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

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Research

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Abstract

Background: Land degradation is increasingly recognized as a serious, nationwide environmental concern in Ethiopia. The key concern is the iterative relationship between land degradation, climate change and agriculture, exacerbating one another via negative and positive feedback loops. Due to the need for an efficient response to land degradation in the country, different sustainable land management practices have been implemented since the late 1980s. In Ethiopia, most of the previous researches were conducted on analyzing the determinants of decisions to implement land management practices. The objective of this study was to analyze land degradation neutrality status using remote sensing data in the study area.

Results: We have studied the land degradation neutrality conditions of North Wello Zone by using indicators data, namely land cover change, land productivity dynamics and soil organic carbon stock. The areas of settlement consistently expanded at the fifth speed (2010-2018) from 1995 to 2010. Between 1995 and 2010, forestland declined by 18 percent, while it indicated an increasing trend of 26.8 percent from 2010 to 2018. The wetlands declined by 21.98 percent from 1995 to 2010; whereas zero net degradation was observed from 2010 to 2020. In addition, between 1995 and 2010, cropland and grassland showed an increasing trend but decreasing trends were detected between 2010 and 2018. Land productivity potential assessment results indicate that 52.8 percent of the total area is stable and characterized by a less stressed land productivity status. Approximately 22.7 percent of the land showed an increase in land productivity status from 2001 to 2018. The results also indicated that 19.64 percent of the land shows an early sign of decline or actual land productivity decline. 3.5 percent of land also shows a decline in productivity. The soil organic carbon is comparatively abundant in the high and midland vegetation areas but very thin in lowland areas.

Conclusion: Most of the highland and midland parts of the study areas are stable and increasing land productivity condition with high biomass and soil organic content. However, most lowland areas showed a decline land productivity condition.

Background

Land is a component of Mother Nature serving as infrastructure for much of life on earth (Safriel, 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. 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). The estimations show that the world population will increase from 6.9 billion people today to 9.1 billion in 2050. 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 iterative relationship, 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 agroecological 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 extensification 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). A synergistic approach, on the other hand, occurs when sustainable agricultural production and land degradation neutrality can be achieved simultaneously (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 (FAO, 2011). 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 security, poverty, and environmental and political stability (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 a US$9.3 billion annual cost 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 most frequently cited causes of land degradation in Ethiopia are population pressure, soil loss through erosion, deforestation, land use change, overgrazing, overcultivation, and climate change(drought) (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 increasingly dependent on food aid (Kassie et al., 2010).

Recognizing this urgent need for an efficient response to land degradation, climate change, and food security in the twenty-first century, united nations conventions on combating desertification (UNCCD) proposed the concept of land degradation neutrality. According to Kust et al. (2017), land degradation neutrality is 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).

For the last three decades, the government of Ethiopia and non-governmental organizations has undertaken a massive program of natural resource conservation to reduce environmental degradation (Kassie et al., 2010). In Northern Ethiopia, significant natural resource rehabilitation and development work was implemented between the mid-to-late 2000s within the framework of the Productive SafetyNet Program (PSNP) and under Managing Environmental Resources to Enable Transition (Abera et al., 2019).

Studies in Ethiopia have demonstrated that existing management has contributed to improved native vegetation composition and diversity, above-ground biomass, land cover, soil quality, and an increase in ecosystem carbon stocks (Abegaza et al., 2020; Damene et al., 2013; 2020; Girma et al.,2020; Meaza et al., 2016; Mekuria et al.,2007; Temesgen, 2015; Shine, 2012). This study adds value to the growing literature on the trends of land productivity dynamics, which may indicate loss or degradation as well as the restoration of land and soil quality. The uniqueness of the current study from the above vast literature presents the land productivity dynamics trends based on the evaluations of land degradation neutrality assessment tools employed by UN indicators under one umbrella. Therefore, the primary aim of this study was to analyze the status of in land degradation neutrality in the North Wello Zone, Northern Ethiopia.

Materials And Methods

Study site description

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.

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. The relief differences would have a significant influence on the climate, soil, and biota variations across the area. The majority of areas are steep slopes (15%-30 gradient) to extremely steep slopes (30%-60 gradient) covering 25.15% and 36.06% of the total area, respectively. As suggested by Hurni (1988), land with slopes of less than 15% is the most suitable for agriculture. However, this area accounted for only 31% of the total area.

In the study area, the monthly temperature averages in the study area for the last 40 years (1979–2020) 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 hottest period was March to May, before the onset of the main rainy season. 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. 2). According to Ethiopia's National Meteorological Service Agency, the main precipitation of Ethiopia produced was 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).

The diversity in climate, topography, and vegetation in the area has given rise to marked variations in soils, even within relatively small areas (Eliays, 2000). In the highlands of Wello, there are various soil types, such as Cambisols, Luvisols, Vertisols, Xerosols, Leptosols, Regosols, and Nitisols. Cambisols are the dominant soil types in the study area, accounting for 46% of the total area. These soils are found in Colluvial materials and on moderate to steep slopes. Orthic Luvisols cover 12% of the total area of the North Wollo Zone. Chromic vertisols accounted for 9% of the total area. Haplic Xerosols cover 7% of the total study area, particularly in the semi-arid parts of the area. Eutric Regoslos covers 6% of the total area of the North Wollo Zone.

