ORIGINAL ARTICLE

Assessment of Land Degradation Neutrality Status in North Wello Zone, Northern Ethiopia

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Abstract

Land degradation is becoming more widely acknowledged in Ethiopia as a critical national environmental issue. This study aimed to analyze land productivity dynamics trends and land degradation neutrality conditions in the North Wello Zone using three United Nations Convention to Combat Desertification (UNCCD) indicators: land cover change, land productivity dynamics, and soil organic carbon stock, during the period between 1995 and 2018 based on a "one out, all-out" approach. Landsat 5 and Landsat 8 satellite images, as well as Normalized Difference Vegetation Index (NDVI), obtained from the Terra Moderate Resolution Imaging Spectroradiometer (MOD13Q1) datasets, were used to examine the land use, land cover change, and land productivity trends. Soil organic carbon data were obtained from the global soil organic carbon database, which is available on the soilgrids.org website. The grided soil carbon map was developed as 250 m soil grids, covering a depth of 0-30 cm. The results showed increases in urban areas, agricultural lands, barren lands, and forest land with the annual rate of change (1995-2018) of 4.4% 0.39%,0.31%, and 0.04 %, respectively. Water bodies and shrubland, on the other hand, decreased by 2.8 percent and 1.3 percent, respectively, each year. Agricultural land, which covered the majority of the surface area during the study period, remained persistent (57%) and expanded to shrublands (10.6%), barren land (3.8%), and forest (0.5 %). Agricultural land, on the other hand, was converted to shrublands (4.6 percent), barren land (0.7 percent), forest land (0.6 percent), and urban areas (0.05 percent) during the study periods. Based on land productivity dynamics parameters, productivity increased across 10% of the study area during the study period and decreased to 7% of the land area. A large proportion of land surface in the study area (57.8%) was characterized as early signs of productivity decline. Stable land under stress (19.5%) was significantly higher than stable areas (6 % of the study area). The lowest content of soil organic carbon stock (less than 50 tons of carbon per hectare) coincided with cropland and barren land areas. In contrast, the highest soil organic carbon concentrations, between 86 and 166 tons of carbon per hectare, were found in areas associated with forest lands. The spatial distribution of degraded status of land in the North Wello administrative zone occurred in 75% of the total area. The areas with "stable" land status covered 15% of the total area, while areas with "improvement" land status covered only 10% of the total area. The findings suggest that balancing measures to achieve land degradation neutrality in the study area should be implemented as soon as possible.

Keywords: Land Degradation, Land Productivity Dynamics, Soil Organic Carbon, Land Use Change

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1. Introduction

The land is a component of mother nature, serving as infrastructure for much of life on earth (Safriel, 2017; Gupta, 2019). It is the primary source of human livelihood and well-being, including the provision of food, clean water, and different other ecosystem services (IPCC, 2019). The Millennium Ecosystem Assessment (MEA, 2005) states that the term 'land' encompasses renewable natural resources, such as soils, water, vegetation, and wildlife in their terrestrial ecosystems. Land scientists estimate that about 11% of the global land surface is prime land, yet this must feed the world's 6 billion people today and the 8.2 billion expected by 2020 (Sivakumar & Ndiang, 2007). In 2013, 37 % of the earth's landmass, except Antarctica, was cultivated to grow food, 12 % as croplands, and 25 % as grazing lands (Searchinger et al., 2014). Food production will increase by 70 % worldwide and 100% in developing countries (FAO, 2011). Food production systems, especially in Africa, face enormous challenges in land degradation and climate change problems (Winterbottom, 2013).

Land degradation and climate change have emerged as major environmental concerns in Sub-Saharan Africa (Gupta, 2019), posing significant threats to food security (Webb et al., 2017; Hermans & McLeman, 2021; Barbier & Hochard, 2018). Land degradation initiates processes that cause negative changes in the biophysical environment and land characteristics. These include changes in soil, water, vegetation cover, and climate (Mohamed & Hendawy, 2019). Climate change and land degradation have interlinked relationships (Reed & Stringer, 2016), with the consequences being felt most acutely by ecosystems and resource-dependent populations in drought-affected areas (Reed & Stringer, 2016). Changes in different biophysical and biogeochemical factors cause complex interactions between land and climate (Hurni et al.,2010; Jia et al., 2019). Land degradation exacerbates the water deficits caused by climate change due to higher temperatures and increased evaporative demand (Henry et al., 2007; Herrick et al., 2013; IPCC, 2019; Webb et al., 2017). The loss and degradation of soil and vegetation significantly reduce potential carbon sinks (FAO, 2013). Climate change, particularly droughts, is a major driver of land degradation, which has a negative impact on resource-dependent rural livelihood systems (Hermans & McLeman, 2021).

In Ethiopia, land degradation is one of the most challenging problems (Bishaw, 2001; Hurni et al., 2010; Hurni et al., 2015; Meseret, 2016; Tesfa & Mekuriaw, 2014). Land-use change and drought are the main drivers of land degradation in Ethiopia (Alemu, 2015; Holden & Shiferaw, 2004; Hurni et al., 2010; Nyssen et al., 2015; Mekonnen et al., 2018). To reverse the land degradation, climate change, and food insecurity problems, the concept of land degradation neutrality is being implemented. Land degradation neutrality is a concept that is described as a state of equilibrium in land systems (Grainger, 2015; Kust et al., 2017; Okpara et al., 2018). The framework of land degradation neutrality is crucial for the achievement of the Sustainable Development Goals (SDG 15.3) with the direction to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (Kust et al., 2017). Sustainable land management is one of the mechanisms for achieving land degradation neutrality (LDN) (Sanz et al., 2017; UNCCD, 2015).

Various land management projects have been implemented in Ethiopia since 1980 to improve land productivity conditions. Food for work programs, integrated watershed management, and sustainable land management programs are some programs implemented on a different scale to achieve sustainable development programs in the country. In this framework, UNCCD proposed a method to assess the land degradation state using three

biophysical indicators: land cover (LC), land productivity dynamics (LPD), and soil organic carbon (SOC). Applying the UNCCD land degradation neutrality framework, the land degradation assessment report in Ethiopia is scarce. However, using only land use land cover change as an indicator, more recently, a number of studies were conducted to assess land degradation status in Ethiopia (Alemu, 2015; Gashaw et al., 2014; Kidane et al., 2019; Mariye et al., 2022; Mekonnen et al., 2018; Tsegaye, 2019).
In Ethiopia in general and the North Wello administrative zone in particular, there are no land degradation neutrality assessment reports, particularly used by soil organic carbon and land productivity dynamics indicators. This study, therefore, employed a land degradation neutrality framework at the zonal administrative level. North Wello administrative zone is part of northern Ethiopia with rugged topographic features, climate variability, and irregular hydro metrological pattern that makes it more susceptible to soil degradation (Damene et al., 2013). Frequent drought (Anteneh, 2021) and poor livelihood systems are linked to the study area. However, information about its land degradation state or potential for degradation is scarce.

The current study aimed to determine the state of land degradation neutrality in the North Wello administrative zone from 1995 to 2018 using the LDN framework indicators. A "one out, all-out" system was used to determine land degradation neutrality status based on LULC change, land productivity dynamics, and SOC measures. The significance of this research output will be to depict positive and negative trends and changes in the three indicators studied. Furthermore, in the context of LDN, this investigation serves as baseline information at the local level, forming the foundation for the development of public policies and strategies for land resource management.

2. Materials and Methods

2.1. Study site

North Wello administrative zone is located in northeastern Amhara Regional states, Ethiopia, between 11°30'0" and 12°30'0" N latitude and 38°30'0" to 40°0'0" E longitude, with a total area of 12, 212 Km2 (Fig.1). Its altitude varies between 900 and 4265 meters above sea level with three major agroecological zones: hot (Lowland), temperate (Midland), and cool (Highland).The study area, North Wello zone, is characterized by a distinctive bi-modal pattern of rainfall with Belg in April-May preceding the primary wet season Kermit, July to September (Conway, 2000).The temperature varies by season with average minimum temperatures ranging from 9.5 °C to 15.6 °C, and the monthly average maximum temperature ranges from 21–29°C during the rainy season to 30–33°C during the dry season. May and June are the hottest months. The predominant soils are Cambisols, Luvisols, Vertisols, Xerosols, Leptosols, Regosols, and Nitisols. Agriculture has long been practiced in the area, and it is the primary economic activity and source of income. The farming system at the subsistence level is a mixed crop-livestock production system. Cereal crops such as sorghum, teff, barley, and wheat are the most important crops grown. Chickpeas, peas, and beans are also significant crops. The most commonly grown fruits are oranges, bananas, papayas, mangoes, lemons, and avocados. Livestock is inextricably linked to the agricultural system, and it is primarily used for plowing and transportation.

