INITIATIVE ON Mixed Farming Systems

CGIAR

Remote sensing-based land degradation assessment to inform Sustainable Development Goal 15.3

A case study in Ghana, West Africa

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The Sustainable Intensification of Mixed Farming Systems Initiative aims to provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socio-economic settings.

Through action research and development partnerships, the Initiative will improve smallholder farmers' resilience to weather-induced shocks, provide a more stable income and significant benefits in welfare, and enhance social justice and inclusion for 13 million people by 2030.

Activities will be implemented in six focus countries globally representing diverse mixed farming systems as follows: Ghana (cereal–root crop mixed), Ethiopia (highland mixed), Malawi: (maize mixed), Bangladesh (rice mixed), Nepal (highland mixed), and Lao People's Democratic Republic (upland intensive mixed/ highland extensive mixed).

Cover photo: Degraded land left over after a mining venture in Dorko in Lawra-Jirapa, Ghana posing a danger to both human and animal life. Photo credit: CGIAR CCAFS.

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Abbreviations and acronyms

GDP	Gross Domestic Product
LD	Land Degradation
LDN	Land Degradation Neutrality
LULC	Land Use Land Cover
SDG	Sustainable Development Goal
SLM	Sustainable Land Management
UNCCD	United Nations Convention to Combat Desertification

Introduction

Land degradation (LD) refers to “the continuous reduction and loss of productivity of the land due to a combination of natural and anthropogenic causes” (UNCCD 2013). It is a global problem that affects humanity and their livelihoods. LD has been defined as the reduction in the present and prospective land quality and production, due to natural and/or anthropogenic dynamics (Beinroth et al 1994). Several mechanisms contribute to LD, and these include physical, chemical, and biological processes (Stocking et al 2013). About 3.2 billion of the global population depend on and live on degraded land (Le et al 2016). LD adversely affects people’s livelihoods (very high confidence) and occurs over a quarter of the Earth’s ice-free land area (medium confidence) (Mbow et al 2017). According to Bruinsma (2009), over half of the agricultural land is classed as moderately or severely degraded, i.e., half of the global area of 4.9 billion ha, which is comprised of 1.5 billion ha of cropland and 3.4 billion ha of grazing land. Moreover, the area of arable land alone classed as degraded is estimated to be increasing by 5-6 million ha each year (Bai et al 2008).

The Earth every year experiences losses of between 25-40 billion tons of topsoil as a result of human activity (FAO and ITPS, 2015). Scientists have estimated that a third of the available soil has been lost since 1970 (Bai et al 2008). Around the world, fertile land is turning to desert at rates 30-35 times greater than in pre-industrial times. Around 54% of the Earth’s land surface area, 2 billion hectares (ha), is degraded to some degree, 124 million ha of land are estimated as being affected on the African Continent Pimentel (2006). More importantly, soils have become less productive due to salinization, waterlogging, and pollution, and acidification, mineral and nutrient depletion Osman (2014). A bigger chunk of the world's most affected, approximately 815 million people are domiciled in the regions of Sub-Saharan Africa and Southern Asia (Niles et al 2019).

The majority of the 1.3 to 3.2 billion affected people (low confidence) are living in poverty in developing countries (medium confidence) (Mbow et al 2017). About a quarter of the world’s lands are affected by LD (IPBES 2018). According to Hansen et al (2013), 2.7 million square kilometers were lost to deforestation worldwide in the first 12 years of the new century. Resultantly, there is expected to be a decline in biodiversity the world over because of LD (IPBES, 2018). Projections show that lower productivity accelerated by prevailing climate change will drive land use and land cover change (LULC) globally (IPCC, 2019). This in combination with population growth will affect the vulnerable people who often rely on agriculture (Bai, Dent, Olsson, & Schaepman, 2008). Consequently, the international community introduced the sustainable development goal (SDG) 15.3 which focuses on “restoring degraded land and striving to achieve an LD-neutral world,” highlighting the importance of the issue of LD Sims et al (2017).

