastructure, particularly within 500 m, 1000 m, and 1500 m, also correlates with increased deforestation. Rural and urban centers attract deforestation at distances of 1 km and 9.4 km, respectively. Although slopes generally repel deforestation, steeper slopes attract it, likely because they are less prone to flooding, which benefits agricultural activities.

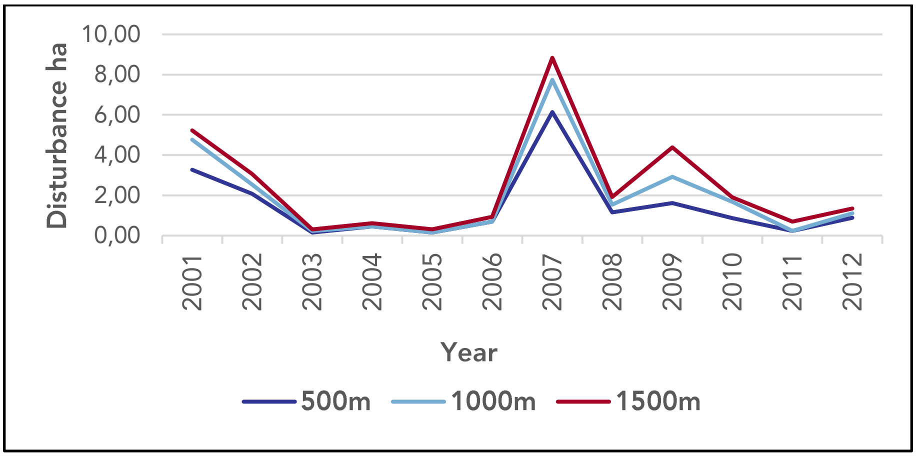


Figure: 4.47: Forest disturbances in proximity of the Guerrilla-Built road.
Red line: 1500m, *Light blue line:* 1000 m, *Dark blue line:* 500 m (Source: Own figure)

Table 4.15: Disturbance comparison within the proximity to the roads built by the FARC and National Army and non-military roads network. (Source: Own table)

Year	500 m CIV	500 m MIL	Total 500 m	1000 m CIV	1000 m MIL	Total 1000 m	1500 m CIV	1500 m MIL	Total 1500 m
2001	6,02	3,28	9,30	8,70	4,76	13,46	11,62	5,22	16,84
2002	3,96	2,07	6,03	6,27	2,53	8,80	8,44	3,07	11,51
2003	0,89	0,15	1,05	2,00	0,23	2,23	2,07	0,31	2,38
2004	0,46	0,46	0,92	1,09	0,46	1,55	2,53	0,61	3,15
2005	1,84	0,15	2,00	2,53	0,15	2,69	2,92	0,31	3,22
2006	1,30	0,69	1,99	1,86	0,70	2,56	2,07	0,93	3,00
2007	3,82	6,14	9,96	4,59	7,74	12,33	6,22	8,84	15,05
2008	1,15	1,15	2,30	2,09	1,53	3,62	2,44	1,92	4,36
2009	0,68	1,62	2,30	1,88	2,93	4,81	2,38	4,39	6,77
2010	1,88	0,87	2,75	4,58	1,68	6,25	6,62	1,90	8,52
2011	0,95	0,23	1,18	1,77	0,23	2,00	2,00	0,69	2,68
2012	1,85	0,88	2,72	2,15	1,11	3,26	2,96	1,34	4,30

The disturbance analysis covered three proximity distances—500 m, 1000 m, and 1500 m—in two road network groups (direct and indirect influence of conflict) from 2001 to 2012. Post-2012, the disturbance data were minimal or absent. Disturbances near the constructed guerrilla road (direct influence area) were notably higher within the first 500 m (*Table 4.15*). Therefore, direct deforestation through road construction is relevant. However, could have an even more significant influence, as roads grant access to previously untouched areas, and access to road networks enhances the development of indirect activities such as agriculture and cattle ranching. Moreover, roads facilitate wood extraction by facilitating transportation. FARC has contributed to deforestation by making remote forested areas accessible through road construction.

4.4. Landscape and armed conflict: *Sumapaz Páramo Region* community's perceptions

Printed (n=19) and online (n=13) survey responses were combined and digitized (total =32). First, self-reported demographic and socioeconomic background information was collected. In the second part, I assessed people's perceptions of the influence of armed conflict on the landscape of the region. The landscape-conflict perceptions responses were classified into five categories; (I) Environmental benefits and ecosystem services, (II) Landscape-changes causes, (III) Landscape-changes consequences, (IV) Landscape-changes belligerent forces (V) Landscape conservation and preservation (*Appendix 8*).

4.4.1. Demographic characteristics

Basic demographic and socioeconomic data were processed to profile the respondents, with a visual analysis of age, education, occupation, place of birth, place of residence, and gender. The gender distribution was 55% female and 45% male. Half of the respondents held professional degrees, 25% had technician degrees and the remaining 25% had only completed primary or high school education. The age distribution was as follows: 37% were 31-45 years old, 28% were 18-30 years old, 19% were 46-60 years old, and 13% were over 60. Regarding occupation, education was the most common occupation (31%), followed by public-sector work (25%). Additionally, 75% of the respondents had lived in the region for at least 25 years.

4.4.2. Paramo's ecosystem services

I used the term "*benefits*" in the survey rather than a more technical term such as "*ecosystem services*" (Kadykalo *et al.*, 2019; Pedraza *et al.*, 2020) to be more understandable to the respondents. From the responses to Question 1b (*Appendix 8*), I identified that the most referenced benefits (ecosystem services) by the respondents were air purification (87.5%), biodiversity (84.4%), and water provision (71.9%). Climatic regulation (65.6%), scenic beauty/landscape enjoyment (65.6%), and economic support (50%) were also highly referenced as a benefits provided by the ecosystem. On the other hand, benefits such as recreation/ecotourism (34.3%), landslide mitigation (31.2%), and spiritual and religious services (25%) were the ecosystem services less relevant to the respondents (*Figure 4.48*).

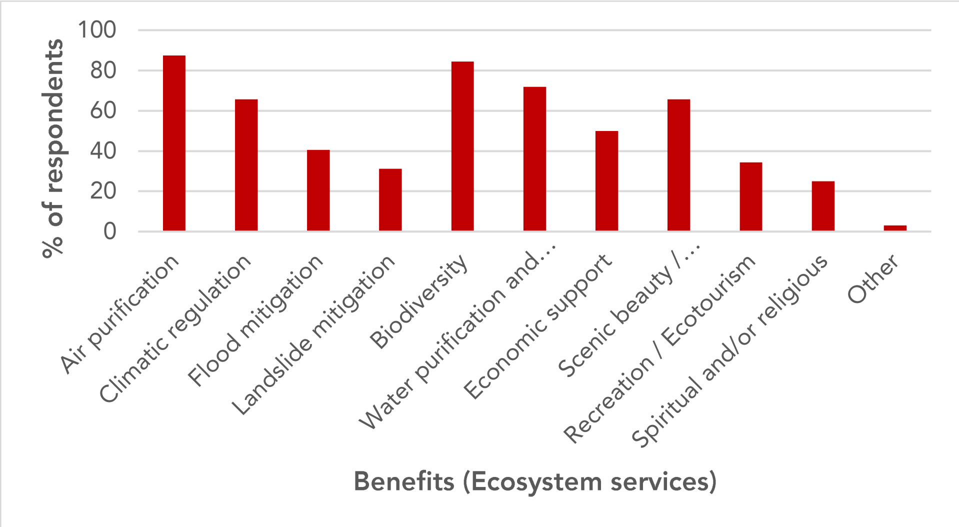


Figure 4.48: Benefits provided by the paramo.

Based on the responses to Question 1c (*Appendix 8*), the ecosystem services that showed the highest importance for the local population were mostly concerned with environmental and primary supply services (air purification, 56.2%; water supply, 50%). These services directly affect the quality of life of the local population. Perceptions related to biodiversity (43.7%) and scenic beauty/landscape enjoyment (28.1%) were significant, but less relevant. Similarly, perceptions of benefits such as economic support (15.6%), climatic regulation (15.6%), flood mitigation (6.2%), and spiritual and religious values (3.1%) showed little relevance for locals. Finally, benefits such as recreation/ecotourism and landslide mitigation showed no importance for the local communities as a main ecosystem services provided by the paramo (*Figure 4.49*).

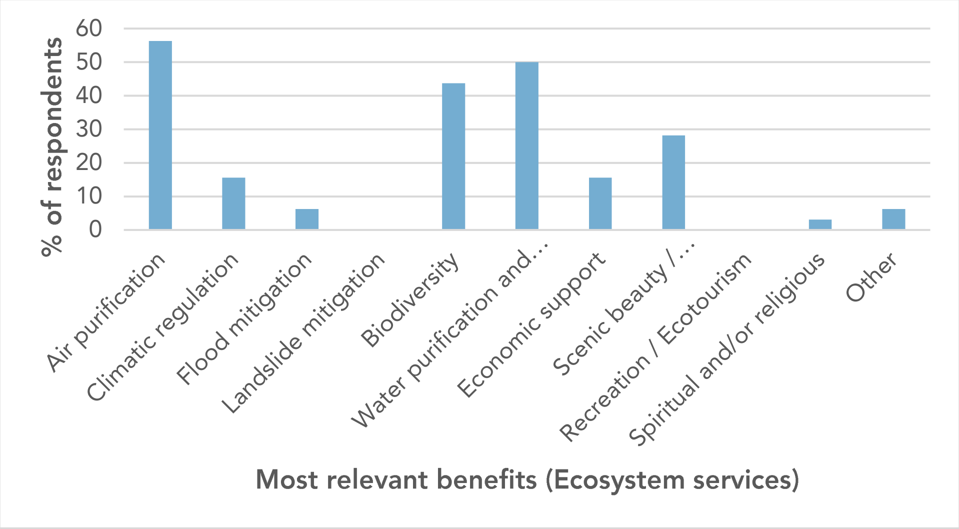


Figure 4.49: Relevant paramo's benefits. (Source: Own figure)

Respondents were highly aware of the diverse benefits the ecosystem provided to their well-being, with more than half of the benefits (6) recognized by at least half of the participants. Locals view the paramo as the primary source of clean air and water for their consumption and for nearby communities, including Bogotá, emphasizing its conservation as vital for their survival and well-being. They also regarded the conservation of paramo as essential for preserving biodiversity. Notably, economic profit and recreation are not strongly emphasized as the most relevant benefits. In contrast, approximately one-third of the respondents highly valued the scenic beauty and contemplation of the paramo landscape. Overall, the community perceives the paramo as a provider of essential survival services and quality-of-life improvements, rather than economic, religious, spiritual resources, or natural disaster prevention.

4.4.3. Landscape-changes causes

In addition to asking, what types of direct or indirect conflict-derived causes can trigger landscape changes; I also asked when they considered that those causes occurred during the conflict period or the post-agreement period. From the responses to Question 2a (*Appendix 8*), I identified that the causes referenced most by the respondents during the conflict period were military confrontations (68.8%), bombing (62.5%), and military infrastructure (62.5%). Manmade fires (56.2%), forced migration (53.1%), agriculture (53.1%), and landmines (50%) were highly referenced. In contrast, non-forced migration (21.9%) and mining (18.8%) were less relevant to respondents. The most referenced causes during the post-agreement period were cattle ranching (56.2%), military infrastructure (53.1%) and agriculture (50%). Manmade fires (37.5%), logging (34.4%), road construction (34.4%), litter, debris, liquid pouring (25%), and forced migration (18.8%) were also referenced. On the other hand, landmines (9.4%), military confrontations (3.1%), and mining (0%) were less relevant to respondents during peace periods (*Figure 4.50*). I identified 190 positive responses for causes during wartime compared with 115 responses for causes during peacetime.

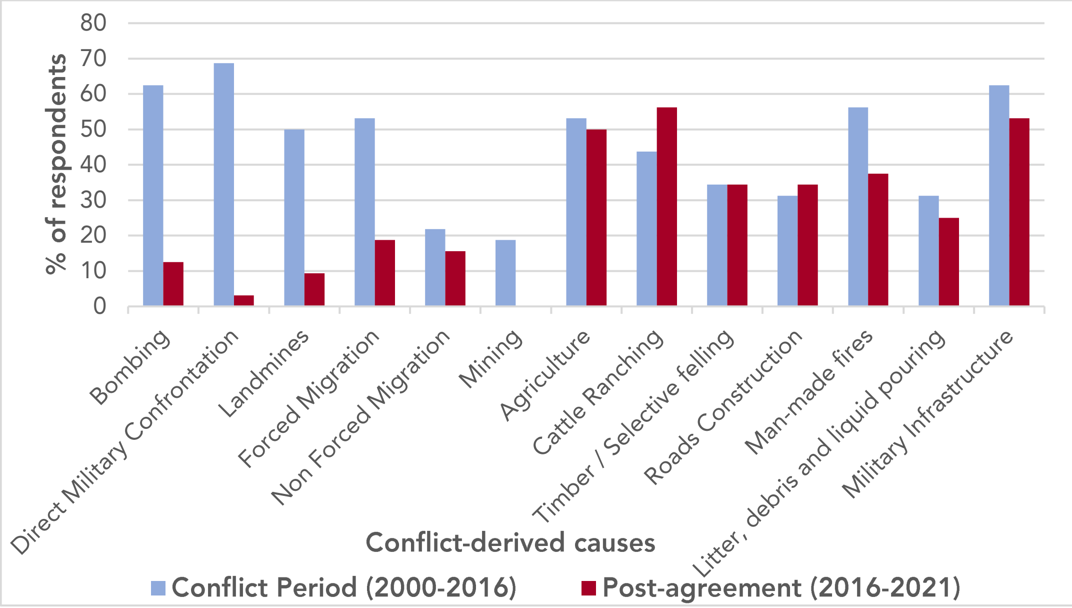


Figure 4.50: Causes during conflict period and post-agreement period.

Based on the responses to Question 2b (*Appendix 8*), the causes that most affected the people in the Sumapaz region were mostly related to the military infrastructure (34.4%) and direct military confrontations (28.1%). Events that directly affect the safety perception of the local population. Causes related to forced migration (22%), agriculture (18.8%), cattle ranching (15.6%), and litter, debris, and liquid pouring (15.6%) were relevant. Additionally, causes such as logging (9.4%), landmines (6.2%), and non-forced migration (6.2%) were less relevant to locals. Finally, events such as mining (0%) and road construction (0%) are not relevant (*Figure 4.51*).

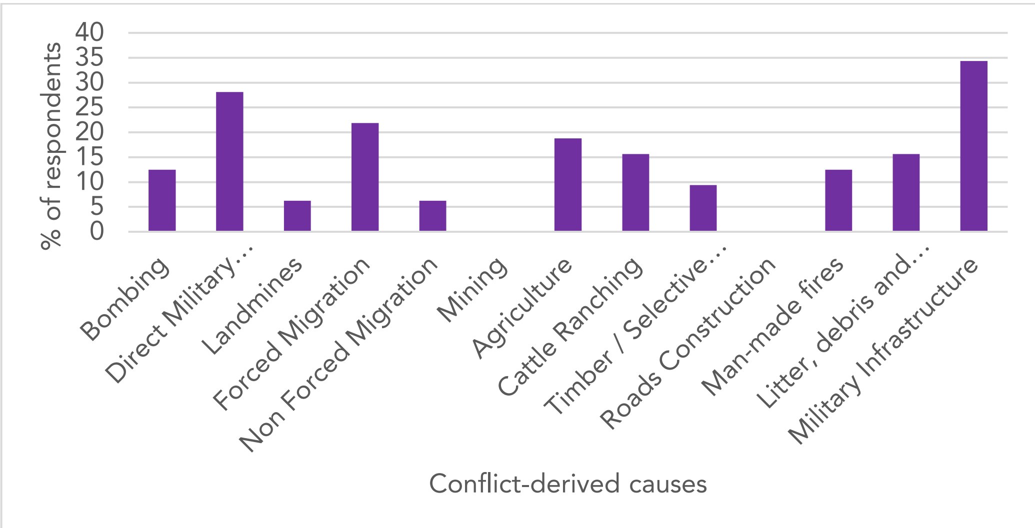


Figure 4.51: Relevant causes. (Source: Own figure)

The local population reported that during periods of intense conflict, landscape changes were influenced by nearly twice as many factors as in the post-agreement period. Military confrontations, bombings, and military infrastructure construction were the primary causes of landscape changes during the high-intensity violence period. However, over half of the respondents cited indirect conflict-related causes such as forced migration, landmines, and human-induced fires. In the post-agreement period, non-military activities such as agriculture, logging, and livestock farming became the main drivers of landscape changes. Despite this shift, the construction of military infrastructure remained the most significant factor for landscape change in both peace and conflict periods. Notably, the respondents did not consider mining and road construction significant.

4.4.4. Landscape-changes consequences

Concerning the armed conflict-derived consequences in the landscape, I asked which can be seen in the paramo provoked directly or indirectly by the armed conflict, and when these consequences occurred during the conflict period and/or in the post-agreement period. From the responses to Question 3a (*Appendix 8*), I identified that the most referenced and relevant consequences during the conflict period were deforestation (75%), pollution, and a decrease in bodies of water (50%). Extension and increase in farmland (46.9%), land use/cover changes (40.6%), abandonment of agricultural lands (40.6%), and extension or increase in land for livestock (40.6%) were also highly referenced by locals. Additionally, desertification or land degradation (34.4%) and craters or trenches (31.2%) were mentioned by approximately one-third of the respondents. On the other hand, a positive consequence such as forestation /vegetation growth was reported by 15.6% of the respondents. During the post-agreement period, the most common consequence was pollution and decrease in bodies of water (50%), followed by deforestation (46.9%), land use/cover changes (46.9%), and extension or increase of farmland (46.9%). Additionally, extension and increase of land for livestock (34.4%), desertification/land degradation (31.2%) and forestation /vegetation growth (28.1%), were also significantly referenced. In contrast, the abandonment of agricultural lands (18.8%) and craters or trenches (9.4%) was less relevant to respondents during peace periods. (*Figure 4.52*). I identified 123 positive responses for consequences during wartime compared with 102 responses for consequences during peacetime.

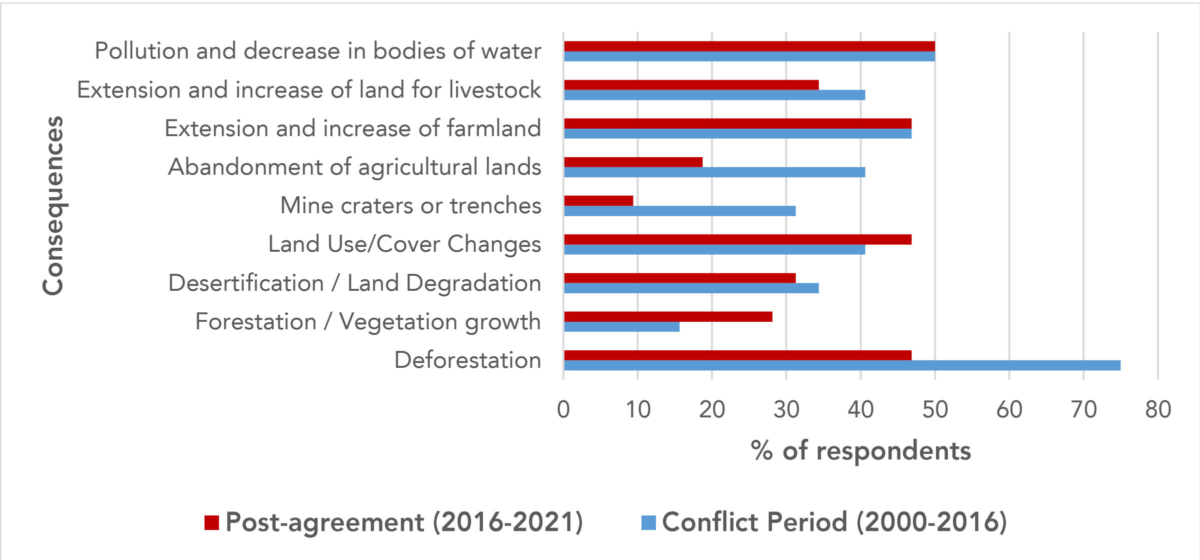


Figure 4.52: Consequences during conflict period and post-agreement period.

Based on the responses to Question 3b (*Appendix 8*), the consequences that most affected the people in the Sumapaz region were mostly related to deforestation (43.8%), pollution, and a decrease in bodies of water (40.6%), with significant differences compared to other consequences.

Events related to land use, such as land use/cover changes (18.8%), abandonment of agricultural land (15.6%), and the extension and increase of land for livestock (12.5%) were less relevant. Additionally, consequences such as craters or trenches (9.4%), extension and increase in farmland (3.1%), and desertification/land degradation (3.1%) were less relevant for locals (*Figure 4.53*).

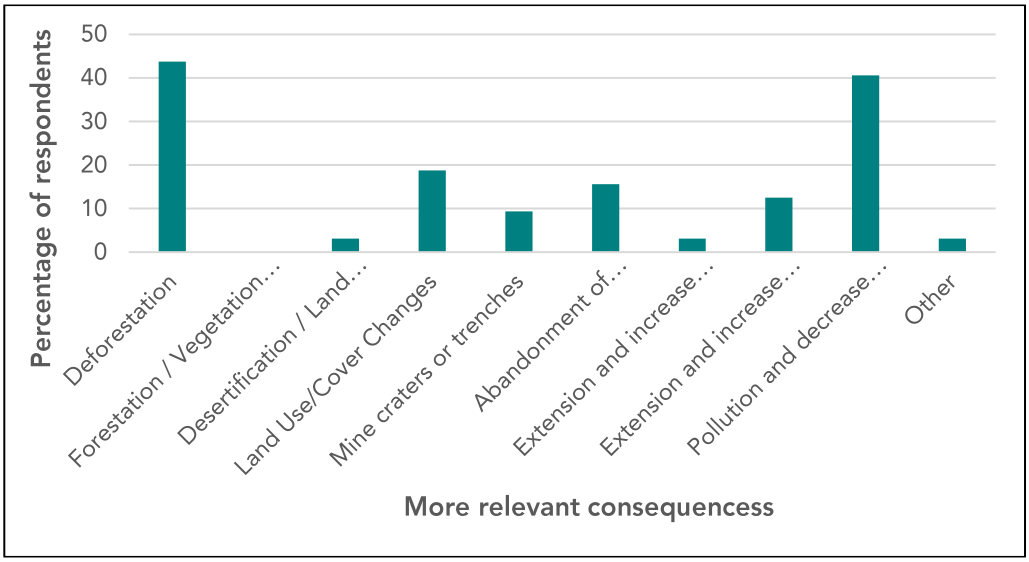


Figure 4.53: Relevant consequences.

Based on local population perceptions, the conflict period had slightly more consequences than the post-agreement period. Furthermore, the consequences were related to the main ecosystem services (water, air, and biodiversity). These were the most common changes in the landscape during periods of intense violence and peace. During the post-agreement period, the perceptions of the locals changed slightly, as water pollution and deforestation were still the most important consequences. However, during peacetime, consequences related to land use, such as extension and increase in farmland and cattle ranching, land use and land cover changes, and desertification/land degradation became highly significant. The consequence that respondents considered the most visible and most important in the landscape was deforestation, both in periods of peace and conflict.

4.4.5. Perceptions of the influence of belligerent forces on landscape changes

The study identified two primary triggers of landscape change: military belligerent forces (FARC-Guerrilla, National Army, and Paramilitary Groups) and civil actors (local communities, national/local governments, large landowners, and the National Natural Parks Board). Respondents were asked about their perceptions of which actors negatively impacted paramo, either directly or indirectly (through destruction or disturbances), and when these impacts were most significant (during conflict or post-agreement periods). According to their responses to Question 5 (*Appendix 8*), military groups were the most frequently cited. The National Army was identified by 81.25% of respondents as the main contributor to landscape changes, followed by FARC (62.5%), although to a lesser extent. The paramilitary groups were not seen as significant drivers (15.6%). Among civil actors, 50% of respondents attributed landscape changes to national/local authorities and 31.5% pointed to large landowners. The NNPB and Local

Communities were perceived as minimally responsible for landscape changes. During the post-agreement period, the National Army remained the primary driver of negative changes (53%), while the FARC Guerrilla and Paramilitary groups were no longer considered significant. Civil actor trends remained consistent, with national/local authorities still seen as relevant drivers (34%), although less so than during the conflict. The NNPB and Local Communities continued to be perceived as minimally responsible for the negative changes (*Table 4.18*).

Table 4.16: Actors that have affected negatively the landscape *(Intensity: 1 not responsible at all; 5 completely responsible).*

Actor / Period		Conflict Period					Post-agreement				
		1	2	3	4	5	1	2	3	4	5
Military	FARC	2	5	6	8	6	5	4	4		1
	National Army	1		8	7	11	2	4	5	2	10
	Paramilitaries	3	1	3	1	1	3	4	1		1
Civil	National / Local Government	3	1	8	4	4	1	6	4	1	6
	Large landowners	3	4	3	3	4	4	3	3	2	4
	Local communities	1	11	1	4		2	11	3	4	
	National Parks Board	3	7	3	2	1	2	8	4	2	1
	Other	1	1				1	2			

Based on the responses to Question 6 (*Appendix 8*), the actors that positively affected the *Sumapaz Páramo Region* were mostly civil. The respondents perceived local communities and peasant unions (78%) and the National Natural Parks Board (72%) as stakeholders who preserved the paramo. Furthermore, national and local governments are partially relevant drivers of positive changes in the region. On the other hand, local communities' perceptions identify military drivers, and large landowners contribute very little to the conservation and restoration of the paramo. Although the National Army has been promoting reforestation and conservation programs in the region, the locals' perceptions of the army are highly negative (*Table 4.17*).

Table 4.17: Actors that have preserved the landscape (*Intensity: 1 not at all; 5 very helpful*).

Driver / Intensity	1	2	3	4	5
FARC	12	4	2	2	2
National Army	15	9	1		
Paramilitaries	7	1	2		
National / Local Government	5	7	10	5	2
Large landowners	12	3	3		
Local communities	1	2	11	5	9
National Natural Parks Board	2	5	8	9	6
Other	2	1			

The local population's perceptions of actors affecting the *Sumapaz Páramo Region*'s environment are clear. Belligerent forces, including the National Army and FARC-Guerrilla, were the primary causes of environmental degradation during both the conflict and post-agreement periods. Despite the National Army's efforts in landscape restoration and reforestation, locals still view them negatively, asserting that the army continues to contaminate paramo. Conversely, locals and peasant unions, along with the National Parks Board, were the main contributors to environmental conservation and restoration. Local authorities have historically neglected paramo conservation, although it has begun to change in recent years.