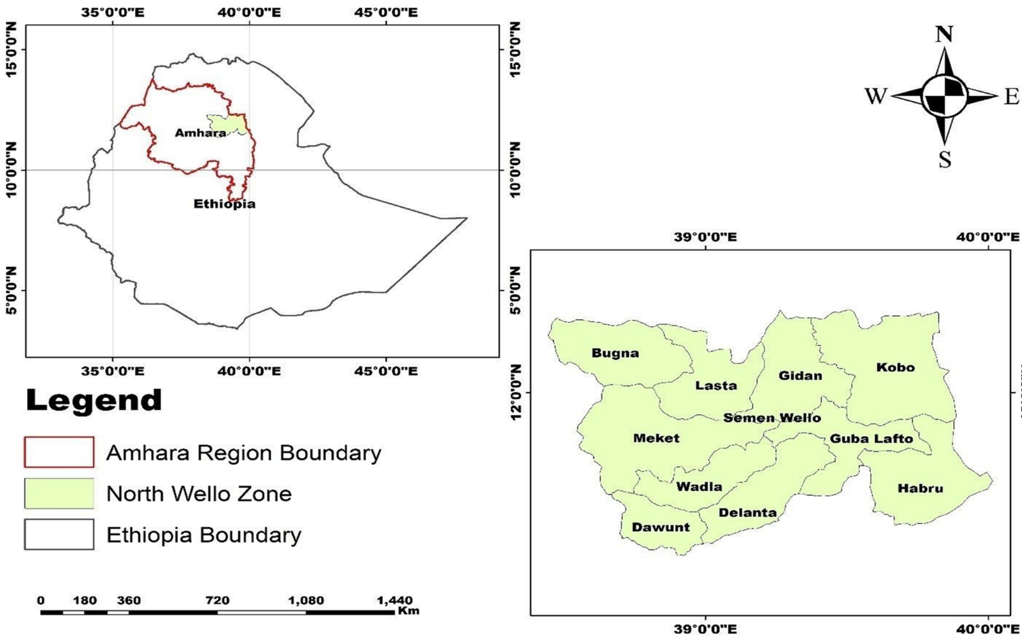

Fig.1: Map of the study area

2.2. Data Sources

In this study, Landsat images acquired in 1995 and 2018 were used. The images, which are georeferenced and radiometrically corrected, were accessed from the United States Geological Survey (USGS) website (http://www.usgs.gov, accessed on 15 March 2022). Landsat images are medium-resolution remote sensing tools that are used for land use and land cover change analyses. Thematic Mapper (TM), and OLI are the two sensors in Landsat, which have been in use for 1995 and 2018, respectively.

Obtaining adequate datasets requires the selection of the type of sensor, relevant wave-length bands, and date(s) of acquisition. Dry season and cloud-free images which less than 10 percent were used since they make conducting the analyses easier. To cover the full study area, three satellite images (three scenes) for each year were acquired and combined by the mosaic tool in arc GIS software. Each satellite image was obtained with a spatial resolution of 30 m, i.e., a single pixel in the image represents 30 by 30 m on the ground.

The soil organic map of the study area was extracted from the global soil organic carbon database available on the soilgrids.org website. The grided soil carbon map was developed as 250 m soil grids, covering a depth of 0-30 cm. The Normalized Difference Vegetation Index (NDVI) was calculated using the Terra Moderate Resolution Imaging Spectroradi-ometer (MODIS, MOD13Q1) dataset. This dataset contains a time series of NDVI images generated at 16-day intervals and annually integrated at a spatial resolution of 250 m.

2.3. Land Use and Land Cover and Change Detection Analysis

Preprocessed Landsat satellite images were classified into separate maps of LULC classes using a pixel-based supervised maximum likelihood classifier (MLC) approach. Six LULC classes identified in the study area—bare land, agricultural land, forestland, urban area, shrubland, and waterbody—have been classified for 1995 and 2018 images separately. To determine the land use and land cover change trend for each category, the total annual surface was quantified for each year of the study (1995 and 2018).

Table 1. Major land use/cover classes and their description.

LULC classes	Descriptions
Agriculture land	The area is covered with crop cultivation and includes rural settlements fenced with trees that are commonly found around homesteads and towns.
Water bodies	An area of land covered with surface water bodies such as lakes and ponds.
Bare land	Areas under degraded lands and bare ground, including sand, gravel, bedrocks, and riverbed gravels.
Shrublands	Areas comprised of several plant growth forms with widely dispersed perennial woody and herbaceous plants, eucalyptus plantation, and annual plant species
Forest land	Areas covered by dense natural trees forming closed or nearly close canopies, mainly growing naturally in the reserved land and along the riverbanks and the hillsides.
Urban area	All built-up areas include small towns, industries, factory site

Land use and land cover changes were analyzed with the start (1995) and end (2018) maps using a cross-tabulation matrix and post-classification methods. A change was considered positive or negative according to the transition from one land use and land cover category to another in the study period. Post-classification by intersection tool was used to compare change detection between pairs of consecutive classified images. Accordingly, the years 1995 and 2018 were compared using a change detection matrix. The annual rate of change for each class of LULC was calculated using the following formula proposed by Batar et al. (2017):

$$\Delta = \left(\frac{1}{t2-t1}\right) \times \ln\left(\frac{A2}{A1}\right) \times 100,$$

where Δ is the change for each class per year, A2 and A1 are the class areas at the end and the beginning, respectively, for the period being evaluated, and t is the number of years spanning that period.

2.4. Analysis of Land Productivity Dynamics and Soil organic carbon stock

The NDVI was calculated by taking the monthly average of the area for each year (2000 and 2018). Landsat 5 TM images for 1995 were used to calculate the NDVI of the year 1995. The index has no dimensions and has values ranging from -1 to +1, with higher values indicating greater vegetation abundance, density, or health (Baskan et al.,2017). Following that, NDVI values between 1995 and 2018 were divided into five categories: no vegetation (0.18); very weak (0.18–0.40); weak (0.40–0.63); moderate (0.63–0.80); and intensive (>0.80) (Baskan et al.,2017). The normalized difference vegetation index (NDVI) value is determined by using the near-infrared (NIR) and visible reflectance bands. Thus, NDVI is calculated as NDVI=(NIR-RED)/(NIR+RED), Where NDVI = normalized difference vegetation index, NIR = reflection from near-infrared wavelength region, and RED = reflection from red wavelength region.

The dynamics of land productivity can indicate levels of sustained land quality and are thus used as the first step in determining land degradation hotspot areas (Baskan et al.,2017; RotllanPuig et al., 2019; Detalela Fuente et al., 2020; Arroyo et al.,2022). Land productivity trends are classified into five qualitative categories on the LPD map: declining productivity, early signs of decline, stable but stressed, stable but not stressed, and increasing productivity (Baskan et al., 2017). The spatial distribution of LPD in the study area was made from a double-entry matrix with the determined 2018 NDVI classes and 2018 land use categories in arc GIS software. First, each land use category (with or without changes) was assigned as LPD classification following the procedures by Arroyo et al., 2022). Then, the area of each LPD class was then determined using the same method used to calculate land use and land cover changes. The average for the year 2018 was used to calculate the SOC stock trend. The area of each SOC class was then calculated using the same method that was used to calculate land use and land cover changes, as well as LPD.

2.5. Land degradation neutrality status

We used the “one out, all out” principle to determine the land degradation neutrality status (Speranza et al., 2019). The one-out, all-out principle assumes that if any of the indicators show a significant negative change, the goal of land degradation neutrality is not met; if at least one indicator shows a positive trend and none shows a negative trend, the goal is met. As a result of evaluating the change processes in each of the indicators, negative changes were labeled “degradation”, positive changes as “improvement”, and areas that did not show transformation as “stable”. An intersection of the change maps of the three indicators in arc GIS software produced a final map of degraded land (Arroyo et al.2022).

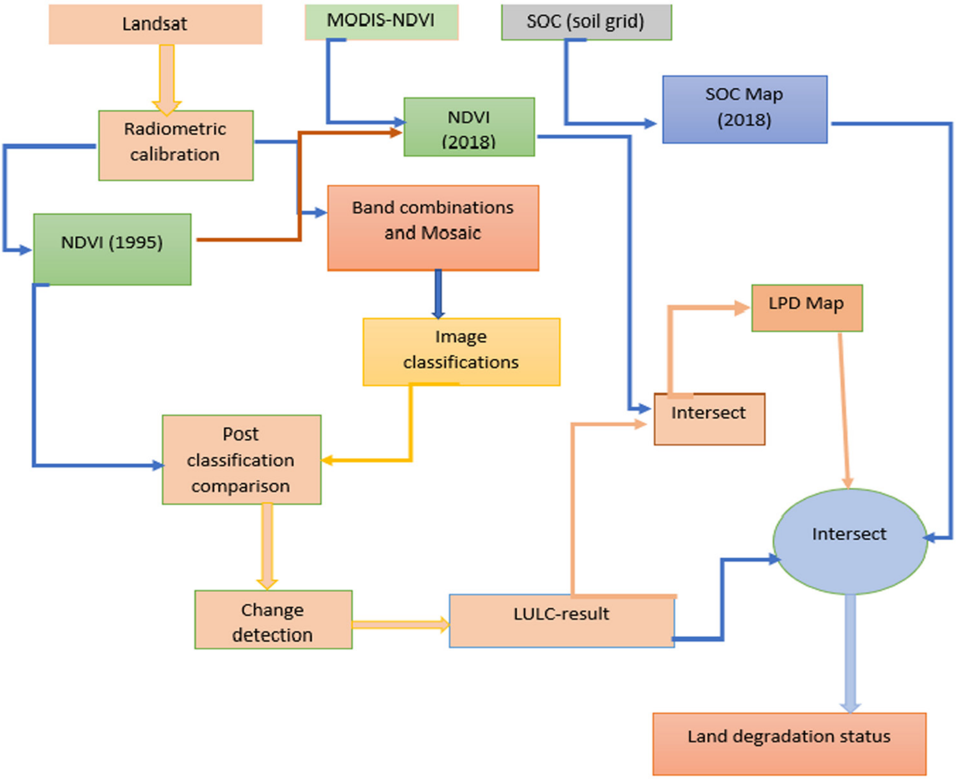

Fig.2. Schematic presentation of the land degradation neutrality assessment methodology

3. Results

3.1. Land cover map and status

Land cover maps were created using Landsat 5 (TM) and Landsat 8 (OLI) satellite data between 1995 and 2018, with six land use land cover classes: water, agriculture, forest, bare land, urban areas, and shrubland. Fig.3 and 4 depict the supervised classification's final output, which consists of two classified maps of the administrative zone of north Wello. In 1995, agricultural land (cropland and rural settlement) comprised 47.87 percent of the North Wello administrative zone, followed by shrubland (23.522 %), forest land (16.77%), barren land (11.5%), urban areas (0.25%), and water bodies (0.11%).