LD affects ecosystems in all agro-climatic zones. In dry lands, an estimated 12 million ha of formerly productive land becomes unproductive each year through drought and unsustainable management practices (UNCCD 2013); this represents a loss

equivalent to 20 million tons of grain every year. However, about 78% of all land assessed as degrading is found in non-dry land areas (UNCCD 2013); these lands produce much of the world's food. There is wide variation in estimates of the rate of productivity losses due to land degradation. It is important to note that these variations arise from differences in baseline assumptions, indicators of degradation and modeling approaches, and how productivity loss is defined (Wiebe, 2003). Net productivity loss is commonly defined as the sum of yield losses and cost increases, estimated cumulative productivity losses for cropland and pasture ranging from 0.1 to 0.2 percent per year Crosson (1997). Wiebe (2003) summarized estimates of productivity loss in agricultural land in the United States, finding reported values from as little as 0.04% productivity loss (considering yield loss and cost increases) per year across most crops (Alt et al. 1989) to 8% per year decline in maize yields (Pimentel et al. 1995). Wiebe (2003) concluded that land degradation impacts on productivity are sensitive to location-specific biophysical and economic factors and are, therefore, difficult to predict at regional and global scales.

Land degradation in Africa

Africa is one of the continents with excessive LD and its negative effects are felt mostly in Sub-Saharan Africa (IPBES, 2018). For instance, in Tanzania, more than half of the country shows signs of LD (Le et al 2016). Tanzania as a country has the highest area net loss of annual forest in East Africa and is also in the fifth position in Africa (FAO 2015). Likewise, Zimbabwe has faced unprecedented levels of deforestation. In 2010, Zimbabwe had 1.06Mha of tree cover, extending over 2.7% of its land area, and in 2021 it lost 9.05kha of tree cover, equivalent to 3.82Mt of carbon dioxide emissions (Mujuru et al 2019). Therefore, this means losses in renewable natural capital such as agricultural lands and forests (Lange, Wodon, and Carey, 2018). Consequently, poverty levels have heightened since many people in these countries are dependent on subsistence farming (World Bank 2020).

Like other African countries, Ghana is one of the countries with elevated levels of LD. It has 35% of its land under threat of desertification (UNCCD 2017) and because of LD, grasslands, woodlands, and forests are being lost while natural water bodies are drying up due to prolonged droughts and sedimentation of water sources. Archibald, Scholes, Roy, Roberts, and Boschetti (2010) revealed that LD levels are concentrated in the Upper East region which is one of the poorest in the country. The annual cost of LD in Ghana is estimated at USD 1.4 billion, and this is equal to 6% of the country's Gross Domestic Product (GDP) (UNCCD, 2017). Thus, LD has become an issue demanding urgent attendance. 5.4 million people in 2010 were living on degrading agricultural land which translates to an increase of 26% in a decade, bringing the share of rural residents who inhabit degraded agricultural land up to 45% of the total rural population (Global Mechanism of the UNCCD 2018). Between the periods of (2000-2010), people residing in remote degrading agricultural areas with limited market access increased by 28%, reaching 730 thousand people. With an annual cost of land degradation in Ghana estimated at 1.4 billion United States dollars (USD), this is equal to 6% of the country's Gross Domestic Product (Global Mechanism of the UNCCD 2018). Land management processes that are ecologically balanced are key to achieving economic and environmental benefits (Randolph

2004). Any rural investments that are not premised on sustainable land management are likely to fail, hence the maintenance of agriculture will be successful if there is environmental sustainability (Randolph 2004).

Land degradation assessment and SDG 15.3.1 indicator

Indicators of land quality are needed to guide communities and countries. However, the major constraint that prevents action is the lack of spatial information on LD (Kimaro et al 2015). In contrast to the laborious fieldwork, remote sensing offers the unique opportunity to assess vast areas over a long period consistently (Bai et al 2008; Dubovyk 2017).

The 2030 Agenda for Sustainable Development has created opportunities for countries to respond to the growing threats of land degradation and harness socio-economic benefits associated with LDN. Sustainable Development Goal 15 'Life on Land' and its target 15.3 on LDN encourages countries to 'combat desertification, restore degraded land and soil, including land affected by desertification, drought, and floods, and strive to achieve a land degradation-neutral world by 2030 (Chasek et al 2019). In April 2018, 116 countries committed to translating the global goal of achieving LDN by 2030 into national action by setting national voluntary targets with the support of the LDN Target Setting Programme (LDN TSP) Akhtar-Schuster et al (2017).

Ghana set a national voluntary LDN target, established an LDN baseline, and formulated associated measures UNCCD (2017). The LDN targets provide Ghana with a strong vehicle for fostering coherence of policies and actions by aligning the national LDN targets with measures from the Nationally Determined Contributions and other national commitments, such as the restoration of 2 million hectares of degraded land under the Bonn Challenge and AFR100 initiatives. As such, during SDG implementation, standard methods were introduced to assess LD (Sims et al 2019). Nevertheless, there is a dearth of literature that addresses the issue of LD in Ghana and its impacts, especially in the Upper East and Northern regions. In this regard, it is important to assess spatially LD according to SDG 15.3.1 indicator for Ghana.