4.4.6. Landscape conservation and preservation

The following findings present respondents' perceptions of the preservation status of the natural environment and landscape during armed conflict processes (Question 7, *Appendix 8*). The results indicated that half of the respondents considered that the conservation status of the environment was the same during both periods (conflict and post-agreement periods), or had presented minor changes. Additionally, 28% of the respondents considered the environment to be better preserved after the peace agreement was signed in 2016. However, 13% of the respondents perceived a better environmental preservation and conservation status during the conflict period from 2000 to 2016. 9% of participants did not answer this question (*Figure 4.54*). Interestingly, I found that the perception of the environmental conservation status was not strongly affected by the armed conflict with extreme changes in both periods; however, there was a significant tendency to perceive the post-agreement period as beneficial to paramo preservation. This peace period creates appropriate conditions for local communities, and governmental authorities can develop environmental restoration, preservation, and education programs.

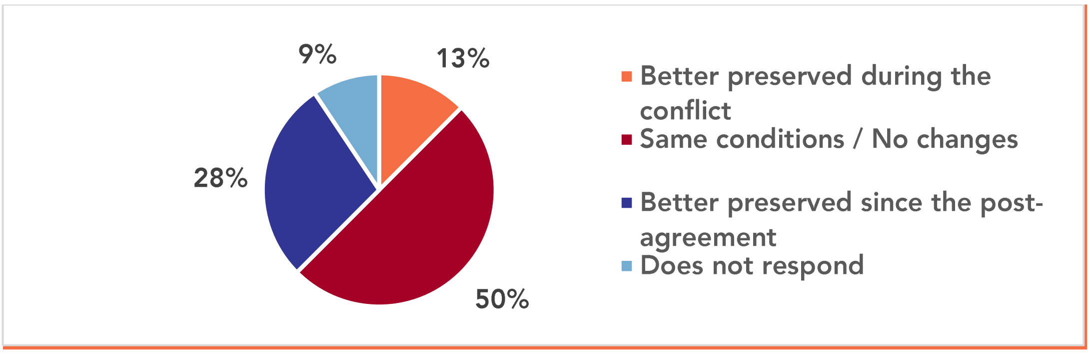


Figure 4.54: Paramo's conservation status during conflict and peace periods.

In concordance with the previous finding, Question 4 (*Appendix 8*) referred to the perception of the current state of nature and landscape at *Sumapaz Páramo*. Almost half of the respondents perceived as "good" the status of the ecosystem (44%). Additionally, 19% of the stakeholders considered them "very good" preservation, however, one-quarter of the respondents (25%) think that the paramo is currently under "acceptable" conditions. On the other hand, a small percentage of the respondents (6%) consider the Sumapaz region preservation status as "bad" or "very bad." Finally, 6% of participants did not answer this question (*Figure 4.55*).

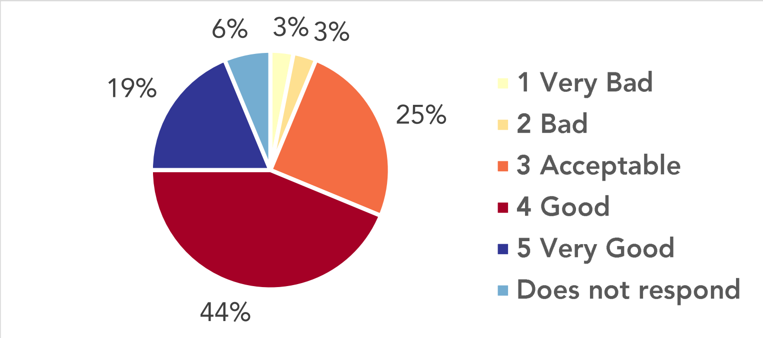


Figure 4.55: Paramo's current conservation state. (Source: Own figure)

Based on the responses to Question 8 (*Appendix 8*), the relationship between *Sumapaz Páramo* and armed conflict, the respondents perceived the landscape as a victim (negative consequences caused by the war) of armed conflict (75% during the conflict period and 35% during the post-agreement period). Furthermore, around half of the respondents (54% during the conflict period and 31% during the post-agreement period) recognized the paramo as a spoil of war, which means that the physical environment was a military objective. Additionally, 56% of local communities' perceptions identified the role of the paramo as a scenario in which conflict occurred. Paradoxically, one-quarter (25%) of the respondents affirmed that the ecosystem was a beneficiary of the development of armed conflict, contributing to its conservation (*Figure 4.56*).

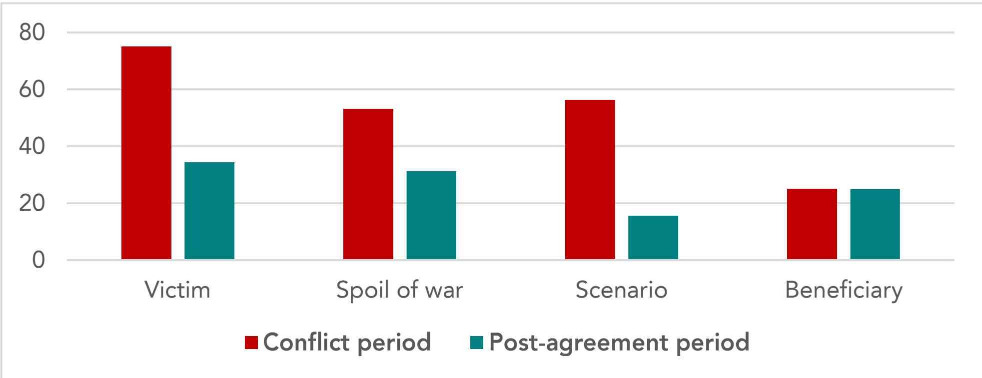


Figure 4.56: Role of the *Sumapaz Páramo* within armed conflict process.

Local communities generally perceive paramo conservation positively but express concerns about future threats. Mass tourism, climate change, extensive agriculture, livestock, mining, and urban expansion are considered significant threats by residents and local authorities. During intense armed conflict, the paramo landscape was mainly affected by bombings and military infrastructure, although less extensively than in other regions. Community initiatives and NNPB programs have partially restored these damages during the peace period following the 2016 peace agreements. However, concerns about conflict reactivation persist due to statements from FARC dissidents, which the central government vowed to counter. The local population has varied views on the relationship between the paramo and the armed conflict. Most view the landscape as a conflict victim, acknowledging its limited negative impacts. Half view the paramo as a war spoil, recognizing its strategic military importance. A quarter believed that armed conflict processes have benefited the paramo and aided its conservation.

CHAPTER 5. NEW SCIENTIFIC RESULTS

First Stage. Worldwide case studies.

THESIS 1. Identification of the relationship between armed conflict's consequences assessment, and geographical location.

I have found a direct link between assessing the consequences of armed conflicts and the density of forest cover. In tropical biomes affected by war, where forest density is higher, more significant environmental studies have been conducted on deforestation, land use, and land cover, regardless of the intensity or type of armed conflict in the region. Post-conflict periods have led to an increase in the development of these studies.

I identified that the majority of scientific studies on armed conflicts have focused on medium-scale assessments (covering landscape-scale areas of 1000-9999 km2 and regional-scale areas of 10000-99999 km2. I determined that armed conflict data variables were used in only one-third of the case studies Independent variables used, land-use data have been widely employed, followed by demographic variables.

a) I identified that the post-peace agreement periods prompted the development of studies, which revealed a substantial increase in the number of studies conducted from 2008 to 2019. During the period from 1998 to 2007, the average publication rate was 0.8 articles per year, but this rate increased to 4.92 publications per year from 2008 to 2021.
b) I found that most case studies were conducted in countries near the equator. Countries, such as Colombia, South Sudan, and Sudan, accounted for more than one-third (38.3%) of the studies.
c) From the 77 case studies analyzed, 37 armed conflicts were assessed. Within this group, 22.6% of the cases involved interstate conflicts between two or more states, while 39.3% evaluated internationalized internal armed conflicts. The remaining 37% of the studies analyzed internal armed conflicts between the government of a state and internal opposition groups. I observed that 33.7% of the researchers investigated minor armed conflicts, 30.1% focused on intermediate-intensity conflicts, and 36.2% explored high-intensity conflicts.
d) The data showed that 35% of the researchers analyzed satellite imagery of pre-conflict periods, 87% examined conflict period imagery, and 58.4% assessed post-conflict period imagery.
e) I observed a strong relationship between the consequences of armed conflict and forest cover density. Of the 18 existing biomes worldwide, armed conflict consequences were identified in 14 (78%). An analysis of 170 biome cases revealed that armed conflicts were more prevalent in torrid zones, with a focus on six tropical biomes (60.5%). Most of these case studies were located near the equatorial line, where there were high biodiversity hotspots and increased forest cover density, including 41.55% in Tropical Rainforest, 31% in Grass Savanna, 27% in Monsoon Forest/Dry Forest, 26% in Montane Forest, and 23% in Semiarid Desert, with Tree Savannah and Grassland accounting for 22%.
f) I found that Landscape-scale studies were the most recurrent, accounting for 36.3% of the total, followed by regional-scale studies at 24.7%, national/global-scale studies at 23.4%, and local-scale studies at 18.2%.
g) Moderate-resolution sensors such as Landsat 4-5 TM, Landsat 7 ETM+, and Landsat 8 OLI were the most commonly used, particularly for studies at medium to large scales such as Landscape, Regional, and National sample sizes. I identified that to analyze small areas at local

and landscape scales, fine (1-10m), and very fine resolution (≤1m) satellite imagery sensors such as Quick Bird II, Google Earth VHR, SPOT-5, World View II, and IKONOS are more often used.

h) I found that the majority of studies (80.5%) used multivariate data for their research, with only 62% of them having a unidirectional relationship with independent variable data. However, Armed Conflict data variables were used in only 27% of the studies, while socioeconomic variables and infrastructure were used in approximately 15% of the studies.

THESIS 2. Identification and linking of causes derived from armed conflict with consequences in the landscape.

I identified that in tropical biomes, such as rainforests, monsoon forests, montane forests, and savannas, indirect causes of armed conflict, such as forced and non-forced migration, agriculture, and illegal crops, primarily drive landscape changes such as deforestation and land-use alterations. These aspects have been extensively studied, whereas short-term impacts, such as military confrontations and bombings, are less explored. Conversely, within the temperate biomes with sparse forest cover, such as broadleaf forests, Mediterranean vegetation, dry steppe, and semiarid desert, experience landscape changes mainly due to direct causes such as bombings, military confrontations, and landmines. These biomes observe land use changes, agricultural abandonment, craters, and water pollution, with long-term indirect effects such as forced migration, logging, agriculture, and fires being minor. I determined that Landsat satellite imagery sensors were deemed most suitable for assessing the impact of armed conflicts in dense forest areas, such as tropical rainforests, monsoon forests, and montane forests, because of their effectiveness in detecting changes in forest cover through contrasting bands that capture chlorophyll variances and reflectance.

a) I classified armed conflict-derived consequences in the landscape into two groups: Direct and Indirect. Direct consequences are activities that are physically linked to the direct action of military confrontation such as bombings, direct military confrontations, and landmines. In contrast, the indirect consequences are non-military activities triggered by armed conflict processes such as forced migration, non-forced migration, mining, illegal crops, agriculture, cattle ranching, logging, and fires.

b) I determined that Indirect causes, which accounted for 73.2% of the case studies, were the most common cause. These included forced migration (36.3%), agriculture (26%), illegal crops (13%), non-forced migration (13%), cattle ranching (11.6%), and logging (11.6%).

c) Direct causes, which represented 26.8% of the total case studies, were less common causes. However, the most common direct causes were military confrontation, accounting for 27% of the total, and bombing, accounting for 21%.

d) I identified and categorized the most prevalent and significant consequences of armed conflict on landscapes; they are land-use changes (63.3%), deforestation (61%), abandonment of agricultural lands (15.6%), and forestation (13%).

e) I found that military confrontations have a direct influence with changes in land use (18%) and deforestation (17%). Bombings were found to have a direct impact on changes in land use (13%), the abandonment of land for agriculture (8%), and reforestation (6.5%). Among the causes of changes in land use and deforestation, forced migration had the most significant impact (26%), and by agriculture (19.5%).

f) Research on the impact of bombings as a cause of forest disturbances (21%) was concentrated in countries located primarily in temperate zones. Most studies on military confrontation and/or military infrastructure as a cause of environmental impacts (27.3%) were conducted in Colombia (7) and spread across diverse regions, such as the Middle East and sub-Saharan Africa.
g) The most commonly studied indirect cause was forced migration (36.3%), which is prevalent in African countries, Colombia, the Middle East, and Southeast Asia.
h) I have determined that for analyzing high-density forest biomes like tropical rainforests, monsoon forests, and montane forests, moderate-resolution sensors such as Landsat 7 ETM+ and Landsat 4-5 TM are most accurate and suitable, used in 66.2% of studies. Conversely, studies on medium- or low-density forest biomes, such as tree savannas, grass savannas, and semiarid deserts, predominantly used very fine sensors (22%), mainly Quickbird II, IKONOS, and World View II. Aerial photographs were chiefly used for temperate broadleaf forest analyses.

Second Stage. Colombian case studies.

THESIS 3. Identification of the relationship between assessment methods, causes, and consequences generated by Colombian armed conflict.

The 2016 peace agreement between the Colombian government and the FARC Guerrilla spurred increased research into the environmental consequences of armed conflict and landscape changes. I identified that RS studies primarily focus on national-scale assessments and the general environmental impacts of armed conflict, with study areas chosen based on forest cover density rather than military activity. Few studies have explored conflict-derived causes and consequences locally or regionally. In Colombia, indirect conflict-related causes, such as agriculture, illegal crops, cattle ranching, and non-forced migration, drive the most studied forest disturbances, while short-term consequences of direct conflict activities, such as military confrontations or bombings, though less studied, significantly impact the landscape. I determined that the most significant and recurrent environmental changes identified were deforestation and LULCC, which are closely linked to illegal activities resulting from the conflict.

a) I determined that the 2016 peace agreement had a significant and positive impact on the number of RS studies. From 2001 to 2012, during the intense conflict period, the publication rate averaged 0.16 studies annually. During the 2013-2016 negotiation period, it rose to 1.6, and during the post-conflict period (2016-2021), it reached two studies per year. The end of the Colombian armed conflict has increased interest and investment in understanding the environmental impact of warfare.
b) Indirect causes have been the most studied triggers of environmental impacts. Non-regulated agriculture was the most studied cause (47%), followed by coca crops (42%). In addition, illegal cattle ranching (37%) and forced migration (21%) have been extensively studied as generators of forest disturbances. Similarly, non-forced migration (16%), illegal mining (16%), illegal logging (16%), and fires (11%) have been studied less.
c) I found that Military confrontation (37%) was the most studied direct cause of environmental degradation. Conversely, other events directly related to the Colombian armed conflict, such as air and ground bombings and the location of anti-personnel mines, have scarcely been studied.

d) I determined that Colombian armed conflict significantly increased environmental deterioration and forest cover (deforestation) in 95% of cases, and land cover and land-use changes in 42% of cases. However, some exceptions are noticeable, where the conflict has unintentionally promoted environmental conservation in the short term, such as forest preservation in 31% of the studies.
e) I found that 42% of the studies were related to the FARC guerrilla, paramilitary groups such as AUC in 31% of the studies, and the ELN guerrilla in 5%. More than 50% of the case studies did not explicitly mention which armed group generated environmental changes, and none of the studies mentioned the National Army as a driver.
f) I found that the Colombian armed conflict have been studied mainly through national-scale case analysis and, to a lesser extent, medium-scale case studies. I determined that the smallest scales, Local and Landscape study areas, were used in only one study each (5%). The regional scale was used in 21% of the studies and the national scale was the most employed in 68% of the studies.
g) I identified the existence of warfare repercussions in all 13 existing types of ecoregions in Colombia. I analyzed 64 different cases of biomes and found that the presence of armed conflicts was higher in high biodiversity spots and high forest cover density, such as Northern Andean (47%), Mag-Urabá Moist (42%), Cordillera Oriental (42%), Caquetá Moist (37%), Northwestern Andean (26%), and Apure-Villavicencio (21%).
h) I found that most studied departments were not necessarily the largest or most populated, except for Antioquia. Northern Antioquia and Caquetá foothills were studied in 42% of the studies, followed by Putumayo, with a recurrence in 37%. Guaviare and Meta were mentioned in 31.5% of studies. Additionally, 26% of the studies were conducted in Cordoba and Nariño. Comes after Amazonas, Guainía, Huila, Santander, and Vaupes were examined in 21% of studies.

Third Stage. Sumapaz Páramo Region case study. Forest disturbances.

THESIS 4. Detection of forest disturbances in the *Sumapaz Páramo Region*'s ecosystems during periods of armed conflict.

Through remote sensing and statistical analysis, I determined that vegetation disturbance was linked to armed conflict periods. A noticeable pattern was observed, revealing a direct connection between higher forest disturbance during high-intensity conflict periods (2001-2003 and 2006-2010) compared to a decrease in deforestation rates during peace talks (2012-2016) and the post-agreement period (2016-2020). Additionally, it was demonstrated that ecosystems with high forest density, such as the high Andean forest or the sub-paramo, suffered more consequences from armed conflict than ecosystems at higher altitudes and low forest density, such as the paramo and the super paramo.

a) I detected the vegetation disturbance in the SPR from 2001–to 2020. I determined that 239,934.172±38.29 ha of the vegetation/land cover remained stable, and 765.82±38.29 ha (95% confidence interval) of forest were disturbed, corresponding to 0.318% of the study area of *Sumapaz Páramo*. During the high-intensity conflict period (2001–2012) I detected 705.66 ha (0.29% of the study area) of vegetation disturbance. During negotiations (2013–2016), 21.29 ha (0.0089% of the study area), and during the post-peace agreement (2017–2020) 38.66 ha (0.016% of the study area).

b) I detected the vegetation disturbance in the 1 km buffer area – *Forest-Páramo Transition Zone* (FPTZ) throughout the entire study period from 2001–to 2020. I determined that 69,970.68±30.66 ha of the vegetation/land cover remained stable, and 613.32±30.66 ha (95% confidence interval) of forest were disturbed, corresponding to 0.87% of the study area of *Sumapaz Páramo*. During the high-intensity conflict period (2001–2012), I detected 507.51 ha (0.72% of the study area) of vegetation disturbance, and during negotiations and post-peace agreement periods (2013–2020), 105.81 ha (0.15% of the study area).
c) I identified that the forest disturbance detection in the Extended Study Area (XSPR), including the 1 km outer buffer throughout the entire study period of 2001–2020, was 309,904±68.95 ha of the vegetation cover remained stable and 1379.15±68.95 ha (95% confidence interval) of forest were disturbed, corresponding to 0.44% of the study area. During wartime (2001–2012), I detected 1213.18 ha (0.39% of the study area) of vegetation disturbance, during negotiations (2013–2016) 49.81 ha (0.016%), and during the post-peace agreement (2017–2020) 116.15 ha (0.037%).
d) I found that vegetation disturbance was more evident in 2001, 2007, 2009 and 2012.
e) The pattern shows that since 2015, disturbances in the landscape have been higher in FPTZ than in SPR, not only percentage-wise but also in terms of total hectares, with even more significant percentages in 2016 (ha 0 0.27%–ha 1 0.73%) and 2020 (ha 0 0.25%–ha 1 0.75%).
f) Landsat disturbances were primarily concentrated on the periphery of the paramo, encompassing montane forest, subparamo, and paramo ecosystems, particularly in lower altitude areas where they transition into high-Andean, low-Andean, and montane forests between 2100 and 3100 m a.s.l. Significantly higher vegetation disturbance was detected within the 1 km outer buffer zone (forested areas and valleys below 2900 m; these valleys exhibit denser vegetation cover) compared to the study area above 2900 m, where the forest density was lower.
g) I detected that although the study area (SPR) was 3.4 times larger than the buffer area (FPTZ), the distribution of disturbances was significantly higher in the buffer area during the conflict period (2001–2005, 2007, 2008, 2010–2012), except in 2006 when there was no significant difference, and in 2009, when the difference was slightly significant. Similarly, disturbances were significantly higher in the buffer area during the post-agreement period (2017-2020).

THESIS 5. Detection and comparison of forest disturbances in protected (Sumapaz National Park) and non-protected areas within the *Sumapaz Páramo Region* during armed conflict periods.

I detected that SNP experienced fewer disturbances than non-protected areas, with significantly lower vegetation disturbance in high-altitude areas (<2900 m.a.s.l.). High Andean forests and sub-paramo were more affected than paramo and super paramo because of higher forest density. However, disturbances in the fragile SNP landscape have substantial environmental impacts and slower recovery. The Remote sensing and statistical analysis revealed a direct correlation between armed conflict intensity and forest disturbances in the Sumapaz Páramo Region protected (SNP) and non-protected (SPR-SNP) areas. Heightened disturbances occurred during intense conflict periods (2001-2003 and 2006-2010), while near-zero deforestation rates were observed during peace talks (2012-2016) and post-agreement (2016-2020).

a) The variation in impact levels between protected and non-protected areas is due to several factors, including altitude, forest density, strategic military location, accessibility, and civilian population. The higher altitudes within the protected area had lower forest density and more exposed rocky soil, reducing disturbances compared to the lower altitude and higher forested non-protected areas. The remote, steep, and inaccessible areas of the national park led guerrillas to prefer lower-altitude areas with greater forest cover for hiding, resulting in most confrontations and bombings occurring outside the protected area.
b) The limited accessibility and lower population within the park limits contributed to fewer disturbances, while the management of national park rangers and peasant associations maintained low disturbances within the paramo compared to non-protected areas, with less environmental control and greater influence of belligerent forces.
c) I detected vegetation disturbance in the Sumapaz National Park (SNP) within the SPR from 2001 to 2020. I determined that 129,694±9.10 ha of the vegetation/land cover remained stable, and 182.05±9.10 ha (95% confidence interval) of forest were disturbed, corresponding to 0.14% of the national park area within the study area. During the high-intensity conflict period (2001–2012), I detected 178.98 ha (0.14% of the study area) of vegetation disturbance, and during negotiations and post-peace agreement periods (2013–2020), 3.07 ha (0.002% of the study area).
d) I detected vegetation disturbance in the area of the SPR, excluding the area under the Sumapaz National Park (SNP) limits, from 2001 to 2020. I determined that 110,824±29.19 ha of the vegetation/land cover remained stable, and 583.77±29.19 ha (95% confidence interval) of forest were disturbed, corresponding to 0.53% of the study area excluding SNP. During the high-intensity conflict period (2001–2012), I detected 526.68 ha (0.47% of the study area) of vegetation disturbance, and during negotiations and post-peace agreement periods (2013–2020), 57.09 ha (0.05% of the study area).
e) The area outside SNP had significantly higher disturbance rates during the three periods. During the years of the highest intensity of the conflict (2001-2012), the difference was an average ratio of 4:1, but it was higher in 2006 and 2009, and lower in 2011. I identified significantly lower disturbance rates within the protected area compared to the area outside the SNP, not only percentage-wise but also in terms of total hectares.
f) The spatial distribution of Landsat disturbances within the National Park is concentrated on the northern and eastern periphery of the protected area and some inner valleys, that is, mostly in the lower altitude areas of the paramo where they border the transition zone with the high-Andean forest, low-Andean forest, and montane forest located between altitudes of 2100 and 3100 m.a.s.l.
g) The distribution of disturbances was significantly higher in the study area (excluding the SNP) during the conflict period (2001–2010 and 2012) than within the SNP study area, except in 2011, where the difference was slightly significant.

THESIS 6. The link between armed conflict intensity rates (causes) and forest disturbances (consequences) during armed conflict periods in the *Sumapaz Páramo Region*.

I observed a significant unidirectional relationship between vegetation disturbance rates and armed conflict intensity rates regardless of the conflict period. I identified that the area was highly sensitive to changes in conflict intensity, as evidenced by the flow between the number of

cases, victims, and disturbed hectares. I identified a clear and direct relationship between the two variables, with higher levels of forest disturbance observed during more violent periods (2001-2003 and 2006-2010) and a subsequent decrease in deforestation rates during peace talks (2012-2016) and the post-agreement period (2016-2020). The relationship between forest disturbance and violence rates has gradually declined over time.

a) During the high-intensity conflict period (2001-2003), deforestation rates experienced a rapid decrease from high to medium intensity in the SPR and FPTZ, whereas the conflict intensity rates increased during the same period. The first two years (2001 and 2002) showed high rates of vegetation disturbance and violence. The most violent year was 2003, which coincided when the disturbance rates presented a large drop; in 2004 and 2005, the vegetation disturbance remained relatively steady and lower than in the first years, but the conflict intensity rates decreased significantly. Since 2005, the number of conflict cases and victims has considerably decreased. However, the deforestation rates have increased significantly since 2007. Around 2009, there was an increase in violence, accompanied by an increase in forest disturbance.
b) During the negotiation period (2013–2016), the rates of conflict intensity and disturbance remained very low, almost at zero levels. However, since the peace agreement was signed in 2016, the violence rates remained very low, but the disturbance rates started to increase slowly.
c) In general, during the entire study period (2001-2020) Pearson's correlation coefficient was positive, linking vegetation disturbance rates in the study areas with conflict intensity rates. Pearson's correlation coefficient (r) was used to measure the linear unidirectional relationships.
d) Unidirectional relationships were visible during the war and post-agreement periods; however, they were not significant during the negotiation period.
e) I found a unidirectional relationship between the number of victims and disturbances in the study area (R2 = 0.61; $p < 0.001$). Regarding the number of armed conflict events and forest disturbances, R2 = 0.54, $p < 0.001$.
f) Armed conflict intensity and forest disturbance pathways showed a positive relationship between forest disturbances and ($\log_e$) the number of victims and forest disturbances and ($\log_e$) conflict events with a positive relationship.

THESIS 7. The link between forest disturbances (consequences) and military road networks during armed conflict periods in the *Sumapaz Páramo Region*.

The direct influence of belligerent forces in the area is evident through the construction of military roads such as the* Troncal Bolivariana *by both the army and the FARC, as well as military infrastructure such as military bases, trenches, outposts, camps, and even the reported use of frailejones and other types of vegetation as construction material and fuel.