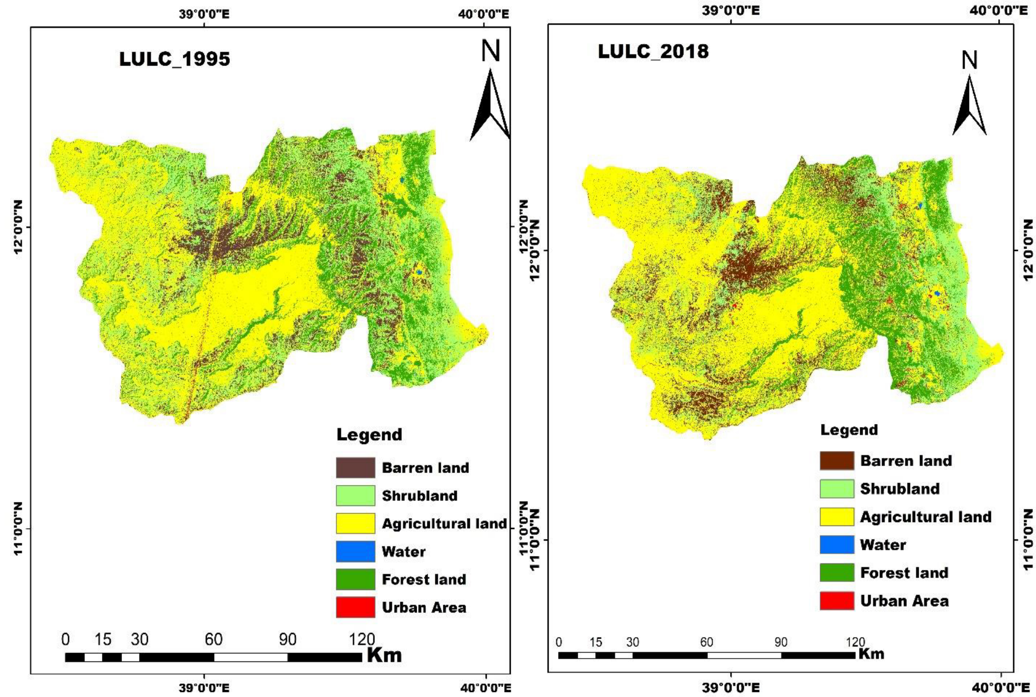

Fig.3. Land cover map for the year (1995-2018)

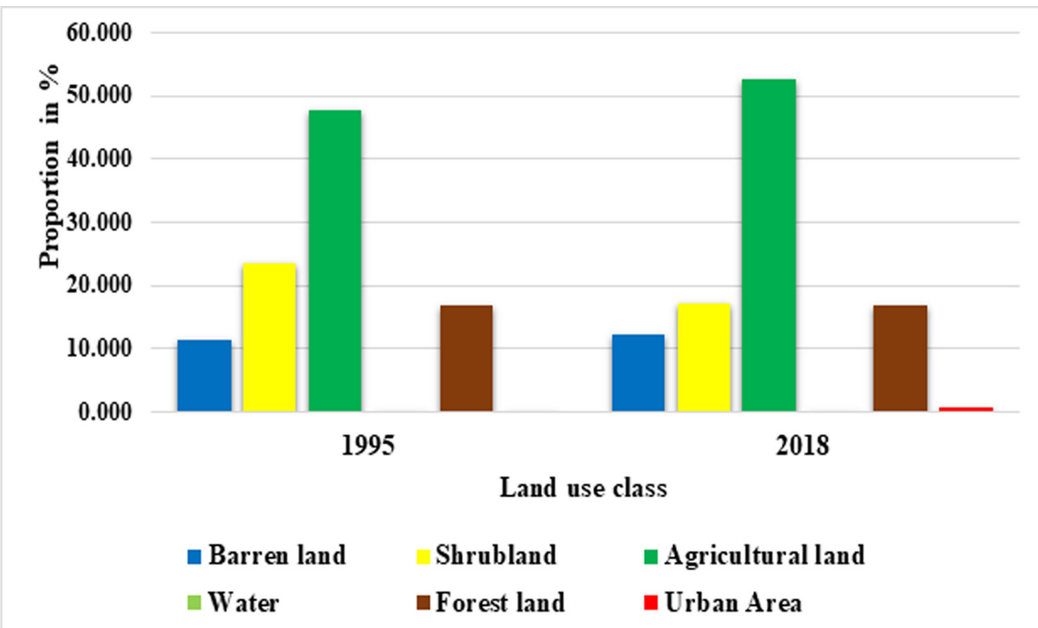

Fig.4: Proportion of land cover and land use type

3.2. Land-Use and Land-Cover (LULC) Change

Table 2 summarizes the results of the land cover change and the annual rate of change in the area of each class for the North Wello administrative zone. The area of agriculture increased from 47.87 % (5846.26 km2) in 1995 to 52.64 % (6428.19 km2) in 2018. Similarly, the urban area increased from 0.25 % (31.13 km2) in 1995 to 0.74% (90.31 km2) in 2018. The area of forest cover slightly increased from 16.77 % (2048.2 km2) in 1995 to 16.95 % (2069.82 km2) in 2018. Bare land areas also show expansion from 11.47% (1401.17 km2) in 1995 to 12.39 % (1512.57 km2) in 2018.On the other hand, the shrubland cover decreased from 23.52 % (2872.61 km2) in 1995 to 17.24 % (2104.94 km2) in 2018. The area of the water body also decreased from 0.11% (12.89 km2) in 1995 to 0.05 % (6.532 km2) in 2018.

The overall annual rate of change in the declining rate of water bodies and shrubland from 1995 to 2018 was approximately 2.83 % and 0.04 %, respectively. Urban areas, agricultural land, and barren land, on one hand, and forest land areas, on the other hand, expanded at a rate of 4.4%, 0.39%, 0.31%, and 0.04%, respectively. During the study period (1995–2018), the highest increasing annual rate of change was observed for urban areas.

Table 2. Temporal change in the spatial extent of LULC classes in percentage

LULC class	Change (1995-2018)	Change	Annual Rate of Change (1995-2018) %
Barren land	Area km 2	(1995-2018) %	0.31
Shrubland	111.397	0.912	-1.29
Shrubland	-767.675	-6.286	-1.29
Agricultural land	581.934	4.765	0.39
Water	-6.360	-0.052	-2.83
Forest land	21.622	0.177	0.044
Urban Area	59.183	0.485	4.44

3.3. Land-Use and Land-Cover (LULC) Trends

Table 3 indicates the areas changed with their corresponding percentages based on the change matrix cross-tabulation from 1995 to 2018. In the table, the LULC class is compared to another in terms of the total area LULC class. During the study duration, no changes in water body area were observed, as 92.14% remained intact, followed by agricultural land at 83 %, forest at 82%, shrubland at 79 %, and bare land at 57.3%, and urban area at 14 %. Although the agricultural land did not change much, it was gained from shrubland (506.53 km2) followed by bare land (353.1 km2), forest land (208.4 km2), and18.5 km2 from urban areas. Between 1996 and 2018, shrubland was mainly converted to barren land and forest land, while agriculture was mainly converted to barren land and shrubland. Relatively, greater modifications took place from agricultural land to urban areas.

Table 3. Land Use and Land-Cover (LULC) change matrix between 1995 and 2018.

Land Class	Unit	Agriculture	Bare land	Forest	Shrubland	Urban	Water
Agriculture	Km2	**5335.248**	353.077	208.397	506.525	18.488	6.457
	%	**82.998**	5.493	3.242	7.880	0.288	0.100
Bare land	Km2	145.493	**865.919**	27.718	473.356	0.000	0.084
	%	9.619	**57.248**	1.832	31.295	0.000	0.006
Forest	Km2	102.372	42.469	**1692.730**	232.104	0.000	0.141
	%	4.946	2.052	**81.782**	11.214	0.000	0.007
Shrubland	Km2	194.343	135.773	116.104	**1658.510**	0.000	0.207
	%	9.233	6.450	5.516	**78.791**	0.000	0.010
Urban	Km2	68.522	3.813	3.136	2.197	**12.639**	0.002
	%	75.875	4.222	3.473	2.433	**13.995**	0.002
Water	Km2	0.281	0.121	0.110	0.000	0.000	**6.000**
	%	4.316	1.856	1.689	0.000	0.000	**92.139**

The bold numbers on the diagonal represent unchanged LULC proportions from 1995 to 2018.

3.4. Land Productivity Dynamics

The highest average monthly NDVI value was recorded in August (0.53), September (0.52), and October (0.43). With the exception of the three rainy months, the average NDVI in this area from 2000 to 2020 is very low (NDVI value below 0.4) (Fig.5). The lowest values were found in the less vegetated soils and seemingly because of the reflection from bare soils indicating small NDVI values. In a real sense, the values between 0.2 and 0.4 correspond to rain-fed cropland and grasslands, and higher NDVI (above 0.4) are indicators of high photosynthetic activity linked to shrublands, Eucalyptus tree plantations, and forests in sloppy and mountainous areas of the North Wello Zone (Fig.6). Higher NDVI values help to identify the conditions of vegetation remaining green throughout the year, indicating the effectiveness of land restoration programs. The spatial distribution of NDVI classes for the years 2000 and 2015 in the North Wello administrative zone is shown in Fig.6. The "very weak" and "weak" classes dominate the area, where more croplands and grasslands were observed, which is dry in the Ethiopian dry season. On the other hand, NDVI values higher than 0.63 (moderate and intensive classes) were found in the Raya Kobo, Habru, and Gubalafto districts, in areas associated with forest lands and irrigated agriculture.

