Assessment of land degradation ‘on the ground’ and from ‘above’

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Abstract

Assessments of land degradation vary in methodology and outcome. The objective of this study is to identify the state, extent and patterns of land degradation in Eastern Africa (Ethiopia, Kenya, Malawi and Tanzania). More recently (2000s), satellite-based imagery and remote sensing have been utilized to identify the magnitude and processes of land degradation at global, regional and national levels. This involves the use of Normalized Difference Vegetation Index (NDVI) derived from Advanced Very High Resolution Radiometer data and the use of high-quality satellite data from Moderate Resolution Imaging Spectroradiometer. This study is the first in Eastern Africa to complement remote sensing with ground-level assessments in evaluating the extent of land degradation at national and regional scales. The results based on NDVI measures show that land degradation occurred in about 51%, 41%, 23% and 22% of the terrestrial areas in Tanzania, Malawi, Ethiopia and Kenya, respectively, between the 1982 and 2016 periods. Some of the key hot spot areas include west and southern regions of Ethiopia, western part of Kenya, southern parts of Tanzania and eastern parts of Malawi. To evaluate the accuracy of the NDVI observations, ground-truthing was carried out in Tanzania and Ethiopia through focus group discussions (FGDs). The FGDs indicate an agreement with remotely sensed information on land degradation in seven sites out of eight in Tanzania and five sites out of six in Ethiopia. Given the significant magnitude of land degradation, appropriate action is needed to address it.

Keywords Land degradation · Sustainable land management · Land use change · Ground-truthing · Eastern Africa

1 Introduction

Land degradation is defined as “the persistent reduction of the production capacity of a land, which may be manifest through any combination of a number of interrelated processes, such as: soil erosion, deterioration of soil nutrients, loss of biodiversity, deforestation or declining vegetative health” [31]. More recently, the Economics of Land Degradation (ELD) initiative defines land degradation as ‘reduction in the economic value of ecosystem services and goods derived from land’ (ELD 2013). Assessments of land degradation vary in methodology and outcome [30, 52, 61]. There are two broad approaches to evaluate land degradation: ground-based measurements and remote sensing.

Ground-based measurements, also referred to as survey-based (direct) field observations, include approaches such as experts’ opinions, land users’ opinion, field monitoring and measurements, productivity changes, farm-level studies and modeling. These approaches are important in evaluating land degradation process at the national and local levels [55]. On the other hand, aboveground measurements involves the use of remotely sensed satellite imagery, Radio Detection and Ranging (RADAR) and GIS data. An extensive review of these methods including their appropriateness, strengths and limitations is provided in [39] and [27].

Ground-based measurements have been utilized to evaluate the severity, degree and extent of land and soil degradation at global, regional, national and local

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levels. For example, the Global Assessment of Human-induced Soil Degradation (GLASOD) which is based on expert opinion provides information on the global distribution, intensity and the causes of erosional, chemical and physical degradation [7, 26]. The World Overview of Conservation Approaches and Technologies (WOCAT) provides information on soil and water conservation (SWC), conservation approaches and technologies to combat desertification in 23 countries spread across six continents [3, 37]. Other studies that use expert opinions conducted at national and local levels include [50] in Ethiopia and [5] in Chile.

Direct field observations using soil erosion indicators such as eroded clods, flow surfaces, pre-rills and rills have been used to effectively monitor the effects of erosion from tillage and harvesting in Kenya [12]. Further examples include the participatory degradation appraisal carried out in Botswana [46]. This approach combines three approaches; the land user opinion, the farm-level field observations and assessment of productivity changes. [51] also uses a participatory approach that integrates the expert opinions and the experiences of the local land users (key informant interviews, focus group discussions and questionnaires) to enhance accuracy, coverage and relevance of land degradation assessment in Botswana and Swaziland.

Soil erosion and its related risks have been studied using various models such as Universal Soil Loss Equation (USLE), Wind Erosion Equation (WEE) [1], Revised Universal Soil Loss Equation (RUSLE) [53], Coordination of Information on the Environment (CORINE) [14], and Pan-European Soil Erosion Risk Assessment (PESERA) [28]. Soil erosion also has been researched by experimental approach [41]; Lieskovský and Kenderessy, [11, 33, 36, 43, 49].