I identified a significant unidirectional relationship between vegetation disturbance rates near the military-derived road network and conflict intensity rates. The area is sensitive to changes in conflict intensity, and the proximity to road infrastructure shows a positive association with deforestation. Higher levels of forest disturbance were observed during high-intensity conflict periods (2001, 2002, and 2010) and a substantial decrease in deforestation during less violent years in the negotiation (2012-2016) and post-agreement periods (2016-2020). However, anomalies were detected in 2007, with high disturbance and low conflict intensity rates, and in 2003, with low disturbance and conflict intensity rates. Deforestation directly linked to road construction is relatively low, accounting for 7% to 18% (varying by year) of the total disturbed

area in SPR. However, proximity to roads significantly attracts deforestation, especially within the 0.5-1.5 km range, with the most significant impact within the first 500 meters. This indicates that military infrastructure and roads exert pressure on the region's vegetation by providing access to previously untouched areas, notably in the southern SPR, where the guerrilla-built **Troncal Bolivariana** ***facilitated access to formerly inaccessible regions.***

a) I identified two large groups of road networks: the network of civil roads built by the national government, the local government, and/or the community that mainly connects the region with Bogotá to the north. The military road network was built by the FARC guerrilla during the '90s and the early 2000s, beginning in the town of La Unión and heading south, seeking to connect the paramo with the Duda River Canyon and then to the Amazonian foothills.
b) I found that the years with the highest intensity of conflict (2001, 2002, 2003, and 2004) had the highest rate of disturbance near highways, as did 2007, the year in which there was a peak in conflict intensity again. I found that at least 50% of the total disturbance occurred in the first 500m near the road, whereas between 500 and 1000 m, only an average of 20% of the total disturbance occurred, and the remaining 30% occurred between 1000 and 1500 m.
c) I detected that the disturbance in the vicinity of the roads built by the guerrillas was less in its totality concerning civilian highways, which is not the case concerning the proportion since civilian highways are four times more extensive in kilometers compared to roads of military origin.

Fourth Stage. Sumapaz Páramo Region case study. Local communities' perceptions.

THESIS 8. The local community's perception of *Sumapaz Páramo* landscape during and after the armed conflict.

Based on interviews and surveys of the local community, I determined that during the high-intensity conflict period, there were nearly twice as many landscape impacts as in the post-peace agreement period. According to respondents, these changes were mainly due to the direct consequences of armed conflict, such as military confrontations, bombings, and construction of military infrastructure. Over half of the respondents also cited indirect causes such as forced migration, antipersonnel mines, and human-origin fires. Deforestation and a decrease in water bodies were the most impactful consequences in the Sumapaz region during both the intense violence and peace periods. The local population predominantly perceives belligerent forces, including the National Army and FARC-Guerrilla, as the main negative influences on the environment during both the conflict and post-agreement periods. According to the respondents, the local communities, peasant unions, and the National Parks' Board were self-perceived as primarily responsible for environmental conservation and restoration. Additionally, local authorities have not been perceived as contributing significantly to landscape conservation, neglecting Paramo for decades. However, the population has recently prioritized Paramo conservation for its survival and well-being, generally holding a positive perception of its preservation.

a) Based on the respondent's perceptions the predominant armed conflict causes that affected the landscape during the conflict period were military confrontations (68.8%), bombing (62.5%), and military infrastructure (62.5%). Other significant factors included manmade fires (56.2%), forced migration (53.1%), agriculture (53.1%), and land mining (50%). The most cited causes in the post-agreement period were cattle ranching (56.2%), military infrastructure (53.1%) and agriculture (50%), manmade fires (37.5%); logging (34.4%); road construction (34.4%); litter, debris, liquid pouring (25%); and forced migration (18.8%).

b) Based on the respondents' perceptions, the primary armed conflict consequences identified during the conflict period were deforestation (75%), pollution, and a reduction in water bodies (50%). Additionally, there was an expansion of farmland (46.9%), changes in land use/cover (40.6%), abandonment of agricultural land (40.6%), and increased land for livestock (40.6%). The most common issues in the post-agreement period were pollution and reduced water bodies (50%), followed by deforestation (46.9%), land use/cover changes (46.9%), and farmland expansion (46.9%). Notably, there was an increase in references of consequences such as land for livestock (34.4%), desertification/land degradation (31.2%), and forestation/vegetation growth (28.1%).

c) There were 190 positive responses for wartime causes compared to 115 for peacetime causes. The most impactful causes in the Sumapaz region were linked to military infrastructure (34.4%) and direct military confrontations (28.1%). The consequences that most affected the people in the Sumapaz region were mostly related to deforestation (43.8%) and a decrease in water bodies (40.6%).

d) The National Army was identified by 81.25% of respondents as the primary driver of forest disturbances. Additionally, 62.5% of respondents attributed significant negative impacts to the FARC guerrilla. Paramilitary groups were held responsible for 15.6% of respondents. Among the non-military actors, 50% blamed national/local authorities, while 31.5% pointed to large landowners as key drivers of change. The NNPB and Local Communities saw themselves as minimally responsible for landscape change drivers. In the post-agreement period, 53% of respondents still viewed the National Army as the main driver of negative changes.

e) Half of the respondents perceived that the environmental paramo's conservation status remained unchanged or showed minor changes between the conflict and post agreement periods. Additionally, 28% thought the environmental status improved after the 2016 peace agreement, while 13% felt it was better preserved during the 2000-2016 conflict period. Furthermore, 44% rated the current ecosystem status as "good," 19%, as "very good," and 25% considered the paramo to be in "acceptable" condition.

f) Seventy-five percent of the local respondents perceived the landscape as a victim of Colombian armed conflict. Additionally, 54% recognized the paramo as a military, and 56% identified it as the warfare's scenario. Paradoxically, 25% of the respondents considered that the ecosystem benefited from the conflict, aiding its conservation.

CHAPTER 6. CONCLUSIONS AND SUMMARY

6.1. The role of the *Sumapaz Páramo Region* during the armed conflict processes

As a victim: Unlike the Amazon rainforest, which has paradoxically been preserved by the conflict, the *Sumapaz Páramo Region* in Colombia has experienced significant effects from high-intensity conflict. The region has suffered landscape changes, including deforestation, land-use changes, landslides, abandoned agricultural lands, and water contamination. Vegetation disturbance rates are linked to direct causes of conflict, such as military road construction, infrastructure, debris, bombings, and landmines. Although the deforested area is smaller than other regions, the changes are significant because of the fragility of the paramo ecosystem and the extended time needed for recovery, as well as its crucial role in providing ecosystem services.

As a Stage: The region was a crucial stage for the armed conflict. Even if the number of military confrontations was not exceptionally high and despite some bombings and combats in the region, the violence and the armed conflict presence were notorious and firmly affected the local population and the environment.

As a Loot: The *Sumapaz Páramo Region* was of significant military importance because of its role as a strategic corridor used by the FARC to transport troops, provisions, weapons, and hostages between the Amazonian foothills and Bogotá. Consequently, the region was contested in an effort to gain control over both the movement of people and materials within the area.

As a Beneficiary: During the high-intensity period, *Sumapaz Páramo* benefited significantly from negotiations and peace agreements, resulting in notably decreased disturbance rates. The period of peace led to a heightened institutional and governmental presence, enabling the creation of conservation programs and the restoration of affected areas. Reduced demographic pressure due to decreased forced migration has allowed communities to manage better the croplands and cattle plots, fostering sustainable economic development and environmental conservation. Nonetheless, threats, such as human-induced fires, uncontrolled tourism, unregulated agriculture, cattle ranching, and mining, persist.

6.2. Practical implications, limitations and recommendations for future case studies

This study evaluated forest disturbances in the *Sumapaz Páramo Region* using geospatial data and considering the unique features and ecosystems of the region. It produces a disturbance evaluation map assessing the current and past states of paramo based on specific spatial criteria related to the region's socioeconomic and geographical conditions. The main output of this study is an integral analysis using objective and subjective approaches. The objective approach evaluated forest disturbances and the statistical link between armed conflict intensity and proximity to military road networks. The subjective approach involved survey data from the local communities (*Appendix 8*). The evaluation process highlighted the importance of considering the relationship between forest disturbances and armed conflict in the post-agreement processes for truth, justice, and reparation. This relationship is crucial for planning conservation and restoration programs in conflict-affected areas, and the approach can be applied to other regions impacted by Colombian armed conflict. Moreover, combining forest disturbance detection (RS), analysis of armed conflict intensity data, and local community perception offers a comprehensive understanding of conflict consequences, the relationship between conflict actors, and their environmental impacts.

This study provides a foundation for planners and decision-makers to collaborate with national, regional, and local authorities and communities to develop, enhance, and implement conservation and restoration programs. These efforts can aid in protecting natural resources and fostering long-term sustainable development of local communities. The case study approach can be applied to the *Sumapaz Páramo Region* and other regions affected by the Colombian armed conflict, adapting to each region's specific conditions for landscape evaluation processes. These methods are also applicable to evaluating landscapes in conflict-affected countries. Several ecosystems in the country have been declared as subjects of rights (e.g., the *Atrato-Chocó* River, *Cauca River*, *Magdalena River, Pance-Valle del Cauca, La Plata-Huila, Otún-Risaralda, Pisba-Boyacá* paramo, and the Colombian Amazon). This study can help identify paramo de Sumapaz as a subject of rights and a victim of armed conflict, promoting its care, conservation, maintenance, and restoration by the state and local communities. The *Sumapaz Páramo* is being considered for UNESCO intangible heritage status due to its natural and cultural importance. Research highlights the significance of the paramo landscape and its unique connection with local inhabitants, supporting the need for special protection.

This study offers numerous applications for the development of more effective evaluation policies. However, limitations arise owing to insufficient data access, financial resources, and time constraints for deeper data collection. National security concerns and data access restrictions impeded obtaining geospatial locations for bombings and military confrontations, resulting in unclear definitions of conflict extension. Hence, the accurate and prompt assessment of these direct impacts has become extremely challenging. Similar issues occur when accessing data on military infrastructure and road networks. Additionally, a larger sample size would have better illuminated the variations in residents' attitudes and perceptions across different areas. As the survey sample was limited to the central region, the results might not fully apply to the southern part of Sumapaz, which is difficult to access.

Although resident participation was considerable, accessing remote areas was challenging owing to poor infrastructure, restricting the data collection period to a few days. Consequently, the number of participants was relatively low compared with the population density in the study area. Future research should address these limitations by examining perceptions on larger spatial and temporal scales. Attempts to interview the military and involve National Park rangers were unsuccessful because of national security concerns, military confidentiality, and the neutrality of government officers in armed conflicts. Additionally, efforts to interview FARC ex-combatants at their *Icononzo* and *Tolima* concentration camps were hindered by logistical issues and time constraints, despite initial agreement.

Recommendations from the study data for future studies include the following:

(I) Involved actively all stakeholders; the civil population (peasant unions), government authorities (Central Government, Government, Mayor's Office, and Local Mayor's office), environmental authorities (Ministry of the Environment, Regional Autonomous Corporation, and National Parks of Colombia), academia (National University of Colombia, Humboldt Institute, and SENA), regular military forces (National Army and National Police), and ex-combatants. Individual initiatives may fall short, but collaborative efforts among stakeholders have proven successful in restoration, conservation, and repair programs.

(II) Establish accurate cause-consequence relationships by relating different independent variables (socioeconomic, land-use, environmental, infrastructure, armed conflict, demographic, biodiversity, etc.) in the study area rather than relying solely on isolated and context-less remote sensing data.

(III) Each region should be evaluated independently in future studies, considering its specific physical and social characteristics, despite the uniqueness of the paramo landscape and its similarities with other ecosystems.

6.3. Conclusions and considerations

This study provides the first analysis of the relationship between forest disturbances and the intensity of armed conflict in the paramo of Sumapaz. A unidirectional relationship exists between the number of victims, conflict events, and forest disturbance dynamics. Disturbances expand broadly during intense armed conflict characterized by infrastructure military development and limited environmental regulation, which occurred in the Republic of Congo and Ethiopia. There is an elevation shift in disturbance detection: during the conflict, disturbances reached 4000m; after negotiations, disturbances were not found higher than 3500m. While these documented results seem beneficial for the Sumapaz area, after 2018, forest disturbances — while small, showed a gradual increase. This study highlights the legacy of armed conflict, the fragility of the paramo during times of war and the need to comprehensively address the region’s socioeconomic and environmental challenges in the peace era.

Remote sensing of vegetation disturbance rates, compared with local perceptions, showed a correlation between deforestation and the state of Paramo and high Andean forests with armed conflict intensity. High vegetation disturbance during peak conflict years matched respondents' perceptions of significant deforestation. Post-peace agreements, disturbance rates, and perceived deforestation have decreased, although not equally. Military confrontations between the government and the FARC guerrilla, alongside overall conflict intensity, significantly impacted communities and the environment, influencing deforestation and ecosystem conservation, both directly and indirectly. Conflict should be viewed as a catalyst for other causes of forest disturbances, not the primary cause. This study cannot definitively link specific conflict events (e.g., military clashes or bombings) to land cover changes due to the lack of precise spatiotemporal data. However, these events tangibly alter the landscape, making it impossible to associate directly any disturbance patch with a violent event.

Significant conflict causes, such as forced displacement, military infrastructure construction, illegal agriculture, ranching, and arson, are associated with deforestation drivers. Geospatial analysis of satellite imagery showed disturbance patches mainly in valleys, where subparamo transitions to a high Andean forest. These patches were also near civil and military roads, military infrastructure, and landslide areas, possibly because of bombings, as noted in the community leader interviews.

During high-intensity conflict periods, the relationship between armed conflict and forest disturbances was evident. The absence of government during these times led to weak governance, hindering effective deforestation control and halting paramo restoration and conservation efforts. Conversely, conservation and restoration efforts in the paramo landscape have increased during peaceful periods. Since negotiations began in 2012, forest disturbances and violence rates have decreased, which is attributed to greater government presence and collaboration with local communities on reforestation and conservation programs.

After the peace agreement signing, urbanization and population growth in *Sumapaz Páramo*, influenced by proximity to Bogotá, have led to socioeconomic and land cover changes, notably urban expansion near the southern area of Usme. Small-scale subsistence farmers and livestock ranchers still affect conservation efforts. Presently, illegal livestock farming, extensive crops, fires (intentional and natural), and military infrastructure significantly shape perceptions of anthropogenic disturbances in the Andean Paramo and Sumapaz forests. Local communities cite unregulated tourism, demographic expansion (including voluntary migration), illegal mining, and the potential resurgence of armed conflict among FARC dissidents, paramilitary groups, and the national government as major threats to paramo conservation.

The paramo's relatively good conservation during and after the conflict was largely due to local communities organized as peasant unions and other groups, as well as the national park board and its rangers. Any development, exploitation, preservation, or conservation plan for the paramo must involve both the local community and National Parks' board. Although the total disturbed area during the conflict and post-agreement period was low (0.44%–1379.15 ha of the total study area = 311,284 ha), especially compared to more heavily affected regions, such as the Amazon foothills, the severity of the conflict's effects lies in the difficulty of restoring disturbed hectares to their original state. The paramo's unique features, such as *frailejón* taking up to a year to grow by one centimeter, highlight that the impact of conflict is more about quality than quantity. Thus, even a small number of deforested paramo and high Andean forest hectares can significantly affect water production and alter landscape conservation perceptions because of paramo's fragility and the high effort needed for recovery.

6.4. Summary

The First Question

How has the relationship between armed conflict processes and landscape changes been approached and assessed worldwide?

The end and beginning of various global armed conflicts have heightened interest in examining the link between warfare and environmental change. The impact of conflict is closely tied to forest cover density, with most studies focusing on equatorial regions in Latin America, sub-Saharan Africa, and Southeast Asia. These conflicts occur in tropical areas with dense forests such as rainforests, monsoon forests, montane forests, and grass savannas. Indirect causes such as forced migration, agriculture, illegal crops, and voluntary migration have led to deforestation, land use, and cover changes. However, the immediate impacts of conflict, such as military confrontations and bombings in tropical areas, have been studied less. In contrast, the landscape effects of conflicts in temperate regions, such as the Balkans, Caucasus, and Middle East, characterized by less dense forests, including temperate broadleaf forests, Mediterranean vegetation, dry steppes, and semi-arid deserts, are less explored. Research in temperate regions often examines land-use and cover changes, agricultural land abandonment, craters, and water pollution, with bombings, military confrontations, and landmines being the primary drivers. Most studies employ medium-scale assessments using multivariate remote sensing analysis and multi-temporal images alongside land use and demographic data, but rarely incorporate conflict intensity data..

The Second Question

How has the relationship between Colombian armed conflict processes and forest disturbances been approached and assessed?

The 2016 peace accord between the FARC-Guerrilla and Colombian governments heightened interest in researching the interplay between armed conflict and environmental impact. While many studies offer broad national-scale explanations of conflict and environmental effects, few have examined specific local or regional causes and consequences. Most research has focused on regions with dense forest cover, such as Antioquia, Caquetá, Meta, and Putumayo, or ecoregions like the Northern Andean, Mag-Urabá Moist, Cordillera Oriental, and Caquetá Moist, often overlooking areas with significant military actions. Direct causes of Colombian armed conflict, including military confrontations, bombings, landmines, and terrorist-induced oil spills, are underexplored due to difficulties in accessing geospatial data and linking it to landscape impacts. Conversely, indirect causes, such as unregulated agriculture, illegal crops, cattle ranching, illegal mining, and colonization, have been extensively studied and identified as primary drivers of landscape changes. The most significant recurring changes were deforestation, land use, and land-cover changes.

The Third Question

What has been the relationship between forest disturbances (consequences) and armed conflict processes (causes) during the high-intensity conflict period, negotiation, and post-agreement periods in the Sumapaz Páramo Region?

Remote sensing and statistical analysis revealed that forest disturbances in the *Sumapaz Páramo Region* and Sumapaz National Park were partially linked to armed conflict. The intensity of conflict and deforestation rates showed a clear and unidirectional relationship, with increased forest disturbances during high-intensity conflict periods and decreased rates during peace talks and post-peace agreement. High-altitude, high-forest cover-density ecosystems, such as the Andean forest and sub-paramo, suffered more from war than lower-forest cover-density areas, such as paramo and super-paramo. The protected areas within the study region experienced less disturbance than those outside the National Park. Vegetation disturbance was significantly lower in high-altitude areas within the National Park (<3300 m.a.s.l) than in lower-altitude areas inside or outside the park. Any disturbance to the fragile paramo ecosystem has a substantial environmental impact, owing to its slow recovery process. Although road construction accounted for a relatively low proportion of deforestation (7-18%) in the SPR, proximity to road infrastructure, particularly within the initial 500 m and up to 1500 m, was positively associated with deforestation. The construction of military infrastructure and roads pressurizes vegetation in the region by providing access to previously inaccessible areas, especially in the southern part of the SPR.

The Fourth Question

What has been the perception of local communities about the relationship between armed conflict and the landscape of the Sumapaz Páramo Region?

Residents of the paramo region identified air purification and water supply as the most crucial ecosystem services provided by the paramo. During the high-conflict period, the region experienced nearly double the landscape impacts compared to the post-agreement period, mainly due to direct-armed conflict consequences, such as military confrontations, bombings, and military infrastructure construction. Indirect causes, such as forced migration, anti-personnel mines, and human-caused fires, have also contributed. The most significant impacts were deforestation and a reduction in water bodies, which affected Sumapaz residents during both intense violence and peace. The community generally holds the National Army and FARC-Guerrilla responsible for environmental damage, rather than the civilian population. Conservation and restoration responsibilities fall to local communities, peasant unions, and the National Parks Board. The people of the region prioritized the preservation of paramo for survival and well-being. Overall, the community viewed the current state of the paramo positively, with only a small percentage rating it as "bad" or "very bad."

REFERENCES

1. Abuelgasim, A.A. *et al.* (1999) 'Change Detection Using Adaptive Fuzzy Neural Networks', *Remote Sensing of Environment*, 70(2), pp. 208–223. Available at: https://doi.org/10.1016/S0034-4257 (99)00039-5.
2. Al-Khudhairy, D.H.A., Caravaggi, I. and Giada, S. (2005) 'Structural Damage Assessments from Ikonos Data Using Change Detection, Object-Oriented Segmentation, and Classification Techniques', *Photogrammetric Engineering & Remote Sensing*, 71(7), pp. 825–837. Available at: https://doi.org/10.14358/PERS.71.7.825.
3. Álvarez, M.D. (2003) 'Forests in the Time of Violence: Conservation Implications of the Colombian War', *Journal of Sustainable Forestry*, 16(3–4), pp. 47–68. Available at: https://doi.org/10.1300/J091v16n03_03.
4. Anderson, R.P. *et al.* (2011) *Ecological Niches and Geographic Distributions (MPB-49):* Princeton University Press. Available at: https://doi.org/10.1515/9781400840670.
5. Andrade C., H.J. *et al.* (2017) 'PERCEPCIÓN LOCAL DE LOS SERVICIOS ECOSISTÉMICOS OFERTADOS EN FINCAS AGROPECUARIAS DE LA ZONA SECA DEL NORTE DEL TOLIMA, COLOMBIA', *Luna Azul*, (45), pp. 42–58. Available at: https://doi.org/10.17151/luaz.2017.45.4.
6. Anthelme, F. and Peyre, G. (2020) 'Biogeography of South American Highlands', in *Encyclopedia of the World's Biomes*. Elsevier, pp. 518–529. Available at: https://doi.org/10.1016/B978-0-12-409548-9.11811-1.
7. Arias, M.A., Ibáñez, A.M. and Zambrano, A. (2019) 'Agricultural production amid conflict: Separating the effects of conflict into shocks and uncertainty', *World Development*, 119, pp. 165–184. Available at: https://doi.org/10.1016/j.worlddev.2017.11.011.
8. Armenteras, D. *et al.* (2006) 'Patterns and causes of deforestation in the Colombian Amazon', *Ecological Indicators*, 6(2), pp. 353–368. Available at: https://doi.org/10.1016/j.ecolind.2005.03.014.
9. Armenteras, D. *et al.* (2011) 'Understanding deforestation in montane and lowland forests of the Colombian Andes', *Regional Environmental Change*, 11(3), pp. 693–705. Available at: https://doi.org/10.1007/s10113-010-0200-y.
10. Armenteras, D. *et al.* (2013) 'National and regional determinants of tropical deforestation in Colombia', *Regional Environmental Change*, 13(6), pp. 1181–1193. Available at: https://doi.org/10.1007/s10113-013-0433-7.
11. Armenteras, D. *et al.* (2017) 'Deforestation dynamics and drivers in different forest types in Latin America: Three decades of studies (1980–2010)', *Global Environmental Change*, 46, pp. 139–147. Available at: https://doi.org/10.1016/j.gloenvcha.2017.09.002.
12. Armenteras, D., Gast, F. and Villareal, H. (2003) 'Andean forest fragmentation and the representativeness of protected natural areas in the eastern Andes, Colombia', *Biological Conservation*, 113(2), pp. 245–256. Available at: https://doi.org/10.1016/S0006-3207 (02)00359-2.
13. Armenteras, D., Schneider, L. and Dávalos, L.M. (2019) 'Fires in protected areas reveal unforeseen costs of Colombian peace', *Nature Ecology & Evolution*, 3(1), pp. 20–23. Available at: https://doi.org/10.1038/s41559-018-0727-8.
14. Aung, T.S. (2021) 'Satellite analysis of the environmental impacts of armed-conflict in Rakhine, Myanmar', *Science of The Total Environment*, 781, p. 146758. Available at: https://doi.org/10.1016/j.scitotenv.2021.146758.
15. Ayana, E.K. *et al.* (2016) 'Examining the relationship between environmental factors and conflict in pastoralist areas of East Africa', *Science of The Total Environment*, 557–558, pp. 601–611. Available at: https://doi.org/10.1016/j.scitotenv.2016.03.102.
16. Baird, I.G. and Le Billon, P. (2012) 'Landscapes of political memories: War legacies and land negotiations in Laos', *Political Geography*, 31(5), pp. 290–300. Available at: https://doi.org/10.1016/j.polgeo.2012.04.005.
17. Baumann, M. *et al.* (2015) 'Land-use change in the Caucasus during and after the Nagorno-Karabakh conflict', *Regional Environmental Change*, 15(8), pp. 1703–1716. Available at: https://doi.org/10.1007/s10113-014-0728-3.
18. 'belligerent, adj. & n.' (2023) in *Oxford English Dictionary*. 3rd edn. Oxford University Press. Available at: https://doi.org/10.1093/OED/9816154261.
19. Bernard, J.M. and Tuttle, R.W. (1998) 'Stream Corridor Restoration: Principles, Processes, and Practices', in *Engineering Approaches to Ecosystem Restoration*. *Wetlands Engineering and River*

Restoration Conference 1998, Denver, Colorado, United States: American Society of Civil Engineers, pp. 320–325. Available at: https://doi.org/10.1061/40382(1998)55.
20. de Beurs, K.M. and Henebry, G.M. (2008) 'War, drought, and phenology: changes in the land surface phenology of Afghanistan since 1982', *Journal of Land Use Science*, 3(2–3), pp. 95–111. Available at: https://doi.org/10.1080/17474230701786109.
21. Beygi Heidarlou, H. *et al.* (2020) 'Armed conflict and land-use changes: Insights from Iraq-Iran war in Zagros forests', *Forest Policy and Economics*, 118, p. 102246. Available at: https://doi.org/10.1016/j.forpol.2020.102246.
22. Biswas, A.K. and H. Cecilia Tortajada-Quiroz (1996) 'Environmental Impacts of the Rwandan Refugees on Zaire', *Ambio*, 25(6), pp. 403–408.
23. Bjorgo, E. (2000) 'Using very high spatial resolution multispectral satellite sensor imagery to monitor refugee camps', *International Journal of Remote Sensing*, 21(3), pp. 611–616. Available at: https://doi.org/10.1080/014311600210786.
24. Blackman, A. (2013) 'Evaluating forest conservation policies in developing countries using remote sensing data: An introduction and practical guide', *Forest Policy and Economics*, 34, pp. 1–16. Available at: https://doi.org/10.1016/j.forpol.2013.04.006.
25. Bromley, L. (2010) 'Relating violence to MODIS fire detections in Darfur, Sudan', *International Journal of Remote Sensing*, 31(9), pp. 2277–2292. Available at: https://doi.org/10.1080/01431160902953909.
26. Brown, I.A. (2010) 'Assessing eco-scarcity as a cause of the outbreak of conflict in Darfur: a remote sensing approach', *International Journal of Remote Sensing*, 31(10), pp. 2513–2520. Available at: https://doi.org/10.1080/01431161003674592.
27. Burgess, R., Miguel, E. and Stanton, C. (2015) 'War and deforestation in Sierra Leone', *Environmental Research Letters*, 10(9), p. 095014. Available at: https://doi.org/10.1088/1748-9326/10/9/095014.
28. Butsic, V. *et al.* (2015) 'Conservation and conflict in the Democratic Republic of Congo: The impacts of warfare, mining, and protected areas on deforestation', *Biological Conservation*, 191, pp. 266–273. Available at: https://doi.org/10.1016/j.biocon.2015.06.037.
29. Buytaert, W. *et al.* (2006) 'Human impact on the hydrology of the Andean páramos', *Earth-Science Reviews*, 79(1–2), pp. 53–72. Available at: https://doi.org/10.1016/j.earscirev.2006.06.002.
30. Cabanellas, G. and Cabanellas, G. (2008) *Diccionario enciclopédico de derecho usual. 1: A - B*. 30. ed., rev.actualizada y ampliada. Buenos Aires: Ed. Heliasta.
31. Cabral, A.I.R. and Costa, F.L. (2017) 'Land cover changes and landscape pattern dynamics in Senegal and Guinea Bissau borderland', *Applied Geography*, 82, pp. 115–128. Available at: https://doi.org/10.1016/j.apgeog.2017.03.010.
32. Cabrera, E. *et al.* (2020) 'Colombian Forest Monitoring System: Assessing Deforestation in an Environmental Complex Country', in M. Nazip Suratman et al. (eds) *Forest Degradation Around the World*. IntechOpen. Available at: https://doi.org/10.5772/intechopen.86143.
33. Calderón Díaz, S.L. *et al.* (2016) *Dividendos ambientales de la paz; Retos y oportunidades para construir una paz sostenible*. Documento 451. Bogotá D.C: Departamento Nacional de Planeación, p. 32. Available at: https://colaboracion.dnp.gov.co/CDT/Estudios%20Econmicos/451.pdf.
34. Cantillo, T. and Garza, N. (2022) 'Armed conflict, institutions and deforestation: A dynamic spatiotemporal analysis of Colombia 2000–2018', *World Development*, 160, p. 106041. Available at: https://doi.org/10.1016/j.worlddev.2022.106041.
35. Castaño Uribe, C. (2004) 'Vías, bosques y conflicto social en Colombia', in M. Cárdenas and M. Rodríguez Becerra (eds) *Guerra, sociedad y medio ambiente*. Bogotá: Foro Nacional Ambiental, pp. 397–454.
36. Castro-Nunez, A. *et al.* (2017) 'Land related grievances shape tropical forest-cover in areas affected by armed-conflict', *Applied Geography*, 85, pp. 39–50. Available at: https://doi.org/10.1016/j.apgeog.2017.05.007.
37. 'cause, n.' (2023) in *Oxford English Dictionary*. 3rd edn. Oxford University Press. Available at: https://doi.org/10.1093/OED/8221121488.
38. Célleri, R. and Feyen, J. (2009) 'The Hydrology of Tropical Andean Ecosystems: Importance, Knowledge Status, and Perspectives', *Mountain Research and Development*, 29(4), pp. 350–355. Available at: https://doi.org/10.1659/mrd.00007.
39. Chadid, M. *et al.* (2015) 'A Bayesian Spatial Model Highlights Distinct Dynamics in Deforestation from Coca and Pastures in an Andean Biodiversity Hotspot', *Forests*, 6(12), pp. 3828–3846. Available at: https://doi.org/10.3390/f6113828.