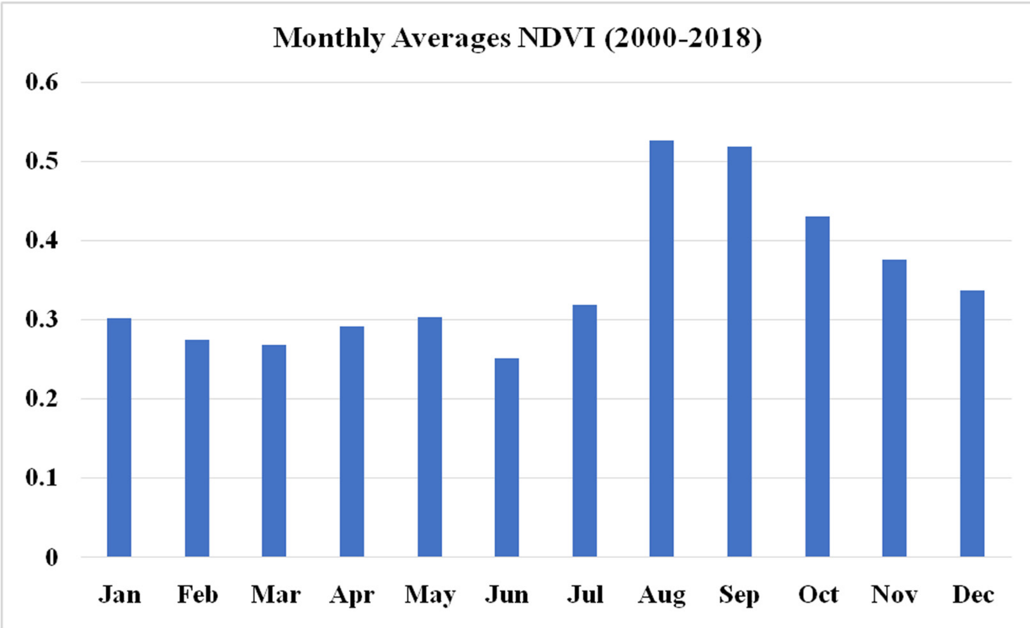

Fig.5. Monthly average NDVI value for the years2000 to 2018

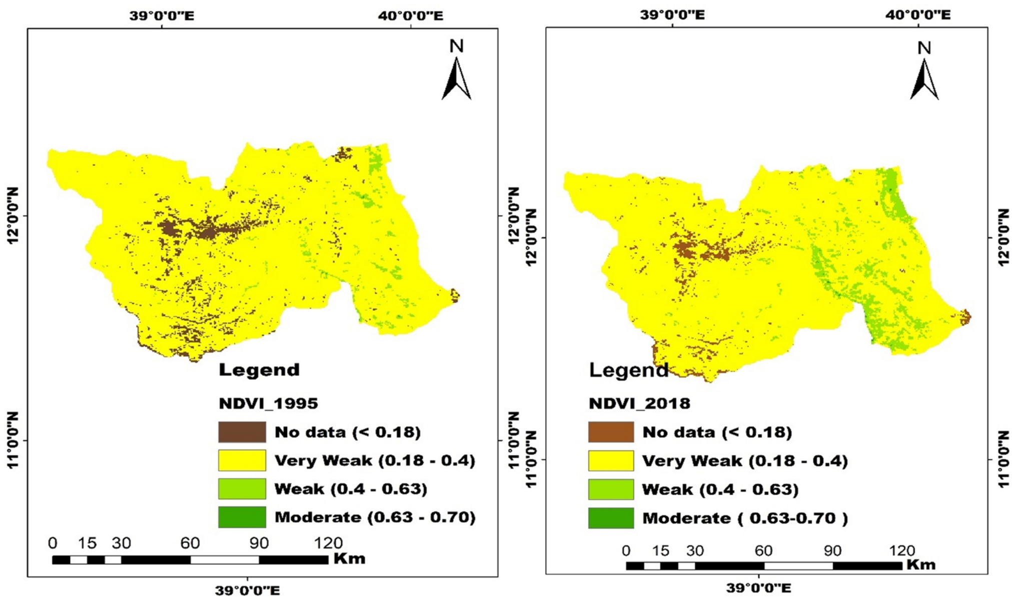

Fig.6: NDVI changes between 1995 and 2020 (Average of January February, and March)

In 1995, the density and abundance of vegetation were classified as "very weak" and "weak," respectively, and were found in nearly 98.6 percent of the study area. Furthermore, the vegetation did not exceed the NDVI value of 0.80 that year, so the "intensive" class did not exist (Table 4). The extension of the "very weak" and "weak" classes decreased in 2018, while the area of the "moderate" and "intensive" classes increased. The rise of more than 4% in the "moderate" class stood out (Table 4). Despite the positive trend, nearly 90% of the area in 2018 was classified as "weak," and the area occupied by the "very weak" and "weak" classes was greater than the "moderate" and "intensive" classes.

Table 4. Distribution of NDVI classes for 1995 and 2018.

NDVI Class	**1995**		**2018**		**Change**	
	Km2	%	Km2	%	km2	%
Moderate	244.202	2.000	796.548	6.526	552.346	+4.525
Very Weak	683.787	5.601	430.347	3.526	-253.440	-2.075
Weak	11280.379	92.399	10959.034	89.783	-321.345	-2.616
Intensive	0.000	0.000	20.271	0.166	20.271	+0.166

Table 5 depicts an analysis of the Land Productivity Dynamics (LPD) calculated from the land cover class and NDVI classes. Forestlands had a "stable, not stressed" productivity (only 4.57 %) in areas with no change in land cover during the period, while persistent grasslands had a "stable but stressed" productivity (8.57 %), and croplands had "stable but stressed" (57.87 %). In areas with negative land cover changes, the most extensive distribution of LPD classes was "declining productivity" (0.001 %) due to shrubland loss; (0.521 %) due to forest loss; (0.055 %) due to agricultural land loss; "early signs of decline" due to forest loss (1.41 %), shrubland loss (10.63 %), and "declining productivity" due to water body decrease (0.002 %).

Fig.7 depicts the spatial and proportional distribution of the LPD classes along the study area. The areas with "increasing productivity" were found in only a few districts across the study area, primarily in the Gubalafto, Mekete, Habru, and Raya Kobo districts, which are considered forest lands (Fig.7). On the contrary, areas classified as "declining productivity" were more prevalent in the Gidan, Lasta, and Ayina Bugna districts of the North Wello administrative zone and were associated with barren land, cropland, and grassland categories.

Most of the territory of the North Wello Zone is stable, with no stressed land productivity condition. It should be noted that land productivity levels differ depending on land cover and land use type, and overall productivity remained stable during the study period. The analysis also revealed that 19.64 percent of the North Wello Zone's total land area exhibits early signs of decline or actual land productivity decline. Land productivity is declining in about 3.5 percent of the study area. Another significant portion of the study area's land, 22.7 percent, demonstrated increased land productivity. In addition, the stable but stressed land productivity class accounts for 1.2 percent of the total study area.

Table 5. Land Cover changes and NDVI classes between 1995 and 2018 for Land Productivity Dynamics

Land cover class 1995	**Land cover class 2018**	**Change**		**NDVI_2018**	**Land productivity Dynamics class**	**Trend**
		Km2	**%**			
Agricultural land	Agricultural land	6976.358	57.868	Very weak	Early signs of decline	No change
Agricultural land	Barren land	94.050	0.780	Weak	Declining productivity	No change
Agricultural land	Forest land	76.366	0.633	Moderate	Increasing productivity	Positive
Agricultural land	Shrubland	557.519	4.625	Weak	Declining productivity	Positive
Agricultural land	Urban Area	6.660	0.055	No vegetation	Declining productivity	Negative
Agricultural land	Water	0.650	0.005	No vegetation	Increasing productivity	Positive
Barren land	Agricultural land	462.335	3.835	Very weak	Increasing productivity	Positive
Barren land	Barren land	172.511	1.431	No vegetation	Declining productivity	No change
Barren land	Forest land	5.314	0.044	Weak	Increasing productivity	Positive
Barren land	Shrubland	6.756	0.056	Weak	Increasing productivity	Positive
Barren land	Urban Area	26.571	0.220	No vegetation	Early signs of decline	Positive
Forest land	Agricultural land	62.767	0.521	Very weak	Declining productivity	Negative
Forest land	Forest land	551.101	4.571	Moderate	Stable, but not stressed	No change

Forest land	Shrubland	170.046	1.411	Moderate	Stable, but not stressed	Negative
Shrubland	Agricultural land	1281.910	10.633	Very weak	Early signs of decline	Negative
Shrubland	Barren land	0.169	0.001	No vegetation	Declining productivity	Negative
Shrubland	Forest land	535.387	4.441	Moderate	Increasing productivity	Positive
Shrubland	Shrubland	1033.960	8.577	Weak	Stable but stressed	No change
Urban Area	Urban Area	33.943	0.282	No vegetation	Declining productivity	No change
Water	Barren land	0.216	0.002	No vegetation	Declining productivity	Negative
Water	Water	0.993	0.008	No vegetation	Stable but stressed	No change

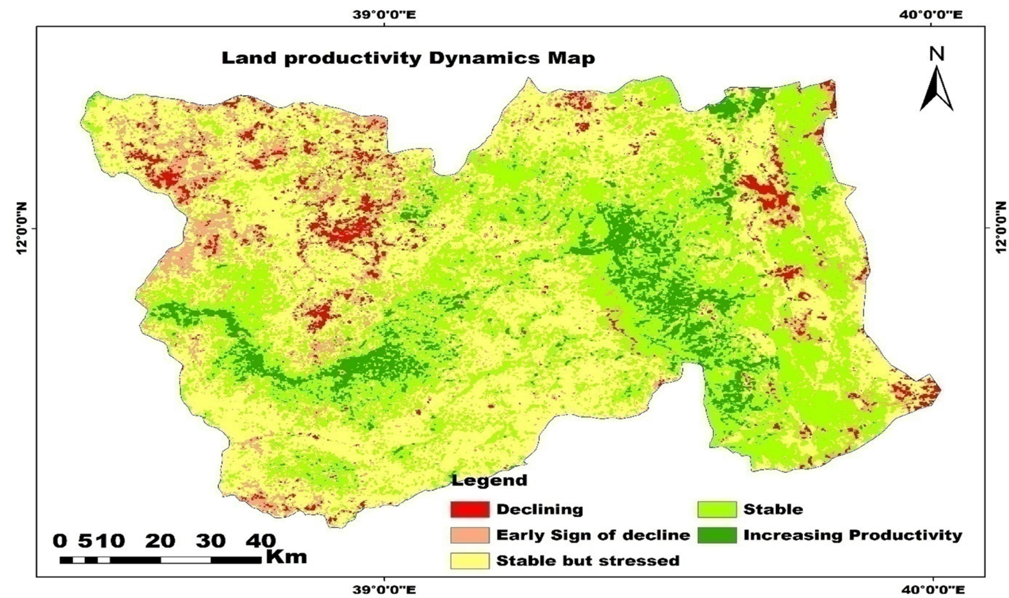

Fig.7. Spatial distribution of Land Productivity Dynamics (LPD) between 1995 and 2018