Land degradation assessment at national and sub-national level in Ghana

LD assessments in Ghana have been far and wide and it has not been consistent. There have not been any recent assessments done to inform the SDG indicator 15.3.1 in Ghana. Several LD studies have been conducted without following the framework of the SDGs, thus this study is an option to fill an existing gap for LD research in Northern Ghana considering the SDG 15.3.1 indicator.

The only relevant LD assessment was focused on monitoring periods 2000 and 2010 and was conducted using Tier 1 default SDG 15.3.1 data (i.e., global datasets available for LDN assessment, (UNCCD 2017). This study yielded LD maps covering the three SDG 15.3.1 sub-indicators for 2010, which therefore presents an opportunity to

contact this study and bridge the information gap for more recent LD assessments. Within 2000 and 2010, the major negative land cover/use change (cover indicator) at the national level was a 1.71 % decrease due to the conversion of 882.86 km^2 of forest lands to 724.23 km^2 of shrubs, grasslands, and sparsely vegetated areas (hitherto referred to as grasslands), and 158.63 km^2 of croplands (UNCCD Ghana Reports 2017). There is generally a lack of proper coordination among stakeholders, and this negatively impacts the implementation of LD intervention measures. The study will thus focus on Northern Ghana and bridge the information gaps.

Research gap

Studies on land degradation tended to ignore the complexity of land degradation impacts and have focused on simpler relationships, such as population increase, soil erosion, and its impact on crop yield, hence the availability of accurate and reliable spatially explicit LD information is critical for LDN to be achieved. Remote sensing to inform SDG 15.3.1 will help address more rigorously the complex relationship of land degradation. In this case, it is important to contextualize the UNCCD methodology to assess SDG 15.3.1 (Sims et al 2019) and deliver the SDG 15.3.1 indicator results for Ghana, which would support accurate and reliable assessments of LD in a bid to avoid misleading policy guidance and support sustainable land management in the country.

Objectives

The main objective of the proposed study is to apply high-resolution remote sensing imagery data and qualitative data from ground surveys to monitor the spatial-temporal trends of LD based on SDG 15.3.1 and identify its drivers in the Northern Region of Ghana.

Specific objectives are:

- To analyze LD in the study area using multi-source remote sensing data.
- Use high-resolution Landsat time series to map the trends of land productivity and land use land cover (LULC) changes in the study area to inform LD indicators.
- Quantify the relative importance of natural (climatic) and anthropogenic factors in explaining the LD trends.
- Identify the sustainable land use management practices employed by farmers to avoid and reduce LD or to rehabilitate degraded land.

The research questions of this thesis are:

- What is the spatial extent of LD in the Northern Region of Ghana?
- Where are the hotspots of land productivity decline and LULC changes in the study area?
- What are the drivers of LD in the Northern Region?
- What can be done to lessen land degradation and its impacts?

Study area

The study area covers three regions in northern Ghana. Ghana has 35% of its land under threat of desertification (UNCCD 2017). As a result of land degradation, grasslands, woodlands, and forests are being lost while natural water bodies are drying up due to prolonged droughts and sedimentation of water courses. The annual cost of land degradation in Ghana is estimated at USD 1.4 billion (UNCCD, 2017), which is equal to 6% of the country's GDP In Ghana, around 135,000 ha of forest is lost every year due to activities like bush burning, cattle grazing, and mining. Deforestation rates are particularly high in the impoverished Upper West Region, where an increasingly variable climate and extreme weather events further contribute to the vulnerability of local farmers, who are seeing soil fertility and yields progressively decline.