Indicator Data Sources and Analysis

To assess the land degradation neutrality status, three global indicators that are in current use by the United Nations conventions on combating desertification (UNCCD,2016) and recently proposed in the use of evaluating land degradation neutrality were provided to countries. Indicator data used in this analysis were: land use/land cover changes over the period 1995 to 2018, land productivity dynamics over the period of 2001 to 2017, and soil organic carbon for 2019. The methods are described in land degradation neutrality target setting technical guide (UNCCD, 2016).

Land Cover Change

For this study, the multi-temporal land cover map classified based on the IPCC Land use classification method on climate change initiatives (CCI data) was downloaded from earthmap.org website in Tiff format. The classification of land use classes was classified based on the Google Earth Engine and available with a complete legends and statistics. The percentages of land use/land cover change were calculated using the following formula:

Percentage LU/LC Change = $\frac{AreaofFinalYear - AreaofInitialyear}{AreaofInitialYear} x100$

Positive values indicate an increase whereas negative values show a decrease in the extent of LU/LC.

Ndvi Change And Land Productivity Dynamics

NDVI is an indicator of vegetation health. The determination of normalized difference vegetation index (NDVI) value was by using the near-infrared (NIR) and visible reflectance bands. Thus, NDVI is calculated as $: NDVI = \frac{NIR - RED}{NIR + RED}$, Where NDVI = normalized difference vegetation index, NIR = reflection from near infrared wavelength region, RED = reflection from red wavelength region. In the Earth map platform, the vegetation indices such as NDVI was derived from MOD13A1 v006 MODIS/Terra Vegetation Indices 16-Day L3 Global 500 m SIN Grid and available from 2000 to 2020. The MOD13A1 vegetation indices were generated from a spatial resolution of 250m x 250 m pixel size and 16 days temporal resolutions. Thus, the current study employed this processed data to interpreted and analyzed the vegetation cover change in the North Wello zone.

Low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8). Based on Nega et al. (2019), satellite images with an NDVI > 0.45 were classified as vegetated and pixels with a value < 0.45 were classified as non-vegetated areas. Land productivity dynamics is a map of persistent decline/stress, stability, and gain of land productivity, strictly during the observation period from 2001 to 2017 generated through the interaction of three NDVI-based indicators: steadiness, initial standing biomass, and standing biomass at change (https://earthmap.org/).

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 prepared for the year 2019.

Results And Discussions

Land Use and Land Cover classifications

The six major land use/ land cover types for the years 1995, 2000, 2010, 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, and water. The total area of the North Wello Zone is 1222152 ha. The land use/ land cover class area and their percentages for 1995, 2000, 2010, 2015, and 2018 are presented in Table (1).

Table 1
Land use/ land cover classes and percentage.

Land Use Type	1995	%	2000	%	2010	%	2018	%
Forest	68387.2	5.595638	68457.19	5.601365	59530.24	4.870934	75458.23	6.174208
Cropland	766908.7	62.75068	763799.6	62.49629	771521.2	63.12807	763576.2	62.47799
Settlement	420.1	0.034374	472.61	0.03867	481.37	0.039387	866.61	0.070909
Grassland	357790.2	29.27543	360776.8	29.5198	362261.9	29.6413	353955	28.96161
Wetland	1312.27	0.107374	1312.27	0.107374	1023.74	0.083765	1023.74	0.083765
Other land	27333.9	2.236538	27333.9	2.236538	27333.9	2.236538	27272.54	2.231517
Source: https://earthmap.org/.								

Land Use/ Land Cover change

From 1995 to 2010, settlement, grassland, and cropland areas increased by 61.5 hectares (14.6 %), 4471.7 hectares (1.3%), and 4612.5 hectares (0.6%) of the total area, respectively. In contrast, forest and wetlands decreased by 8856.96 hectares (13%) and 288.5 hectares (22 %), respectively. Between 2010 and 2018, the area of forest and settlement increased by 15928 ha (28.8 %) and 385.24 ha (80 %), respectively, while grassland, cropland, and other lands (shrub land, sparse vegetation, bare area, and water) reduced by 8306.9 ha (2.3 %), 7945 ha (1.03%), and 61.4 ha (0.22 %), respectively (Table 2).

In the study area, LULC changes showed temporal variability. For example, the areas of settlement consistently expanded at the fifth speed (2010-2018) from 1995 to 2010. This result is consistent with the findings of other studies (Tolessa et al., 2017; Haregeweyn et al., 2012). 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). In Ethiopia, the expansion of settlement areas is at the expense of cultivable land. 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.

Between 1995 and 2010, forest land declined by 8856.96 hectares (13%), while it indicated an increasing trend of 15927.99 hectares (26.8%) from 2010 to 2018. This increase may be due to the closure of mountainous areas. This result is more likely with the findings of Shine (2012) in the Wello area and Bewket (2002) 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. The increase in forest cover in this study area may be due to Ethiopia's PSNP 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.