Remote-sensing approach is vital in measuring land degradation, especially over a larger scale—regional, national to global scales in a consistent manner. This approach is considered a cost-effective and time-efficient because one image can be used to assess land degradation over a big area [20, 34]. Land degradation can be identified in various ways using remote-sensing techniques, including

- (i) Manual visual approach such as image differencing of two images—[10] in Argentina and [6] in sub-Saharan Africa.
- (ii) Interpretation of aerial photography and satellite imagery such as [21] in China and [47] in Spain.
- (iii) Spectral index ('Land degradation Index') such as [9] in Morocco;
- (iv) Land cover mapping and 'Steppe Degradation Index' spatial and temporal metrics of land cover change: [6] in sub-Saharan Africa.

- (v) Object-based method coupling with support vector machine [59]. Recent empirical evaluations of land degradation, however, show a shift from manual visual approaches, interpretation of aerial photography and satellite imagery to a more model-based approach involving indicators and proxy variables, measurable over large areas and over longer periods. These approaches have been criticized for exaggerating the result on the levels of land degradation, and that they are perception-based and semiquantitative, and therefore not built on objective measurements. Land cover exercises map degradation using image brightness values on a snapshot satellite image thus cannot represent persistent land degradation.
- (vi) Model-based approach—involving indicators and proxy variables: The most widely used index for assessment is the vegetation index such as the Normalized Difference Vegetation Index (NDVI).

NDVI is an index of plant 'greenness' or photosynthetic activity. Vegetation indices have been used for a long time in a wide range of fields, such as vegetation monitoring; climate modeling; agricultural activities; drought studies; and public health issues [48]. Vegetation indices are radiometric measures that combine information from the red and near infrared (NIR) portions of the spectrum to enhance the 'vegetation signal.' NDVI allows reliable spatial and temporal intercomparisons of terrestrial photosynthetic activity and canopy structural variations. NDVI is generally computed for all pixels in time and space, regardless of biome type, land cover condition and soil type, and thus represents true surface measurements. There are varied NDVI datasets available including the Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR), and Landsat satellite sensors [4, 8, 18].

Some studies utilizing this approach include [15] in Senegal; [45] [25, 38] in the Sahel; [44] in Zimbabwe and Mozambique, [57] in SSA, [3] and Le et al. [32] at the global level. [13] extends NDVI estimation to predict/detect future land degradation and its economic effects globally with inclusion of climate change effects.

However, remote-sensing datasets may have structural errors. These structural errors may be conceptualized as falling into one of three related categories: errors arising from the type of sensor used, errors arising from the spatial and temporal resolution of the analysis and errors arising from the derived data used (i.e., indices, land cover/land use classifications, etc.). A step-by-step procedure to address these shortcomings relating to measurement of biomass productivity (NDVI) changes is presented in Le et al. [32].

It is thus notable that land degradation can take many forms and that some methods are not appropriate for measuring all forms of land degradation. It is therefore necessary to bring together analyses from different approaches to better inform policies.

This study makes a contribution by combining remotely sensed land degradation dataset and ground-based surveys (ground-truthing) to evaluate the extent of land degradation in Eastern Africa. Eastern Africa and sub-Saharan Africa, in general, are some of the global regions which are most affected by land degradation, with significant negative impacts on human well-being and sustainable development [40]; thus, a more accurate identification of land degradation hot spots in the region could be highly useful for national policies to address land degradation. The identification of land degradation hot spots will consequently help in uncovering the proximate and underlying causes. Appropriate mitigation actions can then be appropriately applied to curb degradation in these areas.

Remotely sensed dataset on biomass productivity (NDVI) decline is based on a methodology proposed by Le et al. [32]. Remotely sensed dataset on land use and land cover change (LUCC) is based on Total Economic Value framework proposed by [40] and also applied to Eastern Africa [29]. Survey-based datasets collected through focus group discussions (FGDs) are used to complement the remote-sensing observations. The survey-based observations are important because they provide ground-based estimates of land degradation from the perspectives of the communities involved. The next sections describe the datasets used, methods of analysis, results and the discussions. The implications of these results are presented in Conclusion.

2 The extent of land degradation in Eastern Africa

The total population of sub-Saharan Africa (SSA) is currently estimated at 750 million people [54], but this is projected to grow past the one billion mark by 2020 [23, 54]. The region is the poorest in the world, with an estimated one in every three persons living below the poverty line. The demand for food is putting greater pressures on the natural resource base [58]. Assessments of land degradation in the region vary in methodology and by type of degradation being experienced [30, 52, 61]. The GLASOD survey, based on expert opinion, concluded that in the early 1980s about 16.7% of SSA experienced serious human-induced land degradation [35, 60]. Using standardized criteria and expert judgment, [42] revealed that about 20% of SSA was affected by slight to extreme land degradation in 1990. These assessments were done based on 'experts'

opinion and for varying time periods and only focused on soil degradation, not land as a whole.

