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Assessing Land Degradation Neutrality Status Using Geospatial Techniques in North Wello Zone, Northern Ethiopia

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Abstract

Land degradation is increasingly recognized as a serious, nationwide environmental concern in Ethiopia. The key concern is the interlinked relations between land degradation, climate change and agriculture, exacerbating one another via negative and positive feedback loops. The purpose of this study was to analyze land productivity dynamics trends and land degradation conditions in the North Wello Zone using three United Nations Convention to Combat Desertification (UNCCD) indicators, with land cover change, land productivity dynamics and soil organic carbon stock. Land use land cover data was provided by earthmap.org platform for the time of 1995 to 2018. Moderate Resolution Imaging Spectroradiometer (MOD13Q1) Normalized *Difference Vegetation Index (NDVI) data were used from the year 2000 to 2020 to analyze the net primary productivity. For soil organic carbon,* we used the *global soil organic carbon map for the year 2019. The global soil carbon map was developed as 1 km soil grids, covering a depth of 0-30 cm. The land degradation neutrality (LDN) status of the study area was estimated by integration of results of the three indicators based on a "one out, all out" approach. Over the study periods of 1995 to 2018, significant land use land cover change was observed. Forest land during the last 23 years increased by 70.71 square kilometers. The settlement areas also increased by 4.47 square kilometers in the same period. However, the croplands, grasslands and wetlands shows negative change in 1995 to 2018. The stock of soil organic carbon in North Wello Zone shows spatial variations. Soil organic carbon is highly concentrated in midland areas where forest cover is high. However, the NDVI value calculated for the year 2000 to 2020 did not show significant difference but the trend line shows positive. Concurrently, the land productivity dynamics for the year 2000 to 2020 shows only half of the total study area is stable and less stressed land productivity status. This research indicated alarming signs of declining land capital North Wello Zone. Negative changes occurred one of the three indicators of which shows a tendency for land degradation. Therefore, we believe that balancing measures to achieve land degradation neutrality should be implemented as quickly as possible.*

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

1. Introduction

Land is the component of Mother Nature serving as infrastructure for much of life on earth (Safariel 2007), which provides the principal basis for human livelihoods and well-being, which includes the supply of food, freshwater, and multiple other ecosystem services as well as biodiversity (IPCC, 2019). As to the Millennium Ecosystem Assessment (MEA, 2005), the term 'land' encompasses renewable natural resources, such as soils, water, vegetation, and wildlife, in their terrestrial ecosystems.

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Land scientists estimated that about 11% of the global land surface is prime land, yet this must feed the 6 billion people inhabiting the world today and the 8.2 billion people expected by the year 2020 (Sivakumar & Ndiang, 2007). During 2013, 37 % of the earth's landmass, except Antarctica, cultivated to grow food, 12 % as croplands and 25 % as grazing lands (Searchinger et al., 2013). Food production will increase by 70 % worldwide and by 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 pose enormous risks to global food security (Webb et al., 2017). According to Hurni et al. (2010), the term land degradation refers to all processes that diminish the capacity of land resources to perform essential functions and services in terrestrial ecosystems, due to deforestation, loss of biodiversity, soil degradation, and disturbance of water cycles. Climate change and land degradation have an interlinked, driving or exacerbating one another through positive and negative feedback loops (Reed et al., 2016). The quality of the land can be influenced by climatic factors and the deterioration of land conditions, in turn, has been shown to have an impact on the atmosphere and future climate (Henry et al., 2007). Land degradation increases the vulnerability of agro-ecological systems to climate change and reduces the effectiveness of adaptation options (Webb et al., 2017). The relationship between agriculture and land degradation may be conflicting (win-lose) or synergistic (win-win) (Tengberg & Torheim, 2007). A win-lose relationship occurs when agricultural activities are driven by land degradation and climate change (IPCC, 2007). For instance, increased food production through intensification or the use of more inorganic inputs may cause land degradation and climate change. However, the loss and degradation of soil and vegetation significantly reduce potential carbon sinks (FAO, 2013). Whereas, a synergistic linkages of agriculture and land resources can be described as when sustainable agricultural production and land degradation neutrality is achieved concurrently (FAO, 2013).

According to the FAO (2011), land and water systems are declining their productive capacity due to high population pressure and unsustainable agricultural practices. The physical limits to land and water availability within these systems may be further exacerbated by land-use change, land-use intensification, and climate change (IPCC, 2019). Climate change can exacerbate and accelerate land degradation through various means, including accelerated soil erosion, increased evapotranspiration rates, drought, and changes in biodiversity, pests, and diseases (Webb et al., 2017). On the other hand, land degradation is a threat to natural resources, resulting in food insecurity, poverty, and environmental and political instability Sivakumar & Ndiang, 2007).

Long-term food productivity is threatened by soil degradation, especially in Sub-Saharan Africa (Sivakumar & Ndiang, 2007). The World Bank estimation shows that at least 485 million Africans are affected by land degradation, and Africa costs $9.3 billion annually due to this phenomenon (Thiombiano & Tourino-Soto, 2007). In Ethiopia, land degradation is one of the most challenging problems (Badege, 2001; Hurni et al., 2010; Mekuria et al., 2007; Taddese, 2001; Teketay, 2001). The causes of land degradation in Ethiopia are population pressure, soil loss through erosion, deforestation, land use change, overgrazing, intensive cultivation and climate change (Holden & Shiferaw, 2004; Hurni et al., 2010; Taddese, 2001; Teketay, 2001). As a cumulative effect of land degradation, increasing population pressure, and low agricultural productivity, Ethiopia has become dependent on food aid (Kassie et al., 2010).

Hence, UNCCD develops the concepts of land degradation neutrality to reverse the land degradation, climate change, and food insecurity problems. Land degradation neutrality is a concept which is described as a state of equilibrium in land systems (Kust et al., 2017). It represents an urgent and comprehensive action to address degradation (Okpara et al., 2018). The aspirational goal of a land degradation neutral world, to be realized by reducing the rate of land degradation and increasing the restoration of degraded land, was agreed at the Rio+20 Conference in 2012 (Grainger, 2015). One of the Africa Consensus Statements to Rio+20 in sustainable development goals is achieving zero net land degradation and the target of food security and poverty eradication (UNCCD, 2012). The scientific community asserted that sustainable land management is one of the mechanisms for achieving land degradation neutrality (LDN) (Sanz et al., 2017). This is because land management practices can contribute significantly to climate change mitigation through carbon sequestration and improve land productivity and production (UNCCD, 2015).