Other significant land-use changes in the study area also occurred in wetlands. The Wetlands declined by 288.53 hectares (21.98%) from 1995 to 2010; whereas zero-net degradation was observed from 2010 to 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. Most recently, the community-based watershed development programs in the study area have saved it from further degradation.

Besides, between 1995 to 2010, cropland and grassland show an increasing trend but decreasing trends were detected between 2010 and 2018 time period. Although the change was small (61.4 ha) or 0.22% of the shrubland, sparse vegetation, bare area, and water changed negatively after 2010.

Table 2: Land use/land cover change during (1995–2010 and 2010- 2018)

Land Use Type	1995-2010 Area (ha)	%	2010-2018 Area (ha)	%
Forest	-8856.96	-12.9512	15927.99	26.75613
Cropland	4612.5	0.6014406	-7945	-1.02978
Settlement	61.27	14.584623	385.24	80.02991
Grassland	4471.7	1.2498106	-8306.9	-2.29306
Wetland	-288.53	-21.98709	0	0
Other land	0	0	-61.36	-0.22448

Source: https://earthmap.org/.

NDVI index and Soil Organic Carbon

The NDVI is widely used to determine the production of green vegetation and understand vegetation changes. Because, it is an indicator for biomass and soil organic carbon concentration. In this study, we examined the vegetation change of North Wello Zone from 2002 to present. In the period between 2002 and 2020, the average annual minimum NDVI value of the study area was +0.30 recorded in 2013, and the average maximum NDVI value was +0.37 in 2019. Between 2000 and 2020, the monthly average NDVI during the dry months of Ethiopia (January and February) was +0.2 and +0.18, respectively.

We also processed the MOD13A1 vegetation indices for only the month of January corresponding to the driest period from the spatial resolution of 250 x 250 m pixel size and 16 days temporal resolutions for the year 2002, 2011, 2016, and 2020. The results show that interannual variations in the greenness of the area. For example, NDVI of 0.45-0.6 covers 156,325 ha (13%), 40,412.5 ha (3.3%), 68.137.5 ha (5.6%), and 29,100ha (2.4%) of the total area for the year 2002, 2011, 2016, and 2020 respectively. The results also show that a larger proportion of the area is sparsely vegetated. The NDVI values above 0.6 covers 11,969 ha (1%), 881.25 ha (0.07%), 2850ha (0.2%) and 618.75 ha (0.05%) of the total area for the year 2002, 2011, 2016 and 2020 respectively (Table 3).

Table 3 shows the most of the study area covered by the NDVI value ranges from 0.15 to 0.3. It is an agricultural field which is ready for cropping.

Table 3: index value of vegetation in North Wello Zone

NDVI value	2002		2011		2016		2020	
	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%
<0	106	0	325	0.3	43.75	0	25	0
0-0.15	49169	4	2631.25	0.22	18168.8	1.5	34300	2.8
0.15-0.3	585463	48	808625	66.2	815450	66.7	885575	72.5
0.3-0.45	418806	34	369219	30.2	317444	26	272475	22.3
0.45-0.60	156325	13	40412.5	3.3	68137.5	5.6	29100	2.4
>0.6	11969	1	881.25	0.07	2850	0.2	618.75	0.05

The annual average NDVI value in the study available on earth map.org platform shows that the minimum NDVI values occurring in the years between 2017 and 2020 was 0.2, and the maximum annual average NDVI was 0.75 (Figure 4)

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 rainfed 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 (Figure 5). 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 (Figure 5).

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). We present the results obtained from the map of the global soil organic carbon in the earth map.org platform in Figure 6. 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 Figure 6 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 [illegible] tation 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 (Figure 6). 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.

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 2001 and 2017, 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 (Figure 7). In the North Wello Zone, 645, 520 ha (52.8 %) 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 2001 to 2018. 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 277, 269.5 ha (22.7%) of the land in the study area showed an increase in land productivity during the 2001 to 2018 period. The stable but stressed land productivity class is also covering 16,749 ha (1.2%) of the total study area (Figure 7). 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 [illegible]l.,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 (239,924.7 ha (19.64 %) of the total land area of the North Wello Zone shows an early sign of decline or actual land productivity decline. About 42,389 ha (3.5%) of the study area shows the declining trends of land productivity.

The lowlands (Habru, Raya Kobo, and Bugna Districts) are with the land productivity decline (Figure 8). 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.

Discussion

Assessment of land degradation neutrality based on UNCCD indicators

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 sequestration changes during 2000 to the present.