3.5. Soil Organic Carbon

The maximum and minimum soil organic matter measured at a depth of 30 cm was 248.9 and 10 tons per hectare, respectively. The average soil organic carbon is 46 tons per hectare in the study area. The total soil organic carbon estimated for this study area was 56,211,682 tons. Areal distribution of soil organic carbon is more prevalent on steep slopes and the mountainous regions where the vegetation cover is high. The spatial distribution of SOC stock shows that the lowest content (less than 50 tons of carbon per hectare) coincided with cropland and barren land areas, which were the most extensive in the lowland parts of the study area (Fig.8.). In contrast, the highest SOC concentrations, between 86 and166 tons of carbon per hectare, were found in areas associated with forest lands in the highland parts of the study area. In Fig.8 below, it is clear that soil organic carbon content is higher in forest areas of highlands than in the midland and lowland areas. The highlands of the North Wello zone are relatively higher annual NDVI values than the corresponding topographical positions. Hence, soil organic carbon is associated with the NDVI values in the study area.

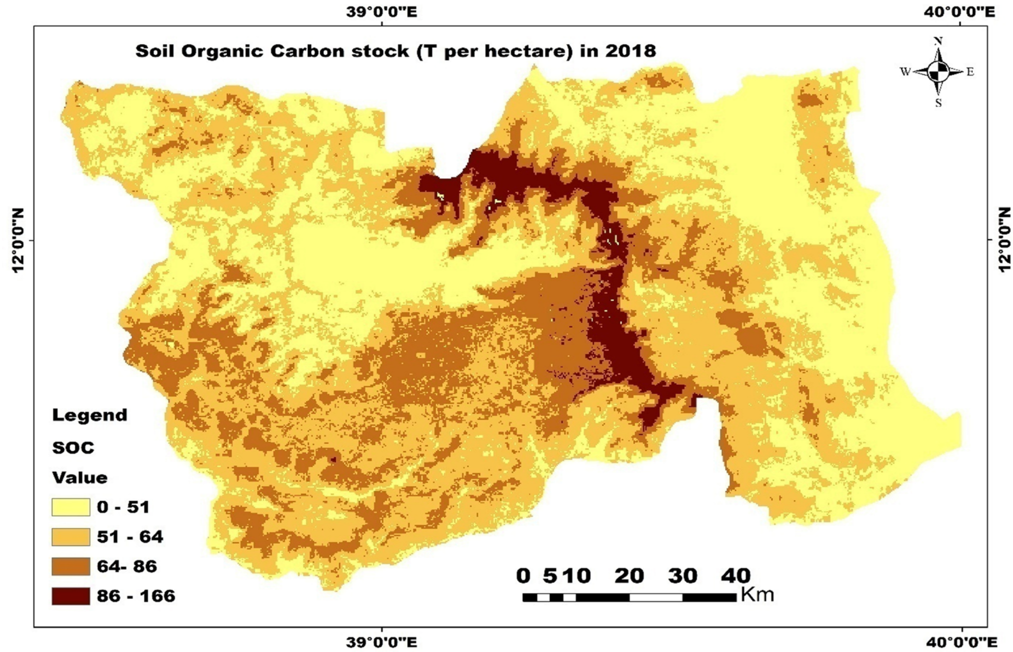

Fig.8: Soil organic carbon Map for North Wello Zone.

The average SOC stock in tons per hectare in each land-use class is presented in Table 6 below. The highest average stock of SOC in tons per hectare was observed in the conversion of barren land to forest land, followed by the conversion of barren land to shrubland, agricultural land to forest land, and barren land to urban area. The lowest stock was observed in barren land and agricultural land which is below 130 tons per hectare.

3.6. Land Degradation Condition

The spatial distribution of land degradation in the North Wello administrative zone occurred in 75 % of the total area. At the same time, the areas with "stable" covered 15 % of the total area. The area with "improvement" status covered only 10 % of the total area (Fig.9). In the study area, in most of the areas in Gubalafto, Habru, and to some extent in Raya Kobo districts, the land productivity conditions show improvement. This is due to the vast implementation of land restoration activities and irrigation practices. In contrast, land productivity conditions are declining in most Lasta and Ayina Bugna districts. This is because of the ineffectiveness of environmental protection. This may be due to the fact that the coordination of institutional support is weak.

Table 6. The average SOC (Soil Organic Carbon) stock of each land cover in 2018

Land cover class 1995	**Land cover class 2018**	**Change**		**SOC stock**
		KM²	%	t ha-1
Agricultural land	Agricultural land	6976.36	57.87	128.76
Agricultural land	Barren land	94.05	0.78	122.19
Agricultural land	Forest land	76.37	0.63	132.07
Agricultural land	Shrubland	557.52	4.62	130.43
Agricultural land	Urban Area	6.66	0.06	126.71
Barren land	Agricultural land	462.34	3.84	126.80
Barren land	Barren land	172.51	1.43	126.99
Barren land	Forest land	5.31	0.04	152.28
Barren land	Shrubland	6.76	0.06	138.03
Barren land	Urban Area	26.57	0.22	132.74
Forest land	Agricultural land	62.77	0.52	122.77
Forest land	Forest land	551.10	4.57	130.16
Forest land	Shrubland	170.05	1.41	128.43
Shrubland	Agricultural land	1281.91	10.63	128.67
Shrubland	Barren land	0.17	0.00	115.74
Shrubland	Forest land	535.39	4.44	128.82
Shrubland	Shrubland	1033.96	8.58	128.31
Urban Area	Urban Area	33.94	0.28	138.47

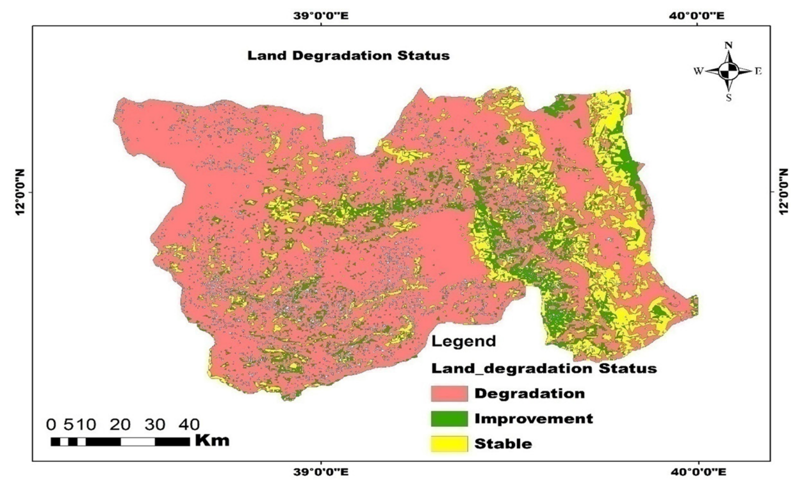

Fig.9. Spatial Distribution of Land Degradation between 1995 and 2018

4. Discussion

The result of this study is obtained by the application of standardized indicators: land cover change, land productivity dynamics, and soil organic carbon, which are used to measure land degradation (UNCCD, 2016; Kust et al., 2017). In the study, the authors employed the approach by Cowie et al. (2018); their “one out, all out” rule states that an area is degraded if at least one of the three indicators shows a negative change. According to this rule, neutrality is the balance of losses and gains for each land-use type in the study area. This study analyzes land use/land cover, productivity dynamics, and soil organic carbon status of the North Wello administrative zone in the Northern parts of Ethiopia.

4.1. Land Use Land Cover Conditions

Unsuitable agricultural practices, combined with high human and livestock population pressure, have resulted in severe land degradation, including biodiversity loss, deforestation, soil erosion, and soil quality degradation (Alemu, 2015; Gashaw et al., 2014). The increase in land degradation in Ethiopia is primarily exacerbated by changes in land use and land cover (Tsegaye, 2019; Mekonnen et al., 2018; Wubie & Assen, 2020; Kidane et al., 2019).

From 1995 to 2018, the forest cover in the study area increased by 21.622 km2. The positive forest cover change may signify high grass biomass and woody plant cover (Reid et al., 2000). However, the forest cover showed spatial variation where the midland seems more forested than the study area’s lowland areas. An increasing expansion of forest land in the study area is due to the plantation of Eucalyptus trees, mainly in the Highlands and Midlands of the North Wello Zone, for better economic benefits.

In this study, between 1995 and 2018, shrubland was mainly converted to the barren land and forest land, while agricultural land was mainly converted to barren land and shrubland. Relatively, greater modifications took place from agricultural land to urban areas. The increase in settlement area in this study result is consistent with the findings of Tolessa et al. (2017) in the central highlands of Ethiopia and Haregeweyn et al. (2012) in Bahirdar. In response to the growing demand for housing and other urban activities, local governments initiated annexing rural land into urban areas through a series of legislative actions (Wubneh, 2018). The peri-urban area is the center where this change is undertaken due to changes in land-use patterns, property rights, and loss of agricultural land. The transformation of agricultural land into urban areas has significant ecological, socio-economic, and environmental impacts.