The data from the FAO TERRASTAT map 67% (16.1 million km²) of the total land area of SSA as degraded [17], with country-to-country variations. These variations are quite large: Ethiopia is the most seriously affected (25% of its territory degraded) while Kenya and Tanzania record 15% and 13%, respectively. Malawi is the least affected (9%). The figure for Tanzania (13%) is quite low compared to a later study [2] based on expert opinion that showed about 61% of the territory affected by land degradation. The TERRASTAT dataset allows the further classification of the degraded lands by the relative degree of severity of degradation. Thus, out of the 67% degraded land in SSA, the four subcategories exist, namely light (24%), moderate (18%), severe (15%) and very severe (10%). Similarly, the GLASOD data show that about 25%, 14% and 13% of land area are degraded in Ethiopia, Kenya and Tanzania, respectively. However, the main weakness of these studies is that they are based on subjective expert judgment and must be approached with caution.

GLASOD global survey and FAO's global forest resource assessment (2005) identified five main types of land degradation predominant across SSA countries (Table 1). Among them, water erosion and wind erosion are the most widespread types of land degradation (46% and 38%, respectively), followed by chemical and physical deterioration of soils (16%). The other types of land degradation include salinization and waterlogging, decline in soil fertility and loss of habitat (especially forests and woodlands). Previous studies have not been successful in quantifying the extent and severity of these types of land degradation in Eastern Africa. However, it is notable that water erosion, declining soil fertility and nutrient depletion are important in all the four countries. While salinization (of irrigated lands) is severe in Kenya (30%) and Tanzania (27%), and the loss of forests and woodlands in these countries is about at 1% per annum [17].

More recently, satellite-based imagery (remote sensing) has been utilized to identify the magnitude and processes of land degradation at global, regional and national levels. This involves the use of Normalized Difference Vegetation Index (NDVI). Several studies have applied this technique, including [3, 16, 24, 57]. While using rain-use efficiency (RUE)-adjusted NDVI, [3] map the global land degradation trends. Their assessment shows that land degradation has affected about 26% of SSA land area. The areas affected are also different from those reported by GLASOD and TERRASTAT surveys and by [42].

Unlike this GLASOD and TERRASTAT assessment, [3] estimated that about 24% of the global land area has degraded (significant decline in NDVI) over the previous 25 years. Much of the areas they identify do not overlap

Table 1 Land degradation types and extent in sub-Saharan Africa. *Source:* Adopted from Global Forest Resource Assessment (FAO, 2005)

Type of land degradation	Affected land (% of total)	Affected population (% of total)	Countries affected	Main cause(s)
Water erosion	46	97	All countries in eastern Africa (Kenya, Tanzania, Ethiopia, Malawi, Zambia)	Deforestation, overgrazing, agric. practices
Wind erosion	38	18	Botswana, Chad, Djibouti, Eritrea, Mali, Niger, South Africa and Sudan	Overgrazing, deforestation
Salinization			Severe in Kenya (30%), Tanzania (27%)	Water management
Soil fertility and nutrient depletion	Approx. 100	Approx. 100	All countries	Agric. practices, overgrazing, deforestation,
Loss of habitat (deforestation)	0.7% of annual change of forest and woodland area in east and southern Africa		Hotspots: Burundi (– 5.2%), Comoros (– 7%), Nigeria (– 3.3%), Togo (– 4.5%), Uganda (– 2.2%), Zimbabwe (– 1.7%)	Deforestation, overgrazing, agricultural practices

with those indicated in the GLASSOD survey. However, sub-Saharan Africa region remains the most affected. Country estimates (Table 2) show that Tanzania was the most affected country; 41% of its land territory degraded. Ethiopia and Malawi both had 26% of their territories degraded, while about 18% of Kenya's land area was degraded during the same period. In terms of populations affected, about 40% and 36% of people in Tanzania and Kenya were living in these degraded areas. Similarly, about 30% and 20% of the Ethiopian and Malawian population were affected by land degradation over the same period. It is, however, notable that these estimates do not take into account the effect of atmospheric fertilization, the rainfall factor and the effect of soil moisture in sparse vegetative areas. Similarly, the work of [56] estimated that 10% of SSA was significantly affected by land degradation. [57] also map the geographic extent of areas in SSA affected by land degradation processes over the period of 1982–2003. While utilizing long-term NDVI, they show that about 27% of the land is subject to degradation processes including soil degradation, overgrazing or deforestation. Following [57], the land degradation 'hot spots' map shows that Ethiopia, Kenya, Tanzania and Malawi are the most affected in

the Eastern Africa region; thus, they were selected as case studies countries for this assessments.