Within this context, many varied solutions were promoted in Ethiopia in response to land degradation, climate change and food insecurity problems through different projects and programs. After 1974 famine in Ethiopia a massive soil and water conservation practices was implemented to respond food insecurity and low agricultural productivity (Kassie et al, 2008). Through food for work incentive approach provided by international, multilateral and bilateral organizations of which the European Economic Commission, UNDP and FAO; massive efforts were undertaken to build physical structures to control soil erosion and to rehabilitate degraded lands (FAO, 2003). The food for work approach was focused on soil and water conservation practices, construction of soil and stone bund, terraces, cut-off drains and micro-basins, and afforestation of fragile and hillside areas(Desta, 2005). Though large areas of the highlands were covered with terraces, soil bunds, area closures and trees the effect was evaluated as under the intended outcome and unsustainable (Bekele and Holden, 1998; Yeraswork, 2000; Menale, et al., 2009). These study also shows the reason for the failure of past soil and water conservation programs had largely due to poor design of structures, inappropriate conservation methods, and poor linkages with livelihoods of the poor and lack of land policy and resource management problems.

In 1980's watershed management program was launched and practiced aiming with to decrease the problem of land degradation and increase land productivity (Gete, 2006). Furthermore, a huge social protection program (productive safety net program) was launched in food insecure districts in 2005 to build community-level assets through soil and water conservation (Devereux et al., 2006). In the early 2000s, community-based integrated watershed development program was also familiarized to promote watershed management as tool to attain integrated natural resource management and livelihood improvement objectives considering agro-ecological and socioeconomic environments. The results suggest that watershed management has had a positive impact on natural resource conservation, crop-livestock production and productivity, socioeconomic conditions and livelihoods (Gebregziabher et al., 2016). All these efforts may help for the achievement of LDN in goal 15 of the Sustainable Development Goals (SDGs) 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." Target 15.3 of the sustainable development goal goes further in its ambitions to: "by 2030, combat desertification, and restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation neutral world" (Kust et al., 2017). In this regard, the land degradation neutrality status information via the evaluation with land degradation neutrality indicators is scarce in North wello zone in particular and Ethiopia in general.

Therefore, the aim of this study was to analyze the status of in land degradation neutrality in the North Wello Zone, Northern Ethiopia. The LDN status was assessed using three indicators consisting of land use/land cover (LULC) change, land productivity dynamics, and soil organic carbon (SOC) change. The integration of LULC change, land productivity dynamics, and SOC change based on a "one out, all out" system was used for the determination of land degradation neutrality status.

2. Materials and Methods

2.1. Study Area

This study was conducted in the northeastern parts of the Amhara Regional states, particularly in the North Wello zone. The capital of North Wello was Woldia. The area is located between 11°30´0´´ and 12°30´0´´ N latitude and 38°30´0´´ to 40°0´0´´ E longitude (Fig.1).

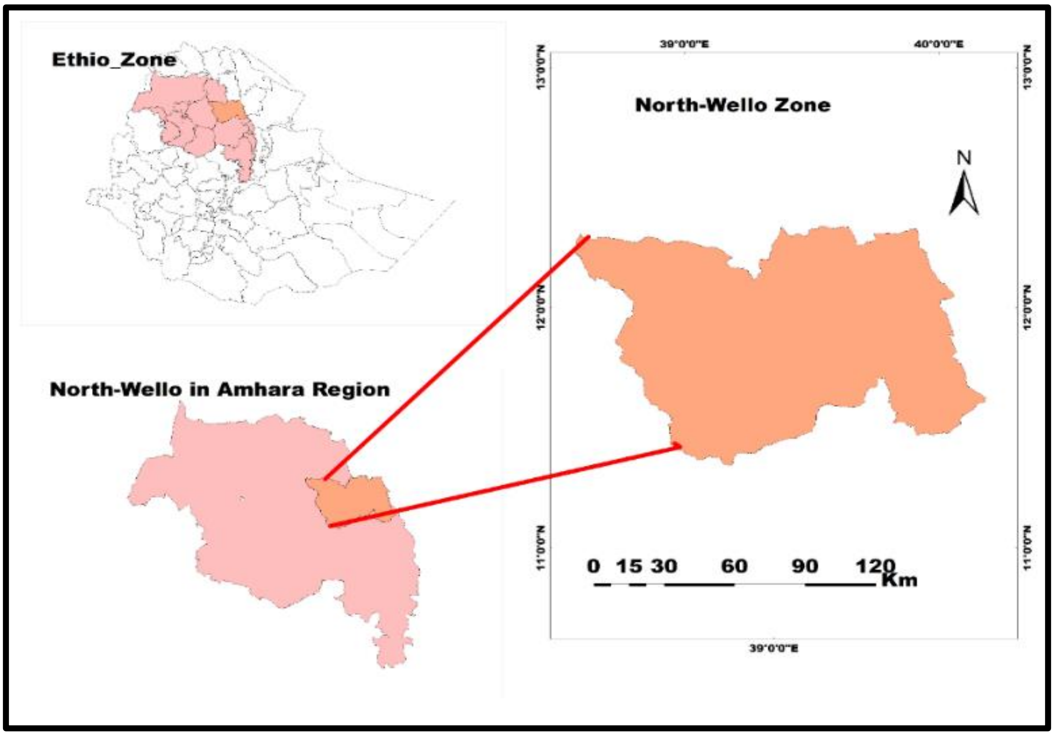

Fig.1: Map of the study area

The elevation in this study area ranges from 960 to 4265 m above the mean sea level. The highest and lowest altitudes in the North Wello Zone are located in the Lasta and Habru districts, respectively (Fig.2). The relief differences would have a significant influence on the climate, soil, and biota variations across the area.