First, we consider the land use/ land cover change as an indicator of land degradation conditions. During the study period, significant land use was observed in the settlement expansion in the study area. This change is mainly through the conversion of arable land to settlement land in the study area. The encroachment of settlement lands into croplands may cause land quality loss. The expansion of built-up areas in the study area is mainly at the expense of agricultural lands that will have ecological and environmental impacts (Haregeweyn et al., 2012). The forest cover in the area also shows a positive change that may increase grass biomass and woody plant cover (Reid et al., 2000). The forest ground and canopy increased with exclosure age in the study area and showed spatial variation in biomass production and vegetation types. The midland seems green throughout the year, whereas greenness is seasonal in lowland where deciduous tree and shrub species dominate the ground cover. Thus, the seasonal microclimate conditions of the area strongly affect vegetation productivity and organic matter decomposition. In the current study, the land-use change analysis indicated that the quantity of cropland is going down. 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. In our cases, the contraction of cropland is mainly due to the expansion of settlement land that will negatively affect land productivity. The grassland in the study area shows temporal variations. Between 1995 and 2010, there was in an increasing trend. However, from 2010 to 2020, it was in a decreasing tendency. This pattern of change may be due to the current watershed development programs that are carried out with community participation. In these programs, many seedlings are planted annually in the grassland areas. Thus, community-based afforestation programs in the study area changed the age-old tradition of clearing steeper land for cultivation (Zeleke et al.,2001). The positive change in forest land and the net balance of wetlands in the year between 2010 and 2020 implying that watershed management shows encouraging impacts.

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, whilst the wetland is stable in the most recent period. The settlement area also shows a dramatic increase. Its increment is mostly at the expense of croplands. The grasslands, shrublands, and bare lands are showing a decreasing trend during 2010 to 2020. Although the NDVI value did not show significant variations across time and space, the land productivity dynamics derived from NDVI products show spatial variations. The organic content estimated in this area is consistent with the land productivity class. Thus, the findings revealed that most of the mid and highlands areas have relatively healthy environments. However, lowlands based on the three LDN indicators are highly degraded. The most troubling issue is large populations inhabiting the lowland areas of Raya Kobo and Habru districts that are practicing very intensive crop and livestock production.

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. In this regard, we believe that our results will be helpful as a source of information for local decision-makers in the North Wello Zone for evaluating policies regarding land-use changes and establishing guidelines and plans for actions to achieve land degradation neutrality in the future.

Conclusion And Recommendation

This study evaluates the different land management programs that are carried out in the region for a decade based on UNCCD land degradation neutrality indicators. The results show significant land use/ land cover changes over the study period. The settlement areas dramatically increased mostly at the expense of arable land in the study area. Settlement expansion without proper planning of land use will cost ecological, social, and environmental services. The forest cover in the study period shows both declining and increasing trends, but the most recent trend of forest cover [illegible] how decreasing trends while wetlands are at the state of balance in the most recent record. The land productivity conditions (net primary production) or NDVI and soil organic carbon content is highly prevalent in the forest lands of the high and midlands of the study area. The current land rehabilitation endeavor under the watershed development programs in many high and midland areas shows encouraging effects. However, in lowland areas, the land management programs and strategies should be contextually suitable to improve the land productivity conditions.

Declarations

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Availability of data and materials

All data and manuscript used in the study are presented in the main paper.

Author's contributions

The main author (Getnet Zeleke) collected, organized, and interpret the data and wrote the manuscript. The second and third authors edited, commented, and improve the ideas of the study. All authors read and approved the final manuscript.

Correspondence author

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Ethics Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