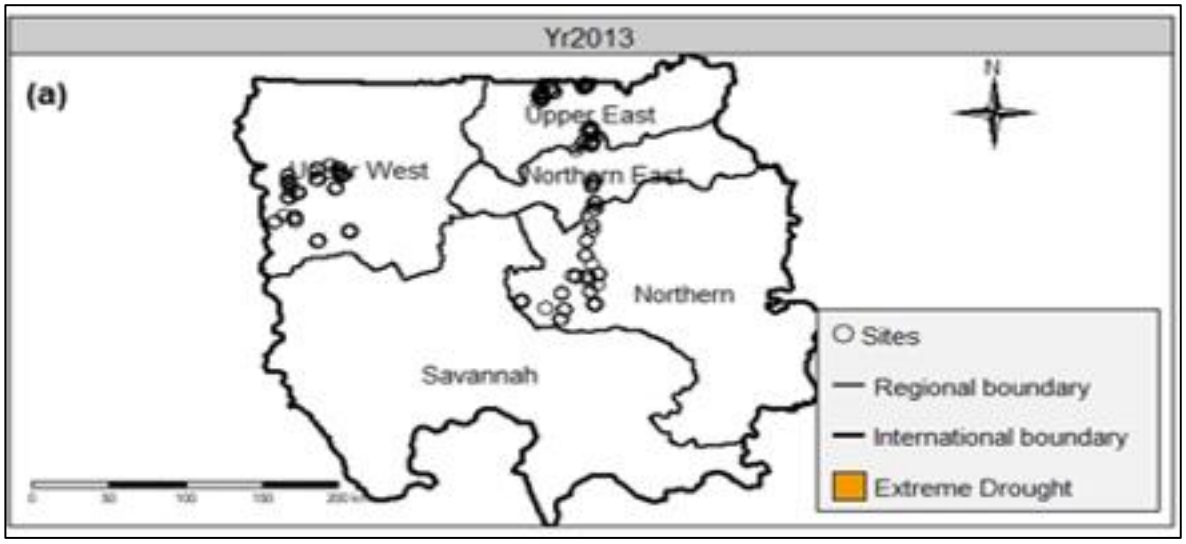

Figure 1. Location of the study area in northern Ghana. The sites show the location of >800 households in surveys conducted in 2014 (baseline) and 2020 (endline).

Research design

This study will be premised on a case study research design. Case study research design is a design that focuses on a single individual, phenomenon, institution, or community (Lune and Berg, (2017). A case study will guide the researcher to draw the parameter on where to conduct the research. According to Saldana (2011), a case study specifically focuses on a single unit of analysis hence it can be intentionally utilized by the researcher based on its uniqueness to permit the researcher to focus on a particular study. This study focuses solely on LD in the Northern Region of Ghana.

Methods and materials

This study will make use of mixed methods. The mixed methods will be based on a quantitative remote sensing data research approach to assess LD as well as surveys. The methodology for indicator 15.3.1 is universal and as stipulated in the Good Practice Guidance the methodology while being universal allows countries to select the most appropriate datasets and national methods for estimating the sub-indicators and determine the most suitable pathway for deriving the indicator (Sims et al 2019). The study will access and interpret data sources for the sub-indicators using EO and geospatial information (Sims et al 2019). For this study, three sub-indicators of SDG Indicator 15.3.1 indicator, namely Land productivity, Land Use/ land cover, and Soil organic carbon, will be calculated to inform SDG Indicator 15.3.1 in the assessment of the area degraded in the study area in Ghana. For the study the integration of the three SDG 15.3.1 sub-indicators will be done following the one-out all-out rule, meaning that if an area in the Northern Region of Ghana is identified as potentially degraded by any of the sub-indicators, the area will be considered potentially degraded for reporting purposes (Sims et al 2019). Customized remote sensing-based datasets for sub-indicators will be developed to overcome the commonly reported limitations of the default coarse spatial resolution data sets (Reith et al 2021).

A default data approach based on 250m MODIS data and a customized approach based on 30m Landsat data will be used to estimate the sub-indicators. The study will utilize both 250m MODIS, 30m Landsat images from 1980-2020 Sentinel 10m 2015-2020, and Planet 5m for validation purposes. The MODIS data will be used to calculate the land productivity sub-indicator as a first step of the study, while the medium resolution Landsat data will be used as a customized approach developed in this study. Sentinel and Planet data will be used for validation. Due to their optimal ground resolution and spectral bands, the Landsat images will be used to track the land changes in the region from 1980 to 2020. The Landsat images will be obtained from the United States Geographical Survey (USGS) Global Visualization website. The image spatial resolution or pixel size will be 30m by 30m, with a cloud cover of less than 10%. Sites will be selected for ground truthing to check the accuracy of classified imagery. Local assessments of the climate, soil, and land use changes in the sub-indicators will be analyzed, the study will identify which land units are to be classified as degraded, sum the total, and report on the indicator providing the appropriate justification. As such the indicator will be derived from a binary classification of land condition (i.e., degraded or not degraded). The study will calculate the indicator by evaluating changes in the sub-indicators over time, to determine the extent of land that is degraded over the total land area (Sims et al 2019).