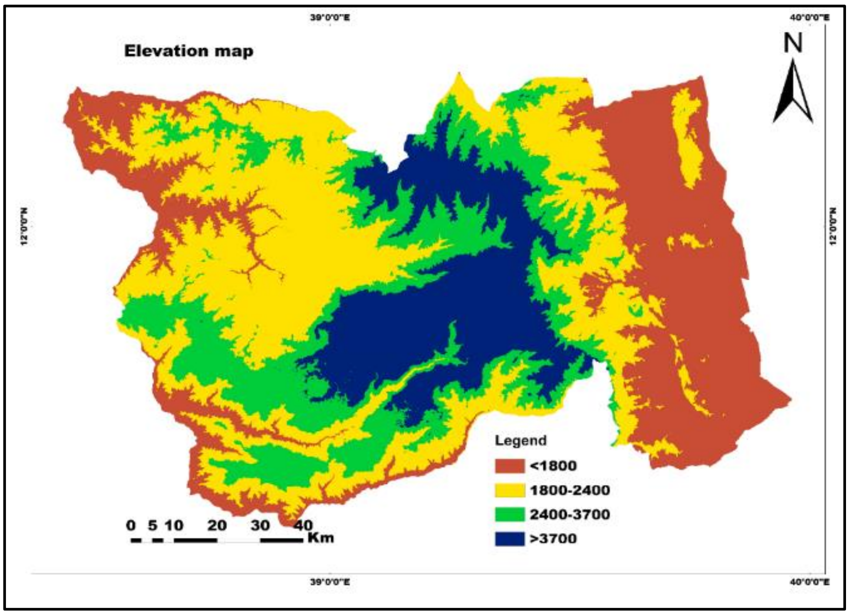

Fig. 2: Elevation map of North Wello Zone: Source Ethiopia DEM map

The DEM analysis also indicates that the majority of areas are steep slopes 15 % to 30 % to extremely steep slopes 30 % to 60 % covering 25.15 % and 36.06 % of the total area, respectively. As suggested by Hurni (1988), land with slopes of less than 15% is suitable for agriculture. However, this area accounted for only 31% of the total area (Fig. 3).

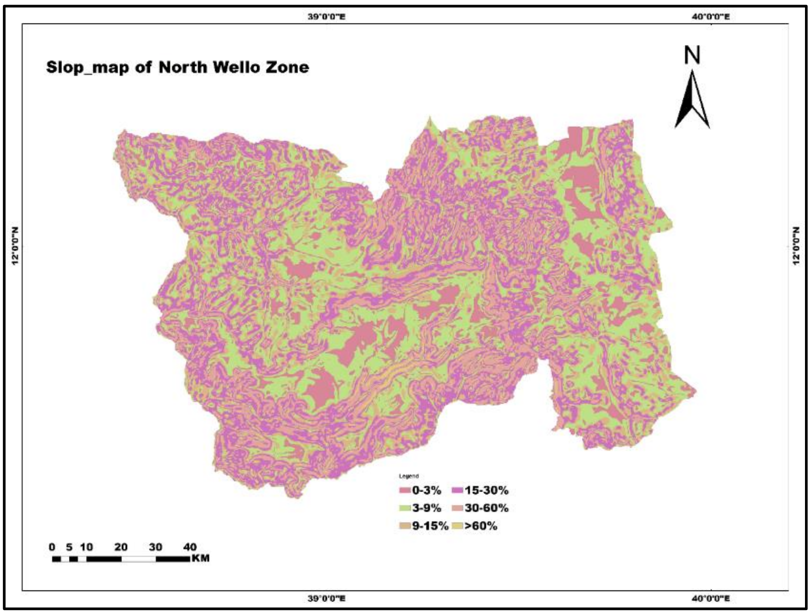

Fig. 3: slope map of North Wello Zone: Source Ethiopia DEM map

In the study area, the monthly temperature averages for the last 40 years ranged from 16 °C in December to 20 °C in May. Its 40 years (1979-2020) monthly maximum temperature averages also range from 25 °C in December to 29 °C in May. The minimum monthly temperature average recorded in the same time range is 7 °C in December to 12°C in May. In the study area, the temperature throughout the year showed little variation, roughly from 3 to 6 °C from the warmest month (between April and June) to the coldest month (between November and February). The variation in temperature and rainfall due to the effect of altitude in this region is significant (Conway, 2000). The maximum Mean Monthly Precipitation averages (mm) were 363.9 in August, and the minimum Mean Monthly Precipitation averages (mm) 18.4 in November (Fig. 4).

According to Ethiopia's National Meteorological Service Agency, the highest rainfall amount in the country was usually recorded in July and August, with the peak rainfall falling in late July and before mid-August. The annual average precipitation ranges from 800 to 1,200 mm.

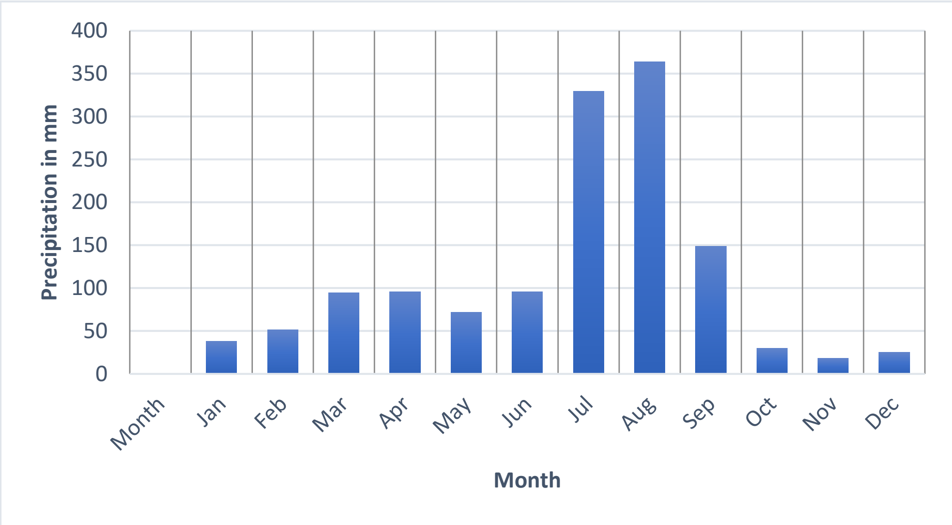

Fig. 4: Mean Monthly precipitation of North Wello (1979-2020)
https://earthmap.org/september2020