3 Materials and methods

3.1 Assessment of land degradation from 'Above'

Two approaches are used to evaluate the extent of land degradation in this study: biomass productivity (NDVI) decline and land use land cover change (LUCC). The Le et al. [32] NDVI land degradation dataset, which improves on the GLADIS methodology, is used to estimate biomass productivity decline. Le et al. [32] dataset is useful in identifying 'global geographic degradation hotspots or improvement hotspots.' Le et al. [32] calculate statistically significant long-term trends in NDVI from 1982–2006 (by main land cover/use types for each country) using data obtained from Global Inventory Modeling and Mapping Studies (GIMMS) which is derived AVHRR. Le et al. [32] dataset is preferred because it corrects for the effects of rainfall and atmospheric fertilization [22]. The dataset also addresses some of the structural challenges associated

Table 2 Statistics of degraded areas by country for Eastern Africa (1981–2003). *Source:* [3] and [17]

Country	Degrading area (km ²)	% Territory	% Total population	Affected people	% Territory (GLASOD)
Ethiopia	296,812	26	29	20 million	25
Kenya	104,994	18	36	11 million	15
Malawi	30,869	26	20	2 million	9
Tanzania	386,256	41	40	15 million	13

with NDVI assessments by masking out pixels with unreliable NDVI trends.

High-quality satellite data from Moderate Resolution Imaging Spectroradiometer (MODIS) is used to evaluate land cover land use change (LUCC) during the 2001–2009 period. MODIS is a valuable source of both NDVI and LUCC information globally, though it is only available from 2001. For this analysis, the land cover information was chosen for the period of 2001–2013 as a measure of recent degradation trends. This study uses a collection 5 of the MODIS land cover type dataset (MCD12Q1), which provides annual land cover information at a 500-metre spatial resolution [19]. Input datasets used in the classification procedure include information from MODIS bands 1–7, the enhanced vegetation index, land surface temperature and nadir BRDF-adjusted reflectance data.

3.2 Assessment of land degradation ‘on the ground’ and ground-truthing of remote-sensing land degradation maps

Ground-truthing refers to a process in which a pixel on a satellite image is compared to what is there in reality. Ground-truthing data are useful in the interpretation, analysis and validation of the remotely sensed data. Ground-truthing is usually done on-site, and it involves performing surface observations or measurements of various properties of the features of the ground resolution ‘cells’ that are being studied on the remotely sensed dataset. It also involves taking geographic coordinates of the ground resolution ‘cell’ with GPS technology and comparing those with the coordinates of the pixel being studied provided by the remote-sensing software. Other alternative ways to carry out ground-truthing include field measurements and surface observations, interviews and personal experiences with local communities and key informants.

Ground-truthing is an expensive and time-consuming exercise. It requires visiting as many sites as possible so as to have sufficiently large training dataset. The logistical challenges of accessing remote locations, communication problems, equipment failure, physical stress, unstable political environments are some of the challenges associated with ground-truthing exercises. Recent advances in affordable GPS receivers and digital data field recorders, however, allow the researcher a greater flexibility in carrying out this exercise. The ground-truthing work (field observations and interviews with local communities) described in this study was carried out in seven locations in Ethiopia and eight locations in Tanzania as discussed in the next section. In this study, the FGDs are used as a complement to the remote-sensing based observations and to evaluate the accuracy and reliability of land degradation ‘hotspots’ map developed in Le et al. [32] and

from MODIS datasets. The surveys provide ground-based estimates of land degradation from the perspectives of the land users or the communities involved. Degradation also needs to be viewed in the context of land use and livelihood systems. What looks like improved greenness using, for example remote-sensing imagery (e.g., increase in bush and shrub cover), can be considered degradation in, e.g., pastoral livelihood systems if such greenness has come at the expense of good grasses.

The sites used to evaluate the accuracy of the land degradation ‘hotspots’ map were selected following a three-step procedure. Firstly, the site selection considered different land use categories (forests, croplands, grasslands, shrublands) based on US Geological Survey (U.S.G.S.) classification. Secondly, for each of land use category, both degraded and improved sites were selected following Le et al. [32]. Thirdly, the site chosen consisted of communities (or groups of communities) that span at least 8 km² which is the size of a single pixel in the Le et al. [32] dataset. Thus, the sites represent a range of agroecological zones, different land use categories and include both degraded and improved areas (Fig. 1).