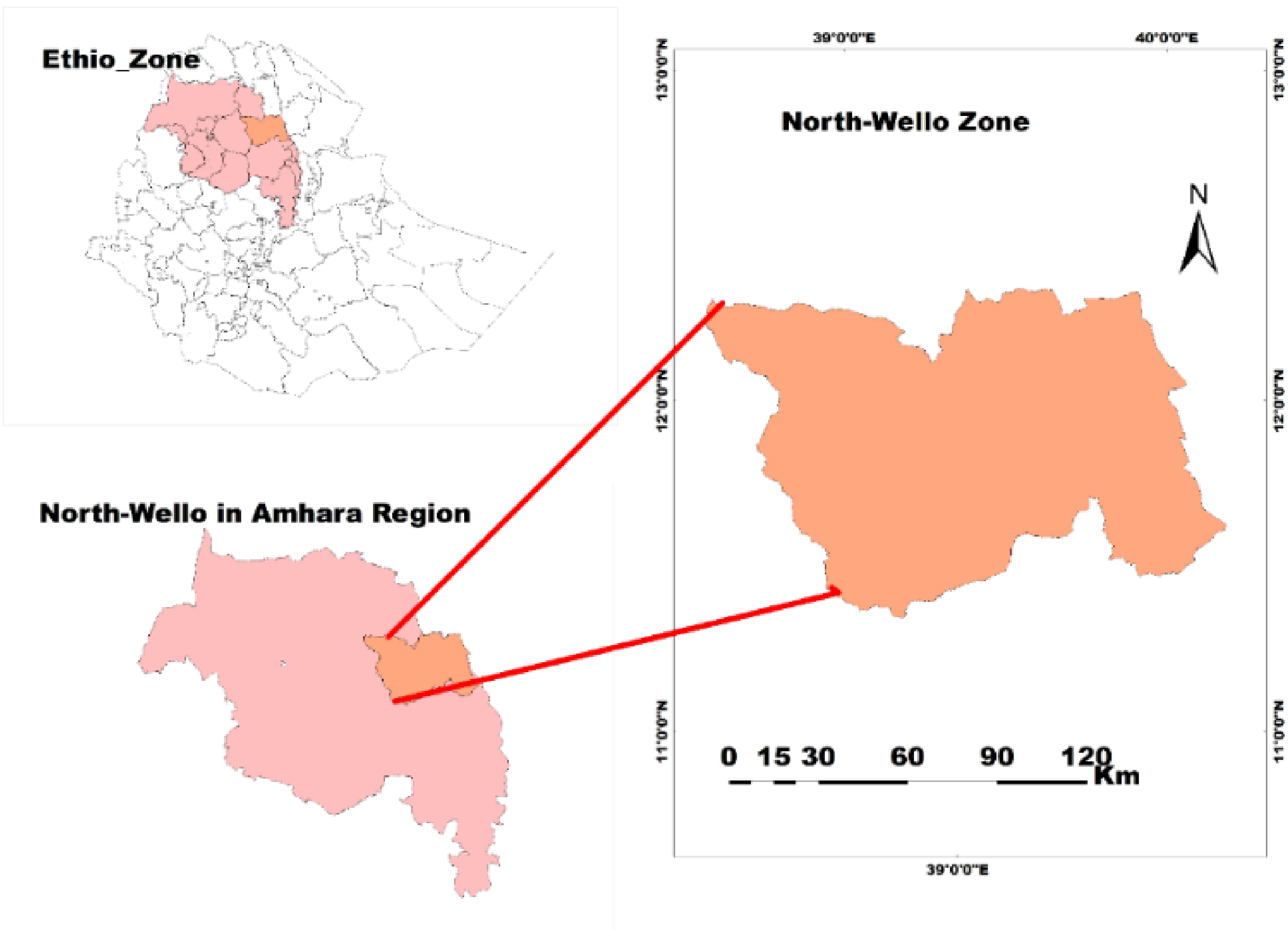

Figure 1

Location of study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

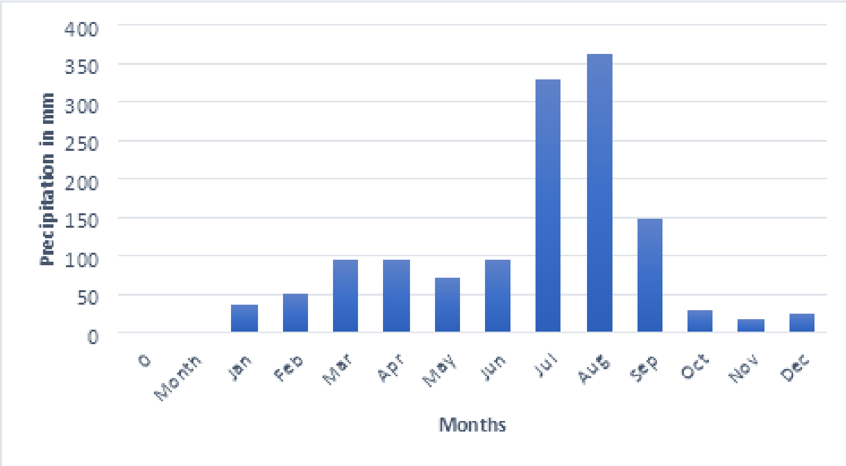

Figure 2

Mean Monthly precipitation of North Wello (1979-2020)