2.2. Indicators and Measures of LDN Assessment

The three global land degradation neutrality assessment indicators proposed by United Nations Conventions on Combating Desertification (UNCCD) includes: land use/land cover changes, land productivity dynamics, and soil organic carbon. The land degradation neutrality status of North Wello Zone was estimated by integrating all these indicators based on a "one out, all out" principle whereby if one indicator reveals significant negative change, land degradation neutrality is not achieved (Speranza et al., 2019). We apply the one out, all out principle to land degradation neutrality assessment such that where any of the indicator shows significant negative change, we considered land degradation neutrality goal is not achieved and conversely, if at least one indicator, shows a positive trend and none shows a negative trend it is considered the goal is achieved. However, it should be noted that using the three indicators under one umbrella may result in "over optimistic" or "over pessimistic" neutrality assessment.

The local context and purposes within the agreed guidelines will be considered with sufficient justification.

2.2.1. Land Use Land Cover Change

The CCI-LC project delivers a new time series of 24 consistent global LC maps at 300 m spatial resolution on an annual basis from 1995 to 2018. The data source for classification was the European Space Agency (ESPA) land cover climate change initiative project. The land cover map was conducted on the Google Earth Engine platform. We have used two land cover maps (1995 and 2018) which is provided earth map.org website (https://earthmap.org/). The two years are selected on the basis the period of implementation of sustainable land management projects. Different sustainable land management practices including integrated watershed management frameworks, productive safety net programs were have been implemented after 2001/2 in Ethiopia. The year 1995 is selected because it is 5 years before the implementation of the project in the study area. The year 2018 is selected because it is more than 15 years after the implementation of the many sustainable land management project including area closure. Hence, using these reference years, we believe it is possible to see the impact of the project on the land cover conditions of the study watershed.

Percentage LU/LC Change = $(Percentage\ of\ Final\ Year - Percentage\ of\ Initial\ year)$
Positive values indicate an increase whereas negative values show a decrease in the extent of Land use /Land cover.

2.2.2. Land Productivity Dynamics

Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI data were used from the year 2000 to 2020 to analyze the net primary productivity. Monthly average Normalized Difference Vegetation Index (NDVI) values were calculated using MODIS (MOD13Q1) from the year 2000 to 2020. MODIS data were preferred because the study area is large and the data has been found 250m by 250 m spatial resolution. This data was acquired from the National Aeronautics and Space Administration’s (NASA) Earth Observing System (EOS). In this study, the MODIS 16-day composite data (MODIS13Q1V6) for the period 2000–2020 was used. MODIS13Q1 dataset was downloaded from the MODIS website of the NASA Land Processes Distributed Active Archive Center (LP DAAC) (https://lpdaac.usgs.gov/). Using the MODIS re-projection tool, the MODIS13Q1 dataset downloaded for the study area were firstly resized, and then re-projected to with the WGS84 datum.

The determination of normalized difference vegetation index (NDVI) value is 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, RED = reflection from red wavelength region.

Land productivity dynamics is a map of persistent decline/stress, stability, and gain of land productivity, strictly during the observation period from 2000 to 2020 generated through the interaction of three NDVI-based indicators: steadiness, initial standing biomass, and standing biomass at change (https://earthmap.org/).

2.2.3. Soil organic carbon density

Soil organic carbon is also an indicator of soil quality (Kust et al., 2017). Studies show that soil conservation practices increase the capacity for long-term C sequestration (Hidalgo et al., 2019). Long-term fertilization with N, P, and K fertilizers (NPK) and combined manure (M) significantly increases the quantity of soil organic matter (Yang et al., 2011). Thus, to use soil organic content as an indicator of land quality change, we used a global soil organic carbon map. The global soil map was accessed using Web Map Services at: http://54.229.242.119/geoserver/GSOC/wms. We downloaded the most recent 2019 global soil organic carbon (GSOC) map layer using crop and download tool. The global soil carbon map was developed as 1 km soil grids, covering a depth of 0-30 cm.

3. Results and discussions

3.1. Land Use / Cover status

The six major land-use/ land cover types for the years 1995 and 2018 (Fig.5) are presented based on the six IPCC land categories, with: cropland, forest, grassland, wetland, settlement, and others. These latter land categories further split into shrub land, sparse vegetation, bare area, & water. The total area of the North Wello Zone is 12,221.52 square kilometers. The land use/ land cover class area and their percentages for 1995 and 2018 are presented in Table 1.

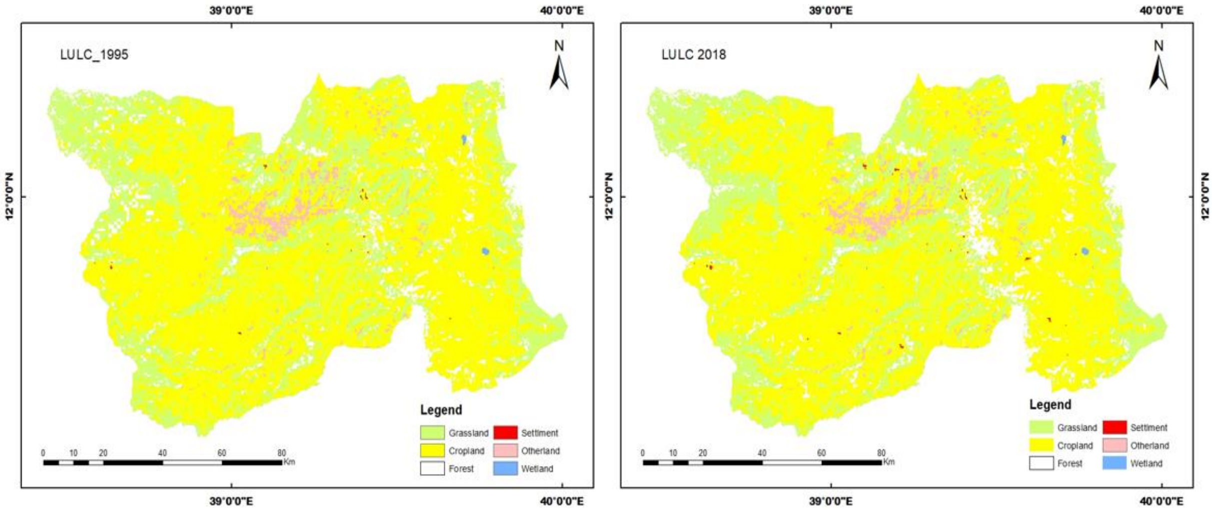

Fig.5: Land Use/ Land Cover Class of North Wello Zone (for the year 1995 and 2018).