Another notable result in this study is the increase in forest cover in the study period. The increase in forest cover in this study area may be due to Ethiopia’s PSNP work, which is conducting land management interventions on approximately 600,000 ha (Woolf et al.,2018), which could have the potential to reduce greenhouse gas (GHG) emissions and sequester carbon in biomass and soils. The result is more likely to the findings of Shine (2012) in the Wello area and Bewket (2002) in Chemoga Watershed, Blue Nile Basin of Ethiopia. However, this contradicts the reports by Belay and Mengistu (2019) in the Muger Watershed, Upper Blue Nile; Bewket & Abebe (2013) in the Ethiopian highland Watershed of Blue Nile; Berihun et al. (2019) in drought-prone areas of Ethiopia. A negative change occurred in grasslands and water bodies in the study area. The study shows that 10.6 % of grassland in the study area was converted into agricultural land and 4.4% into forest cover. Studies show that the decline in grassland cover is mainly due to the change in this land-use into forest, shrubland, cultivated and rural settlement land, bare land, and urban built-up area (Giday et al., 2017; Gebrehiwot et al., 2020).

The wetland area is naturally available as shallow lakes in the eastern parts of the study area near the towns of Hara and Kobo. However, nowadays, their availability is critically threatened. For the causes of wetland reduction in the area, we believe that the combined effect of land-use changes in uplands and climate change are prominent as they can affect the water budget.

4.2. Land Productivity Dynamics

The NDVI is widely used to determine the production of green vegetation and vegetation changes. The results of this study show spatial variations in the greenness of the area. The lowest values were found in the less vegetated soils and seemingly because of the reflection from bare soils indicating small NDVI values. Higher NDVI values help identify the conditions of vegetation remaining green throughout the year, indicating the effectiveness of land restoration programs. Dega (Highland) and Weynadega (Midland) areas show annual greenness dominated by evergreen species in the study area. In contrast, Kolla (lowlands) is dominated by Acacia species that flourish during the dry period. Even though the vegetation index has been largely used as a proxy for land degradation (Easdale et al., 2019), the NDVI for the forest with shading leaves in the drier season may not clearly show the actual situation. Thus, land productivity was estimated using net primary productivity, NPP, set by the United Nations Convention to Combat Desertification (UNCCD, 2016). The dynamics of the Earth's biomass cover, or standing biomass, is a good indicator of its ability to provide ecosystem services in the future (Dengiz, 2018). Based on land productivity dynamics parameters, productivity increased across 10% of the study area during the study period and decreased to 7% of the land area. Across a large area, stable land under stress was observed (57.8 %). Early signs of productivity decline (19.5%) were significantly higher than in stable areas (6 % of the study area). Agricultural land converted to shrubland shows signs of declining productivity (4.6 %) when compared to barren land (0.7 percent) and urban areas (0.05 %) of the total land area in the North Wello zone.

The study also looked at the LPD class in persistent shrublands and found that 1033.96 km2 had an "early sign of decline" in productivity due to the "weak" NDVI class. In contrast, 535.4 km2 had "increasing productivity" due to the "moderate" NDVI class, so this area was considered to have the best vegetation conditions and land productivity. In addition to positive changes in land cover and land use, there were differences in LPD classification. This classification, however, was determined by both the NDVI class and the direction of the land cover change. For example, despite having a "weak" NDVI, the transition from barren land to forest land had an "increasing productivity" LPD class. On the other hand, the transition from forest land to shrubland had productivity categorized as "stable but stressed" due to the moderate NDVI class.

The aerial distribution of this increased productivity class is prevalent mainly in the high and midlands, where annual precipitation is not variable in terms of intensity, duration, and timing. The early sign of decline in productivity or declining productivity class were more likely in the lowlands in the eastern and northwest parts of the study area. This implies that there is an urgent need for drought-specific land management practices in that area.

4.3. Soil Organic Carbon Stock

In this study, we used soil organic carbon as an indicator of land degradation neutrality. This is because soil organic carbon reflects slower changes from the net effects of biomass growth and disturbance/ removal, indicating the resilience of land (Cowie et al., 2018). The maximum and minimum soil organic matter measured at a depth of 30 cm was 248.9 and 10 tons per hectare, respectively. The average soil organic carbon is 46 tons per hectare in the study area. The total soil organic carbon estimated for this study area was 56,211,682 tons. Areal distribution of soil organic carbon is more prevalent in high-altitude areas and the mountainous regions where the vegetation cover is high. In Fig.8 below, it is clear that soil organic carbon content is higher in forest areas of highlands than in the midland and lowland areas. The highlands of the North Wello zone have relatively higher annual NDVI values than the corresponding topographical positions. Hence, soil organic carbon is associated with the NDVI values in the study area. The highest amount of carbon in the soil indicates a stable ecosystem, which is observed in the high and midland vegetation areas. The lowlands are very thin in soil organic content.

The findings of this study are consistent with those findings of Abegaza et al. (2020), Abebe et al. (2020); Cha et al. (2020), and Girma et al. (2020) that clearly show that soils of natural vegetation and protected areas of highlands contain the highest amount of SOC stock. As described in the land use categories above, the major (62%) category is found to be cropland. However, previous studies (Abebe et al., 2020; Abegaza et al., 2020; Girma et al.,2020) show that soil carbon sequestration in croplands is small, which is also true in this study. Particularly in the highland areas, the SOC content in cropland was significantly increased from the upper to lower topographic positions (Abebe et al., 2020). This is because the upper lands are often exposed to soil erosion, serving as a source of runoff and sediment for the lower positions (Sun et al., 2015).

In most North Wello lowland areas, the natural vegetation is dominated by deciduous tree and shrub species that contribute significant amounts of organic matter to the soil. However, higher temperature and lower precipitation conditions make soil carbon production in this region may be slow (Fig.8). Empirically, it is true that SOC stocks generally increase as the mean annual temperature decreases (Stockmann et al., 2013). It has also been shown that minor soil disturbance, more incredible vegetation cover, and organic input from grazing animals would improve the SOC in the highland areas (Abebe et al., 2020). The findings show the need for climate-smart land management practices that contribute to soil organic carbon stock and, at the same time, reduce its emission from croplands and grasslands of the study area.

4.4. Land Degradation Neutrality Status

Land degradation is a major contributor to the country's low and declining agricultural production, persistent food insecurity, and negative social consequences (Adem et al., 2020; Gashu & Muchie, 2018). Despite various efforts to reduce the expansion of land degradation in the north Wello zone, there is no updated scientific information on the current status of forests and other vegetation resources, and soil quality in the study area. Thus, the determination of degradation status in this study allowed for the identification of processes that took place in the intervening time of the period analyzed.
Despite positive changes in forest cover, built-up areas, and agricultural expansions, negative changes occurred in water bodies and shrubland, resulting in an arguably degraded administrative zone because improvement or stability in any of the three indicators could not compensate for degradation in another. The total degradation was considered because

the three indicators represented three-fourths of the total area (75 %). This result is more than the regional average of 66% of the total land area of the Amhara Region (Meseret, 2016). Degradation occurred where there were low SOC and NDVI values, transitions from shrubland to cropland, cropland to the barren land, and negative trends in LPD, primarily in agricultural and shrubland areas, while areas of improvement were observed with tiny segments in the highland areas. Croplands had the greatest amount of degraded land, followed by grasslands. More than 65% of early signs of decline in land productivity were observed in the main agricultural area. Only 6% of the study area showed a stable land productivity trend in the study area. Thus, the result provides insight into the need for improved land management of cultivated land in the study area and other similar environments. Previous research in Ethiopia (Alemu, 2015; Hurni et al., 2015; Meseret, 2016) found that soil erosion is the most common degradation process, especially on cropland. The result of the current study implies the need for agricultural transformation to address land degradation. For instance, agroforestry as a farming practice of cultivating trees that can be woody perennials is important for the restoration of degraded land (Baudron et al.,2017; Chavarria et al.,2018; Kassie, 2016), and for enhancing environmental services (Ango et al.,2014). Scattered trees on farmlands enhance crop productivity and reduce soil erosion (Admasu and Jenberu,2022).

5. Conclusion

This study used a UNCCD LDN framework to evaluate three indicators based on different remote sensing data to determine the degradation neutrality status in the north of the Wello administrative zone in northern Ethiopia. Based on the analysis of the three indicators used in this study, it can be concluded that there were negative trends in the agricultural, shrubland, and forest areas. The most noticeable negative land transitions observed were from agricultural to urban areas, from forest to shrubland and agricultural land, and from shrubland to agricultural and barren lands. The land productivity class was either declining or showing early signs of decline in these land-use transitions, and the soil organic carbon stock was lower than in any other land-use transition between 1995 and 2018.

Between 1995 and 2018, agricultural land productivity declined, and early signs of decline covered 8,321 km2 (69 percent) of the total study area territory. Shrublands converted to agricultural land with early signs of decline cover 1281.9 km2 (10.6 percent) of the total area. Shrubland with declining productivity accounted for 557.5 km2 (4.6 percent) of the total area gained from agricultural lands during the study period. The five classes show trends of land productivity over 24 years derived from land use land cover change, and NDVI 1995 to 2018 shows 68.7 % of the land surface show early sign of decline over the observation period, and only 8.9 % of the land surface show increasing productivity trends. Eight-point five percent of the study area land surface show signs of stability but stressed trend including 7.7 % of the land surface showing a decline in productivity, and another 6% which show a clear trend of stable, but not stressed productivity trend. In the study area, the highest SOC is observed in the urban area land category followed by forests. Based on the three indicators used, 75 % of the total study area is estimated as a degradation state which mainly occurred on croplands, followed by grasslands.

The present research showed alarming signs of land degradation in the North Wello Zone, as indicated by a net loss in LULC. Similarly, the NDVI and Soil organic carbon only have small spatial coverage, typical in the midlands part of the study area. Therefore, the current management approaches should be improved and supported by well-organized institutions and knowledge-based decision-making by experts to combat land degradation and sustainably increase land productivity on degraded land through sustainable land use management practices. Grassland management, which encompasses erosion control, controlled grazing, availability of strategic watering points for livestock drinking, and different water harvesting structures, could be effective for land degradation neutrality status. It is obvious that land degradation is caused by a combination of factors. Because this is a highly complex process of change, more research is needed to understand the context-specific socioeconomic and biophysical degradation factors. The findings of this study will encourage further research to understand the complex relationships of land change processes and are the first step toward achieving land degradation neutrality.