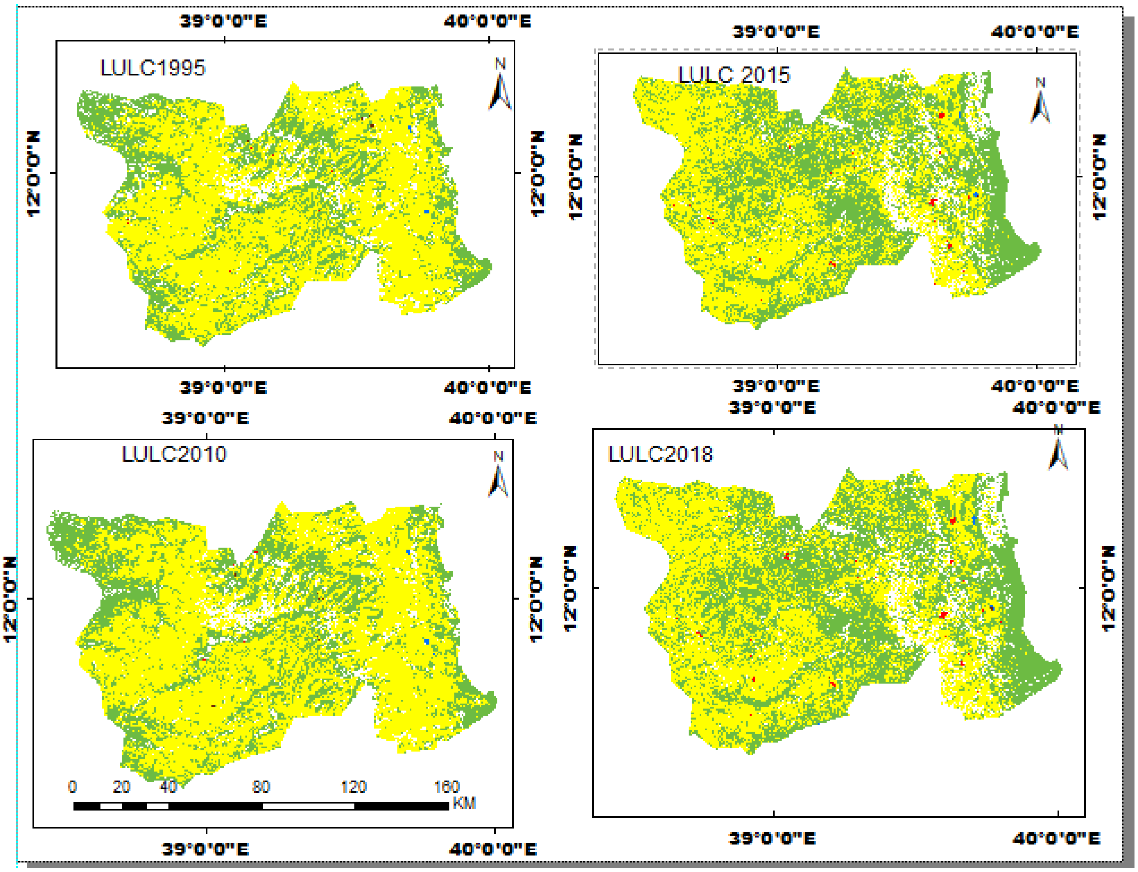

Figure 3

Land Use/ Land Cover Class of North Wello Zone (for the year 1995, 2000, 2010 and 2018). Source: https://earthmap.org/?aoi=et&boundary=level2 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