40. Christiansen, R. *et al.* (2022) 'Toward Causal Inference for Spatio-Temporal Data: Conflict and Forest Loss in Colombia', *Journal of the American Statistical Association*, 117(538), pp. 591–601. Available at: https://doi.org/10.1080/01621459.2021.2013241.
41. Clerici, N. *et al.* (2020) 'Deforestation in Colombian protected areas increased during post-conflict periods', *Scientific Reports*, 10(1), p. 4971. Available at: https://doi.org/10.1038/s41598-020-61861-y.
42. CNMH (2021) *Observatorio de Memoria y Conflicto*. Bogotá: Centro Nacional de Memoria Histórica. Available at: http://micrositios.centrodememoriahistorica.gov.co/observatorio/ (Accessed: 20 August 2021).
43. Collet, C., Chanussot, J. and Chehdi, K. (2010) *Multivariate image processing*. London, UK : Hoboken, NJ: ISTE ; J. Wiley.
44. Corson, M.W. and Palka, E.J. (2004) 'Geotechnology, the U.S. Military, and War', in S.D. Brunn, S.L. Cutter, and J.W. Harrington (eds) *Geography and Technology*. Dordrecht: Springer Netherlands, pp. 401–427. Available at: https://doi.org/10.1007/978-1-4020-2353-8_18.
45. Dávalos, L.M. (2001) 'The San Lucas mountain range in Colombia: how much conservation is owed to the violence?', *Biodiversity and Conservation*, 10(1), pp. 69–78. Available at: https://doi.org/10.1023/A:1016651011294.
46. De Merode, E. *et al.* (2007) 'The impact of armed conflict on protected-area efficacy in Central Africa', *Biology Letters*, 3(3), pp. 299–301. Available at: https://doi.org/10.1098/rsbl.2007.0010.
47. De Pourcq, K. *et al.* (2019) 'Exploring Park–People Conflicts in Colombia through a Social Lens', *Environmental Conservation*, 46(2), pp. 103–110. Available at: https://doi.org/10.1017/S0376892918000413.
48. DeFries, R.S., Foley, J.A. and Asner, G.P. (2004) 'Land-use choices: balancing human needs and ecosystem function', *Frontiers in Ecology and the Environment*, 2(5), pp. 249–257. Available at: https://doi.org/10.1890/1540-9295(2004)002[0249:LCBHNA]2.0.CO;2.
49. Díaz Merlano, J.M., Silva Alvarez, L.A. and Montes Arango, A. (2018) *Región Andina de Colombia*. Edited by S. Montes Veira. Cali, Colombia: Banco de Occidente.
50. Draulans, D. and Van Krunkelsven, E. (2002) 'The impact of war on forest areas in the Democratic Republic of Congo', *Oryx*, 36(1), pp. 35–40. Available at: https://doi.org/10.1017/S0030605302000066.
51. Dudley, J.P. *et al.* (2002) 'Effects of War and Civil Strife on Wildlife and Wildlife Habitats', *Conservation Biology*, 16(2), pp. 319–329. Available at: https://doi.org/10.1046/j.1523-1739.2002.00306.x.
52. Eklund, L. *et al.* (2017) 'How conflict affects land use: agricultural activity in areas seized by the Islamic State', *Environmental Research Letters*, 12(5), p. 054004. Available at: https://doi.org/10.1088/1748-9326/aa673a.
53. van Etten, J. *et al.* (2008) 'Environmental destruction as a counterinsurgency strategy in the Kurdistan region of Turkey', *Geoforum*, 39(5), pp. 1786–1797. Available at: https://doi.org/10.1016/j.geoforum.2008.05.001.
54. Etter, A. and van Wyngaarden, W. (2000) 'Patterns of Landscape Transformation in Colombia, with Emphasis in the Andean Region', *AMBIO: A Journal of the Human Environment*, 29(7), pp. 432–439. Available at: https://doi.org/10.1579/0044-7447-29.7.432.
55. Farr, T.G. *et al.* (2007) 'The Shuttle Radar Topography Mission', *Reviews of Geophysics*, 45(2). Available at: https://doi.org/10.1029/2005RG000183.
56. Fergusson, L., Romero, D. and Vargas, J.F. (2014) 'The Environmental Impact of Civil Conflict: The Deforestation Effect of Paramilitary Expansion in Colombia', *SSRN Electronic Journal* [Preprint]. Available at: https://doi.org/10.2139/ssrn.2516512.
57. Foley, J.A. (2005) 'Global Consequences of Land Use', *Science*, 309(5734), pp. 570–574. Available at: https://doi.org/10.1126/science.1111772.
58. Forman, R.T.T. and Godron, M. (1986) *Landscape ecology*. New York: Wiley.
59. Galvis Hernández, M. (2014) *Constitución y transformación del orden local en el Alto Sumapaz. Gestión ambiental y violencia 1994 - 2010*. Tesis para optar al Grado de Maestría en Estudios Interdisciplinarios sobre Desarrollo. Universidad de los Andes. Centro de Estudios Interdisciplinario.
60. Garcia Corrales, L.M., Avila, H. and Gutierrez, R.R. (2019) 'Land-use and socioeconomic changes related to armed conflicts: A Colombian regional case study', *Environmental Science & Policy*, 97, pp. 116–124. Available at: https://doi.org/10.1016/j.envsci.2019.04.012.

61. Geist, H.J. and Lambin, E.F. (2002) 'Proximate Causes and Underlying Driving Forces of Tropical Deforestation', *BioScience*, 52(2), p. 143. Available at: https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2.
62. Gergel, S.E. and Turner, M.G. (eds) (2017) *Learning Landscape Ecology*. New York, NY: Springer New York. Available at: https://doi.org/10.1007/978-1-4939-6374-4.
63. Gheyle, W. *et al.* (2018) 'Scratching the surface of war. Airborne laser scans of the Great War conflict landscape in Flanders (Belgium)', *Applied Geography*, 90, pp. 55–68. Available at: https://doi.org/10.1016/j.apgeog.2017.11.011.
64. Gleditsch, N.P. (2015) 'Armed Conflict and the Environment', in Gleditsch, N. P., *Nils Petter Gleditsch: Pioneer in the Analysis of War and Peace*. Cham: Springer International Publishing (SpringerBriefs on Pioneers in Science and Practice), pp. 81–103. Available at: https://doi.org/10.1007/978-3-319-03820-9_6.
65. Gómez-Rodríguez, M.E. *et al.* (2017) 'Cambios en la cobertura del suelo en el municipio de Nechí: Una aproximación al impacto ambiental de la minería, 1986-2010', *Revista Facultad de Ingeniería*, 26(45). Available at: https://doi.org/10.19053/01211129.v26.n45.2017.6423.
66. González-González, A. *et al.* (2021) 'Spatial-temporal dynamics of deforestation and its drivers indicate need for locally-adapted environmental governance in Colombia', *Ecological Indicators*, 126, p. 107695. Available at: https://doi.org/10.1016/j.ecolind.2021.107695.
67. Gorelick, N. *et al.* (2017) 'Google Earth Engine: Planetary-scale geospatial analysis for everyone', *Remote Sensing of Environment*, 202, pp. 18–27. Available at: https://doi.org/10.1016/j.rse.2017.06.031.
68. Gorsevski, V. *et al.* (2012) 'Analysis of the Impacts of armed conflict on the Eastern Afromontane forest region on the South Sudan — Uganda border using multitemporal Landsat imagery', *Remote Sensing of Environment*, 118, pp. 10–20. Available at: https://doi.org/10.1016/j.rse.2011.10.023.
69. Gorsevski, V., Geores, M. and Kasischke, E. (2013) 'Human dimensions of land use and land cover change related to civil unrest in the Imatong Mountains of South Sudan', *Applied Geography*, 38, pp. 64–75. Available at: https://doi.org/10.1016/j.apgeog.2012.11.019.
70. Grima, N. and Singh, S.J. (2019) 'How the end of armed conflicts influence forest cover and subsequently ecosystem services provision? An analysis of four case studies in biodiversity hotspots', *Land Use Policy*, 81, pp. 267–275. Available at: https://doi.org/10.1016/j.landusepol.2018.10.056.
71. Hagenlocher, M. (2011) 'Assessing the impact of IDP/refugee camps on the state of the environment - An indicator-based approach utilizing high-resolution satellite image time series of Zam Zam, northern Darfur', in *Geospatial Crossroads*. Salzburgo, pp. 22–31.
72. Hagenlocher, M., Lang, S. and Tiede, D. (2012) 'Integrated assessment of the environmental impact of an IDP camp in Sudan based on very high resolution multi-temporal satellite imagery', *Remote Sensing of Environment*, 126, pp. 27–38. Available at: https://doi.org/10.1016/j.rse.2012.08.010.
73. Hansen, M.C. *et al.* (2013) 'High-Resolution Global Maps of 21st-Century Forest Cover Change', *Science*, 342(6160), pp. 850–853. Available at: https://doi.org/10.1126/science.1244693.
74. Hanson, T. *et al.* (2009) 'Warfare in Biodiversity Hotspots', *Conservation Biology*, 23(3), pp. 578–587. Available at: https://doi.org/10.1111/j.1523-1739.2009.01166.x.
75. Hecht, S.B. and Saatchi, S.S. (2007) 'Globalization and Forest Resurgence: Changes in Forest Cover in El Salvador', *BioScience*, 57(8), pp. 663–672. Available at: https://doi.org/10.1641/B570806.
76. Henao-Díaz, F. *et al.* (2019) 'Caracterización biológica en la zona de transición bosque-páramo del Complejo de Páramos Chingaza, Colombia', *Biota Colombiana*, 20(1), pp. 132–145. Available at: https://doi.org/10.21068/c2019.v20n01a10.
77. Hoffmann, C., García Márquez, J.R. and Krueger, T. (2018) 'A local perspective on drivers and measures to slow deforestation in the Andean-Amazonian foothills of Colombia', *Land Use Policy*, 77, pp. 379–391. Available at: https://doi.org/10.1016/j.landusepol.2018.04.043.
78. Hofstede, R. *et al.* (2003) *Los páramos del mundo: Proyecto Atlas Mundial de los Páramos 2003*. Quito; Global Peatland Initiative; Ecociencia: UICN ;
79. HUMBOLDT and CEERCCO (2015) *Estudios Técnicos, Económicos, Sociales y Ambientales Para la Identificación y Delimitación del Complejo de Páramos Cruz Verde*. Bogotá, D.C., Colombia: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Comisión Conjunta del Corredor de Ecosistemas Estratégicos de la Región Central de la Cordillera Oriental – CEERCCO, p. 448.
80. HUMBOLDT and UDFJC (2015) *Caracterización Biótica del Complejo de Páramos Cruz Verde-Sumapaz en Jurisdicción de la CAM, CAR, Cormacarena, Corporinoquia y la SDA*. Bogotá, D.C.,

Colombia: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Instituto Humboldt – Universidad Distrital Francisco José de Caldas.
81. Hupy, J.P. and Koehler, T. (2012) 'Modern warfare as a significant form of zoogeomorphic disturbance upon the landscape', *Geomorphology*, 157–158, pp. 169–182. Available at: https://doi.org/10.1016/j.geomorph.2011.05.024.
82. ILPI (2014) *Protection of the Natural Environment in Armed Conflict*. Empirical study. Oslo, Norway: International Law and Policy Institute, p. 68. Available at: https://ceobs.org/wp-content/uploads/2018/03/Protection-of-the-Natural-Environment-in-Armed-Conflict.pdf.
83. INDEPAZ (2013) *Proceso de paz con las Autodefensas Unidas de Colombia -AUC*. Bogotá. Available at: http://www.indepaz.org.co/wp-content/uploads/2013/04/Proceso_de_paz_con_las_Autodefensas.pdf.
84. INDEPAZ, O. de D., Conflictividades y Paz (2021) *5 años del acuerdo de paz, Balance en cifras de la violencia en los territorios*. Bogotá: Instituto de Estudios para el Desarrollo y la Paz -INDEPAZ. Available at: https://indepaz.org.co/5-anos-del-acuerdo-de-paz-balance-en-cifras-de-la-violencia-en-los-territorios/.
85. Ingalls, M.L. and Mansfield, D. (2017) 'Resilience at the periphery: Insurgency, agency and social-ecological change under armed conflict', *Geoforum*, 84, pp. 126–137. Available at: https://doi.org/10.1016/j.geoforum.2017.06.012.
86. IUCN WCPA (2022) 'Parks', *PARKS*, 28.2. Available at: https://doi.org/10.2305/IUCN.CH.2022.PARKS-28-2en.
87. Jahjah, M. *et al.* (2007) 'Archaeological remote sensing application pre-post war situation of Babylon archaeological site—Iraq', *Acta Astronautica*, 61(1–6), pp. 121–130. Available at: https://doi.org/10.1016/j.actaastro.2007.01.034.
88. Jha, U.C. (2014) *Armed Conflict and Environmental Damage*. New Delhi: Vij Books India Pvt Ltd.
89. Jurisdicción Especial Para la Paz (2022) *El Ambiente Como Víctima Silenciosa, Un diagnóstico de las afectaciones en el posacuerdo de paz (2017 - 2022)*. 1. Bogotá, Colombia: Unidad de Investigación y Acusación, Jurisdicción Especial Para la Paz, p. 58.
90. Kadykalo, A.N. *et al.* (2019) 'Disentangling "ecosystem services" and "nature's contributions to people"', *Ecosystems and People*, 15(1), pp. 269–287. Available at: https://doi.org/10.1080/26395916.2019.1669713.
91. Kaimowitz, D. and Fauné, A. (2003) 'Contras and Comandantes: Armed Movements and Forest Conservation in Nicaragua's Bosawas Biosphere Reserve', *Journal of Sustainable Forestry*, 16(3–4), pp. 21–46. Available at: https://doi.org/10.1300/J091v16n03_02.
92. Kalmanovitz, S. (2003) *Economía y nación: una breve historia de Colombia*. Nueva ed., corr. y aum. Bogotá: Grupo Editorial Norma (Colección Vitral).
93. Kanyamibwa, S. (1998) 'Impact of war on conservation: Rwandan environment and wildlife in agony', *Biodiversity and Conservation*, 7(11), pp. 1399–1406. Available at: https://doi.org/10.1023/A:1008880113990.
94. Knoth, C. and Pebesma, E. (2017) 'Detecting dwelling destruction in Darfur through object-based change analysis of very high-resolution imagery', *International Journal of Remote Sensing*, 38(1), pp. 273–295. Available at: https://doi.org/10.1080/01431161.2016.1266105.
95. Kong, R. *et al.* (2019) 'Understanding the drivers of deforestation and agricultural transformations in the Northwestern uplands of Cambodia', *Applied Geography*, 102, pp. 84–98. Available at: https://doi.org/10.1016/j.apgeog.2018.12.006.
96. Kranz, O., Sachs, A. and Lang, S. (2015) 'Assessment of environmental changes induced by internally displaced person (IDP) camps in the Darfur region, Sudan, based on multitemporal MODIS data', *International Journal of Remote Sensing*, 36(1), pp. 190–210. Available at: https://doi.org/10.1080/01431161.2014.999386.
97. KROC (2020) *Tres años después de la firma del Acuerdo Final de Colombia: hacia la transformación territorial*. 4. Bogotá: Iniciativa Barómetro, Matriz de Acuerdos de Paz, Instituto Kroc de Estudios Internacionales de Paz. Available at: http://peaceaccords.nd.edu/wp-content/uploads/2020/06/Cuarto-Informe-Final-with-Annex-Link.pdf.
98. Kwarteng, A.Y. (1998) 'Multitemporal remote sensing data analysis of Kuwait's oil lakes', *Environment International*, 24(1–2), pp. 121–137. Available at: https://doi.org/10.1016/S0160-4120(97)00129-3.

99. Landholm, D.M., Pradhan, P. and Kropp, J.P. (2019) ‘Diverging forest land use dynamics induced by armed conflict across the tropics’, *Global Environmental Change*, 56, pp. 86–94. Available at: https://doi.org/10.1016/j.gloenvcha.2019.03.006.
100. Le Billon, P. (2001) ‘The political ecology of war: natural resources and armed conflicts’, *Political Geography*, 20(5), pp. 561–584. Available at: https://doi.org/10.1016/S0962-6298(01)00015-4.
101. Leiterer, R. *et al.* (2018) ‘Vegetation monitoring in refugee-hosting areas in South Sudan’, *Applied Geography*, 93, pp. 1–15. Available at: https://doi.org/10.1016/j.apgeog.2018.01.013.
102. Liu, D. *et al.* (2018) ‘Integration of historical map and aerial imagery to characterize long-term land-use change and landscape dynamics: An object-based analysis via Random Forests’, *Ecological Indicators*, 95, pp. 595–605. Available at: https://doi.org/10.1016/j.ecolind.2018.08.004.
103. Lodhi, M.A., Echavarria, F.R. and Keithley, C. (1998) ‘Using remote sensing data to monitor land cover changes near Afghan refugee camps in northern Pakistan’, *Geocarto International*, 13(1), pp. 33–39. Available at: https://doi.org/10.1080/10106049809354626.
104. Londoño Botero, R. (2011) *Juan de la Cruz Varela: sociedad y política en la región de Sumapaz, 1902-1984*. Bogotá D.C: Universidad Nacional de Colombia, Facultad de Ciencias Humanas, Departamento de Historia (Biblioteca abierta. Colección General historia, 400).
105. Loucks, C. *et al.* (2009) ‘Wildlife decline in Cambodia, 1953-2005: exploring the legacy of armed conflict’, *Conservation Letters*, 2(2), pp. 82–92. Available at: https://doi.org/10.1111/j.1755-263X.2008.00044.x.
106. Machlis, G.E. and Hanson, T. (2011) ‘Warfare Ecology’, in G.E. Machlis et al. (eds) *Warfare Ecology*. Dordrecht: Springer Netherlands (NATO Science for Peace and Security Series C: Environmental Security), pp. 33–40. Available at: https://doi.org/10.1007/978-94-007-1214-0_5.
107. Marta-Pedroso, C., Freitas, H. and Domingos, T. (2007) ‘Testing for the survey mode effect on contingent valuation data quality: A case study of web based versus in-person interviews’, *Ecological Economics*, 62(3–4), pp. 388–398. Available at: https://doi.org/10.1016/j.ecolecon.2007.02.005.
108. Martin, A.J.F. (2023) ‘Factors influencing the use of introduced black locust (Robinia pseudoacacia) for slope stabilization in post-war South Korea’, *Trees, Forests and People*, 14, p. 100444. Available at: https://doi.org/10.1016/j.tfp.2023.100444.
109. McGarigal, K. (2013) ‘Landscape Pattern MetricsBased in part on the article “Landscape pattern metrics” by Kevin McGarigal, which appeared in the *Encyclopedia of Environmetrics* .’, in A.H. El-Shaarawi and W.W. Piegorsch (eds) *Encyclopedia of Environmetrics*. Chichester, UK: John Wiley & Sons, Ltd, p. val006.pub2. Available at: https://doi.org/10.1002/9780470057339.val006.pub2.
110. McNeely, J.A. (2003) ‘Conserving forest biodiversity in times of violent conflict’, *Oryx*, 37(2), pp. 142–152. Available at: https://doi.org/10.1017/S0030605303000334.
111. Mendez, F. and Valánszki, I. (2019a) ‘Repercussions in the Landscape of Colombian Amazonas (Caquetá and Putumayo Region) Caused by Deforestation and Illicit Crops During the Internal Armed Conflict; a Review’. Available at: https://doi.org/10.7275/VJ3E-K759.
112. Mendez, F. and Valánszki, I. (2019b) ‘Trends in the use of remote sensing methods for the analysis of areas affected by armed conflicts’, in. *SZIEntific meeting for young researchers Ifjú tehetségek találkozója*, Budapest: Szent István University. Available at: http://itt.budaicampus.szie.hu/sites/default/files/files/ITT_2019_konferencia.pdf.
113. Mendoza, J.P. (2020) ‘Colombia’s transition to peace is enhancing coca-driven deforestation’, *Environmental Research Letters*, 15(10), p. 104071. Available at: https://doi.org/10.1088/1748-9326/abb331.
114. Milcu, A.I. *et al.* (2013) ‘Cultural Ecosystem Services: A Literature Review and Prospects for Future Research’, *Ecology and Society*, 18(3), p. art44. Available at: https://doi.org/10.5751/ES-05790-180344.
115. Monroy, D.M. and Armenteras, D. (2017) ‘Cambio de cobertura del suelo por minería aluvial en el río Nechí, Antioquia (Colombia)’, *Gestión y Ambiente*, 20(1), pp. 50–61. Available at: https://doi.org/10.15446/ga.v20n1.61513.
116. Morales Acosta, C. (2017) *Arando el pasado para sembrar la paz. Cuadernos de la memoria: relatos de las víctimas del conflicto armado en Sumapaz 1990-2017*. 1st edn. Bogotá, D.C., Colombia: Universidad Nacional de Colombia. Rectoría, Facultad de Derecho, Ciencias Políticas y Sociales, Centro de Pensamiento y Seguimiento al Diálogo de Paz.
117. Morales-Rivas, M. *et al.* (2007) *Atlas 2007 de los páramos de Colombia*. 2007th edn. Bogotá: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt. Available at:

http://humboldt.org.co/es/component/k2/item/299-atlas-de-paramos-de-colombia (Accessed: 11 December 2020).
118. Moreno-Rodríguez, M.L. and Díaz-Melo, J.R. (2018) *Narrativas de la Guerra a Través del Paisaje*. Bogotá: CNMH Centro Nacional de Memoria Histórica. Available at: http://www.centrodememoriahistorica.gov.co/micrositios/recorridos-por-paisajes-de-la-violencia/narrativas-guerra.pdf.
119. Murad, C.A. and Pearse, J. (2018) 'Landsat study of deforestation in the Amazon region of Colombia: Departments of Caquetá and Putumayo', *Remote Sensing Applications: Society and Environment*, 11, pp. 161–171. Available at: https://doi.org/10.1016/j.rsase.2018.07.003.
120. Murillo-Sandoval, P., Van Den Hoek, J. and Hilker, T. (2017) 'Leveraging Multi-Sensor Time Series Datasets to Map Short- and Long-Term Tropical Forest Disturbances in the Colombian Andes', *Remote Sensing*, 9(2), p. 179. Available at: https://doi.org/10.3390/rs9020179.
121. Murillo-Sandoval, P.J. (2020) *Fighting and Foliage: Land System Dynamics in the Colombian Andes-Amazon Region*. Oregon State University, College of Earth, Ocean, and Atmospheric Sciences. Available at: https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/3n2045787.
122. Murillo-Sandoval, P.J. *et al.* (2020) 'The end of gunpoint conservation: forest disturbance after the Colombian peace agreement', *Environmental Research Letters*, 15(3), p. 034033. Available at: https://doi.org/10.1088/1748-9326/ab6ae3.
123. Murillo-Sandoval, P.J. *et al.* (2021) 'No peace for the forest: Rapid, widespread land changes in the Andes-Amazon region following the Colombian civil war', *Global Environmental Change*, 69, p. 102283. Available at: https://doi.org/10.1016/j.gloenvcha.2021.102283.
124. Murillo-Sandoval, P.J. *et al.* (2023) 'The post-conflict expansion of coca farming and illicit cattle ranching in Colombia', *Scientific Reports*, 13(1), p. 1965. Available at: https://doi.org/10.1038/s41598-023-28918-0.
125. Murillo-Sandoval, P.J., Clerici, N. and Correa-Ayram, C. (2022) 'Rapid loss in landscape connectivity after the peace agreement in the Andes-Amazon region', *Global Ecology and Conservation*, 38, p. e02205. Available at: https://doi.org/10.1016/j.gecco.2022.e02205.
126. Myers, N. *et al.* (2000) 'Biodiversity hotspots for conservation priorities', *Nature*, 403(6772), pp. 853–858. Available at: https://doi.org/10.1038/35002501.
127. Nackoney, J. *et al.* (2014) 'Impacts of civil conflict on primary forest habitat in northern Democratic Republic of the Congo, 1990–2010', *Biological Conservation*, 170, pp. 321–328. Available at: https://doi.org/10.1016/j.biocon.2013.12.033.
128. Negret, P.J. *et al.* (2019) 'Emerging evidence that armed conflict and coca cultivation influence deforestation patterns', *Biological Conservation*, 239, p. 108176. Available at: https://doi.org/10.1016/j.biocon.2019.07.021.
129. Nietschmann, B. (1990) 'Conservation by conflict in Nicaragua.', *Natural History*, 99(11), pp. 42–49.
130. Note, N. *et al.* (2018) 'A new evaluation approach of World War One's devastated front zone: A shell hole density map based on historical aerial photographs and validated by electromagnetic induction field measurements to link the metal shrapnel phenomenon', *Geoderma*, 310, pp. 257–269. Available at: https://doi.org/10.1016/j.geoderma.2017.09.029.
131. Olaya Angarita, J.A. (2019) 'Composición y estructura de la transición bosque-páramo en el corredor Guantiva-La Rusia (Colombia)', *Revista de Biología Tropical*, 67(4). Available at: https://doi.org/10.15517/rbt.v67i4.31965.
132. Ordway, E.M. (2015) 'Political shifts and changing forests: Effects of armed conflict on forest conservation in Rwanda', *Global Ecology and Conservation*, 3, pp. 448–460. Available at: https://doi.org/10.1016/j.gecco.2015.01.013.
133. Partow, H. (2008) *Environmental impact of wars and conflicts*, pp. 159–172. Available at: http://www.fao.org/fileadmin/user_upload/rome2007/docs/Arab_Environment_Future_Challenges.pdf.
134. Pech, L. and Lakes, T. (2017) 'The impact of armed conflict and forced migration on urban expansion in Goma: Introduction to a simple method of satellite-imagery analysis as a complement to field research', *Applied Geography*, 88, pp. 161–173. Available at: https://doi.org/10.1016/j.apgeog.2017.07.008.
135. Pedraza, S. *et al.* (2020) 'Perception of conservation strategies and nature's contributions to people around Chingaza National Natural Park, Colombia', *Environmental Conservation*, 47(3), pp. 158–165. Available at: https://doi.org/10.1017/S037689292000020X.