The FGD participants expressed land degradation (or improvement) of the major biomes which have occurred in the community over three decades (1982–2013). The first section of the FGDs (changes in land use and land cover changes, cropping intensity and yields, and deforestation) was designed to elicit, either directly or indirectly, the presence or absence of land degradation and the associated impacts. It was primarily designed to allow direct comparison to available remotely sensed estimates in this analysis.

3.3 Sampling procedure of the FGD participants

The processes of land degradation or improvement were identified using FGDs conducted with local communities in each of the selected sites using semistructured questionnaires. To ensure rich discussions on ecosystem values, the selection criteria ensured that a broad variety of land users would be present, especially those knowledgeable of the land use developments from 1982 to 2013. On average, each FGD comprised about ten voluntary participants. Therefore, participants in the FGDs were diverse and were chosen based on the following criteria:

- The opinion leaders and village elders with knowledge about land use changes over the last decades and also aware of the size and boundaries of their communities,
- Participants also included women, youth, customary/cultural leaders,
- A balance between males and females in the group was considered,

Fig. 1 Selected ground-truthing sites [dark red indicates pixels that demonstrate both long-term degradation (1982–2006) and degradation in recent (2000–2006) years, green pixels indicate sites with improved land.] in Ethiopia and Tanzania. *Source:* Authors' compilation

- Both the old and relatively younger participants were selected because they could provide informed perception on land use change over the 30-year reference period,
- People with various occupational backgrounds that typically represented the community—such as local leaders, crop producers, livestock producers, those who earn their livelihoods from forest and non-agricultural activities (teachers, artisans, and traders) were selected.

Table 3 summarizes the main information about the participants of the FGDs per village in the two countries. A total of 58 and 96 people contributed to the FGDs in Ethiopia and Tanzania, respectively. About 34% and 37% of participants were female in Ethiopia and Tanzania, respectively. The average age of the discussants was 46 years and 50 years in Ethiopia and Tanzania, respectively. At least 80% of the participants in Ethiopia and 50% Tanzania had been involved in discussions about environmental

Table 3 Characteristics of focus group discussants in Ethiopia and Tanzania. *Source:* Authors' compilation

District	Village	Total participants	Female participants (%)	Average age (years)	Average years of education (years)	Discussed environmental changes/issues previously (%)
Ethiopia						
1. Guba Goricha	Kemona	8	50	45	2	75
2. Tulo	Ifabas	11	36	45	5	100
3. Becho	Mande Tufisa	13	23	51	4	77
4. Lume	Jogo	6	17	51	6	33
5. Nonsebo	Garambabo	9	44	36	5	100
6. Kokosa	Kawo	12	52	51	4	86
7. Lume	Koka Negewo	11	36	47	3	100
Total		58	34	46	4	81
Tanzania						
8. Kilosa	Zombo	11	45	46	8	81
9. Morogoro	Dakawa	9	56	44	7	22
10. Mufindi	Mtili	15	40	57	8	46
11. Kongwa	Sejeli	13	31	42	6	92
12. Dodoma	Zuzu	11	36	55	7	18
13. Bahi	Maya	11	18	60	5	100
14. Manyoni	Mamba	15	33	51	7	13
15. Handeni	Mazingira	11	37	45	7	55
Total		96	37	50	7	53

changes/issues during the previous year with extension agents, forest experts, local and national NGOs, etc., so they have had a knowledge about the ecosystems and their services and issues related to environmental change in general.

The FGDs were conducted in the local languages with the help of translators at the farmer training centers at the villages or in community meeting rooms for about 4–5 h. The FGDs began with sketching of the community map and identification of different land use types on a flipchart. Some communities had detailed sketches of community maps showing the community boundaries and the different allocations of land use categories. Thus, discussions were carried out around these existing maps to gain a common understanding on the share of different land use types (forest, shrubland, grassland, bare soil, water, cropland, and residential area) of the total community land area. All this information was elicited for 1982, 2000, 2006 and 2013. Information was also collected on the main source of income including crop farming, live-stock farming, mixed farming, forest harvesting, fisheries or nonagricultural activities, etc. Further information collected included qualitative information on the trends on deforestation and its drivers.

The discussion also identified the main crops grown in the community, their yields and the changes in crop farming practices such as single (monocropping), double or triple cropping, and intercropping and mixed-cropping methods, for the years 2000, 2006 and 2013. Various techniques, including relative questions (such as were yields

this year higher or lower than five years ago? How was the rate of deforestation in 2006 compared to 2000?), and collaborative collective sketching of community land use maps were used to elicit the information and guide the discussions. As observed during the FGDs, intense discussions occurred before an agreed response for each of the questions was recorded.