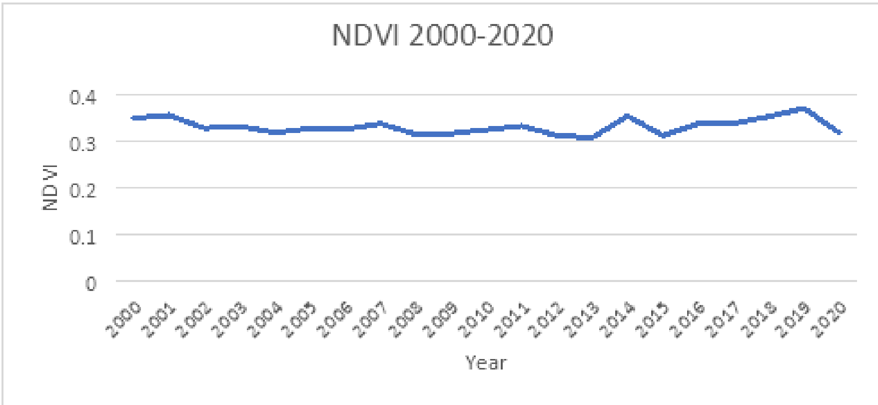

Figure 4

NDVI results for North Wello Zone

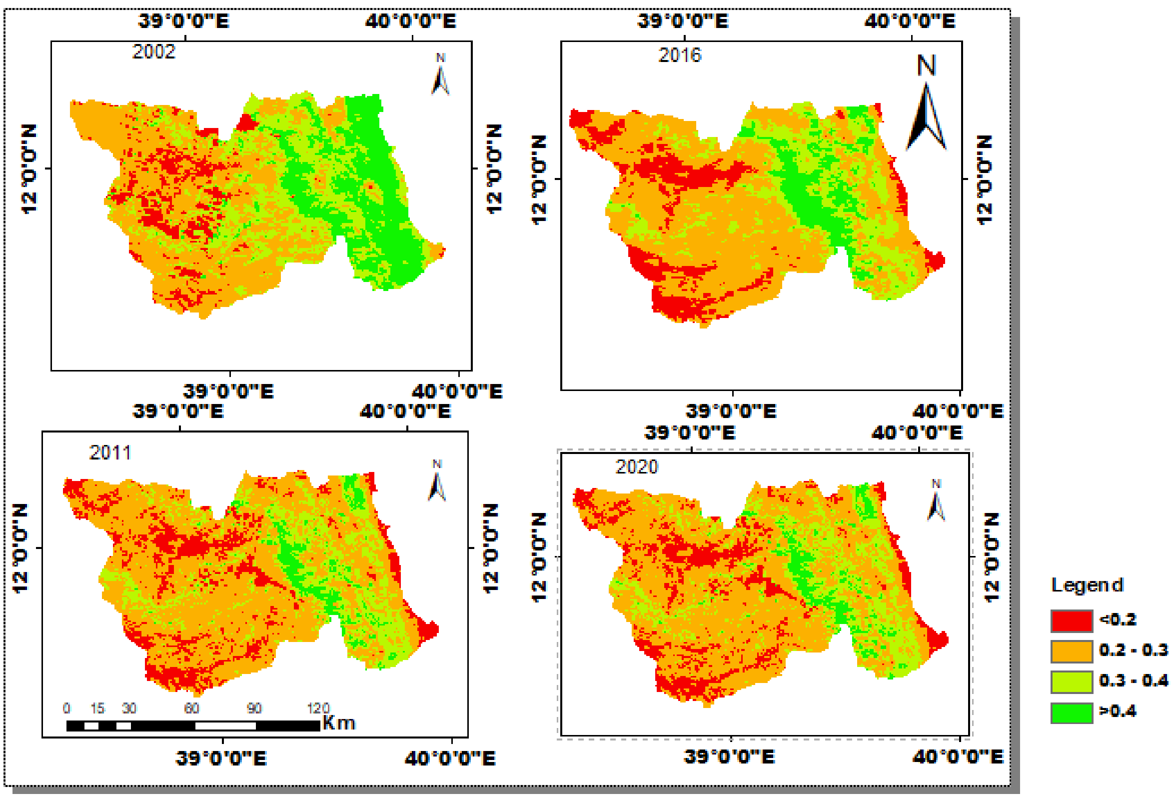

Figure 5

NDVI changes between 2002 and 2020 (January) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

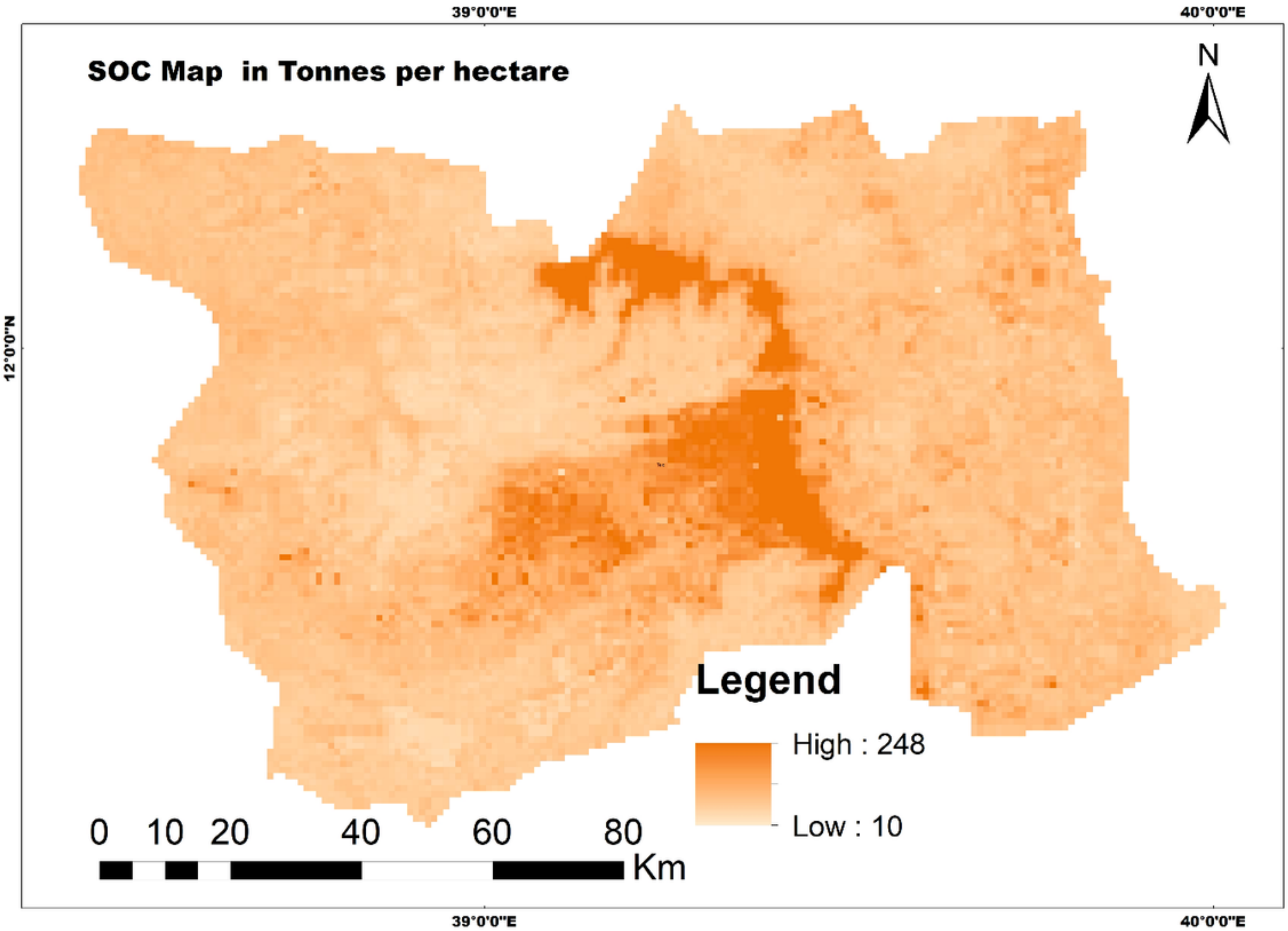

Figure 6

Soil organic carbon Map for North Wello Zone (2015). Source: earth map. Org Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