136. Peñaranda-Currie, I., Otero-Bahamon, S. and Uribe, S. (2021) ‘What is the state made of? Coca, roads, and the materiality of state formation in the frontier’, *World Development*, 141, p. 105395. Available at: https://doi.org/10.1016/j.worlddev.2021.105395.
137. Pereira, P. *et al.* (2022) ‘Russian-Ukrainian war impacts the total environment’, *Science of The Total Environment*, p. 155865. Available at: https://doi.org/10.1016/j.scitotenv.2022.155865.
138. Petit, C., Scudder, T. and Lambin, E. (2001) ‘Quantifying processes of land-cover change by remote sensing: Resettlement and rapid land-cover changes in south-eastern Zambia’, *International Journal of Remote Sensing*, 22(17), pp. 3435–3456. Available at: https://doi.org/10.1080/01431160010006881.
139. Peyre, G. (2015) *Plant diversity and vegetation of the Andean Páramo*. Universitat de Barcelona. Available at: https://www.semanticscholar.org/paper/Plant-diversity-and-vegetation-of-the-Andean-P%C3%A1ramo-Peyre/b07729be80f1bcd6748d905d4d063131212a291c.
140. Podwojewski, P. *et al.* (2006) ‘Overgrazing effects on vegetation cover and properties of volcanic ash soil in the páramo of Llangahua and La Esperanza (Tungurahua, Ecuador)’, *Soil Use and Management*, 18(1), pp. 45–55. Available at: https://doi.org/10.1111/j.1475-2743.2002.tb00049.x.
141. Potapov, P.V. *et al.* (2012) ‘Quantifying forest cover loss in Democratic Republic of the Congo, 2000–2010, with Landsat ETM+ data’, *Remote Sensing of Environment*, 122, pp. 106–116. Available at: https://doi.org/10.1016/j.rse.2011.08.027.
142. Prem, M., Saavedra, S. and Vargas, J.F. (2020) ‘End-of-conflict deforestation: Evidence from Colombia’s peace agreement’, *World Development*, 129, p. 104852. Available at: https://doi.org/10.1016/j.worlddev.2019.104852.
143. Qamer, F.M. *et al.* (2012) ‘Forest cover change assessment in conflict-affected areas of northwest Pakistan: the case of swat and shangla districts’, *Journal of Mountain Science*, 9(3), pp. 297–306. Available at: https://doi.org/10.1007/s11629-009-2319-1.
144. Rembold, F. *et al.* (2013) ‘Mapping charcoal driven forest degradation during the main period of Al Shabaab control in Southern Somalia’, *Energy for Sustainable Development*, 17(5), pp. 510–514. Available at: https://doi.org/10.1016/j.esd.2013.07.001.
145. Renvoize, S. *et al.* (2000) ‘Paramos: A Checklist of Plant Diversity, Geographical Distribution, and Botanical Literature (Memoirs of the New York Botanical Garden Volume 84)’, *Kew Bulletin*, 55(4), p. 1017. Available at: https://doi.org/10.2307/4113659.
146. Rettberg, A., Leiteritz, R.J. and Nasi, C. (2014) ‘Different Resources, Different Conflicts? A Framework for Understanding the Political Economy of Armed Conflict and Criminality in Colombian Regions’, *SSRN Electronic Journal* [Preprint]. Available at: https://doi.org/10.2139/ssrn.2499580.
147. Reyes, L.C. (2014) ‘Estimating the Causal Effect of Forced Eradication on Coca Cultivation in Colombian Municipalities’, *World Development*, 61, pp. 70–84. Available at: https://doi.org/10.1016/j.worlddev.2014.03.024.
148. Rincón Ruiz, A. *et al.* (2013) *Coca crops, forests, people and anti-drug policy in Colombia towards the understanding of a complex relationship*. Barcelona: Universitat Autònoma de Barcelona. Available at: http://hdl.handle.net/10803/117303 (Accessed: 20 November 2020).
149. Rincón-Ruiz, A. and Kallis, G. (2013) ‘Caught in the middle, Colombia’s war on drugs and its effects on forest and people’, *Geoforum*, 46, pp. 60–78. Available at: https://doi.org/10.1016/j.geoforum.2012.12.009.
150. Rincón-Ruiz, A., Pascual, U. and Flantua, S. (2013) ‘Examining spatially varying relationships between coca crops and associated factors in Colombia, using geographically weight regression’, *Applied Geography*, 37, pp. 23–33. Available at: https://doi.org/10.1016/j.apgeog.2012.10.009.
151. Rodríguez-de-Francisco, J.C. *et al.* (2021) ‘Post-conflict transition and REDD+ in Colombia: Challenges to reducing deforestation in the Amazon’, *Forest Policy and Economics*, 127, p. 102450. Available at: https://doi.org/10.1016/j.forpol.2021.102450.
152. Rodríguez-Garavito, C. (2017) ‘Reimagining Human Rights’, *Journal of International Law and International Relations*, 13(1), pp. 10–14.
153. Rotherham, I.D. (2024) ‘An historical review of forests and warfare from the Romans to the twenty-first century’, *Trees, Forests and People*, 15, p. 100495. Available at: https://doi.org/10.1016/j.tfp.2024.100495.
154. Rustad, S.C.A. *et al.* (2008) ‘Foliage and fighting: Forest resources and the onset, duration, and location of civil war’, *Political Geography*, 27(7), pp. 761–782. Available at: https://doi.org/10.1016/j.polgeo.2008.09.004.

155. Sánchez-Cuervo, A.M. *et al.* (2012) ‘Land Cover Change in Colombia: Surprising Forest Recovery Trends between 2001 and 2010’, *PLoS ONE*. Edited by B. Bond-Lamberty, 7(8), p. e43943. Available at: https://doi.org/10.1371/journal.pone.0043943.
156. Sánchez-Cuervo, A.M. and Aide, T.M. (2013) ‘Consequences of the Armed Conflict, Forced Human Displacement, and Land Abandonment on Forest Cover Change in Colombia: A Multi-scaled Analysis’, *Ecosystems*, 16(6), pp. 1052–1070. Available at: https://doi.org/10.1007/s10021-013-9667-y.
157. Sanchez-Cuervo, A.M. and Aide, T.M. (2013) ‘Identifying hotspots of deforestation and reforestation in Colombia (2001–2010): implications for protected areas’, *Ecosphere*, 4(11), p. art143. Available at: https://doi.org/10.1890/ES13-00207.1.
158. Sarmiento Pinzón, C.E. *et al.* (2013) *Aportes a la conservación estratégica de los páramos de Colombia: actualización de la cartografía de los complejos de páramo a escala 1:100.000*. Primera edición. Bogotá, D.C., Colombia: Ministerio de Medio Ambiente y Desarrollo Sostenible : Instituto de Investigación de Recursos Biológicos Alexander von Humboldt.
159. Sarmiento Pinzón, C.E. and León Moya, O.A. (eds) (2015) *Transición bosque-páramo: bases conceptuales y métodos para su identificación en los Andes colombianos*. Primera edición. Bogotá: Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (Páramos vivos).
160. Schoenig, D., Dupras, J. and Messier, C. (2020) *Comment: The effect of post-conflict transition on deforestation in protected areas in Colombia*. preprint. Physical Sciences and Mathematics. Available at: https://doi.org/10.31223/OSF.IO/F2ZXH.
161. Sklenář, P., Dušková, E. and Balslev, H. (2011) ‘Tropical and Temperate: Evolutionary History of Páramo Flora’, *The Botanical Review*, 77(2), pp. 71–108. Available at: https://doi.org/10.1007/s12229-010-9061-9.
162. Solomon, N. *et al.* (2018) ‘Environmental impacts and causes of conflict in the Horn of Africa: A review’, *Earth-Science Reviews*, 177, pp. 284–290. Available at: https://doi.org/10.1016/j.earscirev.2017.11.016.
163. Sosnowski, A. *et al.* (2016) ‘Remote regions, remote data: A spatial investigation of precipitation, dynamic land covers, and conflict in the Sudd wetland of South Sudan’, *Applied Geography*, 69, pp. 51–64. Available at: https://doi.org/10.1016/j.apgeog.2016.02.007.
164. Spröhnle, K. *et al.* (2016) ‘Earth observation-based multi-scale impact assessment of internally displaced person (IDP) camps on wood resources in Zalingei, Darfur’, *Geocarto International*, 31(5), pp. 575–595. Available at: https://doi.org/10.1080/10106049.2015.1062053.
165. Stevens, K. *et al.* (2011) ‘Examining complexities of forest cover change during armed conflict on Nicaragua’s Atlantic Coast’, *Biodiversity and Conservation*, 20(12), pp. 2597–2613. Available at: https://doi.org/10.1007/s10531-011-0093-1.
166. Stichelbaut, B. *et al.* (2016) ‘The First World War from above and below. Historical aerial photographs and mine craters in the Ypres Salient’, *Applied Geography*, 66, pp. 64–72. Available at: https://doi.org/10.1016/j.apgeog.2015.11.020.
167. Suthakar, K. and Bui, E.N. (2008) ‘Land use/cover changes in the war-ravaged Jaffna Peninsula, Sri Lanka, 1984–early 2004’, *Singapore Journal of Tropical Geography*, 29(2), pp. 205–220. Available at: https://doi.org/10.1111/j.1467-9493.2008.00329.x.
168. Tian, Y. *et al.* (2011) ‘Opium poppy monitoring with remote sensing in North Myanmar’, *International Journal of Drug Policy*, 22(4), pp. 278–284. Available at: https://doi.org/10.1016/j.drugpo.2011.02.001.
169. UI-UC/ATMO (2022) *Historical Land-Cover Change and Land-Use Conversions Global Dataset*. Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, NOAA National Centers for Environmental Information. Available at: https://www.ncei.noaa.gov/metadata/geoportal/rest/metadata/item/gov.noaa.ncdc:C00814/html#.
170. UNHCR (2021) *UNHCR’s Refugee Population Statistics Database*. Geneve. Available at: https://www.unhcr.org/refugee-statistics/.
171. Unidad de Victimas (2024) *Gobierno Nacional Notificará a La Comunidad Campesina de Sumapaz Como Sujeto de Reparación Colectiva*. Available at: https://www.unidadvictimas.gov.co/es/gobierno-nacional-notificara-comunidad-campesina-sumapaz-sujeto-reparacion-colectiva/.
172. Uppsala University (2021) *Uppsala Conflict Data Program*. Uppsala, Sweden: Uppsala University, Department of Peace and Conflict Research,. Available at: https://www.pcr.uu.se/research/ucdp/definitions/.

173. Uribe, S., Otero-Bahamón, S. and Peñaranda, I. (2021) 'Hacer el estado: carreteras, conflicto y órdenes locales en los territorios de las FARC', *Revista de Estudios Sociales*, (75), pp. 87–100. Available at: https://doi.org/10.7440/res75.2021.08.
174. Vadas, A. and Baráth, Z. (2024) 'Impact of pre-modern war on forests: The case of the Hungarian-Ottoman Military Frontier (ca. 1521–1690)', *Trees, Forests and People*, 15, p. 100500. Available at: https://doi.org/10.1016/j.tfp.2024.100500.
175. Valencia, J. *et al.* (2021) *Páramos at Risk: The Interconnected Threats to a Biodiversity Hotspot - The Revelator*.
176. Van Dexter, K. and Visseren-Hamakers, I. (2020) 'Forests in the time of peace', *Journal of Land Use Science*, 15(2–3), pp. 327–342. Available at: https://doi.org/10.1080/1747423X.2019.1699614.
177. Van, T.T. *et al.* (2015) 'Changes in mangrove vegetation area and character in a war and land use change affected region of Vietnam (Mui Ca Mau) over six decades', *Acta Oecologica*, 63, pp. 71–81. Available at: https://doi.org/10.1016/j.actao.2014.11.007.
178. Vicepresidencia de la República (2002) *Panorama Actual de la Región del Sumapaz*. 8. Bogotá: Observatorio del Programa Presidencial de DDHH y DIH, p. 16. Available at: https://www.scribd.com/doc/86605786/Panorama-Actual-de-La-Region-Del-Sumapaz.
179. Vuille, M. *et al.* (2008) 'Climate change and tropical Andean glaciers: Past, present and future', *Earth-Science Reviews*, 89(3–4), pp. 79–96. Available at: https://doi.org/10.1016/j.earscirev.2008.04.002.
180. Wales, N.A. (2020) 'An examination of forest cover change at Angkor, Cambodia, using satellite imagery, interviews and interpretation of historical events', *Applied Geography*, 122, p. 102276. Available at: https://doi.org/10.1016/j.apgeog.2020.102276.
181. Warner, T.A., Nellis, M.D. and Foody, G.M. (eds) (2009) *The Sage handbook of remote sensing*. 1st ed. Thousand Oaks, CA: Sage.
182. Wilson, S.A. and Wilson, C.O. (2013) 'Modelling the impacts of civil war on land use and land cover change within Kono District, Sierra Leone: a socio-geospatial approach', *Geocarto International*, 28(6), pp. 476–501. Available at: https://doi.org/10.1080/10106049.2012.724456.
183. Witmer, F.D.W. (2008) 'Detecting war-induced abandoned agricultural land in northeast Bosnia using multispectral, multitemporal Landsat TM imagery', *International Journal of Remote Sensing*, 29(13), pp. 3805–3831. Available at: https://doi.org/10.1080/01431160801891879.
184. Witmer, F.D.W. (2015) 'Remote sensing of violent conflict: eyes from above', *International Journal of Remote Sensing*, 36(9), pp. 2326–2352. Available at: https://doi.org/10.1080/01431161.2015.1035412.
185. Zorro, W.A. *et al.* (2005) *Parque Nacional Natural Sumapaz, Plan de Manejo 2005*. Plan de Manejo. Bogotá: Parques Nacionales Naturales de Colombia, p. 214.
186. Zúñiga-Upegui, P. *et al.* (2019) 'Exploring social-ecological systems in the transition from war to peace: A scenario-based approach to forecasting the post-conflict landscape in a Colombian region', *Science of The Total Environment*, 695, p. 133874. Available at: https://doi.org/10.1016/j.scitotenv.2019.133874.

LIST OF FIGURES

LIST OF TABLES

APPENDICES

Appendix 1: Definitions

Abandonment or Forced Dispossession of Agriculture Land (AAL): It is when a person is arbitrarily deprived of his property, farm or agricultural land, possession or occupation, by committing crimes associated with the situation of violence (CNMH, 2021).
Act of War: An armed confrontation between two groups results in at least one direct death or wounded in an incident (CNMH, 2021).
Armed Conflict (AC): A state-based armed conflict is a contested incompatibility that concerns government or territory where the use of armed force between two parties, at least one is the National Government of a state, results in at least 25 battle-related deaths one calendar year (Uppsala University, 2021).
Attack on a Military Objective: These are all those acts that, in the course of the war, involve a deliberate attack against any military target (Infrastructure or combatants) with indiscriminate impacts. It is possible to infer that the objective was a military one, but could occur considerable physical damage to people or civil goods (CNMH, 2021).
Attacks on the Civilian Population: These are all those acts that, in the course of the war, involve a deliberate attack against any person who does not participate directly in hostilities (civilian population) or who has been left out of hostilities due to the absence of means of defence that place him in a vulnerable situation (CNMH, 2021).
***Autodefensas Unidas de Colombia* / The United Self-Defense Forces of Colombia (AUC):** It was a Colombian far-right paramilitary and drug trafficking group, which was an active belligerent in the Colombian armed conflict during the period from 1997 to 2006.
Belligerent Force: A nation, party, or person waging regular war (e.g.; FARC, ELN, AUC, Army) (‘belligerent, adj. & n.’, 2023).
Biome (Bi): It is a biogeographical unit consisting of a biological community formed in response to the physical environment in which they are found and a shared regional climate. Biome is a broader term than habitat and can comprise a variety of habitats. Biomes may span more than one continent.
Bombing (Bo): It is an action at the initiative of the Military Forces or another State Armed Force against an organized armed group, whether it is a moving or fixed unit, especially a guerrilla camp. It is distinguished from strafing from the air by the use of bombs (Uppsala University, 2021).
Causality: The relationship between cause and consequence. The principle is that warfare relates to the changes in the landscape.
Cause: That which produces an effect on the environment; that which gives rise to any action, phenomenon, or condition. Cause and consequence are correlative terms (‘cause, n.’, 2023).
Conflict Intensity (Co): Denotes what level of fighting a state-based conflict or dyad reaches in each specific calendar year. The variable has two categories: The conflict intensity uses two rates; the number of total victims (injured and casualties) and the number of violent actions per year. Compiled data on the following violent acts: homicides, terrorist attacks, massacres, attacks on the population, acts of war, forced disappearances, landmines, and kidnapping (CNMH, 2021; Uppsala University, 2021).
Conflict Period (Con): High and medium intensity conflict stage.
Consequence: The direct or indirect effect, result, or outcome of a military activity.
Corridor: A particular type of patch that links other patches in the matrix. Typically, a corridor is linear or elongated, like a stream corridor (Bernard and Tuttle, 1998).
Deforestation (Df): The direct and/or induced permanent disturbance generating a conversion of forest cover to another type of land cover in a given time caused mainly by human activities (e.g. logging, crops, cattle ranching).
Departments: a Colombian geopolitical administrative division of thirty-two departments. Departments are level-2 subdivisions and are granted a certain autonomy.

Ecoregions: are relatively large geographical units containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities before the significant landscape changes (Sanchez-Cuervo and Aide, 2013).
***Ejército de Liberación Nacional* / The National Liberation Army (ELN):** It is a Marxist–Leninist guerrilla group involved in the continuing Colombian conflict, which has existed in Colombia since 1964. The ELN advocate a composite communist ideology of Marxism-Leninism and liberation theology.
***Ejército Nacional de Colombia* / The National Army of Colombia (Army):** The land warfare service branch of the Military Forces of the Government of the Republic of Colombia.
Forced Migration / Displacement (FM): It is the situation in which a person has been forced to migrate within the national territory, abandoning their place of residence or habitual economic activities, because their life, physical integrity, personal safety or freedom have been violated or are directly threatened on the occasion of an internal armed conflict (CNMH, 2021).
Forest: A piece of land mainly covered by trees that might contain shrubs, palms, guaduas, grass, and vines, in which tree cover predominates with a minimum canopy density of 30%, a minimum canopy height (in situ) of 5 m at the time of identification, and a minimum area of 1.0 *ha* (Cabrera *et al.*, 2020).
Forestation (Fo): is the establishment of a forest or stand of trees in an area where there was no recent tree cover. There are three types of forestation: Natural regeneration, agroforestry and tree plantations.
Forest Disturbance (FD): In this dissertation is considered a stand-replacement disturbance (e.g. fully converted to other land uses) or a forest degradation (e.g. thinning) (Murillo-Sandoval *et al.*, 2020).
Forest-Páramo Transition Zone (FPTZ): The forest-paramo altitudinal transition strip, at its lower limit is characterized by the transition from high Andean forest to tall and low-sized shrubs, and at its upper limit from low-sized shrubs to grasslands. FPTZ areas range from 2500 meters in some sectors to 3380 meters in their highest parts. This transition zone is characterized by the tree line limit and semi-open plant formations, with interdigitating shrub and tree elements, and substantial variability in its floristic composition, cover, and physiognomy (Sarmiento Pinzón and León Moya, 2015; Henao-Díaz *et al.*, 2019; Olaya Angarita, 2019).
***Fuerzas Armadas Revolucionarias de Colombia* / The Revolutionary Armed Forces of Colombia—People's Army (FARC–EP or FARC):** A Marxist–Leninist guerrilla group involved in the continuing Colombian conflict starting in 1964. The FARC–EP was formed during the Cold War period as a peasant force promoting a political line of agrarianism and anti-imperialism.
Illicit / Illegal Crops (IC): Crops or plants that have been deemed illegal to grow by the government. There are two main crops that are the basis of drug crop cultivation; opium poppy (heroin), and coca bush (cocaine).
Internally Displaced Person (IDP): A person that has been forced to migrate within the country, abandoning their place of residence or habitual economic activities, because their life, physical integrity, personal safety or freedom have been violated or are directly threatened on the occasion of an internal armed conflict (CNMH, 2021).
Landmine (LM): An explosive mine laid on or just under the surface of the ground and which detonates when activated by a person, vehicle, etc., passing over or near it.
Landsat Program (LS) is the longest-running enterprise for the acquisition of satellite imagery of Earth. It is a joint NASA / USGS program. It includes several imageries from Landsat 1 in 1975, (LS1-3) Landsat 1-3 MSS, (LS4-5) Landsat 4-5 TM, (LS7) Landsat 7 ETM+, (LS8) Landsat 8 OLI and the most recent, Landsat 9, was launched on 27 September 2021.
Landscape: is the space where the natural environment is interrelated with the human being (natural environment). It is defined within a physical space, natural, rural or urban, where all the physical and emotional elements that compose it interact. It contains the following elements:

climate, soils, covers, minerals, vegetation, relief (mountains, plains or depressions), rivers, lakes, etc. Adapted from (McGarigal, 2013).

Landscape Structure: Is defined by the particular spatial pattern being represented, consisting of two components: composition and configuration. Together, composition and configuration components define the spatial pattern or heterogeneity of the landscape. Landscape structure expresses the spatial pattern of landscape elements and the connections between the different ecosystems or landscape elements. Landscape structure assesses the relationship between ecosystems as a measure, number, size and shape (Forman and Godron, 1986; Gergel and Turner, 2017).

Land Degradation (Ds): The indirect or direct temporal disturbance generating a conversion of forest cover to another type of land cover in a short or medium time caused by human activities or natural phenomena (e.g. fires, drought, flooding).

Land-Use and Land-Cover classification (LULC): A series of maps of an area provides information to help users to understand the current landscape. Land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types. Land use shows how people use the landscape for development, conservation, or mixed uses (UI-UC/ATMO, 2022).

Meters above sea level (m.a.s.l): is a measure of the vertical distance (elevation or altitude) of a location in reference to a historic mean sea level taken as a vertical datum. In geodesy, it is formalized as orthometric heights.

Military Confrontation / Combat (MC): It refers to the legal and active struggle with intervention and personal risk, in which one can count on the participation of two sides, the use of fire by both belligerent sides, and attack, at least of one side in the open field (Cabanellas and Cabanellas, 2008).

Military Infrastructure (MI): It is a structure with strictly military and territorial control purposes, either temporarily or indefinitely, such as military bases, heliports, trenches, cantons, sentry boxes, bunkers, barracks, etc. (CNMH, 2021).

Military Operation refers to all offensive action carried out by the Army and Police Forces against the military objectives of organized armed groups out of the law. This action does not include machine gun fire from the air or bombardments (CNMH, 2021).

Minor Conflict Intensity: At least 25 but less than 1000 battle-related deaths in one calendar year (Uppsala University, 2021).

Mosaic: a collection of patches, none of which are dominant enough to be interconnected throughout the landscape (Bernard and Tuttle, 1998).

Multi-satellite or Multi-sensor (MSa): Geospatial information gathered from two or more different satellite imagery sensors to analyze one scene.

Multi-scale (MSc): A study area is observed using several scopes and extensions. Often could involve using multiresolution imagery. According to the following range of scales: Local (0-999 km2), Landscape (1000-9999 km2), Regional (10,000-99,999 km2), National/global (≥100,000 km2).

Multi-spatial (MSt): Satellite imagery analyzed by two or more research-separated areas within the same study.