Table 1 reveal that in 1995, about 62.75 % (766,908.7 ha), area of North Wello Zone was under cropland cover, 29.28% (357,790.2 ha) under grassland, 5.60% (68,387.2 ha) under forest cover, 2.24 % (27,333.9 ha) under other land categories (shrub land, sparse vegetation, bare area, and water), 0.11 % (1,312.28 ha) under wetland and 0.03% (420.1 ha) area was covered bay settlement. During 2018 the area under these land categories was found 62.48% (763,576.2 ha) under cropland, 28.96 % (353,955 ha) under grassland, 6.17 % (75,458.23 ha) under forest, 0.08 % (1023 ha), 2.23 % (27,272.54 ha) under other land, under wetland and 0.07 % (866.61 ha) under settlement areas.

Table 1. Land Use Type

Land Use Type	1995(km^2)	%	2018(km^2)	%
Forest	683.87	5.60	754.58	6.17
Cropland	7,669.09	62.75	7,635.76	62.48
Settlement	4.20	0.03	8.67	0.07
Grassland	3,577.90	29.28	3,539.55	28.96
Wetland	13.12	0.11	10.24	0.08
Other land	273.34	2.24	272.73	2.23
Total	12,221.52	100.00	12,221.52	100.00

3.2. Land Use/ Cover change

The data presented in Table 2 depicted that both positive and negative land use/cover changes was observed in North Wello Zone. During the last two decades the settlement area has increased from 4.2 km^2 in 1995 to 8.67 in 2018 which accounts for 0.58 % of the total area of the study area. The crop land cover has been decreased 7,669.09 km^2 in 1995 to 7,635.76 km^2 in 2018. These decrease in cropland accounts 0.27 % of the total North Wello Zone. The grassland cover has slightly decreased from 3,577.90 km^2 in 1995 to 3,539.55 km^2 in 2018 which accounts for 0.31 % of the total study area. The settlement area in North Wello Zone has been increased from 4.20 km2 in 1995 to 8.67 km2 in 2018. These increase in settlement accounts 0.04 % of the total study area. A slight decrease has occurred on wetland and other land use types in the study period (Table2).

Table 2. Area and amount of change in different land use/cover categories

Land use/cover type	1995		2018		Change (1995-2018)	
	km^2	Percentage	km^2	Percentage	km^2	Percentage
Forest	683.87	5.60	754.58	6.17	70.71	0.58
Cropland	7669.09	62.75	7635.76	62.48	-33.33	-0.27
Settlement	4.20	0.03	8.67	0.07	4.47	0.04
Grassland	3577.90	29.28	3539.55	28.96	-38.35	-0.31
Wetland	13.12	0.11	10.24	0.08	-2.89	-0.02
Other land	273.34	2.24	272.73	2.23	-0.61	-0.01
Total	12221.52	100.00	12221.52	100.00		

The increase in settlement area in this study result is consistent with the findings of Tolessa et al. (2017) in in the central highlands of Ethiopia and Haregeweyn et al. (2012) in Bahirdar. Most recently, in response to the growing demand for housing and other urban activities, local governments initiated the process of 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 to urban areas has significant ecological, socio-economic, and environmental impacts. Another significant 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 with 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 Ethiopian highland Watershed of Blue Nile; Berihun et al. (2019) in drought-prone areas of Ethiopia. In the study area, a slight negative change is occurred in grasslands and wetlands. Studies shows that the decline in grassland cover is mainly due to the change of this land use into forest, shrub land, and cultivated and rural settlement land, bare land, and urban built up area(Asmame and Abegaz, 2017; 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 of uplands and climate change are prominent as they can affect the water budget.

3.3. NDVI index

The NDVI is widely used to determine the production of green vegetation and vegetation changes. Because, it is an indicator for biomass and soil organic carbon concentration. In this study, we have been calculated monthly average NDVI from the MOD13A1 data for only the month of January corresponding to the driest period of Ethiopia for the year 2000 to 2020. The results show that inter-annual variations in the greenness of the area. The minimum 0.36 NDVI value was recorded in 2000, 2006 and 2012 and the maximum NDVI value 0.46 was recorded in 2001 and 2002 (Fig. 6). Though a slight variation exist, the greenness conditions during 2015 to 2020 was higher and almost positive linear in the study area.

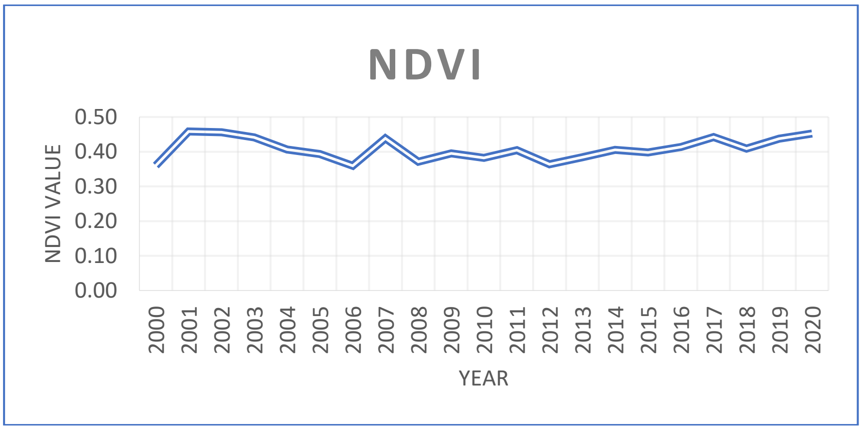

Fig. 6: Monthly average NDVI value for the year 2000 to 2020

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 shrub lands, Eucalyptus tree plantations, and forests in sloppy and mountainous areas of the North Wello Zone (Fig. 7). Higher NDVI values help to identify the conditions of vegetation remaining green throughout the year, which indicates the effectiveness of land restoration programs. The NDVI for the forest with shading leaves in the drier season may not clearly show the real situation. In the study area, Dega (Highland) and Weynadega (Midland) areas show annual greenness dominated by evergreen species, while Kolla (lowlands) is dominated by Acacia species that flourish during the dry period (Fig.7).