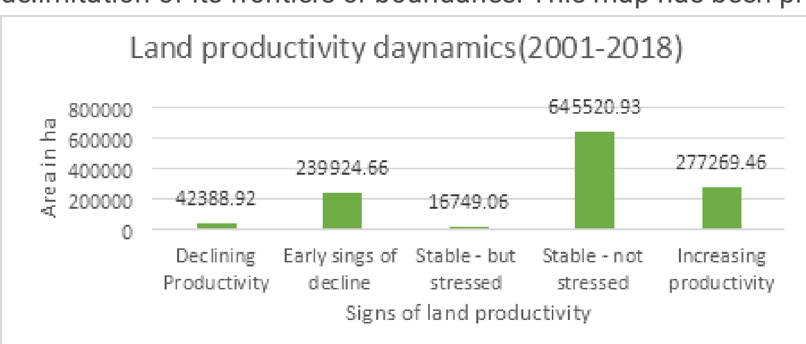

Figure 7

Land productivity signs in North Wello Zone for the period 2001 to 2018

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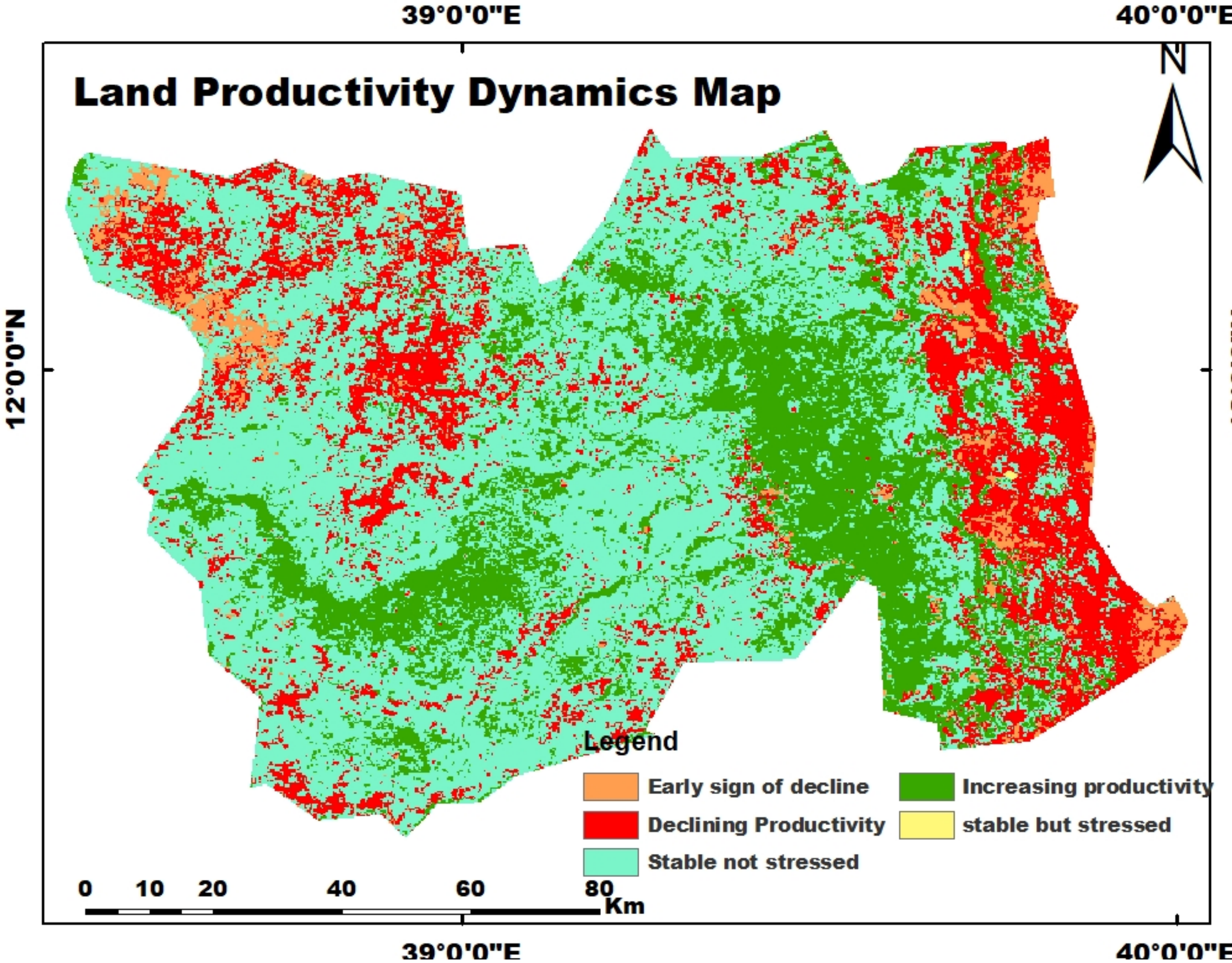

Figure 8

Land productivity Dynamics Map Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.