Multi-spectral (MSp): Satellite imagery image data captured within specific wavelength ranges across the electromagnetic spectrum. It goes from the simplest case of the colour image to the more complex cases of multispectral images (less than ten spectral bands). The wavelengths may be separated by filters or detected using instruments sensitive to particular wavelengths, including light from frequencies beyond the visible light range, i.e. infrared and ultraviolet.

Multi-temporal or Multi-date (MT): Based on multiple time series, the remote sensing analysis compares images taken at different times to observe changes. It often involves forming different images.

Multivariate (MV): Type of statistical analysis having or involving a number of independent mathematical or statistical variables.

National Park (NP): Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems with environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities (IUCN WCPA, 2022).
Non-Forced Migration: In the Colombian case, following the withdrawal of the guerrillas from several areas previously controlled by them, some populations from other regions of the country or from neighboring countries migrate non-forcedly and seek to colonize these territories in search of better living conditions and higher incomes, even carrying out illegal activities such as coca leaf cultivation, illegal mining, illegal cattle ranching and indiscriminate logging.
Normalized Difference Vegetation Index (NDVI): It quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs).
Páramo**:** It is a high mountain Andean ecosystem that includes natural habitats between the montane tree line (2700m) and the permanent snowline (4200m). The paramo landscapes comprehend varied topography shapes, such as valleys, plains, plateaus, mountains and foothills (Morales-Rivas *et al.*, 2007).
Patch: A nonlinear area (polygon) that is less abundant. It is different from the matrix due to its continuity (Bernard and Tuttle, 1998).
Peace Negotiations (Neg): It occurs when peace talks are carried out, and the military actions decrease or stop temporarily or definitively due to a ceasefire or truce, in the Colombian case it occurred during 2012 to 2016.
Post-agreement Period (Post): The stage after the signing of the peace agreement between the FARC and the National Government.
Protected Area (PA): A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values and traditional natural resource management systems (IUCN WCPA, 2022).
Region (Natural); are large territorial Colombian divisions, non-official and non-administrative, made from heterogeneous terrain, climate, vegetation, and soil classes. Based on these conditions, in Colombia, six natural regions can be differentiated: Amazonas, Andes, Caribbean, Insular, Orinoquia, and Pacific.
Remote Sensing (RS): Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring it is reflected and emitted radiation at a distance (typically from satellite or aircraft). Special cameras collect remotely sensed images, which help researchers "sense" things about the Earth.
Sentinel (Se): An earth observation mission from the Copernicus Program that systematically acquires optical imagery at high spatial resolution (10 m to 60 m) over land and coastal waters.
Terrorist Attack (TA): It is understood as any attack perpetrated through the use of explosives, which occurs in densely populated areas and in which there are multiple effects on civilians or civilian property, regardless of whether the objective of the action is civilian or military (CNMH, 2021).
Victim: The wounded and dead civilians are counted as part of the development of war actions such as combats, ambushes, harassment, attacks on Public Force facilities, military operations and bombings (CNMH, 2021).
War Intensity: At least 1000 battle-related deaths in one calendar year (Uppsala University, 2021).
War Actions: these are all acts carried out under the legitimate task of war, considering that they respond to a defined military objective and use lawful means and weapons in combat. At least two parties are involved in war actions, on one side, the government or state armed forces, and on the other side, the organized armed groups out of the law (Uppsala University, 2021).

Appendix 2: Characteristics of the most common sensors. (Source: Adapted from Witmer, 2015)

Sensor	Spatial resolution (m)	Swath width (km)	Spectral bands	Operating period	Active	Domain	Origin
Very fine resolution (≤1m)							
GeoEye	0.46	10	Pan	09-2008 - Currently	Yes	Pr	US
World View II	0.46	18	Pan	oct-09	Yes	Pr	US
QuickBird II	0.6	30	Pan	10-2001 to 12-2014	No	Pr	US
IKONOS	0.82 - 1	11	Pan	09-1999 to 03-2015	No	Pr	US
Fine resolution (>1–10m)							
GeoEye	1.84	10	4	09-2008 - Currently	Yes	Pr	US
QuickBird II (MS)	2.4	30	4	10-2001 to 12-2014	No	Pr	US
ALOS	2.5		Pan	01-2006 to 05-2011	No	Pu	JP
SPOT-5	2.5, 5, 10	60	Pan	05-2002 to 03-2015	No	Pu	FR
CBERS-2B	2.7	27	Pan	09-2007 to 06-2010	No	Pu	CN-BR
IKONOS (MS)	3.28 – 4	11	4	09-1999 to 03-2015	No	Pr	US
KVR-1000 (MS)	3.3	40	4	1994 - N.D.	No	Pu	RU
Rapid Eye	5	77	5	02-2009 to 03-2020	No	Pr	DE-UK
Google Earth VHR	5, 10		Pan	N.D.	Yes	Pr	US
IRS 1C LISS III	6	70	Pan	12-1995 - 09-2007	No	Pu	IN
Moderate resolution (>10–120m)							
Sentinel 2	10, 20, 60	290	13	06-2015 - Currently	Yes	Pu	EU
ASTER	15, 30, 90	60	14	02-2000 - 04-2008	Yes	Pu	US-JP
Landsat 8 OLI	15, 30	185	11	02-2013 - Currently	Yes	Pu	US
Landsat 7 ETM+	15, 30	185	8	10-1993 - Currently	Yes	Pu	US
IRS 1C LISS III	23, 50	142	4	12-1995 to 09-2007	No	Pu	IN
Landsat 4-5 TM	30	185	7	07-1982 to 06-2013	No	Pu	US
Landsat 1-3 MSS	60, 120	N.D.	4	07-1972 to 01-1983	No	Pu	US
Coarse resolution (>250m)							
MODIS	250, 500, 1000	2330	36	1999 to 2005	No	Pu	US
VIIRS	375, 750	3060	22	oct-11	Yes	Pr	US
AVHRR	1100, 4400	2500	5, 6	mar-04	Yes	Pu	US-EU
Radar Data - No Category							
LIDAR Airborne Laser Scanning	1	N.A.	N.A.	N.A.	Yes	Pr	N.A.
Aerial Photos		N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Abbreviations:
Domain: (Pu) Public, (Pr) Private
Origin: (**BR**) Brazil, (**CN**) China, (**DE**) Germany, (**EU**) European Union, (**FR**) France, (**JP**) Japan, (**RU**) Russia, (**UK**) United Kingdom, (**US**) United States of America.
N.D.: No Data, **N.A.**: Not Applicable

Appendix 3: Classification of the characteristics of worldwide case studies.

1. **Metadata:**
- **Time domain:** 1998-2021.
- **Conflict period domain**; Pre-conflict, conflict stage, and Post-conflict.
- **Origin of the researchers**.

2. **Geographical domain**:
- **Continents:** Africa, America, Asia, Europe.
- **Regions:** Europe, Latin America, Middle East & Western Asia, Southeast Asia, and sub-Saharan Africa.

- **Countries:** Afghanistan, Belgium, Bosnia & Herzegovina, Cambodia, Colombia, El Salvador, Kuwait, Liberia, Myanmar, Nicaragua, North Macedonia, Pakistan, Palestine, Republic Democratic of Congo, Rwanda, Sierra Leona, South Sudan, Sri Lanka, Syria, Thailand, Türkiye, Uganda, Zambia.
- **Biomes:** Alpine tundra, Arid desert, Dry steppe, Grass savanna, Ice sheet and Polar desert, Mediterranean vegetation, Monsoon forest / Dry forest, Montane forest, Semiarid desert, Subtropical dry forest, Subtropical rainforest, Taiga, Temperate broadleaf forest, Temperate steppe, Tree savanna, Tropical rainforest, and Tundra, Xeric shrubland.

3. Satellite imagery:

- **Sensor**: Aerial Photo, ALOS, ASTER, AVHRR, CBERS-2B, GeoEye, Google Earth VHR, IKONOS, IRS-1C LISS-III, KVR-1000 (MS), Landsat 1-3 (MSS), Landsat 4-5 TM, Landsat 7 ETM+, Landsat 8OLI, Lidar – ALS, MODIS, QuickBird II, Rapid Eye, Sentinel 2, SPOT-5, VIIRS, and WorldView-2.
- **Spatial resolution**: I used the category found in the SAGE Remote Sensing Manual (Warner, Nellis and Foody, 2009). Very fine spatial resolution images are ≤1 m, fine 1-10 m, moderate 10-250 m, and coarse >250 m.
- **Spatial scales**; Local (0-999 km2), Landscape (1000-9999 km2), Regional (10,000-99,999 km2) and National/Global (≥100,000 km2) (Milcu *et al.*, 2013).

4. Armed conflict:

- **Conflict intensity:** Minor, Intermediate, and War.
- **Type of conflict:** Interstate, Extra-State, Internationalized internal, and internal.
- **Direct causes:** Bombings, Military confrontations, and Landmines.
- I**ndirect causes:** Agriculture, Cattle ranching, Fires, Forced migration, Illegal crops, Mining, Non-forced migration (Colonization), and Logging.
- C**onsequences:** Abandonment of agricultural land, Deforestation, Land degradation, Land-use / Land-cover changes, Military infrastructure, Craters, Forestation, and Water pollution.

Appendix 4: Characteristics of worldwide case studies. (Source: Own table)

Reference	Country	Conflict	Time-lapse	Period	Scale (km2)	Satellite Imagery Sensor	Biome	Cause	Consequence	Multianalysis	Independent Variable
Abuelgasim et al., 1999	Kuwait	Gulf War (1991)	1989 - 1991	Pre, Post	Re 21,000	LS4-5	SD	Bo	LULCC	N.D.	N.D.
Al-Khudhairy et al., 2005	North Macedonia, Palestine	N.D.	N.D.	N.D.	Re	IKONOS	TBF, MV, SD	N.D.	N.D.	N.D.	N.D.
Armenteras et al., 2006	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	1985 - 2001	Pre, Con	Re 42,000	LS1-3, LS4-5, LS7	TR	Ag, CR, Lo	Df	MV, MT, MSa, MSp	Co, PC, PD, Po, Pv, CR, Ps, Bi
Armenteras et al., 2011	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	1985 - 2005	Con	Na 1,142,000	SPOT-5, ASTER, LS1-3 LS4-5, LS7	MF, TR, MnF	FM, IC	Df, Fo	MV, MT, MSa	IDP, Po, Pv, Ag, Df, IC, Ps, PA, RoD, DEM, Pr, Top, Cl, Dr, EnC
Armenteras et al., 2013	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	1990 - 2005	Pre, Con	Na 1,142,000	LS4-5, LS7	TR, MnF	NFM, IC, Ag, CR, Lo, Fi	Df	MV, MT, MSa	Po, Pv, Ag, CR, Df, Fi, IC, Mn, RoD, CC, Top
Armenteras et al., 2019	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2018	Post	Na 1,142,000	MODIS	N.D.	Fi	Df	MV	AF, Fi
Aung., 2021	Myanmar	Myanmar Internal Conflict (1948-Ongoing)	2012 - 2019	Pre, Con, Post	Re 36,769	Pl, LS4-5, LS8	MF, TR	FM, Fi	LULCC	MV, MT, MSa, MSt	IDP, Df, Fi, RoD, Ve
Ayana et al., 2016	Kenya, South Sudan, Ethiopia	Somali Civil War (1991-Ongoing) - South Sudanese Civil War (2013-2020)	1981 - 2006	Con	Na	MODIS, AVHRR	STR,SD, GS	MC	LULCC, AAL	MV, MT, MSa	Co, Ag, Ps, Pr, Cl
Barima et al., 2016	Cote d'Ivoire	First Ivorian Civil War (2002-2011)	1997 - 2015	Pre, Con, Post	La 1024	LS4-5, LS7, LS8	MF, TS	Ag	Df, LULCC	MT, MSa	Ag
Baumann et al., 2015	Armenia - Azerbajan	II Nagorno-Karabakh War (2020)	1987 - 2010	Pre, Con, Post	Re	GE-VHR, LS1-3, LS4-5	DS, MnF	Bo, MC, MI	LULCC, AAL	MT, MSa	N.D.
Beygi Heidarlou et al., 2020	Iran, Iraq	Iran-Iraq War (1980-1988)	1976 - 1998	Pre, Con, Post	La 1381.83	LS1-3, LS4-5	MV, DS	FM, NFM	LULCC	MV, MT, MSa	PC, Po, Pr
Bjorgo, 2000	Thailand	Cambodian–Vietnamese War (1978-1989)	1989	Con	Lo	KVR-1000	MF, TR	FM	LULCC	MV, MT	IDP, Po

Bolognesi et al., 2015	Somalia	Somali Civil War (1991-Ongoing)	2011 - 2013	Con	La 4700	WV2, GE-VHR	SD, GS	Lo	Df, LULCC	MSa	N.D.
Bromley, 2010	Sudan	War of Darfur / Land Cruiser War (2004-Ongoing)	2000 - 2004	Con	La, Re	MODIS	SD, GS, TS	Fi	LULCC	MV, MSc	Fi, PA, CC, Pr
Brown, 2010	Sudan	War of Darfur / Land Cruiser War (2004-Ongoing)	1981 - 2006	Pre, Con	N.D.	AVHRR	SD, GS, TS	N.D.	N.D.	N.D.	N.D.
Burgess et al., 2015	Sierra Leone	Sierra Leone Civil War (1991-2002)	1990 - 2000	Pre, Con, Post	Re 71,740	LS4-5, LS7	MF, TR	Bo, MC	Df	MV, MT, MSa	AF, TA
Butsic et al., 2015	Democratic Republic of Congo	I Congo War / Africa's I WW (1996–1997) - II Congo War / Great War of Africa, II African WW (1998-2003)	1990 - 2010	Con, Post	Na 2,345,409	GE-VHR, LS4-5, LS7	MF, TR	MC, MI, Mn	Df, Fo, LULCC, AAL	MV, MT, MSa	Co, Po, Df, Mn, PA, Ac, RoD, Pr, WS
Cabral and Costa, 2017	Senegal, Guinea Bissau	Casamance Conflict (1982-2014)	1999 - 2015	Post	Re	GE-VHR, LS4-5, LS7, LS8	TS, TR	NFM, Ag, Lo	Df, LULCC	MV, MT, MSa	Df, FD
Cabrera et al., 2020	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2012 - 2017	Con, Post	Na 1,142,000	CBERS, RE, Se, ASTER, LS7, LS8	TR, MnF	Mn, Ag, CR	Df, LULCC	MSa	N.D.
Chadid et al., 2015	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2002 - 2010	Con	Re	LS7	MF, MnF	IC	Df	MV, MT	Po, IC, Ps, Top
Clerici et al., 2020	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2013 - 2015 / 2016 - 2018	Con, Post	Na 1,142,000	LS8	DS, GS, TR, AT, MnF	MC	Df, Fo	MT, MSt	Df, PA
de Beurs and Henebry, 2008	Afghanistan	Afghanistan Conflict (1978–Ongoing)	1982 - 2003	Pre, Con	Re	MODIS, AVHRR	AD, XS, DS	N.D.	LULCC	MT, MSa	Pr, Dr
Eklund et al., 2017	Syria, Iraq	ISIS Syrian-Iraq Conflict (2000-Ongoing)	2000 - 2015	Con	Na	LS4-5, LS7, LS8, MODIS	MV, SD	MC	LULCC	MV, MT, MSa	AF, TA
Enaruvbe et al., 2019	Liberia	I Liberian Civil War (1989-1997) - II Liberian Civil War (1999-2003)	1986 - 2016	Pre, Con, Post	La 1639.57	LS4-5, LS7, LS8	TR	MC, FM, Mn, Ag	Df, Ds, LULCC	MV, MT, MSa, MSp	Ag, Df, Mn, Ps, FD
Fakhri and Gkanatsios, 2021	Iraq	ISIS - Iraq War (2014-2017)	2015 - 2019	Con, Post	Lo	Se, MODIS	SD	Bo	LULCC	MT, MSa	N.D.

Fergusson et al., 2014	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	1990 - 2010	Con	Re	N.D.	TR	MC	Df, Fo	MV, MT	Co, Po, Ag, Df, IC, Ac, DEM, Pr, Cl
Friedrich and Van Den Hoek, 2020	Uganda	South Sudanese Civil War (2013-2020)	2005 - 2018	Con, Post	Lo	Se, LS7, LS8	SD, GS	FM	LULCC	MV, MSa	IDP, Pr, Cl
Gheyle et al., 2018	Belgium	I World War (1914-1918)	1914 - 1918	Con, Post	La 2500	AP, ALS	TBF	Bo, Ml	Cr	MT, MSa	SH, FD
Gomez-Rodriguez et al., 2017	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	1986 - 2010	Con	Lo 935	LS7	MF, TR, MnF	Mn	Df, LULCC	MV, MT	Mn
Gonzalez-Gonzalez et al., 2021	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2013 - 2018 / 2030 - 2050	Post	Na 1,142,000	LS4-5, LS7, LS8, MODIS	STR, MF, GS, TS, SDF, TR, MnF	N.D.	Df	MV, MT, MSa	AF, Mn, PA, RoD, DEM, WS
Gorsevski, 2013	South Sudan	Second Sudanese Civil War (1983-2005)	2009 - 2011	Post	La 1032	SPOT-5	STR, GS, TS	FM	Df	MV, MT	PC, IDP, Fi, PA, Fa, Bi
Gorsevski, et al., 2012	South Sudan, Uganda	Second Sudanese Civil War (1983-2005)	1986 - 2001 / 2003 - 2010	Pre, Con, Post	La 8375	LS4-5, LS7, MODIS, AP	MF, TS, MnF	FM	Df, Fo, Ds, AAL	MV, MT, MSa, MSt	IDP, Po, PA, Pr, FD
Hagenlocher et al., 2012	South Sudan	Second Sudanese Civil War (1983-2005)	2002 - 2008	Pre, Con, Post	La	QB	GS	FM	Df, Ds, LULCC, Wa	MV, MT	IDP, PA, RoD
Hagenlocher et al., 2015	South Sudan	South Sudanese Civil War (2013-2020) - Second Sudanese Civil War (1983-2005)	2002 - 2008 / 2012 - 2013	Pre, Con, Post	La	GE-VHR	GS	FM	Df, Ds, LULCC, Wa	MV, MT	IDP, PA
Hagenlocher, 2011	Sudan	War of Darfur / Land Cruiser War (2004-Ongoing)	2002 - 2008	Con	Lo 64	QB	SD, GS, TS	FM	Df, LULCC	MV, MT	IDP, RoD, Pr
Hecht and Saatchi, 2007	El Salvador	Salvadoran Civil War (1979-1992)	1987 - 2002	Con, Post	Re 21,000	LS4-5, MODIS, AVHRR	TR	FM	Df	MV, MT, MSa	PC, PD, IDP, Ag
Hupy and Koehler, 2012	France, Vietnam	I WW (1914-1918) and Vietnam War / Second Indochina War (1955-1975)	1973 - 2000	Post	Lo 200, La 2700	LS1-3, AP	TBF, TR	Bo	LULCC, Cr	MT, MSa, MSt	SH, FD
Ingalls and Mansfield, 2017	Afghanistan	Afghan Civil War (1989–1992) - War in Afghanistan (2001–Ongoing)	2005 - 2009	Con	La	GE. LS4-5	XS, DS, AT	IC, Ag, CR	Dr, LULCC, AAL	MV, MSc, MSa	Go, Pv, Df, IC

Jahjah et al., 2007	Iraq	Iraq War (2003-2011)	1920 - 2005	Pre, Con, Post	Lo	QB, IKONOS, AP	SD	Bo, MI	LULCC	MT, MSa	N.D.
Knoth and Pebesma, 2017	Sudan	War of Darfur / Land Cruiser War (2004-Ongoing)	2004 - 2010	Con	Lo 105.26	GE, WV2, QB	GS	MC, FM	LULCC	MSa	N.D.
Kong et al., 2019	Cambodia	Cambodia Civil War (1968-1975) - Cambodian–Vietnamese War (1978-1989)	1976 - 2016	Post	La 3200	LS1-3, LS4-5	MF, TS	NFM, Ag	Df, LULCC	MV, MT, MSa	AS, PC, IDP, Po
Kranz et al., 2015	Sudan	War of Darfur / Land Cruiser War (2004-Ongoing)	2000 - 2010	Con	La 4800, Re 11,025 - 13,688	MODIS	GS, TS	FM, Ag	Df, Fo, LULCC, AAL	MV, MT, MSt	PD, IDP, Pr, Cl, Dr
Kwarteng, 1998	Kuwait	Gulf War (1991)	1987 - 1995	Pre, Con, Post	La	LS4-5	SD	Bo, MC	LULCC, Wa	N.D.	Mn
Leiterer et al., 2018	South Sudan	South Sudanese Civil War (2013-2020)	1999 - 2014	Pre, Con, Post	La	WV2, LS4-5, LS7, LS8	GS, TS	FM	Df, LULCC	MV, MT, MSa, MSt	IDP, Pr, Ve, FD
Levin et al., 2018	Arab Countries	Arab Spring	2012 - 2017	Con	Na	VIIRS	MV,SD	Bo, MC	AAL	MV, MT, MSt	Co, TA, AS, AA, Tou, Ex, NL, Fl
Liu et al., 2018	USA	US Civil War (1861-1865)	1867 - 2014	Con, Post	Lo 110	QB, SPOT-5, LS1-3, AP	TBF	Bo, MC	LULCC	MT, MSa	N.D.
Lodhi et al., 1998	Pakistan	Afghan Civil War (1989–1992)	1978 - 1993	Pre, Con	Lo 618	LS1-3, LS4-5	MnF	FM	Df	MV, MT, MSa, MSp	IDP, DEM
Loucks et al., 2009	Cambodia	Cambodian Civil War (1968-1975) - Cambodian–Vietnamese War (1978-1989)	1958 - 2002	Pre, Con, Post	Lo 50	LS7	MF, TR	Bo, MC	Df	MV, MT	AF, Go, Ex, Fa, FD
Lubin and Saleem, 2019	Syria	Syrian Civil Conflict (2011-Ongoing)	2011 - 2017	Con	La	SPOT-5, LS7, LS8	MV, SD	Bo, MC	LULCC	MT, MSa	N.D.
Marx and Loboda, 2013	Sudan	War of Darfur / Land Cruiser War (2004-Ongoing)	2000 - 2004	Con	La	LS7	SD, GS, TS	Fi	AAL	MSp	Fi
Mendoza, 2020	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2006 - 2009	Con, Post	Na 1,142,000	LS4-5, LS7	DS, GS, TR, MnF	MC, LM, FM, IC	Df, LULCC	MV, MSc, MT, MSa	AF, Co, TA, IDP, Po, Pv, Ag, IC, CE, AeS
Monroy and Armenteras, 2017	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2009 - 2014	Con	La 3927.94	LS7, LS8, AP	MF, SDF	Mn, Ag	LULCC	MV, MT, MSa, MSp	Ag, Df, IC, Mn

Murad and Pearse, 2018	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2000 - 2016	Con	Re	LS7, LS8	TR, MnF	IC, Ag, CR	Df, LULCC	MT, MSa, MSp	IC, PA, Pr
Murillo-Sandoval et al., 2020	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2010 - 2018	Con, Post	Na 124,846.3	LS4-5, LS7, LS8	MF, SDF, TR, MnF	MI, NFM, IC, Ag, CR, Lo	Df, Fo, LULCC	MV, MT, MSa, MSp	Po, Go, Df, PA
Murillo-Sandoval et al., 2021	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	1988 - 2018	Pre, Con, Post	Na 1,142,000	LS4-5, LS7, LS8	GS, TR, MnF	MC	Df, Fo, LULCC, AAL	MV, MT, MSa, MSp	Co
Note et al., 2018	Belgium	I World War (1914-1918)	1917 - 1918	Con, Post	Lo 142.5	AP	TBF	Bo	Cr	MV	SH, FD
Ordway, 2015	Rwanda	Rwandan Civil War (1986–2003)	1986 - 2011	Con, Post	Lo 487	GE-VHR, ASTER, LS4-5, LS7	MF, TR, MnF	FM, NFM, Ag, Lg	Df	MV, MT, MSa, MSt	Co, IDP, Df, PA, DEM
Pech and Lakes, 2017	Democratic Republic of Congo	I Congo War / Africa's I WW (1996–1997) - II Congo War / Great War of Africa, II African WW (1998-2003)	1986 - 2015	Pre, Con, Post	La	WV2, GE-VHR, LS4-5, LS7, LS8	TR	FM, NFM	LULCC	MV, MT, MSa, MSp	PC, Po, PA, DEM, FD
Prem et al., 2020	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2011 - 2017	Con, Post	Na 1,142,000	LS4-5, LS7	DS, GS, TR, MnF	MC, Ag, CR	Df	MV, MT, MSa, MSt	AF, Co, Po, Go, Df, PA
Qamer et al., 2012	Pakistan	Insurgency in Khyber Pakhtunkhwa / War in North-West Pakistan (2004-Ongoing)	2001 - 2009	Pre, Con, Post	La 4109	SPOT-5. ASTER. LS4-5, LS7	AT, MnF	FM, Ag, CR	Df, LULCC	MSa	N.D.
Rembold et al., 2013	Somalia	Somali Civil War (1991-Ongoing)	2006 - 2012	Con	Lo 32	WV2, QB, GE-VHR	SD, GS	Lo	Df	MT, MSa, MSt	N.D.
Sanchez-Cuervo and Aide, 2013	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2001 - 2010	Con	Na	QB, GE-VHR, MODIS	MF, GS, TS, TR, AT, MnF	MC, FM, IC, Ag, CR	Df, LULCC	MV, MSc, MT, MSa, MSt	AF, Co, PC, PD, IDP, Po, Pv, Ag, CR, IC, Mn, RiD, RoD, DEM, Top, Bi, EcR
Sanchez-Cuervo and Aide, 2013	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	2001 - 2010	Con	Na 1,142,000	QB, GE-VHR, MODIS	STR, MF, GS, TS, SDF, TR, MnF	MC, FM, IC, Ag	Df, Fo	MV, MT, MSa	AF, Co, PC, PD, IDP, Po, Pv, Ag, IC, PA, Ac, RiD, RoD, DEM, Pr, Cl, Bi, EcR
Sawalhah et al., 2018	Jordan	Syrian Civil Conflict (2011-Ongoing)	2013 - 2015	Con	Re 89,000	LS8	MV, XS, SD	FM	LULCC	MT	IDP
Schneibel et al., 2017	Angola	Angola War (1975-2002)	1989 - 2014	Con, Post	Re	LS4-5, LS7, LS8	GS, SDF	NFM, Ag	LULCC, AAL	MT, MSa	Ag, RoD

Schoenig et al., 2020	Colombia	Colombian Internal Conflict (1964-2016/Ongoing)	N.D.	Post	Na 1,142,000	N.D.	TR	NFM	Df	N.D.	N.D.
Sosnowski et al., 2016	South Sudan	South Sudanese Civil War (2013-2020) - Second Sudanese Civil War (1983-2005)	2000 - 2014	Con, Post	Re 23,000	MODIS	GS, SDF	FM	LULCC	N.D.	PA, Pr, WS
Spröhnle et al., 2016	Sudan	War of Darfur / Land Cruiser War (2004-Ongoing)	2003 - 2008	Con	La 1200	QB, IKONOS, SPOT-5	SD, GS, TS	FM, NFM, Lo	Df, Fo, Ds, LULCC	MV, MSc, MT, MSa, MSt, MSp	IDP, Po, Pr
Stevens et al., 2011	Nicaragua	Nicaraguan Revolution (1978-1990)	1978 - 1993	Pre, Con, Post	La 1600	LS1-3, LS4-5	TR	FM	DF	MV, MT, MSa, MSt	IDP, Df
Stichelbaut et al., 2016	Belgium	I World War (1914-1918)	1917 - 1918	Con	La 1560	AP, ALS	TBF	Bo	Cr	MT, MSa, MSt	SH
Suthakar and Bui, 2008	Sri Lanka	Sri Lankan Civil War (1983-2009)	1984 - 2004	Pre, Con, Post	La 1125.7	IRS, LS4-5	TS, TR	MC, MI, LM, FM, Lo	Df, LULCC	MV, MT, MSa, MSp	Po, Ag, DEM
Tian et al., 2011	Myanmar	Myanmar Internal Conflict (1948-Ongoing)	2005 - 2007	Con	Na 236,342	QB, IKONOS, ALOS, SPOT-5. ASTER	MF, TR	IC	Df, LULCC	MSa, MSp	IC, FD
Van et al., 2015	Vietnam	Vietnam War / Second Indochina War (1955-1975)	1953 - 2011	Pre, Con, Post	Lo 418.62	SPOT-5, LS1-3, AP	TR	Ag	Df, LULCC	MT, MSa	N.D.
van Etten et al., 2008	Türkiye	Kurdish–Turkish Conflict (1978–Ongoing)	1991 - 1994	Con	La 7600	LS4-5	TBF, MF, DS	Bo, MC	Dr, LULCC, AAL	MV, MT	Co, PC, Po, Ag, FD
Wales, 2020	Cambodia	Cambodia Civil War (1968-1975) - Cambodian–Vietnamese War (1978-1989)	1976 - 2002	Post	La	LS1-3, LS4-5, LS7	MF, TS, TR	NFM	Df, LULCC	MT, MSa, MSt	Df
Wilson and Wilson, 2013	Sierra Leone	Sierra Leone Civil War (1991-2002)	1986 - 2007	Pre, Con, Post	La 5397.5	LS4-5	MF	Ag	Df, LULCC	MV, MT	Po, Pv, Ed, Ag, CR
Witmer, 2008	Bosnia & Herzegovina	Bosnian War (1992-1995)	1990 - 2005	Pre, Con, Post	Re 13,887	QB, LS4-5, LS7, AVHRR	MV, MnF	Bo, LM, FM	LULCC, AAL	MV, MT, MSa, MSp	Ag, Ps

Abbreviations:

- ***Period:*** (**Con**) Conflict, (**Post**) Post-conflict, (**Pre**) Pre-conflict.
- ***Scale:*** (**La**) Landscape (1000-9999 km2), (**Lo**) Local (0-999 km2), (**Na**) National/Global (≥100,000 km2), (**Re**) Regional (10,000-99,999 km2).