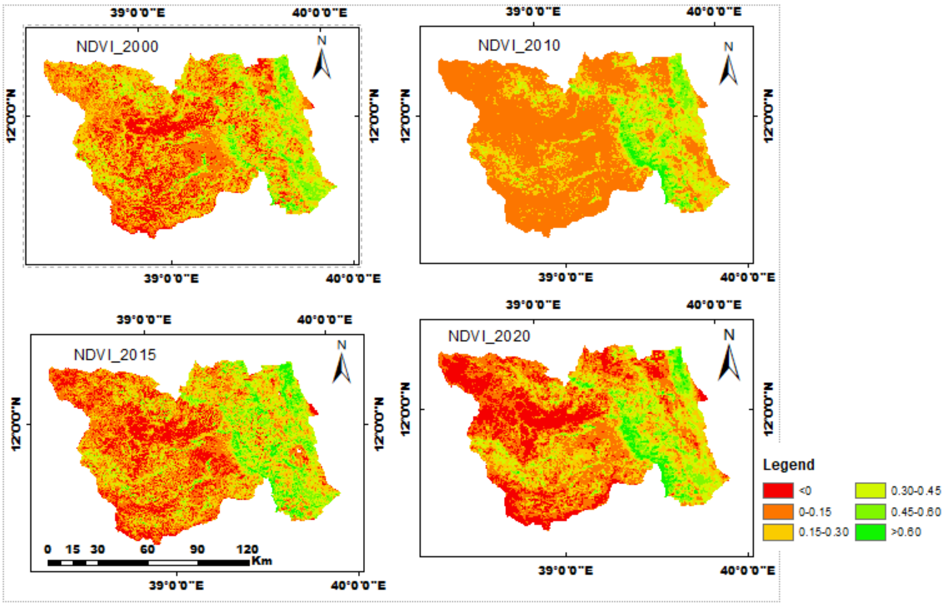

Fig 7: NDVI changes between 2000 and 2020 (January)

3.4. Soil Organic Carbon

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 resilience of land (Cowie et al., 2018). The maximum and minimum soil organic matter measured at 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 amount of 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 mountainous areas 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 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.

The findings of this study are consistent with those of Abegaza et al. (2020), Abebe et al. (2020); Cha et al. (2020) and Girma et al. (2020) 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 majority (62%) 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 of the North Wello lowland areas, the natural vegetation is dominated by deciduous tree and shrub species that commonly contribute large amounts of organic matter to the soil. However, higher temperature and lower precipitation conditions, makes soil carbon production in this region may be slow (Fig.8). Empirically, this is true that SOC stocks generally increase as the mean annual temperature decreases (Stockmann et al., 2013). It has also been shown that less soil disturbance, greater 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 reducing its emission from croplands and grasslands of the study area.

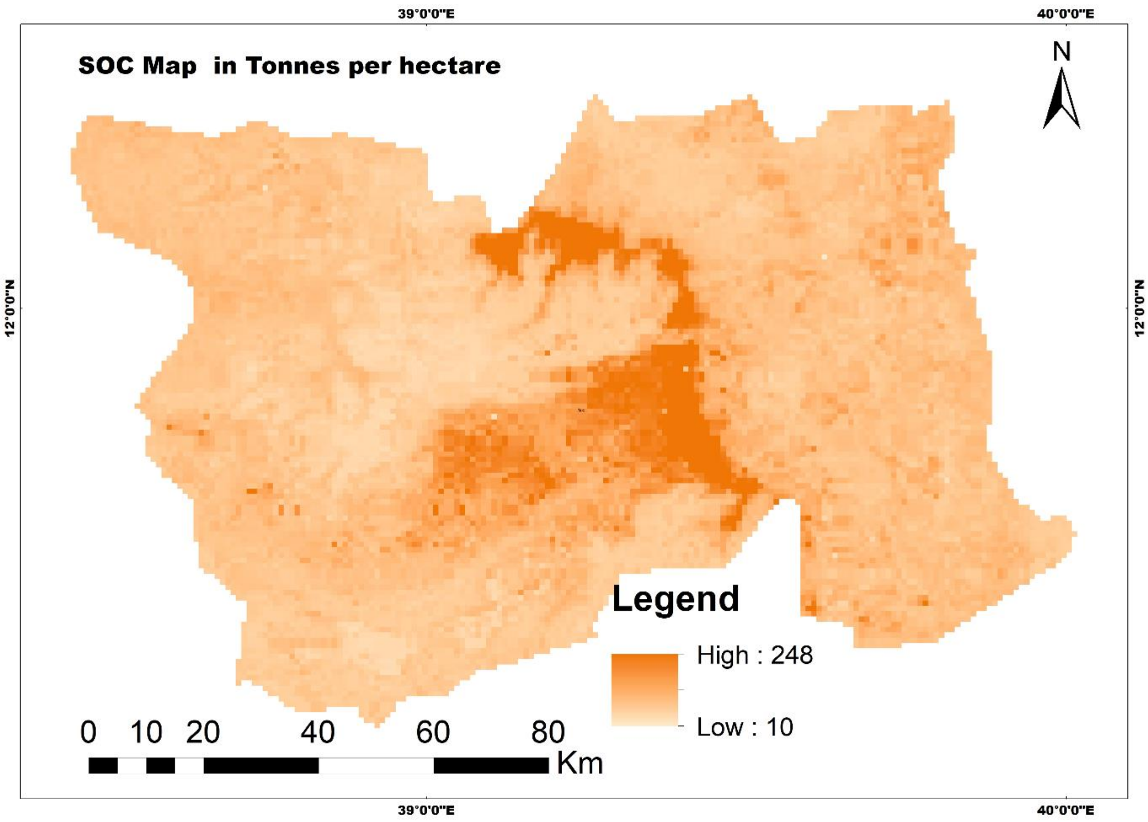

Fig 8: Soil organic carbon Map for North Wello Zone (2019). Source: GLOSIS – GSOC map (http://54.229.242.119/GSOCmap/)