4 Results and discussion

4.1 Extent of land degradation due to NDVI decline

The land degradation hot spots (areas with significant biomass decline) in Eastern Africa are presented in Fig. 2 and Fig. 3. The results (Table 4) show that a total of about 453,888 km² (51%) and 38,912 km² (41%) of Tanzania's and Malawi's land area were degraded respectively. In Ethiopia, land degradation was reported in about 228,160 km² (23%) and just about 127,424 km² (22%) in Kenya. These areas varied across the main land cover-land use type by country. For example, in Ethiopia much of degradation (32%) was experienced in areas with sparse vegetation, in Kenya the highest proportion of degradation was experienced in forested areas (46%), while shrubland and mosaic vegetation and cropland each had 42% degraded. In Malawi, highest proportion of degradation was experienced in mosaic forest-shrub/grass (57%) and grasslands (56%), while in Tanzania 76% of degradation reported was experienced in grasslands.

Fig. 2 Biomass productivity decline in Eastern Africa over 1982–2006. Source: Adopted from Le et al. [32]. Cartography: Oliver K. Kirui

Fig. 3 Biomass productivity decline by biome in Eastern Africa over 1982–2006. *Source:* Adopted from Le et al. [32]. Cartography: Oliver K. Kirui

Table 4 Area (km² and percentage) of long-term (1982–2006) NDVI decline. *Source:* Adopted from Le et al. [32]

Country	Area (km ²) of NDVI decline and in percentages for the corresponding land use							Total
	Cropland	Mosaic vegetation-crop	Forested land	Mosaic forest-shrub/grass	Shrub land	Grassland	Sparse vegetation	
Ethiopia	35,904 (18%)	30,976 (19%)	9984 (16%)	59,776 (27%)	37,824 (20%)	7808 (14%)	45,888 (32%)	228,160 (23%)
Kenya	15,808 (31%)	40,512 (42%)	21,568 (46%)	9664 (10%)	21,952 (42%)	15,232 (18%)	2688 (4%)	127,424 (22%)
Malawi	576 (50%)	6720 (31%)	11,072 (34%)	1088 (57%)	17,984 (51%)	1472 (56%)	N/A	38,912 (41%)
Tanzania	12,608 (32%)	112,768 (62%)	139,968 (36%)	18,688 (66%)	93,504 (70%)	75,712 (76%)	640 (30%)	453,888 (51%)

These findings are different from those presented by both [3] and FAO GLASOD (2000) survey. For example, while our analysis show that 51% of land area in Tanzania is degraded, [3] and GLASOD (2000) estimates are 41% and 13%, respectively. Similarly, results show that 23% of Ethiopia territory experienced biomass decline between 1982 and 2006 as opposed to 26% presented in [3]. These differences, as described in Methods section, may be resulting from difference in assessment approaches and time periods being assessed.

The hot spot areas in Ethiopia are characterized by high population pressure (on land and forests), farming activities on steep slopes and frequent famines occasioned by unreliable rainfall. The hot spots in Kenya are characterized by intensive crop farming that increases pressure on soils. The arid and semiarid conditions of the southern parts of Tanzania and eastern parts of Malawi

may also be a contributing factor to the high degradation levels.

4.2 Extent of land degradation due to land use/cover change

The land use changes between 2001 and 2009 are discussed in this subsection. We specifically focus on the net change within each biome. The net change refers to the total gained area minus the total lost area. The net change in the different LUCC categories in absolute numbers as well as percentage changes relative to the land areas in the baseline year (2001) is discussed. The biggest net areas that increased in Ethiopia in absolute values were croplands (2.8 mha) and shrubland (2.6 mha), while the net losers were grasslands (3 mha) and forests (1.4 mha). The net gainers in Kenya were grasslands (7 mha) and woodlands

(0.13 mha), while the net losers were grasslands (6.1 mha) and bare land (0.7 mha). The net gainers in Malawi were grasslands (1 mha) and forests (0.03 mha), while the net losers were woodland (1 mha) and bare land (0.07 mha). The net gainers in Tanzania were grasslands (5.6 mha) and bare land (0.02 mha), while the net losers were woodlands (2.9 mha) and cropland (1.3 mha).

To provide a more succinct picture, these changes relative to the baseline (2001) land areas are presented (Fig. 4). On this account, the net gainers in Ethiopia were cropland (33%) and shrubland (7%), while net losers were forests (26%), bare land (12%) and grasslands (11%). The net gainers in Kenya were grasslands (32%) and woodlands (3%), while the net losers were bare land (32%), shrubland (24%) and forests (23%). The net gainers in Malawi were bare land (57%) and grasslands (18%), while the net losers were shrubland (81%), cropland (34%) and woodland (31%). The net gainers in Tanzania were bare land (29%) and grasslands (11%), while the net losers were shrubland (59%), cropland (41%) and forests (17%).