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Authors' contributions

The first author generated the idea and designed the study and carried out the data collection, data analysis, and write-up. The second and the third authors read and revised the manuscript. Finally, both authors read and approved the final version of the manuscript.

Competing interests

The authors declare that they have no financial and non-financial competing interests.

Missing Data Availability Statement

The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

References

Abebe, G., Tsunekawa, A., Haregeweyn, N., Takeshi, T., Wondie, M., Adgo, E. ... & Tassew, A. (2020). Effects of Land Use and Topographic Position on Soil Organic Carbon and Total Nitrogen Stocks in Different Agro-Ecosystems of the Upper Blue Nile Basin. *Sustainability,* 12(6), 2425.

Abegaz, A., Tamene, L., Abera, W., Yaekob, T., Hailu, H., Nyawira, S. S. ... & Sommer, R. (2020). Soil organic carbon dynamics along with chrono-sequence land-use systems in the highlands of Ethiopia. *Agriculture, Ecosystems & Environment,* 300, 106997.

Abera, W., Assen, M., & Budds, J. (2020). *Determinants of agricultural land management practices among smallholder farmers in the Wanaka watershed, northwestern highlands of Ethiopia. Land Use Policy,* 99, 104841.

Adem, M., Solomon, N., Movahhed Moghaddam, S., Ozunu, A., & Azadi, H. (2020). The nexus of economic growth and environmental degradation in Ethiopia: time series analysis. *Climate and Development,* 12(10), 943-954.

Adem, M., Solomon, N., Movahhed Moghaddam, S., Ozunu, A., & Azadi, H. (2020). The nexus of economic growth and environmental degradation in Ethiopia: time series analysis. *Climate and Development,* 12(10), 943-954.

Admasu, T. G., & Jenberu, A. A. (2022). The impacts of Apple-based Agroforestry Practices on the Livelihoods of Smallholder Farmers in Southern Ethiopia. Trees, *Forests and People,* 7, 100205.

Alemu, B. (2015). The effect of land use land cover change on land degradation in the highlands of Ethiopia. *Journal of Environment and Earth Science,* 5(1), 1-13.

Ango, T. G., Börjeson, L., Senbeta, F., & Hylander, K. (2014). Balancing ecosystem services and disservices: smallholder farmers' use and management of forest and trees in an agricultural landscape in southwestern Ethiopia. *Ecology and Society,* 19(1).

Anteneh, M. (2021). *Analysing The Feature of Meteorological Drought in North East Ethiopia: The Case of Meket and Wadla Districts in North Wello Zone, Amhara Region.*

Arroyo, I., Cervantes, V., Tamaríz-Flores, V., & Castelán, R. (2022). *Land Degradation Neutrality: State and Trend of Degradation at the Subnational Level in Mexico. Land,* 11(4), 562.

Barbier, E. B., & Hochard, J. P. (2018). Land degradation and poverty. *Nature Sustainability,* 1(11), 623-631.

Baskan, O., Dengiz, O., & Demirag, İ. T. (2017). The land productivity dynamics trend as a tool for land degradation assessment in a dryland ecosystem. *Environmental monitoring and assessment,* 189(5), 1-21.

Baskan, O., Dengiz, O., & Demirag, İ. T. (2017). The land productivity dynamics trend as a tool for land degradation assessment in a dryland ecosystem. *Environmental monitoring and assessment,* 189(5), 1-21.

Batar, A. K., Watanabe, T., Kumar, A., & Kumria, P. (2017). *Land Use/Land Cover Change dynamics and its Impacts using geospatial data in Rudraprayag district, Garhwal Himalaya of India.*

Baudron, F., Chavarría, J.-Y.D., Remans, R., Yang, K., & Sunderland, T. (2017). Indirect contributions of forests to dietary diversity in Southern Ethiopia. *Ecology and Society,* 22(2).

Belay, T., & Mengistu, D. A. (2019). *Land use and land cover dynamics and drivers in the Muga watershed, Upper Blue Nile basin, Ethiopia. Remote Sensing Applications: Society and Environment,* 15, 100249.

Berihun, M. L., Tsunekawa, A., Haregeweyn, N., Meshesha, D. T., Adgo, E., Tsubo, M. ... & Yibeltal, M. (2019). *Exploring land use/land cover changes, drivers and their implications in contrasting agro-ecological environments of Ethiopia.* Land Use Policy, 87, 104052.

Bewket, W. (2002). Land cover dynamics since the 1950s in Chemoga watershed, Blue Nile basin, Ethiopia. *Mountain research and development,* 22(3), 263-269.

Bewket, W., & Abebe, S. (2013). Land-use and land-cover change and its environmental implications in a tropical highland watershed, Ethiopia. *International journal of environmental studies,* 70(1), 126-139.

Bishaw, B. (2001). Deforestation and land degradation in the Ethiopian highlands: a strategy for physical recovery. *Northeast African Studies*, 7-25.

Cha, S., Kim, C. B., Kim, J., Lee, A. L., Park, K. H., Koo, N., & Kim, Y. S. (2020). Land-use changes and practical application of the land degradation neutrality (LDN) indicators: a case study in the subalpine forest ecosystems, *Republic of Korea. Forest Science and Technology,* 16(1), 8-17.

Chavarría, J.-Y.D., Baudron, F., & Sunderland, T. (2018). Retaining forests within agricultural landscapes as a pathway to sustainable intensification: Evidence from Southern Ethiopia. *Agriculture, ecosystems & environment,* 263, 41-52.

Conway, D. (2000). Some aspects of climate variability in the northeast Ethiopian Highlands-Wollo and Tigray. Sinet: *Ethiopian Journal of Science,* 23(2), 139-161.

Cowie, A. L., Orr, B. J., Sanchez, V. M. C., Chasek, P., Crossman, N. D., Erlewein, A., ... & Tengberg, A. E. (2018). Land in balance: The scientific conceptual framework for Land Degradation Neutrality. *Environmental Science & Policy*, 79, 25-35.

Damene, S., Tamene, L., & Vlek, P. L. (2013). Performance of exclosure in restoring soil fertility: a case of Gubalafto district in North Wello Zone, northern highlands of Ethiopia. *Catena,* 101, 136-142.

De la Fuente, B., Weynants, M., Bertzky, B., Delli, G., Mandrici, A., Garcia Bendito, E., & Dubois, G. (2020). Land productivity dynamics in and around protected areas globally from 1999 to 2013.*Plos one,* 15(8), e0224958.

Dengiz, O. (2018). The potential impact of land-use changes on land productivity dynamics with a focus on land degradation in a sub-humid terrestrial ecosystem. *Theoretical and Applied Climatology,* 133(1-2), 73-88.

Easdale, M. H., Fariña, C., Hara, S., León, N. P., Umaña, F., Tittonell, P., & Bruzzone, O. (2019). Trend-cycles of vegetation dynamics as a tool for land degradation assessment and monitoring.*Ecological Indicators,* 107, 105545.

Easdale, M. H., Fariña, C., Hara, S., León, N. P., Umaña, F., Tittonell, P., & Bruzzone, O. (2019). Trend-cycles of vegetation dynamics as a tool for land degradation assessment and monitoring.*Ecological Indicators,* 107, 105545.

Elias, E., & Fantaye, D. (2000). *Managing fragile soils: A case study from North Wollo, Ethiopia.* London, UK: IIED.

FAO. (2013). *Climate-smart agriculture sourcebook.* Food and Agriculture Organizations of United States, Rome Italy,2013.

FAO.Food and Agriculture Organization. (2011). The state of food insecurity in the world: how does international price volatility affect domestic economies and food security?

Gashaw, T. (2015). The implications of watershed management for reversing land degradation in Ethiopia. *Research Journal of Agriculture and Environmental Management,* 4(1), 5-12.

Gashaw, T., Bantider, A., & Mahari, A. (2014). Evaluations of land use/land cover changes and land degradation in Dera District, Ethiopia: GIS and remote sensing-based analysis. I*nternational Journal of Scientific Research in Environmental Sciences,* 2(6), 199.

Gashu, K., & Muchie, Y. (2018). Rethink the interlink between land degradation and livelihood of rural communities in Chilga district, Northwest Ethiopia. Journal of Ecology and Environment, 42(1), 1-11.

Gashu, K., & Muchie, Y. (2018). Rethink the interlink between land degradation and livelihood of rural communities in Chilga district, Northwest Ethiopia. *Journal of Ecology and Environment,* 42(1), 1-11.

Gebrehiwot, K., Teferi, E., Woldu, Z., Fekadu, M., Desalegn, T., & Demissew, S. (2021). Dynamics and drivers of land cover change in the Afroalpine vegetation belt: Abune Yosef mountain range, Northern Ethiopia. Environment, *Development and Sustainability,* 23(7), 10679-10701.

Gidey, E., Dikinya, O., Sebego, R., Segosebe, E., & Zenebe, A. (2017). Modeling the Spatio-temporal dynamics and evolution of land use and land cover (1984–2015) using remote sensing and GIS in Raya, Northern Ethiopia. *Modeling Earth Systems and Environment,* 3(4), 1285-1301.

Girma, D., Wogi, L., & Feyissa, S. (2020). Effect of Land use Types on Soil Organic Carbon Stock at Sire Morose Sub Watershed, Hidabu Abote District of North Shoa Zone, and Central Highland of Ethiopia. *Science Research,* 8(1), 1.

Grainger, A. (2015). Is land degradation neutrality feasible in dry areas? *Journal of Arid Environments,* 112, 14-24.

Gupta, G. S. (2019). Land degradation and challenges of food security. *Rev. Eur. Stud.,* 11, 63.