3.5. Land Productivity Dynamics in North Wello Zone.

In land-degradation neutrality contexts, the aims of RIO+20 are to protect productive land stable with sustained, or improved and maximized food production and other environmental services. Hence, land productivity is an indication of the level of sustainable land use, calculated as the relationship between land quality in general productive terms and what is obtained as output (Cherlet et al., 2013). To do so, the land productivity dynamics map is available from the earth map.org platform, which was produced for the period from 2000 and 2020, generated through the interaction of three NDVI-based indicators: steadiness, initial standing biomass, and standing biomass at change.

The FAO in the earth map.org platform produced a map that shows five classes of land productivity levels (Fig. 9). In the North Wello Zone, 52.8 percent of its territory is stable with no stressed land productivity conditions. It has to be noted that land productivity levels vary according to land cover and land use types, but the overall productivity remained stable during 2000 to 2020. Appropriate agricultural land management, plantations and area closures of the sloppy lands are assumed. Naturally, the highland and midlands have relatively regular climate conditions, which can be assumed to have a positive effect on land productivity. In this regard, the previous finding by Damene et al. (2013) shows that the effect of microclimate on biomass production, vegetation types and organic matter mineralization are significant in the mild zone.

The other significant share of 22.7 percent of the land in the study area showed an increase in land productivity during the 2000 to 2020 period. The stable but stressed land productivity class is also covering 1.2 percent of the total study area (Fig. 9). We assumed that land productivity is improving due to the natural resource rehabilitation and development work under the watershed management framework of PSNP in the study area through area closure and physical soil and water conservation practices. We suggest that conservation practices may not exclusively bring this positive trend, but also the micro-climate on biomass production, vegetation types, and organic matter mineralization plays a significant role in improving this trend, either positively or negatively.

Previous studies have reported that exclosures have contributed to vegetation restoration, improvement in soil nutrient status, reduced erosion, and increased land cover, soil fertility, water retention capacity, and ecosystem carbon stock (Damene et al.,2013; Damene et al.,2020;

Meaz et al.,2016; Mekuria et al., 2007). According to Gashaw (2015), watershed management practices improve, soil quality vegetation cover, and crop production and productivity. The analysis also indicated that 19.64 percent of the total land area of the North Wello Zone shows an early sign of decline or actual land productivity decline. About 3.5 percent of the study area shows the declining trends of land productivity.

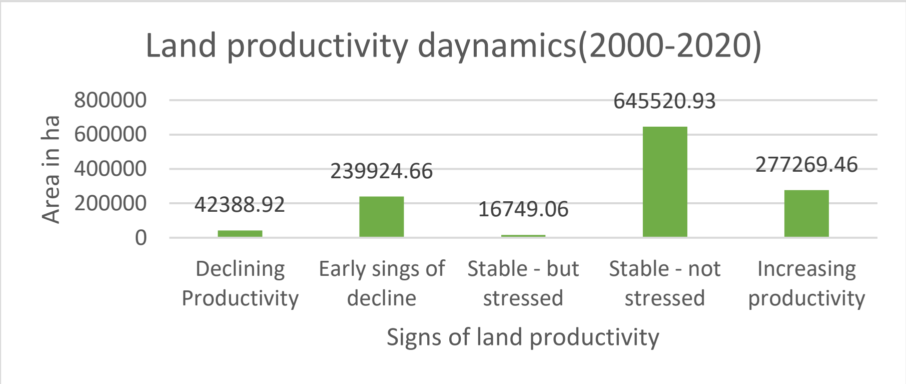

Fig 9: Land productivity signs in North Wello Zone for the period 2000 to 2020

The lowlands (Habru, Raya Kobo, and Bugna Districts) are with the land productivity decline (Figure 10). According to Cherlet et al. (2013), the decline or its early signs of land productivity may be due to climate extremes such as droughts or floods. In the current study, frequent droughts, over-cultivation, and overgrazing may contribute to declining land productivity. Temesgen et al. (2014) reported that population increase, severe soil loss, deforestation, and unbalanced crop and livestock productions causes for the declining of land productivity.