The extent of degradation measured in each of the reporting periods will be compared to the extent of degradation measured in the baseline period to identify whether this area is increasing or decreasing over time. The baseline sets the benchmark extent of degradation against which progress towards achieving SDG Target 15.3 and LDN is assessed (Sims et al 2019). As a result of this study, two

spatially explicit LD assessments will be conducted: (i) based on the default course resolution data and methods; (ii) based on the customized high-resolution data and methods. The results will be validated by survey data provided by the Institute of Tropical Agriculture (IITA). The survey data to be provided by IITA is in the form of household surveys data (>800 HHs) conducted in 2014 (baseline) and 2020 (endline) with information on the household demographics, farming practices, and socio-economic situation, and this data is from available from Africa RISING project. Secondly, data will also be validated based on a rich archive of remotely sensed data on climate, topography, and soils with planet imagery of 5 m resolution, with two imagery per month available from 2018 onwards. In addition, there is analysis-ready Landsat and Sentinel data available from the Digital Earth Africa archive, cropland extent and soil properties map with 30 m resolution and bias-corrected CHIRPS-v2 monthly rainfall. Maps on the rainfall onset, cessation dates, and length of the growing season.

Sustainable land management framework

The study will make use of the Sustainable land management (SLM) framework. SLM is recognized as the key to reducing rates of land degradation. Sustainable Land Management as a framework emerged following the Rio Earth Summit of 1992 and this framework came out to try and address the failures of earlier approaches to halt land degradation (Solecka 2019). The SLM approach has participatory approaches that encompass socio-economic dimensions in technical planning and design of land management approaches (Solecka 2019). Sustainable land management can be defined as "a system of technologies and/or planning that aims to integrate ecological with socio-economic and political principles in the management of land for agricultural and other purposes to achieve intra- and intergenerational equity" Hurni et al (1996). SLM is thus composed of three development components 'technology policy, and in particular, 'land use planning' (Bouma 2004). It involves a holistic approach to achieving productive and healthy ecosystems by integrating social, economic, physical, and biological needs and values, and it contributes to sustainable and rural development (FAO 2017).

Assessing SLM at the local level

The study will conduct a literature review and the aggregation of information from the community to the regional level will be very useful for the coordination of activities and for providing an analysis of local areas. The study will make use of this framework to help understand LD in Ghana and to recommend halting LD based on SLM practices. SLM will be instrumental in combating LD in Northern Ghana and Beyond.

Impacts of SLM

Studies have demonstrated that SLM practices have the potential to prevent, reduce and combat LD and ultimately play a significant role in the achievement of LDN (Garcia et al 2019; GEF, 2016). SLM is a knowledge-based procedure and its ability to sustain livelihoods and environmental management is crucial for the study and will help contribute to SDG 15.3.1 through articulating priorities for investment in SLM in Ghana, defining human-environment relations and identifying key policy, institutional, and incentive reform options that will accelerate the adoption of SLM and the achievement of LDN. Several studies have proved that the costs of land degradation are substantial and the costs of action to address land degradation are often several times lower than those of inaction (Mirzabaev et al 2015). Despite the high returns associated with investments in sustainable land management, land degradation has persisted over the year due to inadequate levels of investments in sustainable land management (Mirzabaev et al 2015). The study will therefore be looking at how policies, stakeholders, and the government of Ghana can incentivize more investments into SLM to help halt drivers of LD and areas showing stress and areas classified by the study as degraded.

Planned Schedule

Phase	Timeline
Chapter 1 Introduction	January 2023 – February 2023
Chapter 2 Literature Review	March 2023
Chapter 3 Methodology	April 2023-May 2023
Data Collection and processing	July 2023 - December 2023
Chapter 4 Data Presentation and Analysis	January 2024 – March 2024
Chapter 5 Conclusion and Recommendations	April 2024- May 2024

Deliverables

- MA Thesis.
- Technical report on the status of land degradation in northern Ghana identifying priority areas for spatial targeting of land rehabilitation.
- Publication of SDG indicators based on improved datasets/methods including spatially explicit recommendations for land rehabilitation.
- Land productivity/degradation maps at 30 m resolution for different MFS typologies.
- GitHub repository of spatial workflow.

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