Haregeweyn, N., Fikadu, G., Tsunekawa, A., Tsubo, M., & Meshesha, D. T. (2012). The dynamics of urban expansion and its impacts on land use/land cover change and small-scale farmers living near the urban fringe: A case study of Bahir Dar, Ethiopia. *Landscape and urban planning,* 106(2), 149-157.

Henry, B., McKeon, G., Syktus, J., Carter, J., Day, K., & Rayner, D. (2007). *Climate variability, climate change, and land degradation. In Climate and land degradation* (pp. 205-221). Springer, Berlin, Heidelberg.

Hermans, K., & McLeman, R. (2021). Climate change, drought, land degradation and migration: exploring the linkages. C*urrent Opinion in Environmental Sustainability,* 50, 236-244.

Herrick, J. E., Sala, O. E., & Karl, J. W. (2013). Land degradation and climate change: a sin of omission. *Frontiers in Ecology and the Environment,* 11(6), 283-283.

Hidalgo, C., Merino, A., Osorio-Hernández, V., Etchevers, J. D., Figueroa, B., Limon-Ortega, A., & Aguirre, E. (2019). Physical and chemical processes determining soil organic matter dynamics in a managed vertisol in a tropical dryland area. *Soil and Tillage Research,* 194, 104348.

Holden, S., Shiferaw, B., & Pender, J. (2004). Non-farm income, household welfare, and sustainable land management in a less-favoured area in the Ethiopian highlands.*Food policy,* 29(4), 369-392.

Hurni, H., Abate, S., Bantider, A., Debele, B., Ludi, E., Portner, B., ...& Zeleke, G. (2010). *Land degradation and sustainable land management in the highlands of Ethiopia.*

Hurni, K., Zeleke, G., Kassie, M., Tegegne, B., Kassawmar, T., Teferi, E., . . . Degu, Y. (2015). E*conomics of Land Degradation (ELD) Ethiopia Case Study: Soil degradation and sustainable land management in the rainfed agricultural areas of Ethiopia: An assessment of the economic implications.*

IPCC (2019). *Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. 2019. In The approved Summary for Policymakers* (SPM) was presented at a press conference on (Vol. 8).

Jia, G., Shevliakova, E., Artaxo, P., De-Docoudré, N., Houghton, R., House, J., . . . Sirin, A. (2019). *Land–climate interactions Special Report on Climate Change and Land: An IPCC Special Report on climate change, desertification, land degrad*ation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (pp. 133-206): IPCC.

Kassie, G. W. (2016). Agroforestry and land productivity: Evidence from rural Ethiopia. *Cogent Food & Agriculture*, 2(1), 1259140.

Kidane, M., Bezie, A., Kesete, N., & Tolessa, T. (2019). The impact of land use and land cover (LULC) dynamics on soil erosion and sediment yield in Ethiopia. *Heliyon,* 5(12), e02981.

Kouassi, J.-L., Gyau, A., Diby, L., Bene, Y., & Kouamé, C. (2021). Assessing land use and land cover change and farmers' perceptions of deforestation and land degradation in South-West Côte d'Ivoire, West Africa. *Land, 1*0(4), 429.

Kust, G., Andreeva, O., & Cowie, A. (2017). Land Degradation Neutrality: Concept development, practical applications and assessment. *Journal of environmental management*, 195, 16-24.

Mariye, M., Mariyo, M., Changming, Y., Teffera, Z. L., & Weldegebrial, B. (2022). Effects of land use and land cover change on soil erosion potential in Berhe district: A case study of Legedadi watershed, Ethiopia. *International Journal of River Basin Management,* 20(1), 79-91.

MEA. 2005. *Ecosystems and Human Well-Being: Synthesis.* World Resources Institute, Washington, DC.

Mekonnen, Z., Berie, H. T., Woldeamanuel, T., Asfaw, Z., & Kassa, H. (2018). Land use and land cover changes and the link to land degradation in Arsi Negele district, Central Rift Valley, Ethiopia. Remote Sensing Applications: *Society and Environment*, 12, 1-9.

Meseret, D. (2016). Land degradation in Amhara Region of Ethiopia: review on extent, impacts and rehabilitation practices. *J. Environ. Earth Sci,* 6(1), 120-130.

Meseret, D. (2016). Land degradation in Amhara Region of Ethiopia: review on extent, impacts and rehabilitation practices. *J. Environ. Earth Sci,* 6(1), 120-130.

Mohamed, E., Belal, A.-A., Ali, R., Saleh, A., & Hendawy, E. A. (2019). Land degradation. *The soils of Egypt,* 159-174.

Nega, W., Hailu, B. T., & Fetene, A. (2019). An assessment of the vegetation cover change impact on rainfall and land surface temperature using remote sensing in a subtropical climate, Ethiopia. Remote Sensing Applications: *Society and Environment,* 16, 100266.

Nyssen, J., Poesen, J., Lanckriet, S., Jacob, M., Moeyersons, J., Haile, M., . . . Adgo, E. (2015). *Land degradation in the Ethiopian highlands Landscapes and landforms of Ethiopia* (pp. 369-385): Springer.

Okpara, U. T., Stringer, L. C., Akhtar-Schuster, M., Metternicht, G. I., Dallimer, M., & Requier-Desjardins, M. (2018). A social-ecological systems approach is necessary to achieve land degradation neutrality. *Environmental science & policy*, 89, 59-66.

Reed, M. S., & Stringer, L. C. (2016). *Land degradation, desertification and climate change: Anticipating, assessing and adapting to future change.* Routledge.

Reid, R. S., Kruska, R. L., Muthui, N., Taye, A., Wotton, S., Wilson, C. J., & Mulatu, W. (2000). Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: the case of southwestern Ethiopia. *Landscape Ecology,* 15(4), 339-355.

Rotllan-Puig, X., Ivits, E., & Cherlet, M. (2021). LPDynR: A new tool to calculate the land productivity dynamics indicator. *Ecological Indicators,* 133, 108386.

Safriel, U. (2017). *Land Degradation Neutrality (LDN) in drylands and beyond–where has it come from and where does it go.* Silva Fennica, 51(1B), 20-24.

Sanz, M. J., De Vente, J. L., Chotte, J. L., Bernoux, M., Kust, G., Ruiz, I., ...& Hebel, A. (2017). *Sustainable land management contribution to successful land-based climate change adaptation and mitigation:* A report of the science-policy interface.

SD Shiene (2012). *"Effectiveness of soil and water conservation measures for land restoration in the Wello area, northern Ethiopian highland."* PhD diss., Universitäts-und Landesbibliothek Bonn, 2012.

Searchinger, T., Hanson, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., ...& Dumas, P. (2014). *Creating a sustainable food future.A menu of solutions to sustainably feed more than 9 billion people by 2050. World resources report 2013-14: interim findings.*

Sivakumar, M. V., & Ndiang'Ui, N. (Eds.). (2007). *Climate and land degradation.Springer Science & Business Media.*

Sivakumar, M. V., & Ndiang'Ui, N. (Eds.).(2007). *Climate and land degradation.Springer Science & Business Media.*

Speranza, C. I., Adenle, A., & Boillat, S. (2019). Land Degradation Neutrality-Potentials for its operationalisation at multi-levels in Nigeria. *Environmental science & policy,* 94, 63-71.

Stockmann, U., Adams, M. A., Crawford, J. W., Field, D. J., Henakaarchchi, N., Jenkins, M., ...& Wheeler, I. (2013). T*he* knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, *Ecosystems & Environment,* 164, 80-99.

Sun, W., Zhu, H., & Guo, S. (2015). Soil organic carbon as a function of land use and topography on the Loess Plateau of China. *Ecological Engineering,* 83, 249-257.

Tesfa, A., & Mekuriaw, S. (2014). The effect of land degradation on farm size dynamics and crop-livestock farming system in Ethiopia: a review. *Open Journal of Soil Science,* 2014.

Tessema, K. B., Haile, A. T., & Nakawuka, P. (2021). Vulnerability of community to climate stress: An indicator-based investigation of Upper Gana watershed in Omo Gibe basin in Ethiopia. *International Journal of Disaster Risk Reduction*, 63, 102426.

Thiombiano, L., & Tourino-Soto, I. (2007). *Status and trends in land degradation in Africa. In Climate and land degradation* (pp. 39-53). Springer, Berlin, Heidelberg.

Tolessa, T., Senbeta, F., & Kidane, M. (2017). The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. *Ecosystem services,* 23, 47-54.

Tsegaye, B. (2019). Effect of land use and land cover changes on soil erosion in Ethiopia. *International Journal of Agricultural Science and Food Technology,* 5(1), 026-034.

UNCCD (2015): C*limate change and land degradation: Bridging knowledge and stakeholders: Outcomes from the UNCCD 3rd Scientific Conference*

UNCCD (2016): *Land Degradation Neutrality Target Setting Programme. Draft for consultation during the Land Degradation Neutrality Target Setting Programme inception phase, May 2016*

Webb, N. P., Marshall, N. A., Stringer, L. C., Reed, M. S., Chappell, A., & Herrick, J. E. (2017). Land degradation and climate change: building climate resilience in agriculture. *Frontiers in Ecology and the Environment,* 15(8), 450-459.

Winterbottom, R., Reij, C., Garrity, D., Glover, J., Hellums, D., McGahuey, M., & Scherr, S. (2013). *Improving land and water management. World Resources Institute Working Paper).*Accessed on April 2, 2014.

Woolf, D., Solomon, D., & Lehmann, J. (2018). Land restoration in food security programmes: synergies with climate change mitigation. *Climate Policy,* 18(10), 1260-1270.

Wubie, M. A., & Assen, M. (2020). Effects of land cover changes and slope gradient on soil quality in the Gumara watershed, Lake Tana basin of North–West Ethiopia. *Modeling Earth Systems and Environment,* 6(1), 85-97.

Wubneh, M. (2018). Policies and praxis of land acquisition, use, and development in Ethiopia. *Land Use Policy,* 73, 170-183.