In summary, these changes are observed as follows:

- i. Deforestation in Ethiopia, Kenya and Tanzania
- ii. Significant reductions in the croplands in Malawi and Tanzania but significant increase in Ethiopia
- iii. Huge shift from shrub lands in Kenya, Malawi and Tanzania to grasslands and to croplands and bare land.
- iv. Increase in bare lands in Malawi and Tanzania but significant reductions in Kenya
- v. Significant increases in grasslands in Kenya and Malawi reductions in the extent of water bodies.

4.3 Land use/cover change elicited in the FGDs

We also provide the changes in land use changes as elicited in the FGDs for the different communities in Ethiopia and Tanzania in Table 5. Results show that the land use changes are dynamic and varied for each selected village and country. In Ethiopia, for example, forests doubled in

Kemona community but declined by more than half in Ifabas community (from 42 to 16% of the community area). During the same period, the area Ifabas village reported a shift to more crop farming as indicated by significant increase in cropland (from about 50% in 2000 to as high as 73% in 2013). In surveyed villages in Tanzania, significant changes are as follows: reduction of forests in Zombo, Dakawa and Mazingira villages; increase in croplands in Zombo, Dakawa, Zuzu, Mazingira and Mamba; significant in shrub land in Sejeli and Mamba; decline in cropland in Mtili; and decline in grasslands in Sejeli and Zuzu. It is also notable that residential areas increased in all sampled villages. Some of the reported reason driving shifts in land use included increasing demand for food and fuelwood occasioned by increasing populations. Ensuring the accuracy of both NDVI and MODIS analyses is important. Therefore, there is a need to ground-truth and triangulate these analyses with household-/plot-level analysis and field observations. We attempt to do this in the next subsection.

4.4 Comparison between remote-sensing and ground-truthing assessments

The comparison between remote-sensing data reported by Le et al. [32], the MODIS land use/cover change analysis and the responses of the perception about trend of land degradation from the FGDs conducted at each site is presented in Table 6. The FGDs assessment showed a relatively high degree of agreement with the remote-sensing data. There was agreement between Le et al. [32] and the FGDs in seven sites out of eight in Tanzania and six sites out of seven in Ethiopia. This presents an accuracy of about 88% and 86%, respectively. Disagreement between the Le et al. [32] and the FGDs was reported in Mamba village in Tanzania and in and Kemona village in Ethiopia. In this two cases, the remote-sensing data showed improvement, while the FGDs showed degradation. The discrepancies in NDVI and FGDs assessments may be explained by a number of reasons. Cropland remained a significant land use category (about 80%) in Kemona and increased

Fig. 4 Net change in land area of terrestrial biomes between 2001 and 2009 (%). Source: Authors' compilation based on MODIS data

Table 5 Land use change elicited from focus group discussions for period 2000–2013 *Source:* Authors' compilation

Village	Forest (%)		Shrubland (%)		Grasslands (%)		Cropland (%)		Bare soil (%)		Water (%)		Residential (%)	
	2000	2013	2000	2013	2000	2013	2000	2013	2000	2013	2000	2013	2000	2013
Ethiopia														
Kemona	3	5.9	4	7.9	1.8	0.7	81	77.5	5.9	2.5	0	0	4.6	5.5
Ifabas	42	16	4	1.3	2	1	49	73.2	<1	2	0	0	3	6
M. Tufisa	17	8	1	0	34	19	36	54	0	2	0	0	13	18
Jogo	4	6	0	0	6	3	51	58	1	1	0	0	6	10
Kawo	38	32	0	0	45	20	4	28	0	0	9	4	4	16
Tanzania														
Zombo	75	50	0	0	0	0	19	41	0	0	0	0	6	8
Dakawa	42	6	0	0	36	29	21	60	0	0	0	0	1	6
Mtili	30	65	0	0	0	0	60	25	0	0	<1	<1	10	10
Sejeli	4	5	50	0	25	0	15	75	0	0	0	0	10	20
Zuzu	0	0	1	1	37	5	52	80	0	0	0	0	10	14
Maya Ma	72	60	72	60	0	0	18	25	0	0	0	0	10	15
Mamba	0	0	65	5	0	0	25	75	0	0	0	0	10	20
Mazingira	60	40	20	10	5	15	5	20	0	0	0	0	5	15

Table 6 Comparison between the Le et al. [32] land degradation map, the focus group discussions (FGDs), and the MODIS land use/cover change analyses. *Source:* Authors' compilation