- ***Satellite Imagery Sensor:*** (**ALOS**) Advanced Land Observation Satellite, (**ALS**) Lidar - Airborne Laser Scanning, (**AP**) Aerial Photo, (**ASTER**) Advanced Spaceborne Thermal Emission and Reflection Radiometer, (**AVHRR**) Advanced Very-High-Resolution Radiometer, (**CBERS**) China–Brazil Earth Resources Satellite, (**GE**) GeoEye, (**GE-VHR**) Google Earth Very High Resolution, (**IKONOS**), (**IRS**) IRS-1C LISS-III Indian Remote-Sensing Satellite, (**KVR-1000**) Kometa, (**LS1-3**) Landsat 1-3 MSS, (**LS4-5**) Landsat 4-5 TM, (**LS7**) Landsat 7 ETM+, (**LS8**) Landsat 8 OLI, (**MODIS**) Moderate Resolution Imaging Spectroradiometer, (**Pl**) Pleiades-1A, (**QB**) Quick Bird II, (**RE**) Rapid Eye, (**Se**) Sentinel 2, (**SPOT-5**) Satellite Pour l'Observation de la Terre, (**VIIRS**) Visible Infrared Imaging Radiometer Suite, (**WV2**) WorldView-2.
- ***Biome:*** (**AD**) Arid Desert, (**AT**) Alpine Tundra, (**DS**) Dry Steppe, (**GS**) Grass Savanna, (**MF**) Monsoon Forest / Dry Forest, (**MnF**) Montane Forest, (**MV**) Mediterranean Vegetation, (**SD**) Semiarid Desert, (**SDF**) Subtropical Dry Forest, (**STR**) Subtropical Rainforest, (**TBF**) Temperate Broadleaf Forest, (**TR**) Tropical Rainforest, (**TS**) Tree Savanna, (**XS**) Xeric Shrubland.
- ***Cause:*** (**Ag**) Agriculture, (**Bo**) Bombing, (**CR**) Cattle Ranching, (**Fi**) Fires, (**FM**) Forced Migration, (**IC**) Illegal Crops, (**LM**) Landmines, (**Lo**) Logging, (**MC**) Military Confrontation / Conflict Intensity, (**MI**) Military Infrastructure, (**Mn**) Mining, (**NFM**) Non-Forced Migration.
- ***Consequence:*** (**AAL**) Abandonment of Agricultural Lands, (**Cr**) Craters, (**Df**) Deforestation, (**Ds**) Desertification / Land Degradation, (**Fo**) Forestation, (**LULCC**) Land Use – Land Cover Changes, (**MI**) Military Infrastructure, (**Wa**) Water Pollution.
- ***Multianalysis:*** (**MSa**) Multi-satellite, (**MSc**) Multi-scale, (**MSp**) Multispectral, (**MSt**) Multi-spatial, (**MT**), Multi-temporal, (**MV**) Multivariate.
- ***Independent variables***: (**AA**) Airport Activity, (**Ac**) Accessibility / Ruggedness, (**AeS**) Aerial Spraying, (**AF**) Armed Forces Presence, (**Ag**) Agriculture Crops, (**AS**) Asylum Seekers, (**Bi**) Biome, (**CC**) Cloud Cover, (**CE**) Manual Coca Eradication, (**Cl**) Climate, (**Co**) Conflict Intensity / Fatalities, (**CR**) Cattle Ranching, (**DEM**) Digital Elevation Model, (**Df**) Deforestation / Fragmentation, (**Dr**) Drought, (**EC**) Energy Consumption, (**EcR**) Ecoregion, (**Ed**) Education, (**Ex**) Exportations, (**Fa**) Fauna, (**FD**) Field Data, (**Fi**) Fires, (**Fl**) Flickr Photos, (**Go**) Governance, (**IC**) Illegal Crops, (**IDP**), Internally Displaced Person Rate, (**Mn**) Mining / Oil, (**NL**) Night Lights, (**PA**) Protected Area Boundaries, (**PC**) Population Change, (**PD**) Population Density, (**Po**) Population Size, (**Pr**) Precipitation, (**Ps**) Pastures, (**Pv**) Poverty, (**RiD**) River Density, (**RoD**) Road Density, (**SH**) Shell Hole, (**TA**) Terrorist Attacks, (**Top**) Topography, (**Tou**) Tourist Arrivals, (**Ve**) Vegetation, (**WS**) Water Surfaces.
- **N.D.:** No Data

Appendix 5: Classification of the characteristics of Colombian case studies.

1. **Metadata:**

- **Time domain:** 2001-2021 (Studies from 2006-2021).
- **Conflict period domain**: High-intensity conflict stage (2001-2012), Negotiation (2013-2015), and Post-conflict (2016-2021).
- **Origin of the researchers**.

2. **Geographical domain**:

- **Administrative units**; 32 Colombian departments + Capital District.
- **Ecoregions**: Apure-Villavicencio, Caquetá Moist, Cauca Valley Montane, Chocó-Darién Moist, Cordillera Oriental, Guajira Xeric, Llanos, Magdalena Valley Dry, Magdalena-Urabá Moist, Northern Andean, Northern Páramo, Northwestern Andean, Sinú Valley Dry.
- **Natural regions**: Amazonas, Andes, Caribbean, Orinoquia, and Pacific.

3. **Satellite imagery:**

- **Sensor:** Aerial Photos, ASTER, CBERS-2B, Google Earth VHR, Landsat 1-3 MSS, Landsat 4-5 TM, Landsat 7 ETM+, Landsat 8 OLI, MODIS, QuickBird II, Radar Data, Rapid Eye, Sentinel 2, and SPOT-5.

- **Spatial resolution:** I used the category found in the SAGE Remote Sensing Manual (Warner, Nellis and Foody, 2009). Very fine spatial resolution images are ≤1 m, fine 1-10 m, moderate 10-250 m, and coarse >250 m.
- **Spatial scales:** Local (0-999 km2), Landscape (1000-9999 km2), Regional (10,000-99,999 km2) and National/Global (≥100,000 km2) (Milcu *et al.*, 2013).

4. **Armed conflict:**

- **Direct causes:** Bombings, Landmines and Military confrontations.
- **Indirect causes:** Agriculture, Cattle ranching, Fires, Forced migration, Illegal crops, Mining, Non-forced migration (Colonization), and Logging.
- **Consequences:** Abandonment of agricultural land, Deforestation, Land degradation, Land-use / Land-cover changes, Military infrastructure, Craters, Forestation, and Water pollution.
- **Belligerent forces:** the main armed groups involved in the Colombian armed conflict; National Army, FARC, ELN, and AUC–Paramilitaries.

Appendix 6: Characteristics of Colombian case studies. (Source: Own table)

Reference	Time-lapse	Period	Scale (km2)	Satellite Imagery Sensor	Region	Ecoregion	Departments	Cause	Consequence	Belligerent Force
Armenteras et al., 2006	1985 - 2001	Pre, Con	Re 42,000	LS1-3, LS4-5, LS7	Am	CM, CO	AMA, CAQ, GUA, GUV, MET, PUT, VAU, VID	Ag, CR, Lo	Df	N.D.
Armenteras et al., 2011	1985 - 2005	Con	Na 1,142,000	SPOT-5, ASTER, LS1-3 LS4-5, LS7	An	MUM, CVM, NWA, CO, NA, NP, AV, MVD	ANT, BOG, BOY, CAL, CAU, CUN, HUI, NSA, NAR, QUI, RIS, SAN, TOL, VAC	FM, IC	Df, Fo	N.D.
Armenteras et al., 2013	1990 - 2005	Pre, Con	Na 1,142,000	LS4-5, LS7	Am, Ca, Or, Pa	CM, MUM, ChDM, NWA, CO, AV, SVD, GX, LI	AMA, ANT, ARA, ATL, BOL, CAQ, CAS, CAU, CES, CHO, COR, GUA, GUV, LAG, MAG, MET, NAR, PUT, SAN, SUC, VAC, VAU, VID	NFM, IC, Ag, CR, Lo, Fi	Df	N.D.
Armenteras et al., 2019	2018	Post	Na 1,142,000	MODIS	Am, An	CM, CO, NA, MVD	AMA, CAQ, GUA, GUV, HUI, MET, NAR, PUT, VAU	Fi	Df	FARC, AUC
Cabrera et al., 2020	2012 - 2017	Con, Post	Na 1,142,000	CBERS, RE, Se, ASTER, LS7, LS8	All	All	All	Mn, Ag, CR	Df, LULCC	N.D.
Chadid et al., 2015	2002 - 2010	Con	Re	LS7	An, Ca	MUM, NA	ANT, BOL, COR, SUC	IC	Df	N.D.

Clerici et al., 2020	2013 - 2015 / 2016 - 2018	Con, Post	Na 1,142,000	LS8	All	CM, MUM, ChDM, CVM, NWA, CO, NA, NP, LI	AMA, ANT, BOG, BOY, CAL, CAQ, CAU, CHO, COR, CUN, GUA, GUV, HUI, LAG, MAG, MET, NAR, PUT, RIS, SAN, TOL, VAC, VAU, VID	MC	Df, Fo	FARC, AUC
Fergusson et al., 2014	1990 - 2010	Con	Re	N.D.	Ca	MUM, NWA	ANT, COR	MC	Df, Fo	AUC
Gomez-Rodriguez et al., 2017	1986 - 2010	Con	Lo 935	LS7	An, Ca	MUM, NA	ANT	Mn	Df, LULCC	N.D.
Gonzalez-Gonzalez et al., 2021	2013 - 2018 / 2030 - 2050	Post	Na 1,142,000	LS4-5, LS7, LS8, MODIS	All	All	All	N.D.	Df	FARC
Mendoza, 2020	2006 - 2009	Con, Post	Na 1,142,000	LS4-5, LS7	All	All	All	MC, LM, FM, IC	Df, LULCC	N.D.
Monroy and Armenteras, 2017	2009 - 2014	Con	La 3927.94	LS7, LS8, AP	An, Ca	MUM, NA	ANT	Mn, Ag	LULCC	N.D.
Murad and Pearse, 2018	2000 - 2016	Con	Re	LS7, LS8	Am	CM, CO	CAQ, PUT	IC, Ag, CR	Df, LULCC	N.D.
Murillo-Sandoval et al., 2020	2010 - 2018	Con, Post	Na 124,846.3	LS4-5, LS7, LS8	Am, An	CM, CO, NA, AV	CAQ, GUV, MET, PUT	MI, NFM, IC, Ag, CR, Lo	Df, Fo, LULCC	National Army, FARC
Murillo-Sandoval et al., 2021	1988 - 2018	Pre, Con, Post	Na 1,142,000	LS4-5, LS7, LS8	Am	CM, CO, NA	CAQ, GUV, MET, PUT	MC	Df, Fo, LULCC, AAL	FARC
Prem et al., 2020	2011 - 2017	Con, Post	Na 1,142,000	LS4-5, LS7	All	All	All	MC, Ag, CR	Df	FARC, ELN, AUC
Sanchez-Cuervo and Aide, 2013	2001 - 2010	Con	Na	QB, GE-VHR, MODIS	All	All	All	MC, FM, IC, Ag, CR	Df, LULCC	FARC, AUC
Sanchez-Cuervo and Aide, 2013	2001 - 2010	Con	Na 1,142,000	QB, GE-VHR, MODIS	All	MUM, ChDM, CVM, NWA, NA, AV, MVD, SVD, GX, LI	ANT, ARA, ATL, BOG, BOL, BOY, CAL, CAQ, COR, CUN, HUI, NAR, QUI, RIS, SAN, TOL	MC, FM, IC, Ag	Df, Fo	AUC
Schoenig et al., 2020	N.D.	Post	Na 1,142,000	N.D.	All	All	All	NFM	Df	N.D.

Abbreviations:

- ***Period:*** (**Con**) Conflict, (**Post**) Post-conflict, (**Pre**) Pre-conflict.
- ***Scale:*** (**La**) Landscape (1000-9999 km2), (**Lo**) Local (0-999 km2), (**Na**) National/Global (≥100,000 km2), (**Re**) Regional (10,000-99,999 km2).
- ***Satellite Imagery Sensor:*** (**ALOS**) Advanced Land Observation Satellite, (**ALS**) Lidar - Airborne Laser Scanning, (**AP**) Aerial Photo, (**ASTER**) Advanced Spaceborne Thermal Emission and Reflection Radiometer, (**AVHRR**) Advanced Very-High-Resolution Radiometer, (**CBERS**) China–Brazil Earth Resources Satellite, (**GE**) GeoEye, (**GE-VHR**) Google Earth Very High Resolution, (**IKONOS**), (**IRS**) IRS-1C LISS-III Indian Remote-Sensing Satellite, (**KVR-1000**) Kometa, (**LS1-3**) Landsat 1-3 MSS, (**LS4-5**) Landsat 4-5 TM, (**LS7**) Landsat 7 ETM+, (**LS8**) Landsat 8 OLI, (**MODIS**) Moderate Resolution Imaging Spectroradiometer, (**Pl**) Pleiades-1A, (**QB**) Quick Bird II, (**RE**) Rapid Eye, (**Se**) Sentinel 2, (**SPOT-5**) Satellite Pour l'Observation de la Terre, (**VIIRS**) Visible Infrared Imaging Radiometer Suite, (**WV2**) WorldView-2.
- ***Regions:*** (**Am**) Amazonas, (**An**) Andes, (**Ca**) Caribbean, (**Or**) Orinoquia, (**Pa**) Pacific.
- ***Ecoregion:*** (**AV**) Apure-Villavicencio, (**ChDM**) Chocó-Darién Moist, (**CM**) Caquetá Moist, (**CO**) Cordillera Oriental, (**CVM**) Cauca Valley Montane, (**GX**) Guajira Xeric, (**Ll**) Llanos, (**MUM**) Mag-Urabá Moist, (**MVD**) Magdalena Valley Dry, (**NA**) Northern Andean, (**NP**) Northern Páramo, (**NWA**) Northwestern Andean, (**SVD**) Sinú Valley Dry.
- ***Departments:*** (**AMA**) Amazonas, (**ANT**) Antioquia, (**ARA**) Arauca, (**ATL**) Atlántico, (**BOL**) Bolívar, (**BOY**) Boyacá, (**CAL**) Caldas, (**CAQ**) Caquetá, (**CAS**) Casanare, (**CAU**) Cauca, (**CES**) Cesar, (**CHO**) Chocó, (**COR**) Córdoba, (**CUN**) Cundinamarca, (**GUA**) Guainía, (**GUV**) Guaviare, (**HUI**) Huila, (**LAG**) La Guajira, (**MAG**) Magdalena, (**MET**) Meta, (**NAR**) Nariño, (**NSA**) Norte de Santander, (**PUT**) Putumayo, (**QUI**) Quindío, (**RIS**) Risaralda, (**SAN**) Santander, (**SUC**) Sucre, (**TOL**) Tolima, (**VAC**) Valle del Cauca, (**VAU**) Vaupés, (**VID**) Vichada.
- ***Cause:*** (**Ag**) Agriculture, (**Bo**) Bombing, (**CR**) Cattle Ranching, (**Fi**) Fires, (**FM**) Forced Migration, (**IC**) Illegal Crops, (**LM**) Landmines, (**Lo**) Logging, (**MC**) Military Confrontation / Conflict Intensity, (**MI**) Military Infrastructure, (**Mn**) Mining, (**NFM**) Non-Forced Migration.
- ***Consequence:*** (**AAL**) Abandonment of Agricultural Lands, (**Cr**) Craters, (**Df**) Deforestation, (**Ds**) Desertification / Land Degradation, (**Fo**) Forestation, (**LULCC**) Land Use – Land Cover Changes, (**MI**) Military Infrastructure, (**Wa**) Water Pollution.
- ***Belligerents:*** (**AUC**) Autodefensas Unidas de Colombia, (**ELN**) Ejército de Liberación Nacional, (**FARC**) Fuerzas Armadas Revolucionarias de Colombia, (**Army**) National Army.
- **N.D.**: No Data.

Appendix 7: Independent variables units. (Source: Own table)

Category	Variable	Units	Spatial Resolution	Description	Source
01. Armed Conflict	**Armed Forces Presence / Acts of War / Combats / Clashes**	No. of armed actions, war actions, combats or confrontations / year	Georeferenced or aggregated to municipality, year	The number of armed actions and confrontations in which the belligerents were involved	OMC-CNMH, 2020; OPPDHDIH, 2011; UARIV, 2020
	Conflict Intensity / Fatalities	No. of violent fatalities / 1000 inhabitants or per year	Municipality/Regional level, year	The number of fatalities resulting from armed confrontations	ACLED-UCDP, 2019; GDELT, 2020; OMC-CNMH, 2020
	Landmines	No. of landmines found / year	Municipality/Regional level, year	The number of antipersonnel mines activated of unexploded, unexploded ammunition, and improvised explosive device	OMC-CNMH, 2020; UARIV, 2020
	Terrorist Attacks / Harassment / Attacks Against the Population	No. of attacks / year	Municipality/Regional level, year - Spatially explicit coordinates.	The number of terrorist attacks in which the belligerents were involved	OMC-CNMH, 2020; OPPDHDIH, 2011; START-GTD, 2017; UARIV, 2020; UCDP, 2019
02. Demographic	**Internally Displaced Person**	Index of displaced people / year	Georeferenced or aggregated to department level, year	The number of displaced people registered	RUV, 2016; SIPOD, 2020; UARIV, 2020; UNHCR, 2020
	Population	No. of inhabitants / year	Municipality/Regional level, year	Total population registered	DANE, 2020; SDP, 2015
	Population Change	No. of births / deaths / year	Municipality/Regional level, year	The number of births / number of deaths	DANE, 2020

	Population Density	No. of inhabitants by area / year	Municipality/Regional level, year	The density of individuals in a specific area	DANE, 2020
	Population Projection	No. of inhabitants projected to the future / year	Municipality/Regional level, year	The number of total inhabitants projected until 2035	SDP, 2020
	Reinserted Guerrilleros	No. of reinserted guerrilleros / year	Regional level, year	The number of people who decides to voluntarily leave an illegal armed group to which he belongs, to turn himself into state authorities and rejoin civilian life, putting aside violence and assuming the commitment to live in peace	UARIV, 2020
03. Socio-economic	Governance / State Presence Index	Average number of public offices of in each municipality	Municipality level, year	Exercise of authority and control from the government that permits to diverse stakeholders, be able to balance interests and needs	Acemoglu et al., 2015
	Poverty	No. of inhabitants / Municipality-Region	Municipality/Regional level, year	Percentage of the population with a household income per capita below the poverty line	DANE, 2020
	Unsatisfied Basic Needs	% of inhabitants / Municipality-Region	Municipality/Regional level, year	Minimum household conditions, access to sanitary services, access to primary education and minimum household economic capacity as basic needs	DANE, 2020
04. Land Use	Agriculture Crops	ha / year	Municipality level, year	Number of hectares of cultivated area, combining permanent and transitional crops	SIGOT-IGAC, 2018
	Cattle Ranching	Head of cattle / year	Municipality level, year	The number of head of cattle	SIGOT-IGAC, 2018
	Deforestation / Fragmentation	Percentage ha / km2	30m / Municipality level, year	ha of primary forest loss as percentage of the total area of the municipality	SIGOT-IGAC, 2018, IDEAM, 2020
	Illegal Crops	ha	10 m / Municipality level, year	Number of hectares of coca crops (*Erythroxylum coca*)	UNDOC. 2006
	Mining	kg	Municipality level, year	Total gold and silver production	SIGOT-IGAC, 2018
	Pastures	ha	Municipality level, year	Total change in pasture area	SIGOT-IGAC, 2018, IDEAM, 2020
	Protected Area	ha	1: 100,000	Area of each municipality under special management as either national protected area or indigenous reserve	SIGOT-IGAC, 2018; WDPA-IUCN, 2020
05. Infrastructure	Accessibility / Ruggedness	km / ha	1: 100.000 Georeferenced / Municipality level, year	Four types of accessibility variables were included: density of rivers, paved roads, unpaved roads, and dirt roads.	SIGOT-IGAC, 2018
	River Density	km / ha	Municipality level, year	Density of rivers in each municipality	SIGOT-IGAC, 2018
	Road Density	km / ha	Municipality level, year	Density of roads in each municipality	SIGOT-IGAC, 2018
06. Physical Environment	Climate	Degrees Celsius	Municipality	Standard deviation of mean monthly, annual and mean temperature	IDEAM, 2020
	Cloud Cover	km2	Monthly	Yearly cloud fluctuations in the study area	IDEAM, 2020
	Droughts	Unit less	Municipality level	Index of water scarcity in a dry year	IDEAM, 2020
	Fires	No. of cases / month	Regional level, by intensity (0-1000), monthly and by year	Number of fire hotpots detected	FIRMS 2012, IDIGER, 2020, IDIGER, 2020
	Precipitation	Yearly average by mm3	1 km2	Mean annual precipitation	IDEAM, 2020; WorldClim 2005
	Slopes	Degrees	90 m	Average maximum slope for each	SIGOT-IGAC, 2018

				municipality	
	Topography / DEM	m.a.s.l	90 m	Altitude above sea level	SIGOT-IGAC, 2018
07. Biodiversity	**Biome / Ecosystem**	Units	Defined by altitude, precipitation and temperature	Large geographic units containing a distinct assemblage of natural communities and species	IDEAM:, 2020; Olson et al, 2011; SSDE & ILSA, 2012; WWF, 2019
	Ecoregion	Units	Defined by altitude, precipitation and temperature	Medium geographic units containing a distinct assemblage of natural communities and species	Olson et al, 2011; Sanchez-Cuervo and Aide 2013; WWF, 2019
08. Unclassified	**Aerial Spraying**	Ha	Municipality level	Measured the number of hectares of coca crops sprayed with glyphosate herbicide	UNODC 2020
	Energy Consumption	Kw/h	Municipality level	Municipality energy consumption	DNP, 2008; SUI, 2008
	Manual Coca Eradication	Ha	Municipality level	Number of hectares that have been eradicated by hand	UNODC 2020

Abbreviations:

ACLED-UCDP: Armed Conflict Location and Event Data and Uppsala Conflict Data Program datasets http://ucdp.uu.se/downloads/
DANE: National Administrative Department of Statistics (Departamento Administrativo Nacional de Estadistica)
DNP: National Planning Department of Colombia (Departamento Nacional de Planeación)
FIRMS: Fire Information for Resource Management System
GDELT: The Global Database of Events, Language, and Tone Project, http://gdeltproject.org/
HUMBOLDT: Alexander von Humboldt Biological Resources Research Institute
IDEAM: Institute of Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM: Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia)
IDIGER: District Institute of Risk Management and Climate Change (Instituto Distrital de Gestión de Riesgo y Cambio Climatico)
OMC-CNMH: Memory and Conflict Observatory – National Center of Historic Memory (Observatorio de Memoria y Conflicto - Centro Nacional de Memoria Historica)
OPPDHDIH: Observatory of the Presidential Program on Human Rights and International Humanitarian Law (Observatorio del Programa Presidencial de Derechos Humanos y Derecho Internacional Humanitario)
RUV: Unique Registry of Victims (Registro Único de Víctimas) http://rni.unidadvictimas.gov.co/ruv.
SDP: District Planning Secretary (Secretaria Distrital de Planeación)
SIGOT-IGAC: Geographic Information System for Planning and Territorial Development - Agustin Codazzi Geographic Institute (Sistema de Información Geográfica para la Planeación y el Ordenamiento Territorial Nacional – Instituto Geográfico Agustín Codazzi)
SIPOD: Information System for the Displaced Population - Presidential Agency for Social Action and International Cooperation (Sistema de Información para la Población Desplazada - Agencia Presidencial para la Acción Social y la Cooperación Internacional) https://prosperidadsocial.gov.co/
SSDE-ILSA: Secretaría Distrital de Desarrollo Económico - Instituto Latinoamericano de Servicios Legales Alternativos
START-GTD: National Consortium for the Study of Terrorism and Responses to Terrorism. Global Terrorism Database
UARIV: Unit for Comprehensive Attention and Reparation to Victims (Unidad para la Atención y Reparación Integral a las Víctimas)
UNDOC: United Nations Office on Drugs and Crime
UNHCR: United Nations High Commissioner for Refugees Population Statistics Reference Database http://popstats.unhcr.org/en/overview
WDPA-IUCN: World Database on Protected Areas of International Union for Conservation of Nature
WorldClim: Global climate and weather data https://www.worldclim.org/data/index.html

Appendix 8: Survey used in the study of locals perceptions in the Sumapaz Páramo area, Colombia. (English version, original in Spanish)

ASSESSMENT OF ARMED CONFLICT – LANDSCAPE RELATION PERCEPTION IN SUMAPAZ

Local Communities

Survey place ____________________________________

- *Please fill below here* - - - - - - - - -- - - - - - - - - - - - - - - -

Date_____________
Age (-18) (18-30) (31-45) (46-60) (+60) _______________
Gender Female ( ) Male ( ) Non Binary ( )
Education Level: None ( ) Preschool ( ) Primary School ( ) High School ( ) Professional ( )
Technician ( )
Other: _________________________
Occupation: Agriculture ( ), Services and commerce ( ), State ( ), Transport ( ), Education ( ), Health ( ),
Home ( ), Other: _________________
Place of birth __________________ **Department** ___________________
Place where you live _____________ **Time living there (years):** _____________
Do you belong to any social union o local community?
Yes ____ No____
Which one? _____________________________

Landscape definition: *It is the space where the natural environment is interrelated with the human being (natural environment), in the case of this survey; the Sumapaz Páramo. It is defined within a physical space, could be natural, rural or urban, where all the physical and emotional elements that compose it interact with each other. It is characterized by containing the following elements: climate, soils, covers, minerals, vegetation, relief (mountains, plains or depressions), rivers, lakes, etc.*

1a. Does the Sumapaz Páramo give benefits to the people who live nearby?
Yes ____ No ____
1b. Which benefits does the Sumapaz Páramo offer you? *You can mark more than one benefit.*
- Air purification ( )
- Climatic regulation ( )
- Flood mitigation ( )
- Landslide mitigation ( )
- Biodiversity ( )
- Water purification and supply ( )
- Economic support ( )
- Scenic beauty / Landscape enjoyment ( )
- Recreation/ Ecotourism ( )
- Spiritual and/or religious ( )
- Other: _______________________________

1c. Which are the most important benefits for you?
1: ____
2: ____
3: ____

2a. What human activities do you identify as causing changes in the landscape at the Sumapaz Páramo or to the wellbeing of people who lives there and when they happened? *Mark with X in which period, with two Xs if it is in both periods, or leave blank if neither.*

	Conflict Period (2000-2016)	*Post-agreement (2016-2021)*
- Bombing	( )	( )

- Direct Military Confrontation	( )	( )
- Landmines	( )	( )
- Forced Migration	( )	( )
- Non Forced Migration	( )	( )
- Mining	( )	( )
- Agriculture	( )	( )
- Cattle Ranching	( )	( )
- Timber / Selective felling	( )	( )
- Roads Construction	( )	( )
- Man-made fires	( )	( )
- Litter, debris and liquid pouring	( )	( )
- Military Infrastructure *(bases / camps / trenches)*	( )	( )
- Other: ______________________	( )	( )

2b. Which of these problems (causes) affect you most?

1: ____

2: ____

3: ____

3a. What consequences do you identify as changes in the landscape of the Sumapaz Páramo and when they happened? *Mark with X in which period, with two Xs if it is in both periods, or leave blank if neither.*

	Conflict Period (2000-2016)	*Post-agreement (2016-2021)*
- Deforestation	( )	( )
- Forestation / Vegetation growth	( )	( )
- Desertification / Land Degradation	( )	( )
- Land Use/Cover Changes	( )	( )
- Mine craters or trenches	( )	( )
- Abandonment of agricultural lands	( )	( )
- Extension and increase of farmland	( )	( )
- Extension and increase of land for livestock	( )	( )
- Pollution and decrease in bodies of water	( )	( )
- Other: _______________________	( )	( )

3b. Which of these consequences affect you most?

1: ____

2: ____

3: ____

4. In a scale of 1 to 5 (*1 very bad; 5 very good*) what do you consider is the current state of the nature and the landscape at Sumapaz Páramo? ________

Why?

____

____

____

5. In a scale of 1 to 5 (*1 not responsible at all; 5 completely responsible*). How much do you consider that the following groups have affected the landscape during the armed conflict and after the peace agreement? *Write 1 if is not responsible at all and 5 if is completely responsible for affecting the landscape for each period.*

	Conflict Period (2000-2016)	*Post-agreement (2016-2021)*
- FARC	( )	
- National Army	( )	( )
- National / Local Government	( )	( )
- Large landowners	( )	( )
- Local communities	( )	( )

- National Natural Parks Board	( )	( )
- Other, which? ________________	( )	( )

6. In a scale of 1 to 5 (*1 not at all; 5 very helpful)*. How much do you think that the following groups have helped to conserve the landscape of the Sumapaz Páramo? *Write 1 if has not been helpful at all and 5 if has been completely helpful to conserve the landscape for each period.*

- FARC	( )
- National Army	( )
- National / Local Government	( )
- Large landowners	( )
- Local communities	( )
- National Natural Parks Board	( )
- Other, which? ________________	( )

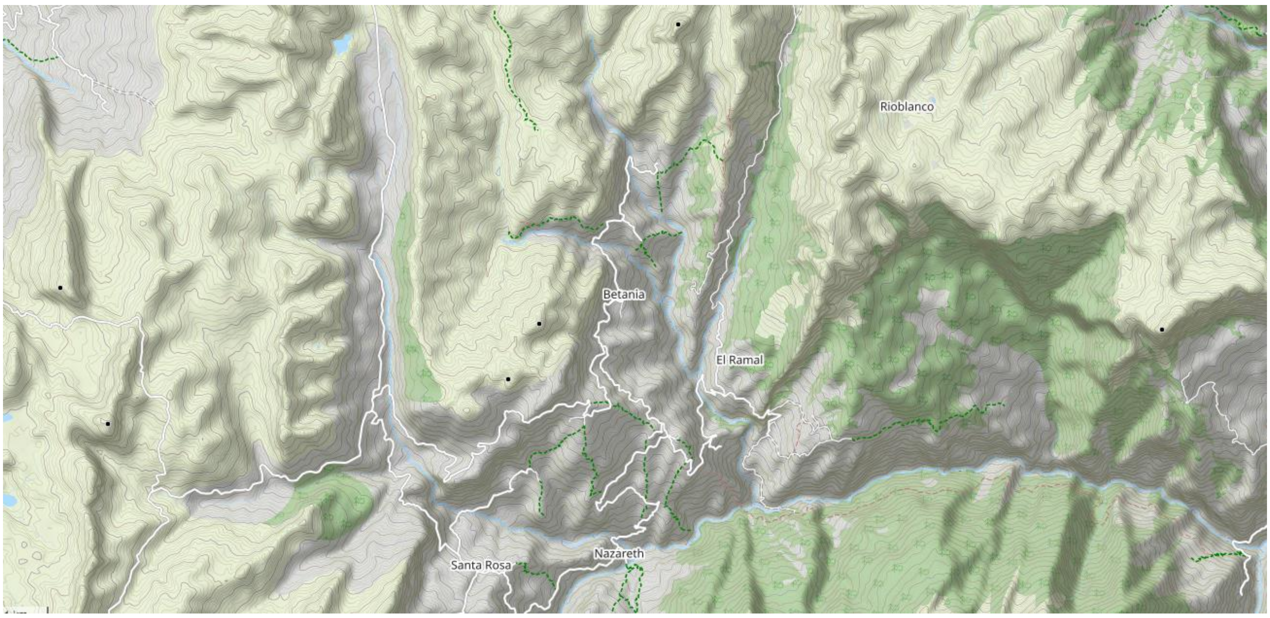
7. ¿ Do you consider that the environment and the landscape of the páramo is currently better preserved compared to the period of the armed conflict (2000-2016)? *Mark with X in which period it is best preserved.*

- Better preserved during the conflict	( )
- Same conditions / No changes	( )
- Better preserved since the post-agreement	( )

8. Do you consider that in relation to the armed conflict, the nature and landscape of the páramo have been… *Mark with X in which period, or two X if it is in both periods. You can mark more than one option for each period.*

	Conflict Period (2000-2016)	*Post-agreement (2016-2021)*
- **Victim** *(Less preserved during and/or after the conflict)*	( )	( )
- **Spoil of war** *(The environment have been a military objective)*	( )	( )
- **Scenario** *(Only as an area where the conflict occurred directly)*	( )	( )
- **Beneficiary** *(Better preserved during and/or after the conflict)*	( )	( )

9. Can you identify on the following map places where changes have occurred in the landscape or where are representative points and landmarks on the landscape? (Lakes, rivers, mountains, hills, sacred places, crops, villages, forests, etc.)



10. Please, describe the relation between landscape and conflict at the páramo by your own words. Free space.

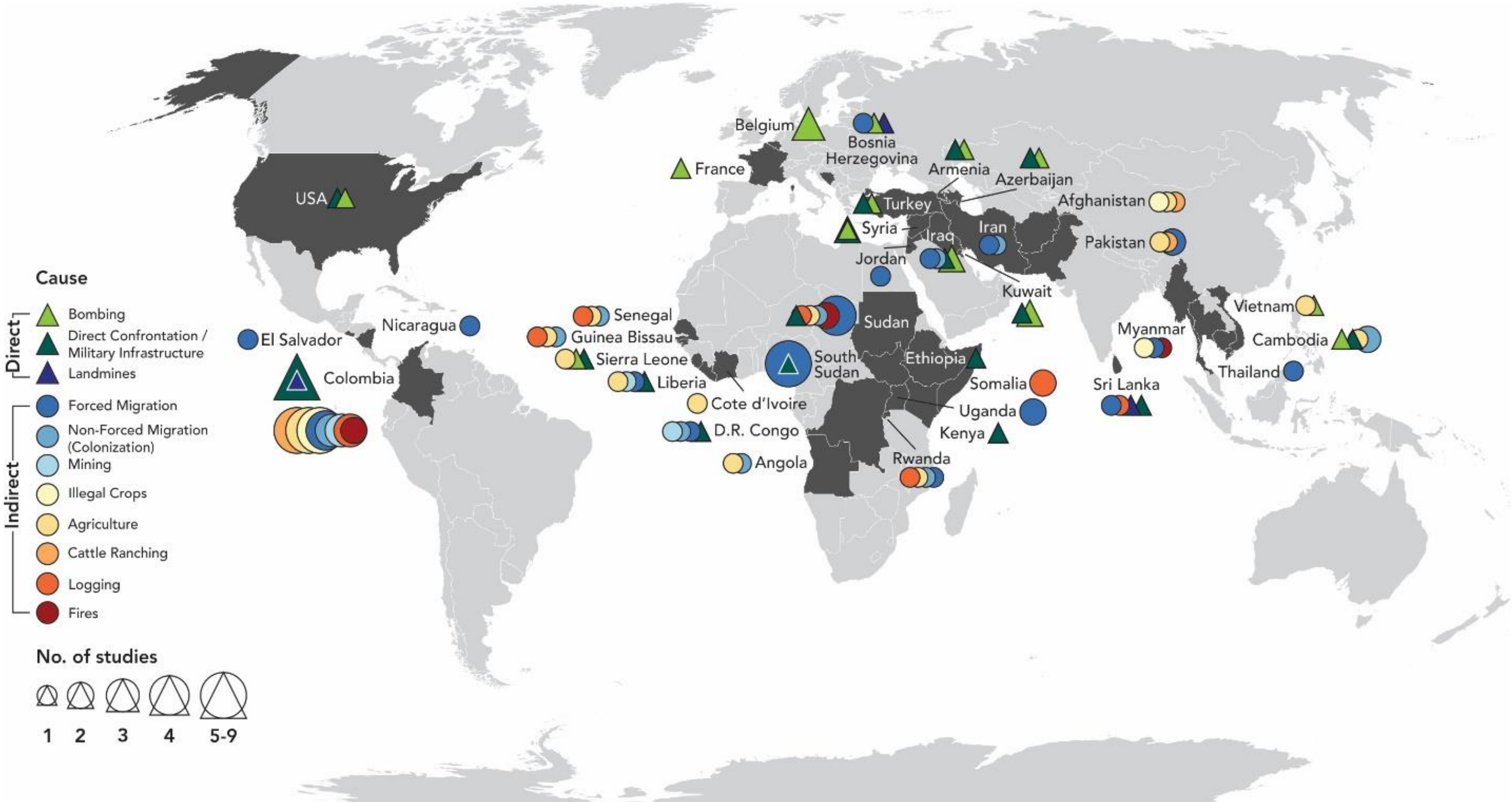
Appendix 9: Characteristics of the studied Armed Conflicts. (Source: Own figure)

Armed Conflict	Country	Type of conflict				Intensity			Reference
		Interstate	Extra state	Internationalized internal	Internal	Minor	Intermediate	War	
Afghan Civil War (1989–1992)	AFG, PAK				X	X			Lodhi et al., 1998; Ingalls and Mansfield, 2017;
Afghanistan War (2001–Ongoing)	AFG	X		X				X	de Beurs and Henebry, 2008; Ingalls and Mansfield, 2017;
Angola War (1975-2002)	AGO			X			X		Schneibel et al., 2017
Arab Spring	ARE, BHR, DZA, EGY, IRQ, JOR, KWT, LBN, LBY, MAR, OMN, PSE, QAT, SAU, SDN, SYR, TUN, YEM			X	X	X	X		Levin et al., 2018
Bosnian War (1992-1995)	BIH	X						X	Witmer, 2008
Cambodia Civil War (1968-1975)	KHM	X		X				X	Kong et al., 2019; Loucks et al., 2009; Wales, 2020
Cambodian–Vietnamese War (1978-1989)	KHM, THA	X					X	X	Bjorgo, 2000; Kong et al., 2019; Loucks et al., 2009; Wales, 2020
Casamance conflict (1982-2014)	GNB, SEN				X	X			Cabral and Costa, 2017
Colombian Internal Conflict (1964-2016/Ongoing)	COL				X	X			Armenteras et al., 2006; Armenteras et al., 2011; Armenteras et al., 2013; Armenteras et al., 2019; Cabrera et al., 2020; Chadid et al., 2015; Clerici et al., 2020; Fergusson et al., 2014; Gomez-Rodriguez et al., 2017; Gonzalez-Gonzalez et al., 2021; Mendoza, 2020; Monroy and Armenteras, 2017; Murad and Pearse, 2018; Murillo-Sandoval et al., 2020; Murillo-Sandoval et al., 2021; Prem et al., 2020; Sanchez-Cuervo and Aide, 2013 (a); Sanchez-Cuervo and Aide, 2013 (b); Schoenig et al., 2020
First Ivorian Civil War (2002-2011)	CIV			X			X		Barima et al., 2016
Gulf War (1991)	KWT	X						X	Abuelgasim et al., 1999; Kwarteng, 1998
I Congo War / Africa's I WW (1996–1997)	COD	X						X	Butsic et al., 2015; Pech and Lakes, 2017;
I Liberian Civil War (1989-1997)	LBR				X		X		Enaruvbe et al., 2019
I World War (1914-1918)	BEL, FRA	X						X	Gheyle et al., 2018; Hupy and Koehler, 2012; Note et al., 2018

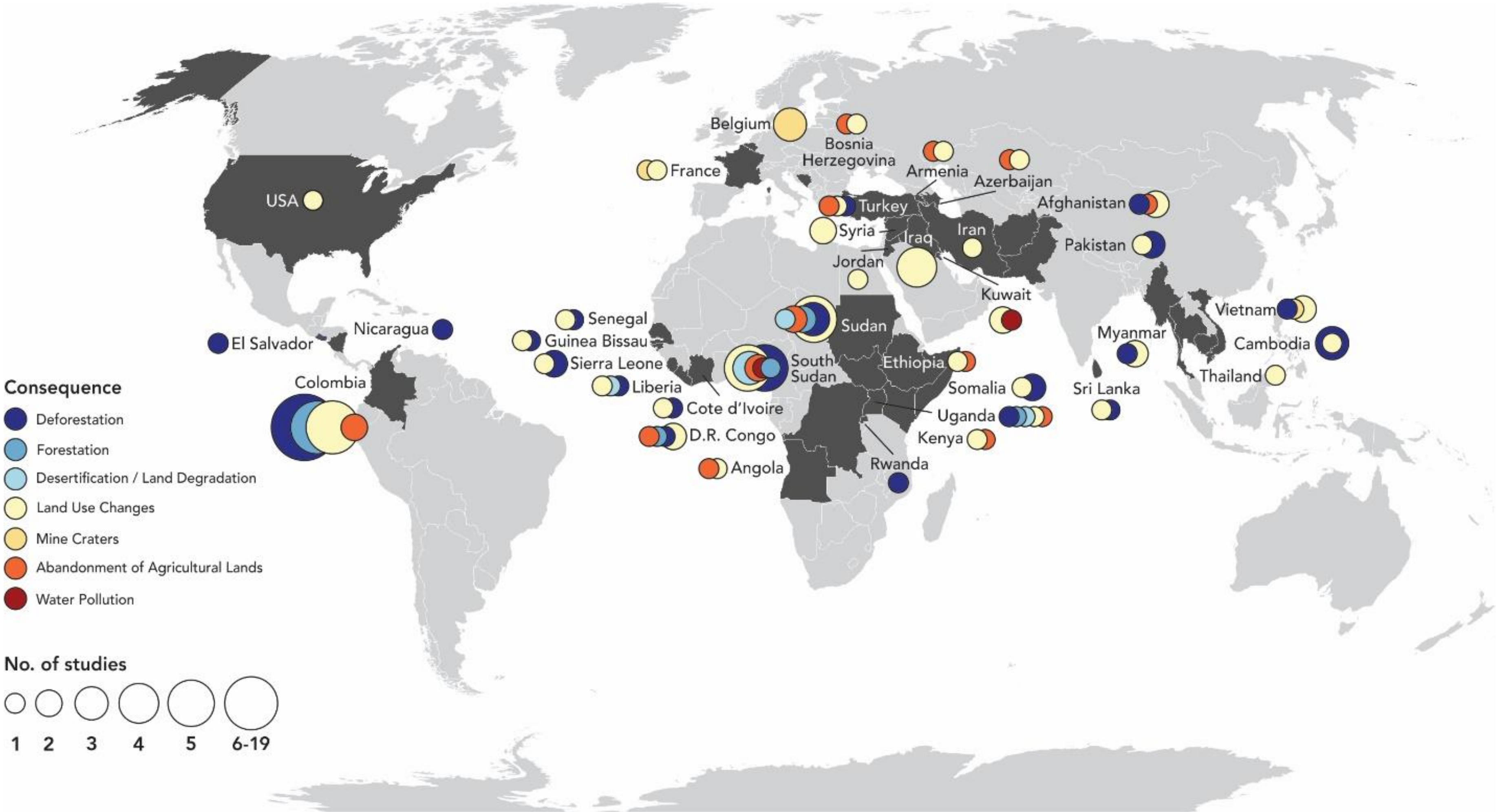
II Congo War / Great War of Africa, II African WW (1998-2003)	COD	X						X	Butsic et al., 2015; Pech and Lakes, 2017;
II Liberian Civil War (1999-2003)	LBR				X		X		Enaruvbe et al., 2019
II Nagorno-Karabakh war (2020)	ARM, AZE	X						X	Baumann et al., 2015
II Sudanese Civil War (1983-2005)	SSD, UGA			X			X		Gorsevski, et al., 2012; Gorsevski, 2013; Hagenlocher et al., 2012; Hagenlocher et al., 2015; Sosnowski et al., 2016
Insurgency in Khyber Pakhtunkhwa / War in North-West Pakistan (2004-Ongoing)	PAK				X		X		Qamer et al., 2012
Internal conflict in Myanmar (1948-Ongoing)	MMR				X	X	X		Aung., 2021; Tian et al., 2011
Iraq War (2003-2011)	IRQ	X						X	Jahjah et al., 2007
Iran-Iraq War (1980-1988)	IRN, IRQ	X						X	Beygi Heidarlou et al., 2020
ISIS - Iraq War (2014-2017)	IRQ			X			X		Fakhri and Gkanatsios, 2021
ISIS Syrian-Iraq Conflict (2000-Ongoing)	IRQ, SYR			X				X	Eklund et al., 2017
Kurdish–Turkish conflict (1978–Ongoing)	TUR		X		X	X	X		van Etten et al., 2008
Nicaraguan Revolution (1978-1990)	NIC			X			X		Stevens et al., 2011
Rwandan Civil War (1986–2003)	RWA			X			X		Ordway, 2015
Salvadoran Civil War (1979-1992)	SLV				X	X			Hecht and Saatchi, 2007
Second Indochina War (1955-1975)	VNM	X						X	Hupy and Koehler, 2012; Van et al., 2015
Sierra Leone Civil War (1991-2002)	SLE			X			X		Burgess et al., 2015; Wilson and Wilson, 2013
Somali Civil War (1991-Ongoing)	SOM			X	X	X	X		Ayana et al., 2016; Bolognesi et al., 2015; Rembold et al., 2013
South Sudanese Civil War (2013-2020)	ETH, KEN, SSD, UGA			X			X		Ayana et al., 2016; Friedrich and Van Den Hoek, 2020; Leiterer et al., 2018; Hagenlocher et al., 2015; Sosnowski et al., 2016
Sri Lankan Civil War (1983-2009)	LKA				X	X			Suthakar and Bui, 2008
Syrian Civil Conflict (2011-Ongoing)	JOR, SYR			X				X	Lubin and Saleem, 2019; Sawalhah et al., 2018
US Civil War (1861-1865)	USA				X			X	Liu et al., 2018
Vietnam War (1955-1975)	VNM	X						X	Hupy and Koehler, 2012; Van et al., 2015
War of Darfur / Land Cruiser War (2004-Ongoing)	SDN			X				X	Bromley, 2010; Brown, 2010; Hagenlocher, 2011; Knoth and Pebesma, 2017; Kranz et al., 2015; Marx and Loboda, 2013; Spröhnle et al., 2016

Abbreviations:
(**AFG**) Afghanistan, (**AGO**) Angola, (**ARE**) Arab United Emirates, (**ARM**) Armenia, (**AZE**) Azerbaijan, (**BEL**) Belgium, (**BHR**) Bahrein, (**BIH**) Bosnia and Herzegovina, (**CIV**) Côte d'Ivoire, (**COD**) Congo, Democratic Republic of the, (**COL**) Colombia, (**DZA**) Algeria, (**EGY**) Egypt, (**ETH**) Ethiopia, (**FRA**) France, (**GNB**) Guinea-Bissau, (**IRN**) Iran, (**IRQ**) Iraq, (**JOR**) Jordan, (**KEN**) Kenya, (**KHM**) Cambodia, (**KWT**) Kuwait, (**LBN**) Lebanon, (**LBR**) Liberia, (**LBY**) Libya, (**LKA**) Sri Lanka, (**MAR**) Morocco, (**MMR**) Myanmar, (**NIC**) Nicaragua, (**OMN**) Oman, (**PAK**) Pakistan, (**PSE**) Palestine, (**QAT**) Qatar, (**RWA**) Rwanda, (**SAU**) Saudi Arabia, (**SDN**) Sudan, (**SEN**) Senegal, (**SLE**) Sierra Leone, (**SLV**) El Salvador, (**SOM**) Somalia, (**SSD**) South Sudan, (**SYR**) Syria, (**THA**) Thailand, (**TUN**) Tunisia, (**TUR**) Türkiye, (**UGA**) Uganda, (**USA**) United States of America, (**VNM**) Vietnam, (**YEM**) Yemen.

Appendix 10: Distribution map of armed conflict-derived causes by country. (Source: Own figure)



Appendix 11: Distribution map of armed conflict-derived consequences by country. (Source: Own figure)



DEDICATION

This dissertation is dedicated to:

My family for their huge encouragement, wise advice,
unconditional support and endless love.

My Beloved Parents Magaly and Luis Arturo,
My Sister Juliana,
My Cousin Edgar,
My Aunts; Lucy, Mary y Consu,
My Grandmothers, Leo and Lelia.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Dr. István Valánszki. He has been the most patient advisor for eight years since my master's degree and then during my PhD. I would like to thank him for his management, continuous support, endless patience, condescendence, and motivation. He had always been for me when I needed guidance and support.

I am particularly grateful for the assistance provided by Dr. Paulo José Murillo-Sandoval for the huge academic support and collaboration. I would also like to thank Professor Dr. Ladányi Márta. and Dr Albert Fekete.

I am grateful for the support provided by the local community of the Sumapaz Region, particularly the *Sindicato Campesino del Sumapaz* and Dr. Mayra Contreras from the National University of Colombia, and his special program, *Universidad al Páramo*.

I would like to thank the Tempus Foundation and the Hungarian Government for funding this study. I feel honoured to have had the opportunity to participate in the Stipendium Hungaricum Scholarship.

Last but not least, I would like to thank my family: my parents, my sister, my aunts, my cousin Edgar, and my friends in Hungary; Bea, Beti, Alin, Lore, Kathe, Andres, Jorge, Ernesto, Sarita and my friends in Colombia; Mayra, Cami, Irene, Nat, Gus, Andres, Julián, Fer among others for the emotional and continuous support and motivation.