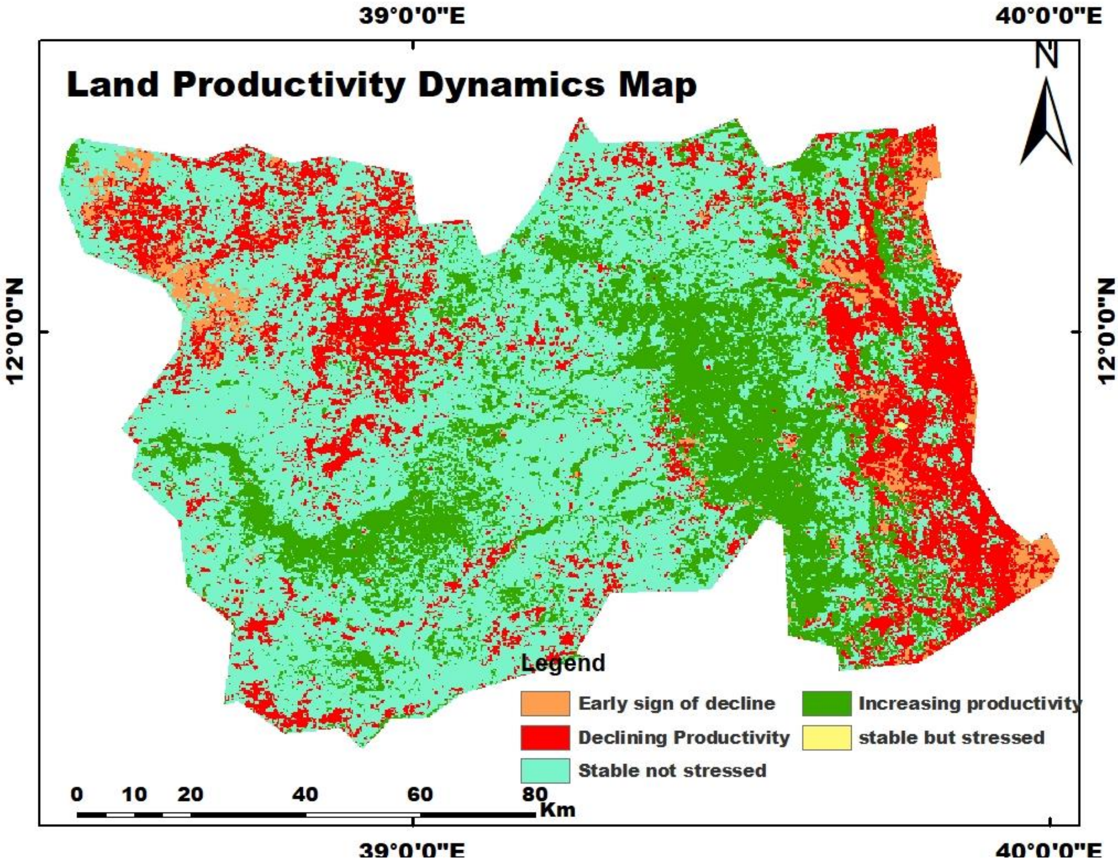

Fig 10: Land productivity Dynamics Map

3.6. Assessment of LDN Status

In the current study, we tried to evaluate the land degradation status based on land degradation neutrality indicators (UNCCD, 2016), based on the results described previously. Kust et al. (2017) defined land cover, productivity, and soil organic carbon which are used to measure land degradation. Cowie et al. (2018) 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, each land-use type in the study area. In this study, we analyze the land use/land cover and land productivity dynamics and also soil organic carbon status.

First, we consider the land use/ land cover change as an indicator of land degradation conditions. During 1995-2018 the forest cover in the study area was increased by 70.71km^2. The positive forest cover change may be a sign of high grass biomass and woody plant cover (Reid et al., 2000). However, the forest cover showed spatial variation where the midland seems highly forested than the lowland areas in the study area. An increasing exapansion of forest land in the study area is due to the plantation of Eucalyptus trees mostly in Highlands and Midlands parts of North Wello Zone for gaining better economic benefits. The cropland area was decreased by 33.33 km^2 during 1995 to 2018. In the line of cropland studies, Reid et al. (2000) argued that the contraction of cropland increased grass biomass and vegetation cover. However, this argument is correct when cropland is converted to forest or agroforestry and other similar land-use types. However, our observation shows that the contraction of cropland is mainly due to the expansion of settlement land that will negatively affect land productivity. The grassland cover was also decreased by 38.35 km^2. Grassland are almost as important as forests in ecosystem balance and that soil organic matter under grassland is the same magnitude as tree biomass (Amede and Tsegaye, 2016). But, this land use change is generally negative. The wetlands in the study area also shows negative change.

Second, 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 expression of its potential to continue supplying ecosystem services (Dengiz, 2017). This study presents the land productivity dynamics for the study area as generated from satellite images based on the interactions of three NDVI-based indicators: steadiness, initial standing biomass, and standing biomass at change (https://earthmap.org/). The results show that 76.7% of the total land area of the North Wello Zone falls under the category of stable and not stressed land productivity, increasing land productivity, and stable but stressed land productivity class. The aerial distribution of this productivity class is mostly prevalent in the high and midlands where annual precipitation is not variable in terms of intensity, duration, and timing. The remaining 23.3% of the land falls either on the early sign of decline productivity or declining productivity. The study also considers that this type of land class is more likely in the lowlands in the eastern parts of the study area. The implication is for the urgent need of drought-specific land management practices in that particular area.

Third, the area with high soil organic carbon content was identified and mapped for the North Wello Zone. The results indicated that the maximum soil organic matter measured at 30 cm depth was 248.9 tons per hectare, and the minimum was 10 tons per hectare. The soil organic carbon in the study area is observed in the high and midland vegetation areas. The lowlands are very thin in soil organic content. The highest amount of carbon in the soil is an indicator of a stable ecosystem.

To summarize, the results of this study using the three UN indicators, the land use of the forest is showing an increasing trend. The settlement area also shows a dramatic increase. Its increment is mostly at the expense of croplands. The grasslands, shrub lands, and bare lands are showing a negative change. In this study, at least one out of the three indicators- LULC was negative. As a result, LDN in North Wello Zone showed a sign of land degradation at an early stage.

This study suggested that land degradation is not uniform, even in the same administrative areas; nevertheless, an overall consensus seems to grow on the fact that many lands are under rehabilitation. The change is due to current policies on natural resource management in the country. To combat land degradation and sustainably increase land productivity on degraded land through sustainable land use, the current management approaches should be improved and supported by well-organized institutions and knowledge-based decision making by experts. Grassland management, which encompasses erosion control, controlled grazing, availability of strategic watering points for livestock drinking, and different forms of water harvesting structures could be effective for land degradation neutrality status.

4. Conclusion and Recommendation

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 prevalent only small spatial coverage which is common in midlands part of the study area. In one of the three indicators negative changes have occurred showing a tendency towards the degradation of land capital in the long run. Therefore, it is necessary to take measures to maintain land quality; and counterbalancing measures to achieve equivalent losses and gains should be implemented as quickly as possible. Land use policy and legislation should be effectively implemented to avoid unforeseen land cover change. However, the LDN status requires a longer period to improve its accurate assessment.

To our knowledge, studies that have been conducted to implement the concept of LDN to reality is scarce. According to the real world, field based empirical sampling and spatial data extraction have the potential to show more accuracy than only secondary data sources. However, in the case of resource limitations such as human, money, and time, secondary data based on the review of several sources would offer proxy results for the study. Similarly the three global indictors should be a minimum guideline. Therefore, soil erosion data should be considered.

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7. Competing interests

The authors declare that they have no competing interests

8. References

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