District	Village	Biomass productivity decline [32]	Focus group discussion (FGDs) assessment	MODIS land cover change	Agreement
Tanzania					
1. Kilosa	Zombo	Degraded	Degraded	Mixed	2/3
2. Morogoro	Dakawa	Degraded	Degraded	Degraded	3/3
3. Mufindi	Mtili	Improved	Improved	Mixed	2/3
4. Kongwa	Sejeli	Degraded	Degraded	Degraded	3/3
5. Dodoma	Zuzu	Degraded	Degraded	Degraded	3/3
6. Bahi	Maya	Degraded	Degraded	Degraded	3/3
7. Manyoni	Mamba	Improved	Degraded	Degraded	2/3
8. Handeni	Mazingira	Improved	Improved	Improved	3/3
Ethiopia					
9. Guba Goricha	Kemona	Improved	Degraded	Improved	2/3
10. Tulo	Ifabas	Degraded	Degraded	Mixed	2/3
11. Becho	Mande Tufisa	Degraded	Degraded	Mixed	2/3
12. Lume	Jogo	Degraded	Degraded	Improved	2/3
13. Nonsebo	Garambabo	Degraded	Degraded	Degraded	3/3
14. Kokosa	Kawo	Improved	Improved	Improved	3/3
15. Lume	Koka Negewo	Degraded	Mixed	Mixed	2/3

significantly in Mamba—from 25% in 2001 to 75% in 2013 (Table 5). There was also an increase in planted forests in Kemona village. This increase in agricultural intensity and the change in crops grown may reflect as an increase in vegetation indices. However, FGDs results indicated an increase in soil erosion, which would not be captured by remote sensing.

On the other hand, the comparison between MODIS land cover change assessments and the FGDs was mixed. There

was agreement between MODIS land cover change and the FGDs in six sites out of eight in Tanzania and in only three sites out of seven in Ethiopia—representing an accuracy rate of 75% in Tanzania and 43% in Ethiopia. Overall, there was complete agreement (3/3, or 100%) in five sites in Tanzania (Dakawa, Sejeli, Zuzu, Maya and Mazingira) and two sites in Ethiopia (Garambabo and Kawo). The other three sites in Tanzania (Zombo, Mtili and Mamba) and the other six sites in Ethiopia (Kemona, Ifabas, Mande Tufisa, Jogo and

Koka Negewo) each had an agreement of 2/3 or 67%. Care should be taken in interpreting the results of comparison between the FGDs survey and the MODIS data. While MODIS land cover changes between the years 2000 and 2006 were chosen to provide estimates of recent degradation trends, available land cover changes from the FGDs survey are for the period 2000 and 2013. Thus, the variation in time periods may explain this inconsistency or low agreement between MODIS and FGDs estimates of land degradation.

FGDs also provide information that may not be observable using satellite imagery such as soil erosion, nutrient depletion or change in crop yields. The field surveys also provide clarity on the ambiguous surface processes such as invasive species that tend to increase vegetative cover which would lead to erroneous conclusions if solely remote-sensing analysis is used. However, some of the information elicited through FGDs—such as land cover, cropping patterns, crop yields—dates back to 30 years; thus, this kind of information relies on the ability of the FGDs to recall these values.

5 Conclusions

By employing the NDVI and LUCC data and combining them with ground-truthing methods, we discuss the state, extent and patterns of land degradation in Ethiopia, Kenya, Malawi and Tanzania. The results from NDVI measures show that during 1982–2006 land degradation occurred in about 51%, 41%, 23% and 22% in Tanzania, Malawi, Ethiopia and Kenya, respectively. Some of the key land degradation ‘hot spot’ areas include western and southern parts of Ethiopia, western part of Kenya, southern and central parts of Tanzania and eastern parts of Malawi. The FGDs assessments showed moderate to high degree of agreement with the remote-sensing data. These assessments indicate agreement with NDVI assessments in seven sites out of eight in Tanzania and five sites out of six in Ethiopia—representing an accuracy of about 88% and 86%, respectively. Further, the FGDs assessments indicate an agreement with LUCC assessments in six sites out of eight in Tanzania and three sites out of seven in Ethiopia—representing an accuracy of about 75% and 43%, respectively. These findings are particularly relevant because proper identification of areas experiencing land degradation is important in designing policies and practices aimed at restoring the degraded lands and in developing policies for improving livelihoods. Given the significant magnitude of land degradation, appropriate action is needed to address it. The complexity of land degradation processes requires a triangulation of a variety of data sources and approaches for proper interpretation.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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